BE3252 - Basic Electrical, Electronics & Instrumentation Engineering.

Unit - 1 : Electrical Circuits

DC circuits : Circuit Components : Conductor, Resistor, Inductor, Capacitor – Ohm's Law - Kirchhoff's Laws – Simple Problems - Nodal Analysis, Mesh Analysis with independent sources only (steady state).

Introduction to AC circuits and Parameters : waveforms, Average value, RMS value, Instantaneous power, real power reactive power and apparent power, power factor - steady state analysis of RLC circuits (simple problems only) Three phase supply - Star and delta connections - power in three phase system.

1.1. DC Circuits - Basic Circuit Components

* Resistor
* Capacitor
* Inductor

Conductor:-

* Some materials allow electric charges to pass through them easily, these materials are called conductors
* Materials that do not allow electric charges to pass through them easily are called Insulators.

* Network (Electrical Circuit)

- Active elements
- Passive elements

Active elements

① - which supply power or energy to the n/w

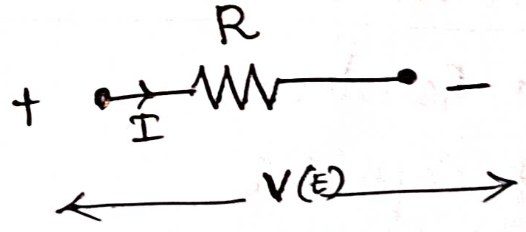
② Exa: Voltage Source & Current source

Passive elements

- elements which either store energy or dissipate energy in the form of heat.
- exa: Resistor, Capacitor, Inductors.

Resistor :-

* Electrical Component which opposes the flow of current through it. Unit of Resistance is ohm (Ω)
It is denoted by R.

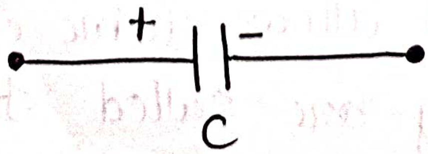


By ohm's law,

$$\boxed{R = \frac{V}{I}} \text{ ohm.}$$

Capacitor :

* Capacitor is a storage element which can store & deliver energy in a electric field. It is denoted by C.
The unit of Capacitance is Farad (F).



The capacitor consists of two metallic plates separated and insulated from each other by a dielect

V-I Relation:

For Capacitor, the voltage is proportional to the charge. ie, $V \propto q$

$$\therefore V \propto \int_{-\infty} i\,dt \qquad \left[\because I = \frac{dQ}{dt} \quad Q = \int I\,dt\right]$$

Q ⇒ charge
I ⇒ current

$$V = \frac{1}{C}\int i\,dt$$

$$i = C\frac{dV(t)}{dt}$$

With zero initial voltage across capacitor, if the current i flows for time t, the energy supplied to capacitor will be

$$W = \int_0^t v.i\,dt$$

$$= \int_0^t V\,C\frac{dV}{dt}\,dt$$

$$= C\int_0^V V\,dV$$

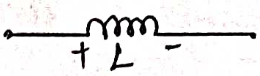
$$W = \frac{1}{2}CV^2 \text{ joules}$$ → Energy stored in capacitor

A Farad is defined as the charge in coulombs which a capacitor will accept for the potential across it to change 1 Volt.

Inductor:

Inductor is the element in which energy is stored in the form of electromagnetic field. It is a device that resists change in current.

The inductance is denoted by 'L' and its unit is Henry (H).



V-I Relation: For inductance the voltage is proportional to rate of change of current.

$$V \propto \frac{di}{dt}$$

$$V = L \frac{di(t)}{dt}$$

$$\Rightarrow i = \frac{1}{L} \int v \, dt$$

Assuming that initially zero current flows through the inductance, if a current i is made to flow through a coil, the energy stored in time t is,

$$W = \int_0^t v.i \, dt$$

$$= \int_0^t \left(L \frac{di}{dt} \right) i \, dt$$

$$= L \int_0^t i \, di$$

$$W = \frac{1}{2} i^2 L \text{ joules}$$ → Energy stored in inductor

Henry is the unit of inductance in which an induced electromotive force of one volt is produced when current is varied at the rate of one ampere per second.

(2)

Element	Voltage across element if current is known	Current through element if voltage is known
R	$V = iR$	$i = \frac{V}{R}$
L	$V = L\frac{di}{dt}$	$i = \frac{1}{L}\int v\,dt$
C	$V = \frac{1}{C}\int i\,dt$	$i = C\frac{dv}{dt}$

Classification of Electrical Networks

The classification of networks can be shown as

Electrical circuits or networks

- (1) Active / Passive
- (2) Linear / Nonlinear
- (3) Unilateral / Bilateral
- (4) Lumped / Distributed

Linear Network

A circuit or n/w whose parameters ie., elements like resistances, inductances and capacitances are always constant irrespective of the change in time, voltage, temperature etc is known as linear n/w.

Ohm's law can only be applied to linear n/w.

Nonlinear Network

A ckt whose parameters change their values with change in time, temperature, voltage etc. is known as non linear n/w. Eg.) N/w with diode.

Active Network

A circuit which contains atleast one source of energy (voltage or current source) is called active n/w.

Passive Network

A circuit which contains no energy source is called passive network.

Bilateral Network

A ckt whose operation is independent on the direction of current through various elements is called bilateral n/w. Eg.) N/w with only resistors.

Unilateral Network

A ckt whose operation is dependent on the direction of current through various elements is called unilateral n/w. Eg.) Ckt with diodes which allows current only in one direction.

Lumped Network

A n/w in which all the network elements are physically separable is known as lumped n/w. Most of the n/ws are lumped which has R, L, C, Vlge source, etc

Distributed Network

A n/w in which the ckt elements cannot be physically separable for analysis is called distributed n/w. Eg.) transmission line where resistance, inductance and capacitance of a transmission line are distributed all along its length which cannot be seperated.

(1)

Basic Phenomena

An Electric circuit or Electric n/w is an interconnection of electrical elements linked together in a closed path so that electric current may flow continuously.

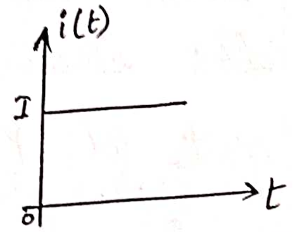
Current

The flow of electrons is called as current. The unit of * current is Ampere (A). It is denoted by I.

$$I = \frac{dQ}{dt}$$

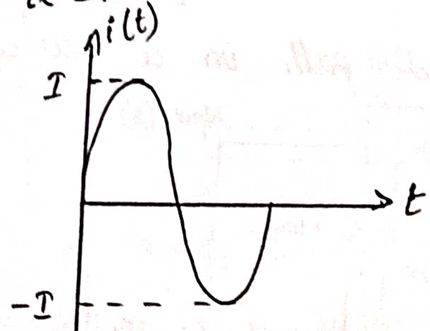
Direct Current

If the current flowing through an element is of constant magnitude, then it is called as direct current or d.c.



* Alternating Current

If the current flowing through an element is varying with time ie, in the form of sinusoidal variation, then it is called as sinusoidal or alternating current or a.c.



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Voltage

Every charge will have a potential energy. The difference in potential energy between the charges is called potential difference. In electrical terminology the potential difference is called voltage. It is denoted by V, the unit is Volt.

Charge

Charge is the characteristic property of the elementary particle of a matter. The unit of charge is Coulomb. It is denoted by 'q' and unit as 'c'.

Electric Power

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

$$P = VI \text{ Watts (or) } P = I^2R = V^2/R \text{ Watts}$$

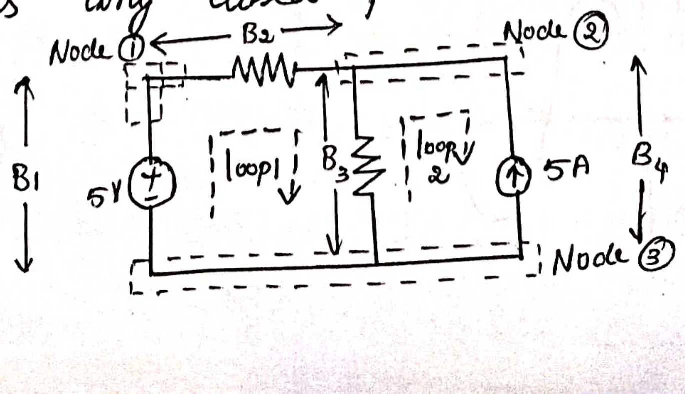
It is denoted as 'P'. The unit of power is Watts or VoltsAmps.

Nodes, Branches and Loops

A branch represents any two circuit elements such as Voltage source, current source, resistors, etc.

Node is the connection point of two or more elements.

Loop is any closed path in a circuit.



B→ Branch

Energy Sources

Energy sources are devices which supply electric energy. They are classified as

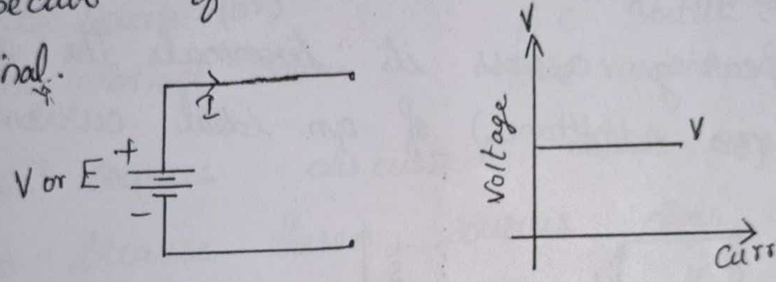
Voltage Source

Current Source

Voltage Source

(i) Ideal Voltage Source

Ideal voltage source is defined as the energy source which gives constant voltage across its terminals irrespective of the current drawn through its terminal.

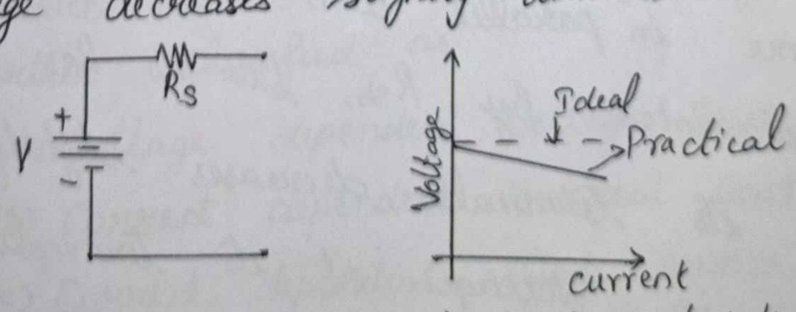


V-I Characteristic

Fig: Ideal Voltage Source

(ii) Practical Voltage Source

Practically every voltage source has small internal resistance in series with voltage source and is represented by R_s. Due to voltage drop across R_s, the voltage decreases slightly with increase in current.

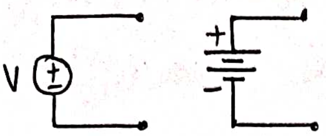


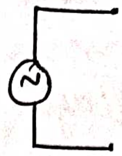
V-I Characteristic

Fig: Practical Voltage Source

Note : For ideal Voltage Source, $R_s = 0$

Voltage Sources are further classified as,





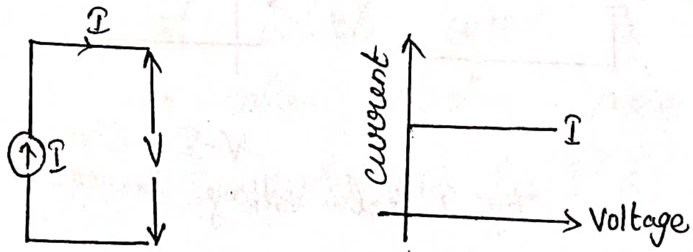
D.C. Source (or) Time Invariant Source

A.C. Source (or) Time Variant Source

Current Source

(i) Ideal Current Source

Ideal current source is the source which gives constant current at its terminals irrespective of the voltage appearing across its terminals. The internal impedance (or admittance) of an ideal current source is zero.



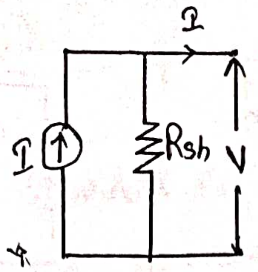
V-I characteristic

Fig: Ideal Current Source

(ii) Practical Current Source

Practically current source has high internal resistance in parallel with current source and its resistance is represented by R_{sh}. Due to R_{sh}, current through its terminals decreases slightly with increase in voltage at its terminals.

Note: For ideal current source, $R_{sh} = \infty$



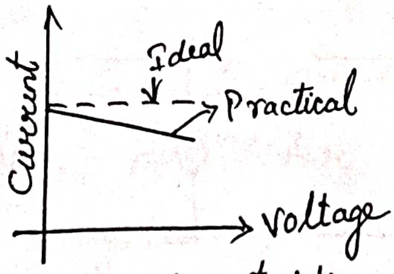
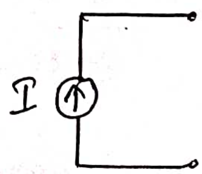
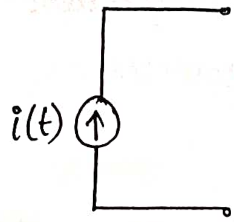


Fig: Practical Current Source

Current sources are further classified as,



D.C. Source (or) time invariant Source



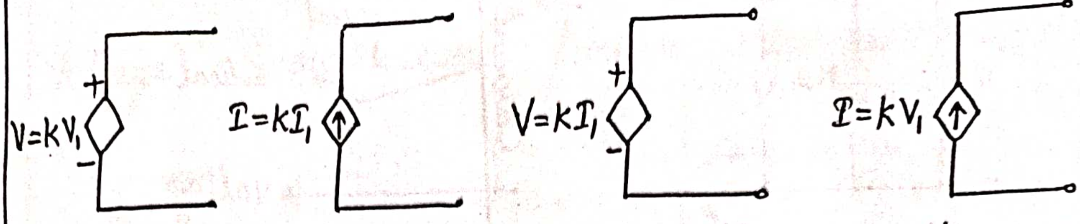
A.C. Source (or) time variant Source

The * sources discussed above are independent sources because these sources does not depend on other voltages or currents in the n/w for their value. These are represented by a circle with a polarity of voltage or direction of current.

Dependent Sources

Dependent sources are those whose value of source depends on voltage or current in the circuit. Such sources are indicated by diamond and further classified as

(a) Voltage dependent voltage source (VDVS)
(b) Current dependent current source (CDCS)
(c) Current dependent voltage source (CDVS)
(d) Voltage dependent current source (VDCS)



(a) VDVS (b) CDCS (c) CDVS (d) VDCS

K is constant and V_1 and I_1 are the voltage and current respectively, present elsewhere in the given circuit. The dependent sources are also known as controlled sources.

Ohm's Law

This law gives relationship between the potential difference (V), the current (I) and the resistance (R) of a d.c. circuit. It states that,

> At constant temperature, the current flowing through the conductor is directly proportional to the voltage across the conductor.
>
> $$V(t) \propto I(t)$$
>
> $$V(t) = R\, I(t)$$
>
> where R is the proportionality constant i.e., Resistance of the conductor

The power absorbed by the resistor is,

$$P(t) = V(t) \cdot i(t)$$

$$= i^2(t) \cdot R$$

$$P(t) = \frac{V^2(t)}{R} \quad [\because V(t) = i(t) \cdot R]$$

Limitations of Ohm's Law:

1. Ohm's law cannot be applied to non-metallic conductors
2. It cannot be applied to non-linear devices such as zener diode, voltage regulator, etc.
3. Ohm's law holds good only for constant temperature. If the temperature changes, the law cannot be applied.

Electrical Energy

Energy is the total amount of work done and hence is the product of power and time.

$$W = Pt = V \cdot I t$$

$$= I^2 R t \text{ joules}$$

$$= \frac{V^2}{R} t \text{ joules (or) Watt-sec}$$

PROBLEMS

1. A resistor with a current of 3A through it converts 500J of electrical energy into heat energy in 12 sec. What is the voltage across resistor?

Solution

$$Energy = V \cdot I \cdot t$$

$$500 = V \cdot 3 \times 12$$

$$V = \frac{500}{3 \times 12}$$

$$\therefore \boxed{V = 13.88\,V}$$

2. A 5Ω resistor has a voltage rating of 100 V, what is its power rating?

Solution

$$\text{Power} = \frac{V^2}{R} = \frac{100^2}{5}$$

$$\boxed{P = 2000\ W}$$

3. An electric heater draws 8A from 250V. What is its power rating? Also find the resistance of the heater element.

Solution

Given: $I = 8\ A$

$V = 250\ V$

$P = ?$

$R = ?$

$P = V \cdot I$

$= 250 \times 8$

$$\boxed{P = 2000\ W}$$

$$R = \frac{V}{I} = \frac{250}{8}$$

$$\boxed{R = 31.25\ \Omega}$$

4. If 50J of energy is available for 20C of charge, what is the voltage?

Given: $W = 50J$, $Q = 20C$

Soln

$$V = \frac{W}{Q} = \frac{50}{20} \quad \therefore \boxed{V = 2.5V}$$

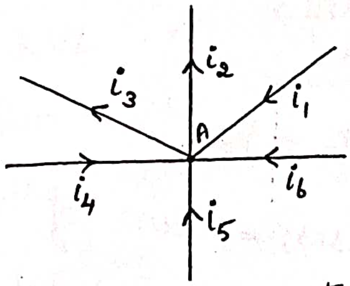
KIRCHOFF'S LAWS

In 1847, a German Physicist, Kirchoff, formulated two fundamental laws of electricity. These laws are of tremendous importance from n/w simplification view point

Kirchoff's Current Law (KCL):

Kirchoff's First Law or Current Law states that,

> The sum of the currents flowing towards a junction is equal to the sum of the currents flowing away from it.
>
> (or)
>
> Algebraic sum of all currents in a node is zero.



Here, A is a junction (or node) formed by six conductors. According to KCL,

$$i_1 + i_4 + i_5 + i_6 = i_2 + i_3$$

flowing towards A = flowing away from A

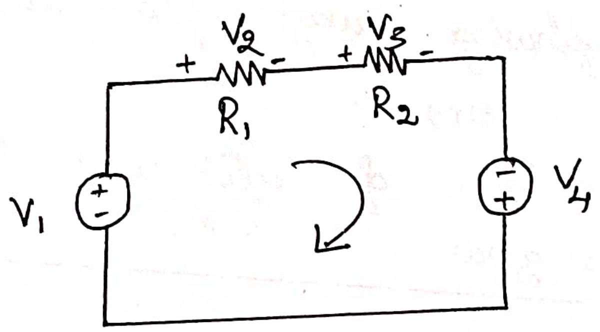
Also, $i_1 - i_2 - i_3 + i_4 + i_5 + i_6 = 0$

By taking the currents entering the jn. as positive and those flowing away from the jn. as negative.

Kirchoff's Voltage Law (KVL):

Kirchoff's second law or Voltage law states that,

In any n/w, the algebraic sum of the voltage drop across the circuit elements of any closed path (or loop or mesh) is equal to the algebraic sum of the voltage rises in the path. (or) The algebraic sum of all the voltages around a closed path (loop) is zero.



According to KVL,

$$V_1 + V_4 = V_2 + V_3$$

Sum of voltage rises = Sum of voltage drops

Also, $V_1 - V_2 - V_3 + V_4 = 0$

i.e., sum of all voltages = 0

Note:

Potential rise or voltage rise i.e., travelling from negative to positive terminal. It is considered as positive.

Potential drop or voltage drop i.e., travelling from positive to negative terminal. It is considered as Negative.

Note:

For passive elements R, L and C the terminal where the current enters is treated as positive with respect to the terminal where the current leaves.

Steps to apply Kirchoff's Laws

Step 1: Draw the circuit diagram and write all the values of sources and resistances.

Step 2: Mark all the branch currents. Keep the no. of unknown currents minimum as far as possible.

If the assumed direction of current is wrong, then the answer of that current will be mathematically negative.

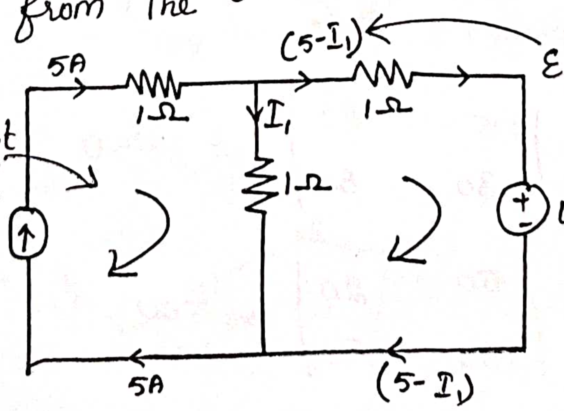
Step 3: Mark the polarities of all the resistances as per the direction of the branch current.

Step 4: Apply KVL to different closed path in the n/w and obtain the equations.

Step 5: Solve the equations for the unknown currents.

Note: While applying KVL, the loops should not be considered involving current source. Because drop across current source is unknown. But current distribution from the current source can be considered.

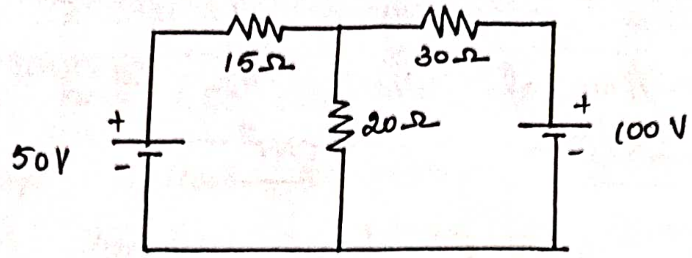
This loop cannot be considered for KVL



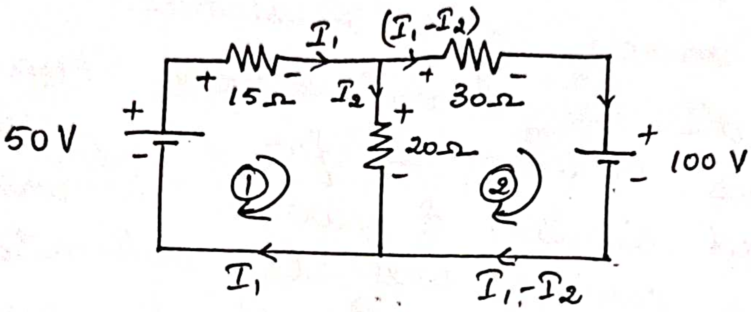
Effect of current source is considered interms of current distribution

PROBLEMS

1. Apply KCL and KVL to the circuit given below,



Solution:



Apply KVL to loop 1,

$$-15I_1 - 20I_2 + 50 = 0$$

$$15I_1 + 20I_2 = 50 \rightarrow ①$$

Apply KVL to loop 2,

$$-30(I_1 - I_2) - 100 + 20I_2 = 0$$

$$-30I_1 + 30I_2 - 100 + 20I_2 = 0$$

$$-30I_1 + 50I_2 = 100 \rightarrow ②$$

Apply Cramer's Rule,

$$D = \begin{vmatrix} 15 & 20 \\ -30 & 50 \end{vmatrix} = 1350$$

$$D_1 = \begin{vmatrix} 50 & 20 \\ 100 & 50 \end{vmatrix} = 500$$

$$I_1 = \frac{D_1}{D} = \frac{500}{1350} = 0.37A$$

$$D_2 = \begin{vmatrix} 15 & 50 \\ -30 & 100 \end{vmatrix} = 3000$$

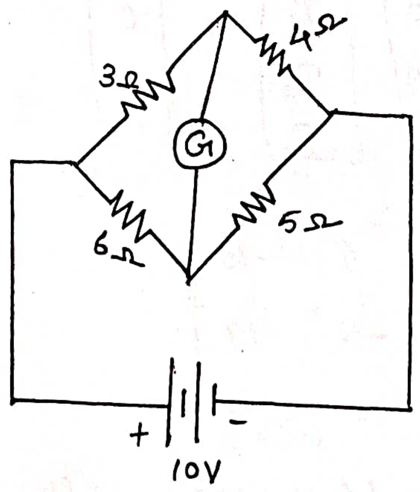
$$I_2 = \frac{D_2}{D} = \frac{3000}{1350} = 2.22\,A$$

For I_1 and I_2 answer is positive and hence assumed direction is correct.

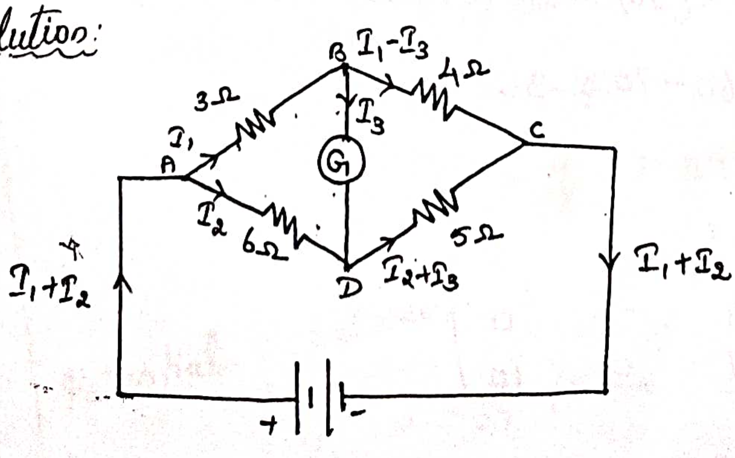
$$I_1 - I_2 = 0.37 - 2.22$$
$$= -1.85\,A$$

Negative sign indicates assumed direction is wrong.
i.e., $I_1 - I_2 = 1.85\,A$ flows in the opposite direction to that of the assumed direction.

2. In the Wheatstone bridge circuit, G is a galvanometer of resistance $10\,\Omega$. Find the current through it.



Solution:



Apply KVL in loop ABDA,

$$-3I_1 - 10I_3 + 6I_2 = 0$$

Apply KVL in loop BDCB,

$$-10I_3 - 5(I_2 + I_3) + 4(I_1 - I_3) = 0$$

$$-10I_3 - 5I_2 - 5I_3 + 4I_1 - 4I_3 = 0$$

$$4I_1 - 5I_2 - 19I_3 = 0$$

Apply KVL in loop ABCA,

$$-3I_1 - 4(I_1 - I_3) + 10 = 0$$

$$-3I_1 - 4I_1 + 4I_3 = -10$$

$$-7I_1 + 4I_3 = -10$$

$$7I_1 - 4I_3 = 10$$

By applying Cramer's rule,

$$\begin{bmatrix} -3 & 6 & -10 \\ 4 & -5 & -19 \\ 7 & 0 & -4 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 10 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} -3 & 6 & -10 \\ 4 & -5 & -19 \\ 7 & 0 & -4 \end{vmatrix}$$

$$= -3(20) - 6(-16+133) - 10(0+35)$$

$$= -60 - 702 - 350$$

$$= -1112$$

$$\Delta I_3 = \begin{vmatrix} -3 & 6 & 0 \\ 4 & -5 & 0 \\ 7 & 0 & 10 \end{vmatrix}$$

$= -3(-50) - 6(40)$

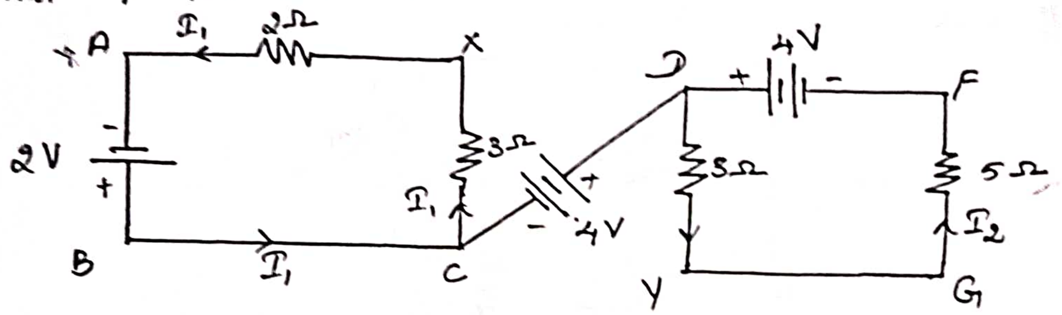
$= -90$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{-90}{-1112}$$

$= 0.0809\ A$

$\therefore$ Current through galvanometer $= 0.0809\ A$

3. What is the difference in potential between points X and Y in the circuit shown below



Solution:

For loop ABCXA,

$2 - 3I_1 - 2I_1 = 0$

$2 - 5I_1 = 0$

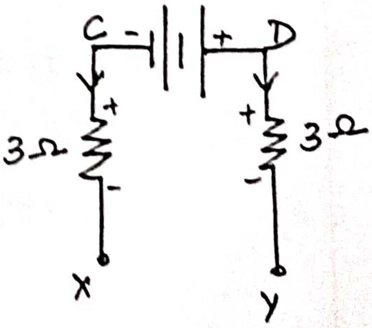
$I_1 = \frac{2}{5} = 0.4A$

For loop DYGFD,

$-3I_2 - 5I_2 + 4 = 0$

$-8I_2 = -4$

$I_2 = \frac{4}{8} = 0.5A$



Potential between X and Y $= V_{XC} + V_{CD} + V_{DY}$

$V_{XC} = 3I_1$ (rise)

$= 3 \times 0.4 = 1.2\ V$

$V_{CD} = 4\ V$ (rise)

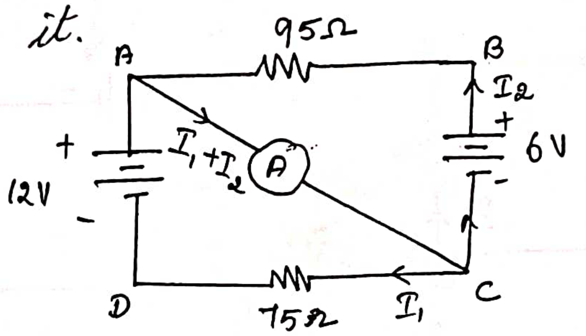
$V_{DY} = 3 I_2$ (drop)

$= 3 \times 0.5 = 1.5\ V$

$\therefore\ V_{XY} = 1.2 + 4 - 1.5$ (Since V_{DY} is a drop)

$= 3.7\ V$ (rise from x to y)

4. In the circuit, A is a milliammeter of resistance 5Ω. Find the direction and magnitude of current through it.



Solution:

For loop ACDA,

$$-5(I_1 + I_2) - 75 I_1 + 12 = 0$$

$$-5I_1 - 5I_2 - 75 I_1 = -12$$

$$-80 I_1 - 5 I_2 = -12$$

$$80 I_1 + 5 I_2 = 12$$

For loop ACBA,

$$-5(I_1 + I_2) + 6 - 95 I_2 = 0$$

$$-5 I_1 - 5 I_2 + 6 - 95 I_2 = 0$$

$$-5 I_1 - 100 I_2 = -6$$

$$5 I_1 + 100 I_2 = 6$$

(12)

By applying Cramer's rule,

$$\begin{bmatrix} 80 & 5 \\ 5 & 100 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 12 \\ 6 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 80 & 5 \\ 5 & 100 \end{vmatrix} = 7975$$

$$\Delta I_1 = \begin{vmatrix} 12 & 5 \\ 6 & 100 \end{vmatrix} = 1170$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{1170}{7975} = 0.1467A$$

$$\Delta I_2 = \begin{vmatrix} 80 & 12 \\ 5 & 6 \end{vmatrix} = 420$$

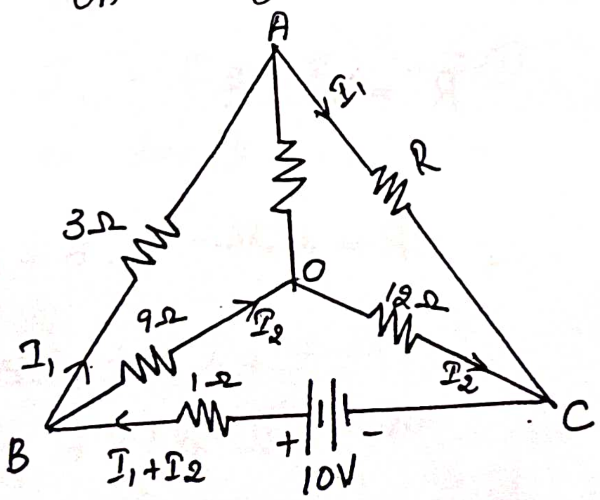
$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{420}{7975} = 0.0526A$$

Current through ammeter $= I_1 + I_2$

$= 0.1467 + 0.0526$

$I = 0.1993A$

5. In the circuit it is given that the current in the branch OA is zero. Find R and current in it.



Solution:

Since there is no current in OA, the current I_1 in BA flows to AC.

For loop BOCB,

$$-9I_2 - 12I_2 + 10 - 1(I_1 + I_2) = 0$$

$$-21I_2 + 10 - I_1 - I_2 = 0$$

$$-I_1 - 22I_2 = -10$$

$$I_1 + 22I_2 = 10 \rightarrow (1)$$

For BAOB,

$$-3I_1 + 9I_2 = 0$$

$$-3I_1 = -9I_2$$

$$I_1 = 3I_2 \rightarrow (2)$$

Sub. eq. (2) in eq. (1),

$$I_2 = \frac{10}{25} = 0.4\ A$$

$$I_1 = 3 \times 0.4$$

$$= 1.2\ A$$

At Balance,

$$\frac{3}{9} = \frac{R}{12}$$

$$R = \frac{3 \times 12}{9}$$

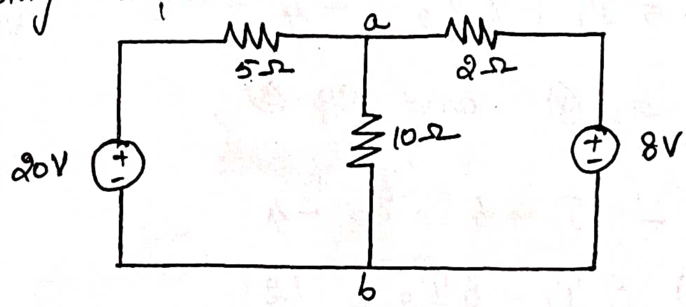
$$\therefore R = 4\ \Omega$$

Branch current Method

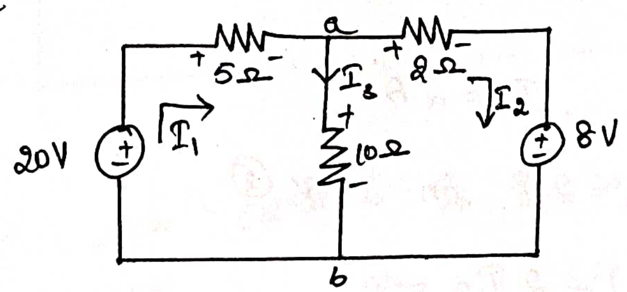
In branch current method a current is assigned to each branch in an active n/w. Then KCL is applied at the principal nodes and the Voltages b/w the nodes employed to relate the currents. This produces the equations which can be solved to obtain the currents.

PROBLEM

1. Obtain the current in each branch of the given n/w using branch current method.



Solution



Currents I_1, I_2 and I_3 are assigned to branches.

Apply KCL at node a,

$$I_1 = I_2 + I_3 \rightarrow (1) \qquad \Rightarrow I_3 = I_1 - I_2$$

Apply KVL to loop (1),

$$20 - 5I_1 - 10I_3 = 0$$

$$5I_1 + 10I_3 = 20$$

$$5I_1 + 10(I_1 - I_2) = 20 \qquad \because I_3 = I_1 - I_2$$

$$5I_1 + 10I_1 - 10I_2 = 20$$

$$15I_1 - 10I_2 = 20$$

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

Apply KVL in loop (2),

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

$$2I_2 - 10(I_1 - I_2) = -8 \quad \because I_3 = I_1 - I_2$$

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

$$-10I_1 + 12I_2 = -8$$

$$-5I_1 + 6I_2 = -4 \rightarrow (3)$$

Solving eq.(2) and eq.(3),

$$(3) \Rightarrow -5I_1 + 6I_2 = -4$$

$$3 \times (2) \Rightarrow 9I_1 - 6I_2 = 12$$

$$4I_1 = 8$$

$$\therefore I_1 = 2A$$

Put $I_1 = 2A$ in eq (2),

$$3(2) - 2I_2 = 4$$

$$-2I_2 = 4 - 6$$

$$I_2 = 1A$$

$$I_3 = I_1 - I_2$$

$$= 2 - 1$$

$$\therefore I_3 = 1A.$$

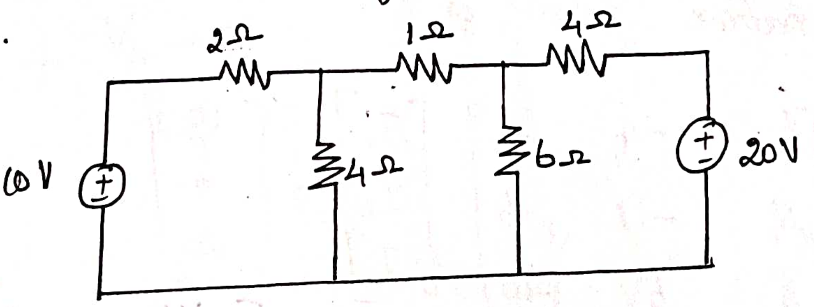
$\therefore I_1 = 2A$, $I_2 = 1A$ and $I_3 = 1A$

Mesh Current Method (or) Mesh Analysis (or) Loop Analysis

This method of analysis is specially useful for the circuits that have many nodes and loops. The difference b/w application of Kirchoff's laws and loop analysis is, in loop analysis instead of branch currents, the loop currents are considered for writing the equations. Here, each branch of the n/w may carry more than one current. The total current must be decided by the algebraic sum of all currents through that branch.

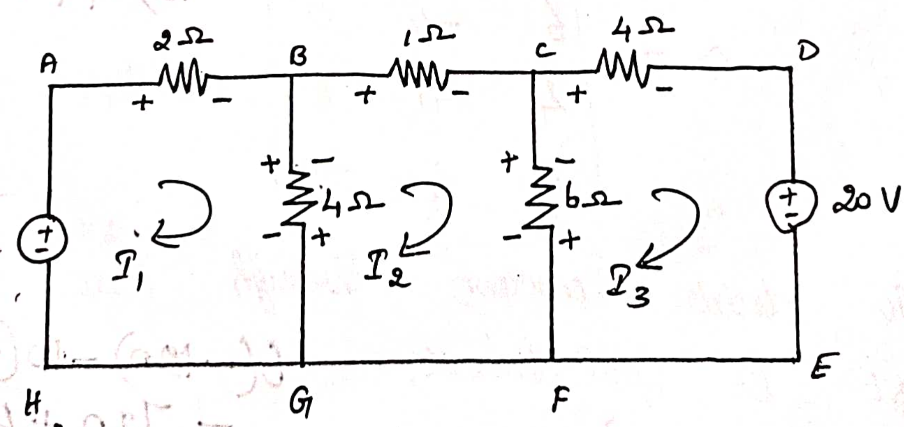
PROBLEM

1. Calculate current through 6 Ω resistance using loop analysis.



Solution:

Assume loop currents I_1, I_2 and I_3.



Also show the polarities of voltage drops for each loop assuming the loop currents

Apply KVL in loop 1,

$$-2I_1 - 4(I_1 - I_2) + 10 = 0$$

$$6I_1 - 4I_2 = 10 \rightarrow (1)$$

Apply KVL in loop 2,

$$-1I_2 - 6(I_2 - I_3) - 4(I_2 - I_1) = 0$$

$$4I_1 - 11I_2 + 6I_3 = 0 \rightarrow (2)$$

Apply KVL in loop 3,

$$-4I_3 - 20 - 6(I_3 - I_2) = 0$$

$$6I_2 - 10I_3 = 20 \rightarrow (3)$$

The matrix form is,

$$\begin{bmatrix} 6 & -4 & 0 \\ 4 & -11 & 6 \\ 0 & 6 & -10 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 10 \\ 0 \\ 20 \end{bmatrix}$$

Apply Cramer's Rule,

$$6[(-11 \times -10) - 36] - (-4)[-40]$$

$$\Rightarrow 444 - 160$$

$$\Delta = \begin{vmatrix} 6 & -4 & 0 \\ 4 & -11 & 6 \\ 0 & 6 & -10 \end{vmatrix} = 284$$

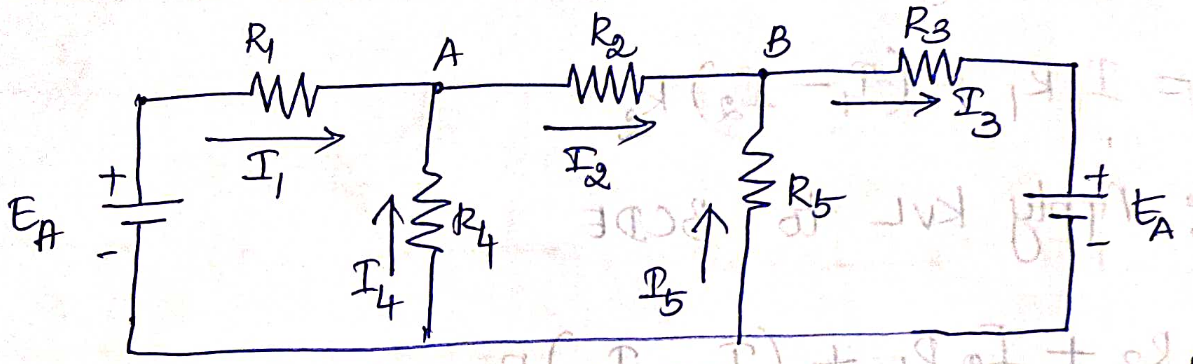
To decide current through 6Ω, I_2 and I_3 must be calculated,

$$6(-120) - 10(-40)$$

$$-720 + 400$$

$$\Delta I_2 = \begin{vmatrix} 6 & 10 & 0 \\ 4 & 0 & 6 \\ 0 & 20 & -10 \end{vmatrix} = -320$$

Nodal Method (Nodal Analysis) - KCL.



- Consider principal nodes (A and B). The ground is considered as zero.
- The voltage at node A is V_A and node B is V_B.

* At Node A: Apply KCL.

$$I_1 + I_4 - I_2 = 0$$

$$\frac{V_A - E_A}{R_1} + \frac{V_A - 0}{R_4} - \left(\frac{V_B - V_A}{R_2}\right) = 0.$$

$$V_A\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_4}\right) - V_B\left(\frac{1}{R_2}\right) = \frac{E_A}{R_1} \longrightarrow (1)$$

* At node B: Apply KCL.

$$I_2 + I_5 - I_3 = 0$$

$$\frac{V_B - V_A}{R_2} + \frac{V_B - 0}{R_5} - \left[\frac{E_B - V_B}{R_3}\right] = 0$$

$$-V_A\left[\frac{1}{R_2}\right] + V_B\left[\frac{1}{R_2} + \frac{1}{R_5} + \frac{1}{R_3}\right] = \frac{E_B}{R_3} \longrightarrow (2)$$

Mesh 1 :- Apply KVL to ABEF

$$V = I_1 R_1 + (I_1 - I_2) R_2$$

Mesh 2 : Apply KVL to BCDE

$$I_2 R_3 + I_2 R_4 + (I_2 - I_1) R_2 = 0$$

* Rearrange the eqn based on I_1 and I_2

$$(R_1 + R_2) I_1 - R_2 I_2 = V$$

$$-R_2 I_1 + (R_2 + R_3 + R_4) I_2 = 0$$

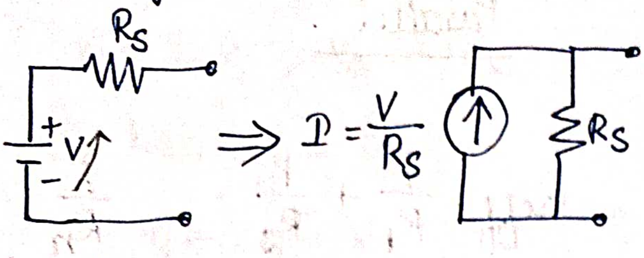
* write eqn in matrix form

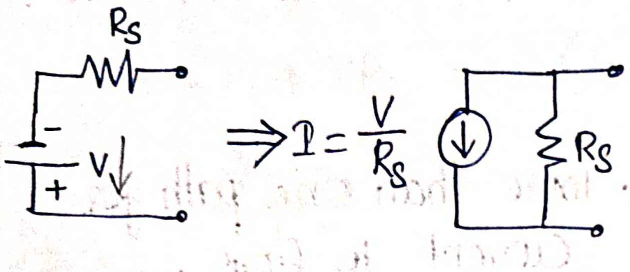
$$\begin{bmatrix} R_1 + R_2 & -R_2 \\ -R_2 & R_2 + R_3 + R_4 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} V \\ 0 \end{bmatrix}$$

* Using cramer's rule to find the value of I_1 and I_2.

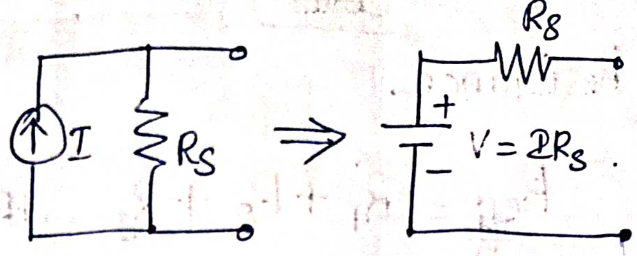
Source Transformation

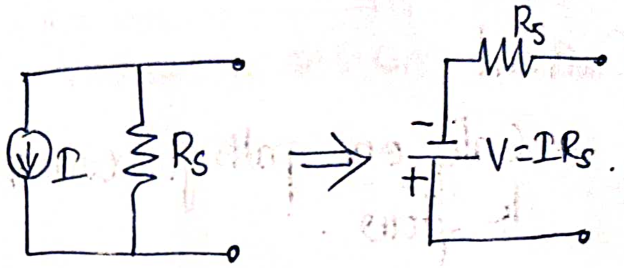
Voltage to Current





Current to voltage source



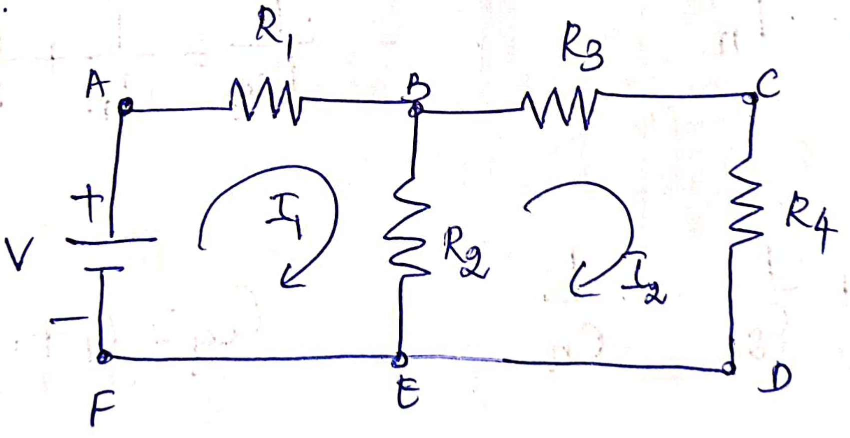


* Voltage source in series with resistor is transformed to resistor in parallel with current

* if current source has resistance connected in parallel, it is transformed into equivalent voltage source with resistor in series

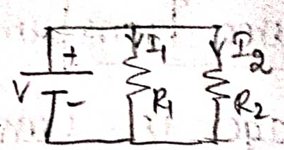
Mesh and Nodal Analysis

Mesh Analysis: In mesh method, KVL is applied to the network.

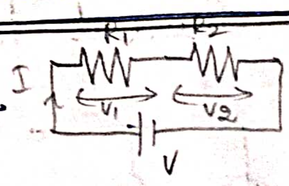


* Fig consists of two meshes ABEF and BCDE the current through each mesh is I_1 and I_2.
(Identify node, give notation alphabet letter for each node
Identify the no. of meshes in the circuit)

Difference b/w series & Parallel circuit



Series	Parallel



* Resistance

$$R_{eff} = R_1 + R_2 + R_3 \ldots + R_n$$

$$R_{eff} = \frac{1}{R_1} + \frac{1}{R_2} \ldots \frac{1}{R_n}$$

* Current

Series:
- Only one path for current to flow.
- current in all resistor is same

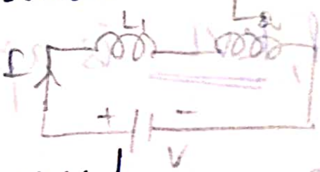
Parallel:
- more than one path for current to flow.
- current flowing through each resistor is different

* Voltage

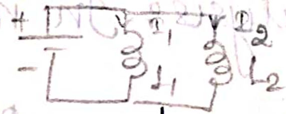
Series:
- voltage is divided across each resistor

Parallel:
- voltage across each resistor is same.

* Inductance

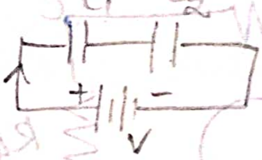


$$L_{eq} = L_1 + L_2 \ldots L_n.$$

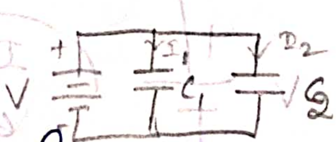


$$- \frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \ldots + \frac{1}{L_n}$$

* Capacitance

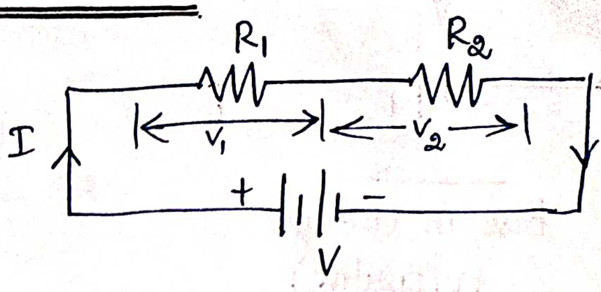


$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} \ldots \frac{1}{C_n}$$



$$C_{eq} = C_1 + C_2 + \ldots + C_n.$$

Division of Voltage in Series Circuit



By ohm's law.

$V_1 = I_1 R_1$; $V_2 = IR_2$

By Kirchoff's law

$V_1 + V_2 = V$

$V = IR_1 + IR_2 = I(R_1 + R_2)$

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

To find V_1 ; $(I_1 = V/R_1)$

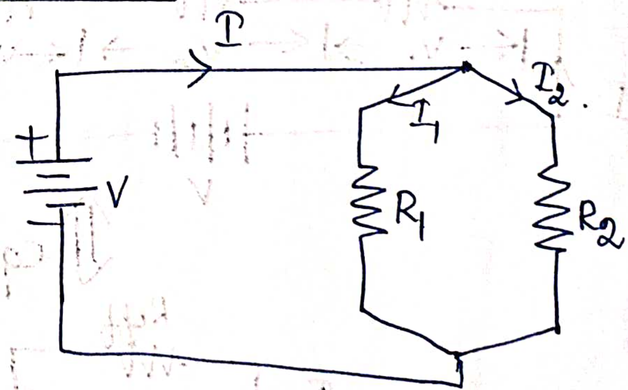
$$V_1 = \left(\frac{V}{R_1+R_2}\right) R_1$$

$$V_2 = \frac{V}{R_1+R_2} \cdot R_2.$$

Voltage across one of the resistors =

$$\frac{\text{Total voltage} * \text{Value of particular resistor}}{\text{sum of individual Resistors}}.$$

Division of current in parallel circuit



$I = I_1 + I_2$

$V = I_1 R_1 = I_2 R_2$.

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

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

$= I_1 (1 + R_1/R_2)$

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

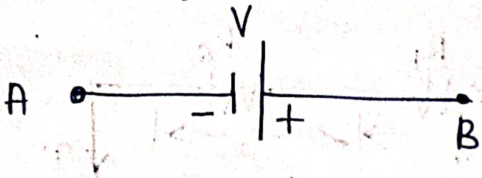
$$I_1 = I \cdot \frac{R_2}{R_1 + R_2}$$

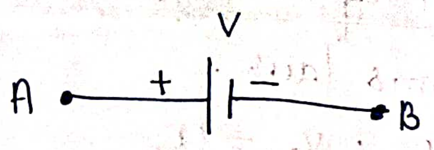
$$I_2 = I \frac{R_1}{R_1 + R_2}$$

Current in branch =

$$\frac{\text{total current} * \text{opp branch resistor value}}{\text{Total resistances}}.$$

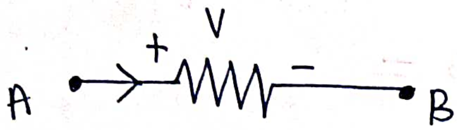
Sign of EMFs

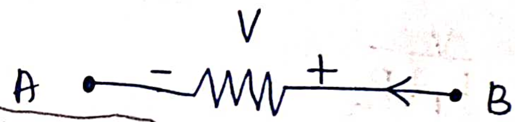




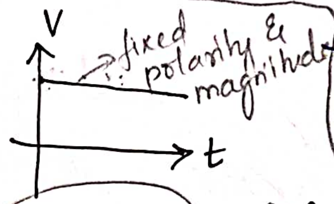
* Rise in voltage +V (positive) → Fall in voltage −V (negative).

Sign of Voltage Drops



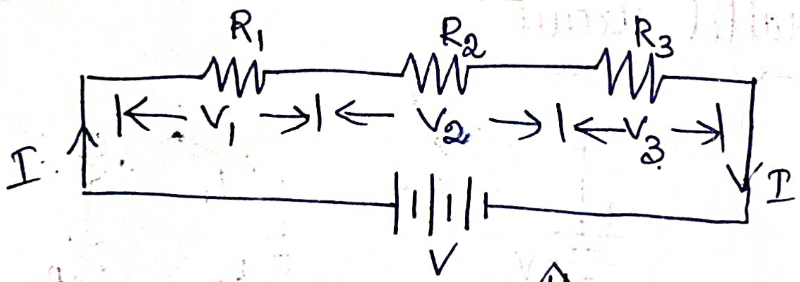


* Fall in voltage −V (negative) → Rise in voltage +V (positive)



Steady State Solutions of DC Circuits : Current & voltage sources have fixed polarity & a constant magnitude.

* Resistors in series.

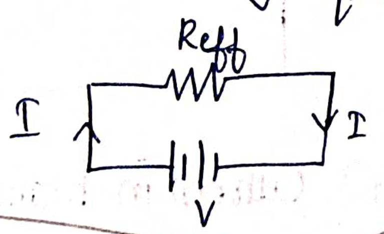


By ohms law.

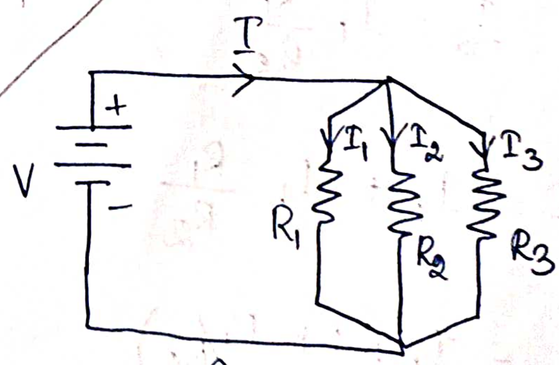
$$V = I(R_1 + R_2 + R_3)$$

$$R_{eff} = R_1 + R_2 + R_3$$

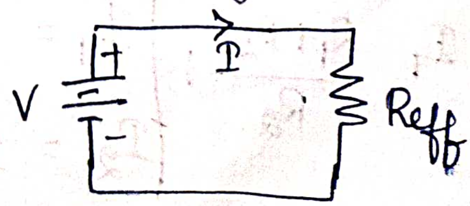
⇕ equivalent to



* Resistance in parallel.



⇕



By ohm's law.

$$I = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

$$R_{eff} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

* Rearrange ① & ②

$$\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_4}\right)V_A-\left(\frac{1}{R_2}\right)V_B=\frac{E_A}{R_1}$$

$$-\left(\frac{1}{R_2}\right)V_A+\left(\frac{1}{R_2}+\frac{1}{R_5}+\frac{1}{R_3}\right)V_B=\frac{E_B}{R_3}$$

* In matrix format.

$$\begin{bmatrix} 1/R_2+1/R_1+1/R_4 & -1/R_2 \\ -1/R_2 & 1/R_2+1/R_3+1/R_5 \end{bmatrix}\begin{bmatrix} V_A \\ V_B \end{bmatrix}=\begin{bmatrix} E_A/R_1 \\ E_B/R_3 \end{bmatrix}$$

* Use Cramer's rule, find the value of V_A and V_B

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{-320}{284} = -1.1267\ A$$

$$\Delta I_3 = \begin{vmatrix} 6 & -4 & 10 \\ 4 & -11 & 0 \\ 0 & 6 & 20 \end{vmatrix} = -760$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{-760}{284} = -2.676\ A$$

Current through $6\Omega = I_2 - I_3$

$= -1.1267 + 2.676$

$= 1.5493\ A$ [from C to F]

Mesh Equations By Inspection Method

The procedure for writing the mesh equation in matrix form can be simplified as follows.

① Convert current source into equivalent voltage source by source transformation.

② All the resistance through which I_1 flows are summed up and denoted by R_{11}. It is called self resistance of loop 1.

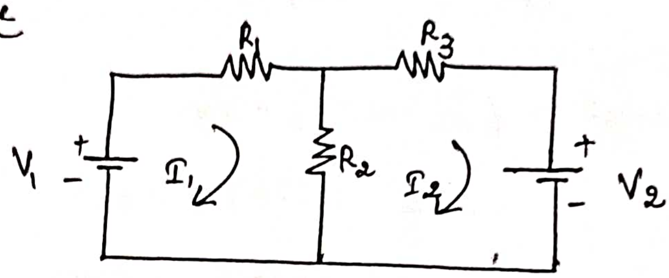
③ R_{12} is the mutual resistance through which loop currents I_1 in the first loop and I_2 in the second loop flows. The sign of R_{12} is negative if two currents I_1 and I_2 flow in opposite direction, otherwise the sign is positive.

④ Let V_1 be the effective voltage on the first loop through which the loop current I_1 flows. It is written on the right hand side of the equation. Zero, is written if there is no source.

The general matrix form of mesh equation is

$$\begin{bmatrix} R_{11} & R_{12} \\ R_{12} & R_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

<u>Example</u>



By using inspection method the matrix form is

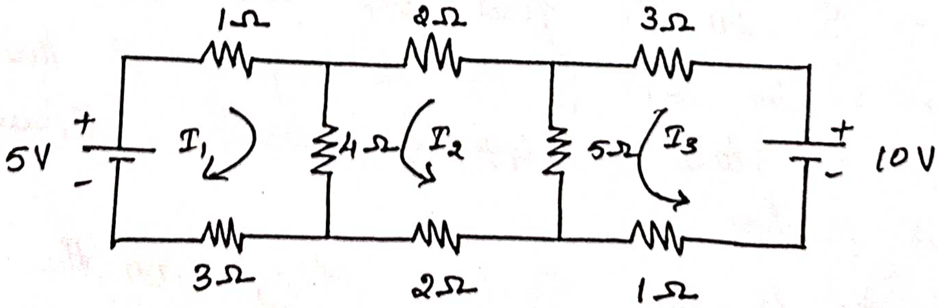
$$\begin{bmatrix} R_1+R_2 & -R_2 \\ -R_2 & R_2+R_3 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} V_1 \\ -V_2 \end{bmatrix}$$

$R_{11} = R_1 + R_2$
$R_{22} = R_2 + R_3$
} self resistances

$R_{12} = R_{21} = -R_2$ → mutual resistance

<u>PROBLEM</u>

1. Find the power supplied by each of the voltage source in the ckt using mesh inspection method.



(16)

Solution

$$R_{11} = 1+4+3 = 8\,\Omega$$

$$R_{22} = 2+4+2+5 = 13\,\Omega$$

$$R_{33} = 3+5+1 = 9\,\Omega$$

$R_{12} = R_{21} = 4\,\Omega$ (current flows in same direction)

$$R_{13} = R_{31} = 0$$

$R_{23} = R_{32} = -5\,\Omega$ (opposite direction)

$V_1 = 5V$, $V_2 = 0V$, $V_3 = 10V$

The general matrix form is,

$$\begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

$$\therefore \begin{bmatrix} 8 & 4 & 0 \\ 4 & 13 & -5 \\ 0 & -5 & 9 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 5 \\ 0 \\ 10 \end{bmatrix}$$

By applying Cramer's rule, we can find I_1 & I_3

$$\Delta = \begin{vmatrix} 8 & 4 & 0 \\ 4 & 13 & -5 \\ 0 & -5 & 9 \end{vmatrix} = 592$$

$$\Delta I_1 = \begin{vmatrix} 5 & 4 & 0 \\ 0 & 13 & -5 \\ 10 & -5 & 9 \end{vmatrix}$$

$$= 5(117-25) - 4(0+50)$$

$$= 260$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{260}{592} = 0.439\,A$$

$$\Delta I_3 = \begin{vmatrix} 8 & 4 & 5 \\ 4 & 13 & 0 \\ 0 & -5 & 10 \end{vmatrix}$$

$$= 8(130) - 4(40) + 5(-20)$$

$$= 780$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{780}{592} = 1.3175\,A$$

Power supplied by 5V source $= 5 \times I_1$

$= 5 \times 0.439$

$= 2.195\,W$

Power supplied by 10V source $= 10 \times I_3$

$= 10 \times 1.3175$

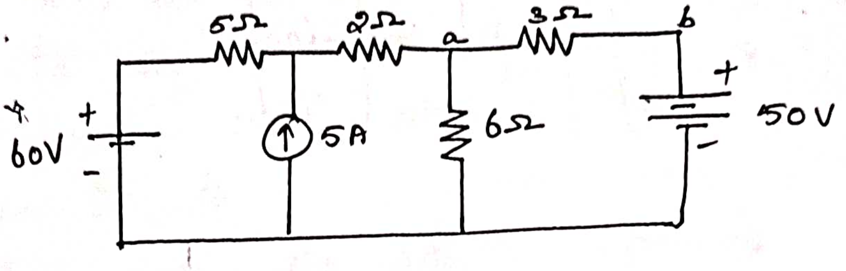
$= 13.175\,W$

Supermesh

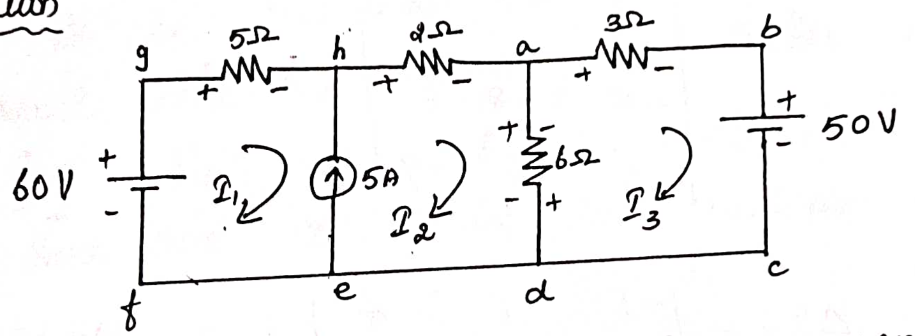
If there exists a current source in any of the branches of the n/w then a loop cannot be defined through the current source as drop across the current source is unknown, from KVL point of view. In such case, analyse the branch consisting of a current source independently. Then apply KVL to the remaining loop which are existing without involving the branches consisting of current sources. The loop existing, around a current source which is common to the two loops is called supermesh.

PROBLEM

1. Find the current through branch a-b using mesh analysis.



Solution



As branch h-e consist of a current source, before applying KVL, analyse the branch h-e separately.

$I_2 - I_1 = 5$ → (1)   [∵ I_2 direction is same as that of current source and so it should be greater]

Now applying KVL to other loops without considering the current source we get eqns as follows.

For loop g-h-a-d-e-f-g,

$$-5I_1 - 2I_2 - 6I_2 + 6I_3 + 60 = 0$$

$$-5I_1 - 8I_2 + 6I_3 = -60 \rightarrow (2)$$

For loop a-b-c-d-a,

$$-3I_3 - 50 - 6I_3 + 6I_2 = 0$$

$$6I_2 - 9I_3 = 50 \rightarrow ②$$

The matrix form is

$$\begin{bmatrix} -1 & 1 & 0 \\ -5 & -8 & 6 \\ 0 & 6 & -9 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 5 \\ -60 \\ 50 \end{bmatrix}$$

Apply Cramer's rule,

$$\Delta = \begin{vmatrix} -1 & 1 & 0 \\ -5 & -8 & 6 \\ 0 & 6 & -9 \end{vmatrix} = -81$$

$$\Delta I_3 = \begin{vmatrix} -1 & 1 & 5 \\ -5 & -8 & -60 \\ 0 & 6 & 50 \end{vmatrix} = 140$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{140}{-81} = -1.7283\ A$$

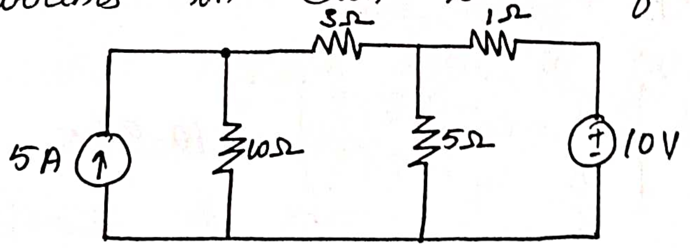
So current through branch a-b is 1.7283 A flowing from b to a.

Nodal Analysis or Node Voltage Method

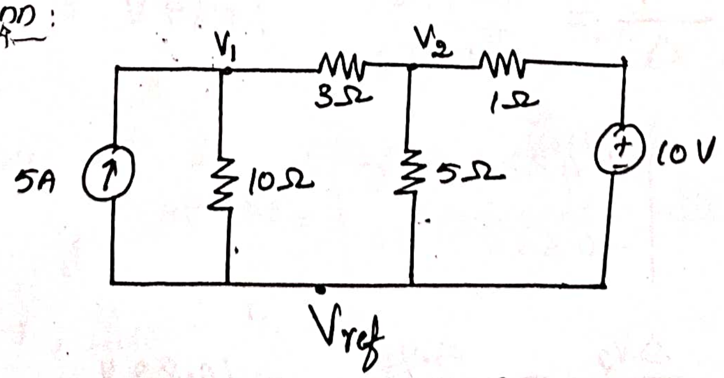
This method is mainly based on Kirchoff's Current law (KCL). This method uses the analysis of the different nodes of the n/w. Every jn. point in a n/w, where two or more branches meet is called a node. One of the node is assumed as reference node whose potential is assumed to be zero. It is also called zero potential node or datum node. At other nodes the different voltages are to be measured with respect to this reference node. The advantage of this method lies in the fact that we get $(n-1)$ equations to solve if there are 'n' nodes. This reduces calculation.

PROBLEM

1. Write the node voltage equation and determine the currents in each branch for the gn. n/w.



Solution:



V_{ref}

(Base or Reference Node)

Apply KCL at node 1,

$$5 = \frac{V_1}{10} + \frac{V_1 - V_2}{3}$$

$$V_1\left(\frac{1}{10} + \frac{1}{3}\right) - V_2\left(\frac{1}{3}\right) = 5$$

Apply KCL at node 2,

$$\left(\frac{V_2 - V_1}{3}\right) + \frac{V_2}{5} + \frac{V_2 - 10}{1} = 0$$

$$-V_1\left(\frac{1}{3}\right) + V_2\left(\frac{1}{3} + \frac{1}{5} + 1\right) = 10$$

The matrix form is,

$$\begin{bmatrix} 0.433 & -0.333 \\ -0.333 & 1.533 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 5 \\ 10 \end{bmatrix}$$

By Using Cramer's Rule,

$$\Delta = \begin{vmatrix} 0.433 & -0.333 \\ -0.333 & 1.533 \end{vmatrix} = 0.5529$$

$$\Delta V_1 = \begin{vmatrix} 5 & -0.333 \\ 10 & 1.533 \end{vmatrix} = 10.995$$

$$V_1 = \frac{\Delta V_1}{\Delta} = \frac{10.995}{0.5529} = 19.89\,V$$

$$\Delta V_2 = \begin{vmatrix} 0.433 & 5 \\ -0.333 & 10 \end{vmatrix} = 5.98$$

$$V_2 = \frac{\Delta V_2}{\Delta} = \frac{5.98}{0.5529} = 10.82\,V$$

Current through 10Ω resistor $= \frac{V_1}{10} = 1.989$ A

Current through 3Ω resistor $= \frac{V_1 - V_2}{3} = 3.02$ A

Current through 5Ω resistor $= \frac{V_2}{5} = 2.16$ A

Current through 1Ω resistor $= \frac{V_2 - 10}{1} = 0.82$ A

Node equations by inspection method

The following steps are used in writing the node equations in matrix form.

① Convert all voltage sources to equivalent current sources.

② The conductances of all branches connected to node 1 are added and denoted by G_{11}. G_{11} is called the self conductance of node 1.

③ All the conductances connected to nodes 1 and 2 are added and denoted by G_{12}. G_{12} is called mutual conductance of nodes 1 and 2. This G_{12} is written with negative sign. If no conductance is connected between nodes 1 and 2 then $G_{12} = 0$.

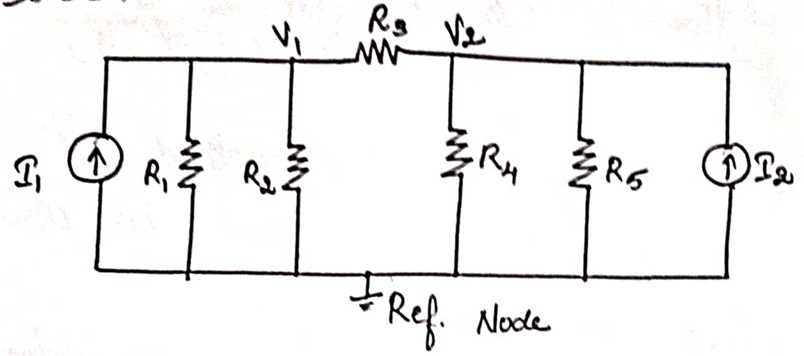
④ I_1 denotes the value of the current source current to node 1 and is written on the right hand side of the equation. The sign I_1 is positive if it is flowing towards node 1, otherwise it is negative. If no current source is connected to node 1, then $I_1 = 0$.

Note: $G_{12} = G_{21}$

The general matrix form of node eqn. is

$$\begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

Example.



By using inspection method the matrix form is

$$\begin{bmatrix} \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} & -\frac{1}{R_3} \\ -\frac{1}{R_3} & \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

$$\left.\begin{aligned} G_{11} &= \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \\ G_{22} &= \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} \end{aligned}\right\} \text{Self conductance}$$

$$G_{12} = G_{21} = -\frac{1}{R_3} \rightarrow \text{Mutual Conductance}$$

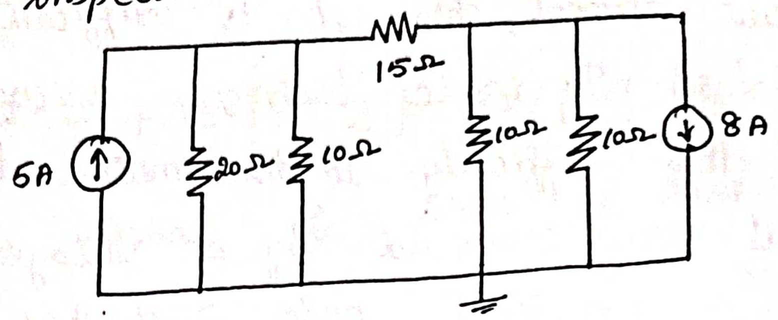
Note: Conductance is the inverse of resistance and it is denoted by G. The unit is ℧ (mho).

$$G = \frac{1}{R}$$

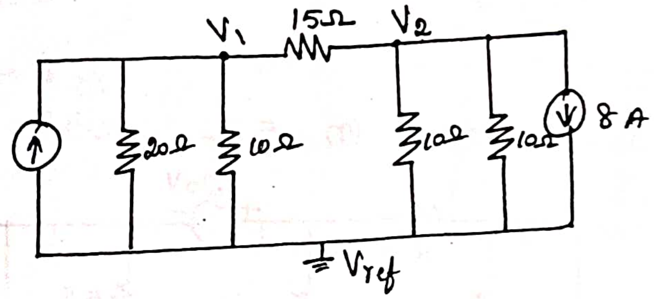
20

PROBLEM

1. Write the matrix form of the given circuit using inspection method (nodal analysis)



Solution



At node 1, current is 5A

At node 2, current is −8A

Node eqn. in matrix form by inspection method,

$$\begin{bmatrix} \frac{1}{20}+\frac{1}{10}+\frac{1}{15} & \frac{-1}{15} \\ \frac{-1}{15} & \frac{1}{15}+\frac{1}{10}+\frac{1}{10} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 5 \\ -8 \end{bmatrix}$$

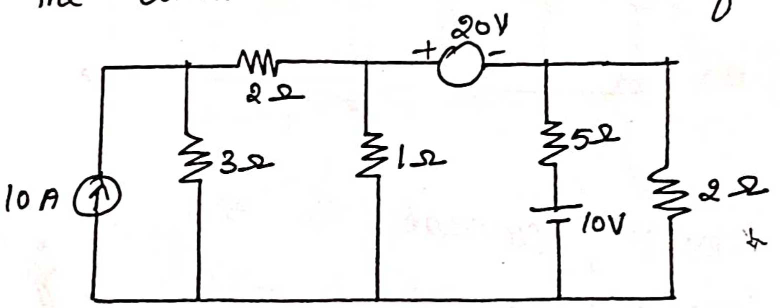
$$\begin{bmatrix} 0.216 & -0.066 \\ -0.066 & 0.266 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 5 \\ -8 \end{bmatrix}$$

Super Node Analysis

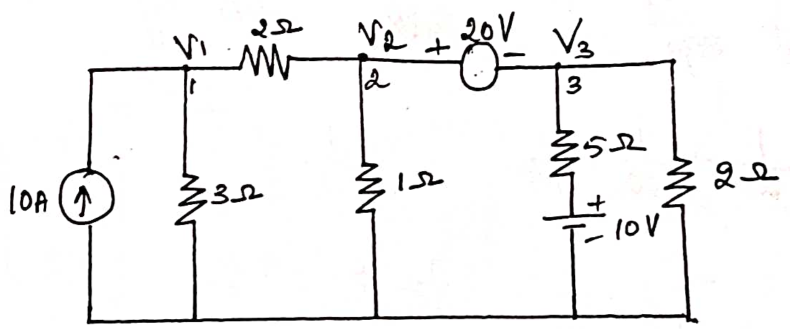
If a n/w has a single voltage source without any circuit element, then it is difficult to apply nodal analysis. Supernode technique is used to overcome this difficulty. In this method, two adjacent nodes that are connected by a voltage source are reduced to a single node and KCL is applied. The single voltage source is analysed separately.

PROBLEM

1. Determine the current in 5Ω resistor for the gn. ckt:



Solution



At node 1 applying KCL,

$$10 = \frac{V_1}{3} + \frac{V_1 - V_2}{2}$$

i.e., $V_1\left[\frac{1}{3} + \frac{1}{2}\right] - V_2\left[\frac{1}{2}\right] = 10 \longrightarrow (1)$

(Q1) At nodes 2 and 3, the Super node eqn. is

$$\frac{V_2}{1} + \frac{V_2 - V_1}{2} + \frac{V_3 - 10}{5} + \frac{V_3}{2} = 0$$

i.e., $-\frac{V_1}{2} + V_2\left[1 + \frac{1}{2}\right] + V_3\left[\frac{1}{5} + \frac{1}{2}\right] = 2 \rightarrow (2)$

Voltage across the nodes 2 and 3 is

$V_2 - V_3 = 20 \rightarrow (3)$

In matrix form,

$$\begin{bmatrix} 0.833 & -0.5 & 0 \\ -0.5 & 1.5 & 0.7 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 10 \\ 2 \\ 20 \end{bmatrix}$$

By Cramer's Rule,

$$\Delta = \begin{vmatrix} 0.833 & -0.5 & 0 \\ -0.5 & 1.5 & 0.7 \\ 0 & 1 & -1 \end{vmatrix} = -1.5826$$

$$\Delta V_3 = \begin{vmatrix} 0.833 & -0.5 & 10 \\ -0.5 & 1.5 & 2 \\ 0 & 1 & 20 \end{vmatrix} = 13.324$$

$$V_3 = \frac{\Delta V_3}{\Delta} = \frac{13.324}{-1.5826} = -8.42\ V$$

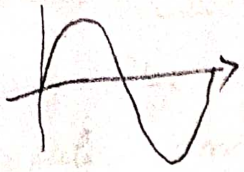
∴ Current in 5Ω resistor $= \frac{V_3 - 10}{5}$

$$= \frac{-8.42 - 10}{5} = -3.684\ A$$

∴ Current = 3.684 A [flowing towards node 3]

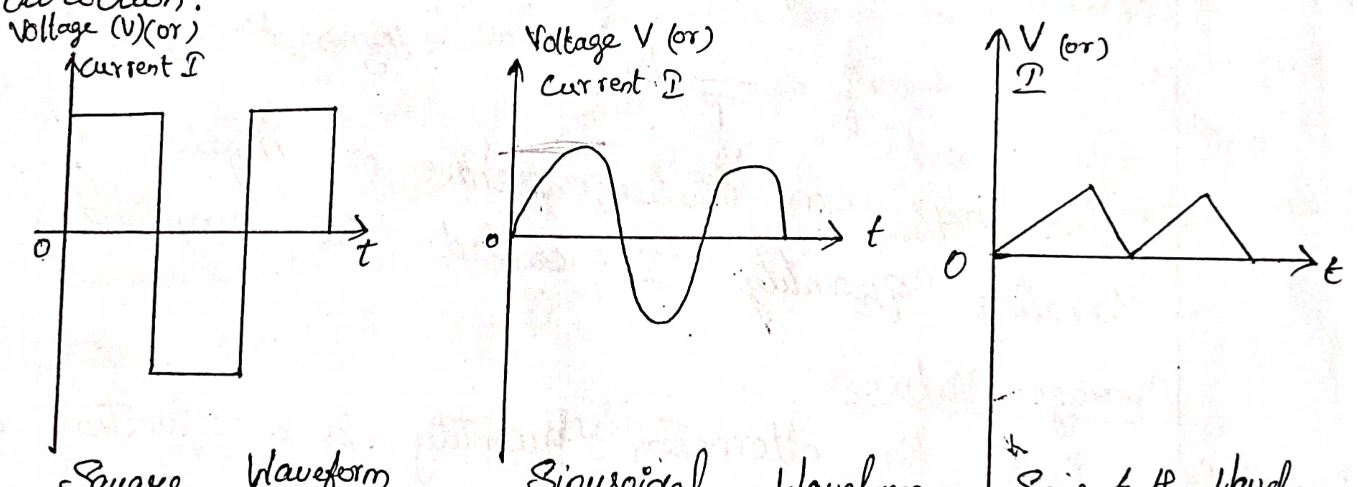
(22)

4,5,6



Introduction to AC circuits

Alternating current and voltage sources are widely used in practical. The AC source gives a voltage (or current) that varies with time. The voltage changes not only in magnitude but also in direction.



Square Waveform — Sinusoidal Waveform — Saw tooth Waveform

Various shapes of alternating waveforms are shown in figure. Sinusoidal waveform is more useful than other waveforms due to the reason that the response of any second order system is sinusoid in nature. The amplitude is represented by voltage or current on vertical axis and angular measurement in degrees or radians is represented on horizontal axis.

In general sine wave is represented by the eqn,

$v(t) = V_m \sin\omega t$ [where $\omega = 2\pi f$]

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

where $v(t)$ and $i(t)$ are instantaneous values

V_m and I_m are the peak values

ω is the angular frequency in radians per sec

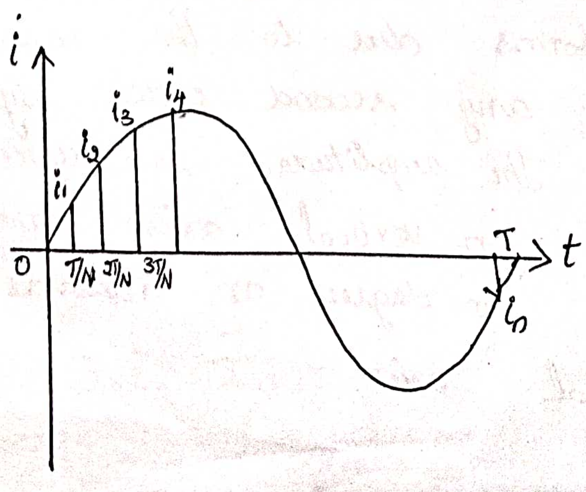
The time taken to complete one cycle (or the time interval, T after which the waveform repeats itself) is called the time period of the quantity. The number of such cycles occuring per second is called frequency, f. Hence

$$f = \frac{1}{T} \text{ Hz}$$ Hz → Hertz

The maximum value, positive or negative of the alternating quantity is called its amplitude.

Average Value

Since the alternating quantity is a function of time, it becomes difficult to specify the quantity. Hence one of the way of doing it is to specify an average value.



The average value is

$$I_{av} = \frac{i_1 + i_2 + i_3 + i_4 + \dots + i_N}{N}$$

A better way to find the average value is i integrate over a period and find the area under it and divide by T. Hence,

$$I_{av} = \frac{1}{T}\int_0^T i\,dt$$

$$\text{Average value} = \frac{\text{Area under the curve over one complete cy.}}{\text{Time Period}}$$

For symmetrical waves the average value ove one full cycle is zero and hence the average value is taken over half a cycle only. For unsymmetrical wave, average value is taken over the complete cycle.

Effective (RMS) value

When a current passes through a resistor, he is produced irrespective of the direction of curre flow. The heat produced by an alternating current of maximum value say I_m will not be equal to the heat produced by DC of I_m amperes. The effective value of an alternating current is that value of steady direct current which produ the same heat as that produced by the alternating current (AC) when passed through the same resistor for the same interval of time.

If $i(t)$ is the time varying current passed through a resistor of R ohms, then for a small interval of time, dt secs, the heat produced dH is equal to,

$$dH = i^2(t) R\, dt$$

Over one complete cycle,

$$H = \int_0^T i^2(t) R\, dt$$

If this heat is equal to that produced by a steady DC of I amperes passed through R for T secs, then

$$I^2 R T = \int_0^T i^2(t) R\, dt$$

$$I^2 = \frac{1}{T} \int_0^T i^2(t)\, dt$$

If $I = I_{eff}$ = RMS current

$$I_{eff} = \sqrt{\frac{1}{T} \int_0^T i^2(t)\, dt}$$

RMS → Root Mean Square Value

(04)

The RMS value of a wave may also be found by finding the area under squared curve

$$\text{RMS value} = \sqrt{\frac{\text{Area of squared cure for one cycle}}{\text{Time Period}}}$$

$$\text{RMS value} = \sqrt{\frac{i_1^2 + i_2^2 + \dots i_N^2}{N}}$$

where $i \rightarrow$ instantaneous value.

Form Factor and Crest Factor

Form factor is defined as the ratio between RMS value and average value.

$$\text{Form Factor} = \frac{\text{RMS Value}}{\text{Average Value}}$$

Crest or peak factor is defined as the ratio between maximum value and RMS value.

$$\text{Crest (Peak) factor} = \frac{\text{Maximum Value}}{\text{RMS value}}$$

Note:

Sinusoidal voltage and current is

$e = E_m \sin\omega t$ (or) $V = V_m \sin\omega t$

$i = I_m \sin\omega t$

where $\omega = 2\pi f$

$$f = \frac{\omega}{2\pi} = \frac{1}{T}$$

RMS Value

$$I_{Rms} = \frac{I_m}{\sqrt{2}}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

PROBLEMS

1. An alternating voltage is given by $V = 310 \sin 314t$. Calculate (i) frequency (ii) Period (iii) Maximum value (iv) RMS value.

Solution

gn: $V = 310 \sin 314t$

(i) we know, $V = V_m \sin \omega t$

$\therefore V_m = 310\ V \quad ; \omega = 314$

$\omega = 2\pi f$

$f = \frac{314}{2\pi} = 50 Hz.$ $\boxed{f = 50 Hz}$

(ii) Period, $T = \frac{1}{f} = \frac{1}{50}$

$\boxed{T = 0.02 sec}$

(iii) Maximum value, $V_m = 310\ V$

(iv) RMS value, $V = \frac{V_m}{\sqrt{2}} = \frac{310}{\sqrt{2}}$

$\boxed{V_{RMS} = 219.2\ V}$

2. An alternating current is expressed as $i = 14.14 \sin 31$. Determine rms current, frequency and instantaneous current when $t = 0.02 ms$.

Solution

gn: $i = 14.14 \sin 314t$

We know, $i = I_m \sin \omega t$

$I_m = 14.14$

$\omega = 314$

(25)

(i) RMS current, $I = \frac{I_m}{\sqrt{2}} = \frac{14.14}{\sqrt{2}}$

$$\boxed{I_{RMS} = 10\,A}$$

(ii) Frequency, $f = \frac{\omega}{2\pi} = \frac{314}{2\pi}$

$$\boxed{f = 50\,Hz}$$

(iii) Instantaneous current when $t = 0.02\,ms$

$$\omega t = 2\pi \times 50 \times 0.02 \times 10^{-3}$$

$$= 6.283 \times 10^{-3}\ rad.$$

This value converted to degree

$$6.283 \times 10^{-3} \times \frac{180}{\pi} = 0.36^\circ$$

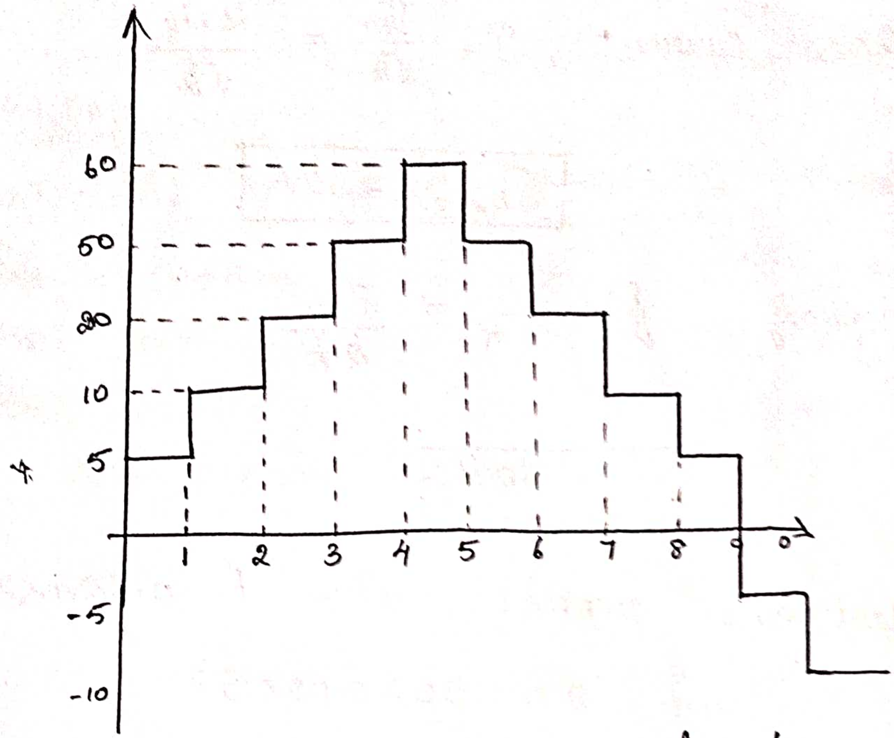
$$i = I_m \sin \omega t = 14.14 \sin 0.36$$

$$\boxed{i = 0.088\,A}$$

3. Find the average value, rms value, form factor & peak factor of a periodic wave having the following values for equal time intervals changing suddenly from one value to the next. 0, 5, 10, 20, 50, 60, 50, 20, 10, 5, 0, −5, −10, etc. What would be the rms value of a sine wave having same peak value?

Solution

$$\text{Average value} = \frac{\text{Area under half cycle}}{\text{Period}}$$



Since this waveform is symmetrical the average value is found over half a cycle.

$$\text{Average value} = \frac{(1\times5)+(1\times10)+(1\times20)+(1\times50)+(1\times60) + (1\times50)+(1\times20)+(1\times10)+(1\times5)}{9}$$

Average value = 25.55

$$\text{RMS value} = \sqrt{\frac{\text{Area under squared wave}}{\text{Period}}}$$

$$= \sqrt{\frac{(1\times25)+(1\times100)+(1\times400)+(1\times2500)+(1\times3600) + (1\times2500)+(1\times400)+(1\times100)+(1\times25)}{9}}$$

RMS value = 32.74

$$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}} = \frac{32.74}{25.55}$$

Form factor = 1.281

$$\text{Peak factor} = \frac{\text{Maximum value}}{\text{RMS value}} = \frac{60}{32.74}$$

Peak factor = 1.832

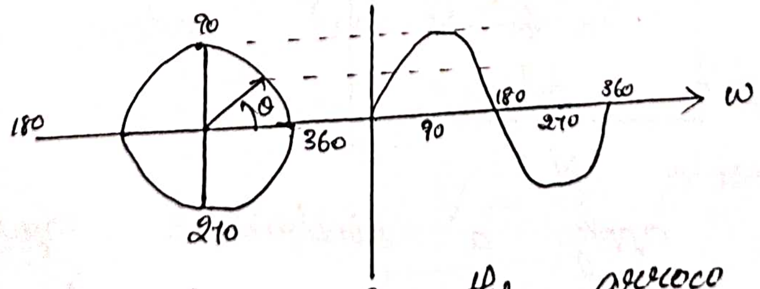
RMS value of a sine wave having same peak factor i.e., 60.

$$\text{RMS value} = \frac{\text{Max. value}}{\sqrt{2}} = \frac{60}{\sqrt{2}}$$

RMS value = 42.42

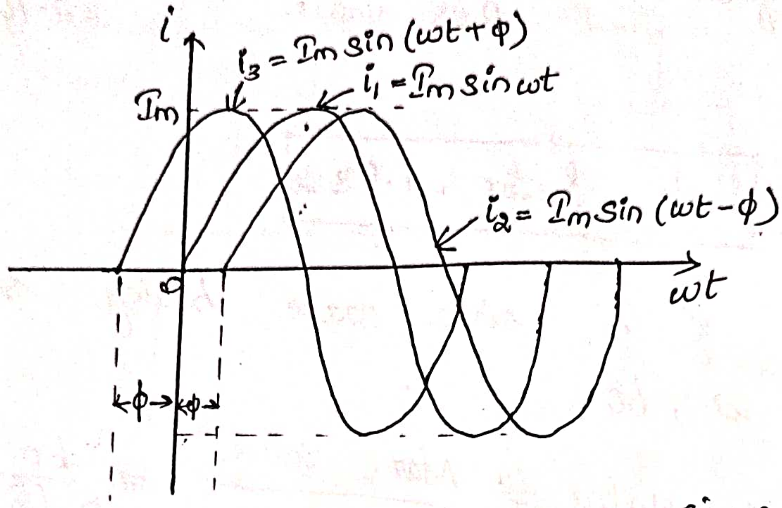
Phasor Diagram Representation

An alternating quantity (voltage or current) is a vector quantity. Since the instantaneous values are continuously changing, it must be represented by a rotating vector or phasor. A vector is a phasor that is rotating at a constant angular velocity.



The length of the arrow represents the magnitude of the sine wave and angle θ represents the angular position of the sine wave.

Phase and Phase Difference



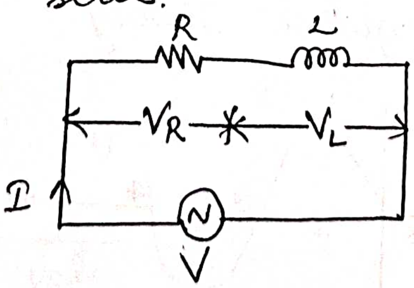
Here i_1, i_2 and i_3 are sinusoidally varying with same peak value and frequency. They do not reach the maximum and minimum at the same time.

The current i_1 leads i_2 by ϕ degrees or i_2 lags behind i_1 by ϕ. Also, i_3 leads i_1 by ϕ degrees and i_1 lags i_3 by ϕ degrees.

Sinusoidal Steady State Analysis.

RL Series Circuit

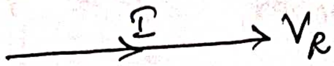
Consider a circuit containing resistance and inductance connected in series.



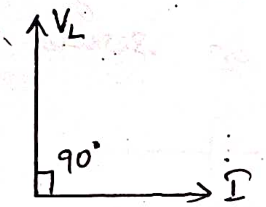
If we apply a sinusoidal input to RL circuit, all the currents in the element and the voltage across the element are sinusoidal. On

(Q7) analyzing the RL series circuit, we can find the impedance, current, phase angle and voltage drop.

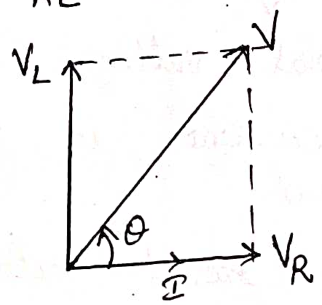
The voltage across resistance (V_R) and current (I) are in phase with each other.



While considering inductor current I is said to be lagging by 90° with respect to V_L.



Combining the two figures we can get phasor diagram for RL series circuit. It is as follows



$V_L \Rightarrow$ vlge drop across Inductance

$V_R \Rightarrow$ vlge drop across resistance

$V \Rightarrow$ Source vlge

In RL circuit,

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

where X_L = inductive reactance

$X_L = 2\pi f L$

Source Voltage V is the phasor sum of V_R + V_L

i.e., $V = \sqrt{V_R^2 + V_L^2}$

Phase angle, $\theta = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{V_L}{V_R}\right)$

Power factor, $p.f = \cos\theta$ (lag) $= \frac{R}{Z}$

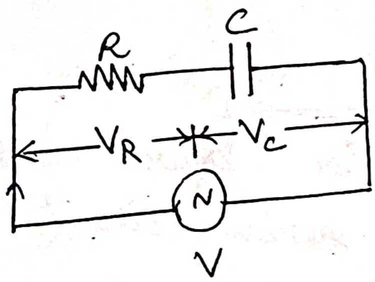
Apparent power, $S = V.I$

Real Power, $P = VI\cos\theta = S\cos\theta$

* Reactive Power, $Q = VI\sin\theta = S\sin\theta$

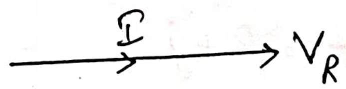
RC series circuit

Consider a circuit containing resistance and capacitance connected in series.

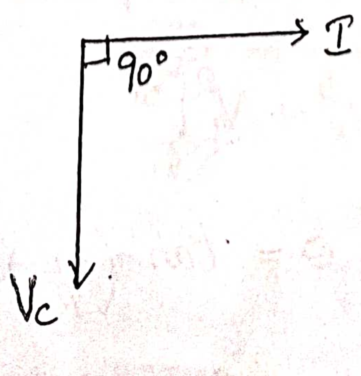


When a sinusoidal voltage is applied to RC series circuit the current in the circuit and voltage are sinusoidal.

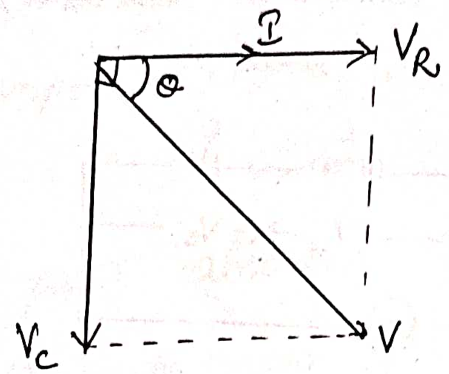
While considering resistor alone, V_R and I are in phase and is as shown,



While considering capacitor alone current I is said to be leading by 90° with respect to V_c. It is as shown



(28) Combining the two figures we get the phasor diagram for RC series circuit. It is as follows,



In RC circuit,

Impedance $Z = R + (-jX_C) = \sqrt{R^2 + X_C^2}$

where X_C = Capacitive reactance

$$X_C = \frac{1}{2\pi f C}$$

Source voltage is given by

$$V = \sqrt{V_R^2 + V_C^2}$$

Phase angle, $\theta = \tan^{-1}\frac{V_C}{V_R} = \tan^{-1}\frac{X_C}{R}$ (lead)

Power factor, $P.f = \cos\theta = \frac{R}{Z}$

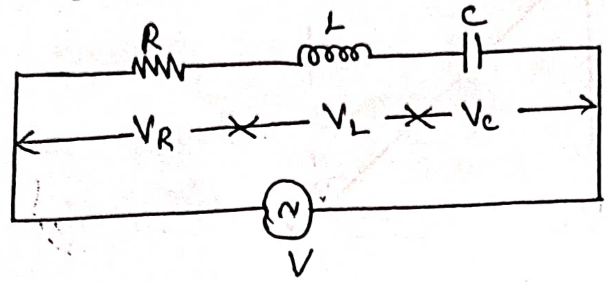
Apparent Power, $S = VI$

Real Power, $P = VI\cos\theta$

Reactive Power, $Q = VI\sin\theta$

RLC series circuit

Consider a circuit containing resistance, inductance and capacitance connected in series.

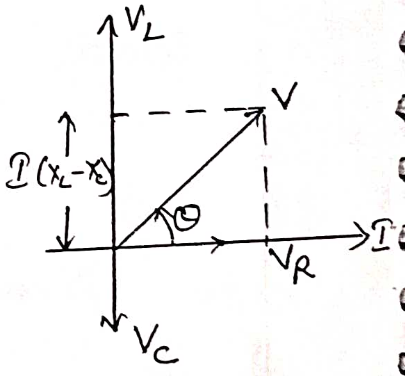


In RLC circuit,

Impedance, $Z = R + jX_L - jX_c = R + j(X_L - X_c)$

$$= \sqrt{R^2 + (X_L - X_c)^2}$$

Source voltage V is given by,



$$V = IR + jIX_L - jIX_c$$

$$= I\{R + j(X_L - X_c)\}$$

$$V = \sqrt{V_R^2 + (V_L - V_c)^2}$$

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

Power factor, $p.f = \cos\theta = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_c)^2}}$

Apparent Power, $S = V \cdot I$

Real Power, $P = VI\cos\theta$

Reactive Power, $Q = VI\sin\theta$

(29) Apparent Power, Reactive Power and Power factor

Apparent power is the product of rms values of applied voltage and circuit current. The unit is volt-ampere (VA).

$$S = VI$$

The power absorbed by a pure inductive reactance (X_L) in an a.c. circuit is called reactive power. The unit is VAR.

$$Q = I \sin\theta$$

Power factor is the cosine of the phase angle between voltage and current

$$P.f = \cos\theta = \frac{\text{Resistance}}{\text{Impedance}} = \frac{R}{Z}$$

$$\cos\theta = \frac{\text{Real Power}}{\text{Apparent Power}}$$

Power factor varies from 0 to 1.

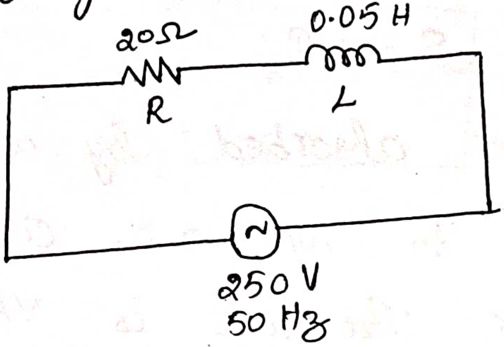
For purely resistive circuits, phase angle between voltage and current is zero and hence p.f. is unity.

In RC ckt, p.f. is referred as leading power factor because the current leads the voltage. In RL ckt, p.f. is referred as lagging p.f. because the current lags behind the voltage.

0 $V = 160 \angle 0° V$

PROBLEMS

1. A series R-L circuit has $R = 20\Omega$ and $L = 0.05\,H$ and is connected to 250 V 50 cycle source. Calculate (a) the impedance (b) current (c) Power factor (d) draw the phasor diagram.



Solution

(a) Impedance, $Z = R + jX_L$

$$X_L = 2\pi f L = 2\pi \times 50 \times 0.05$$

$$= 15.708\,\Omega$$

$$\therefore Z = 20 + j15.708$$

$$\boxed{Z = 25.43 \angle 38.15^\circ\ \Omega}$$

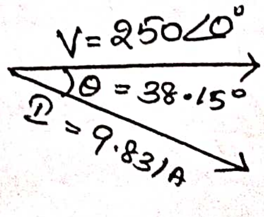
(b) Current, $I = \frac{V}{Z} = \frac{250}{25.43 \angle 38.15^\circ}$

$$\boxed{I = 9.831 \angle -38.15^\circ\ A}$$

(c) Power factor $= \cos 38.15$

$$\boxed{P.f = 0.786\ (lag)}$$

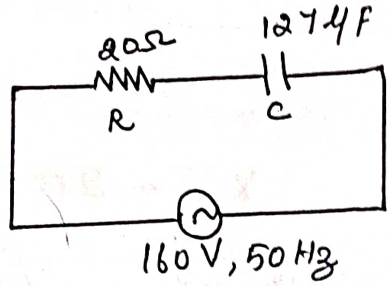
(d) Phasor diagram



2. A series RC circuit with $R = 20\,\Omega$ and $C = 127\,\mu F$ has 160 V, 50 Hz supply connected to it. Find (a) the impedance (b) current (c) Power factor (d) Power. Draw the phasor diagram.

(30)

Solution



(a) impedance $Z = R - jX_C$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 127 \times 10^{-6}}$$

$$X_C = 25\,\Omega$$

$$\therefore Z = 20 - j25 = 32 \angle -51.3^\circ\ \Omega$$

(b) current, $I = \frac{V}{Z} = \frac{160}{32 \angle -51.3^\circ}$

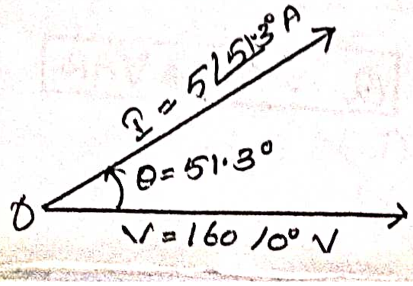
$$\boxed{I = 5 \angle 51.3^\circ\ A}$$

(c) Power factor, $P.f = \frac{R}{|Z|} = \frac{20}{32}$

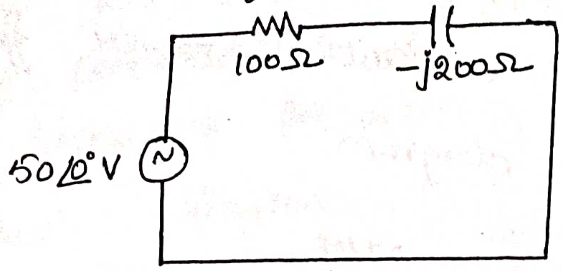
$$\boxed{P.f = 0.625\ (\text{lead})}$$

(d) Power $= |V|\,|I| \cos\theta$

$= 160 \times 5 \times 0.625$ $\boxed{P = 500\ W}$



3. Find the apparent power, real power and reactive power for the gn. ckt.



Solution

gn: $R = 100\Omega$, $X_C = 200\Omega$

Impedance, $Z = \sqrt{R^2 + X_C^2} = \sqrt{100^2 + 200^2}$

$Z = 223.6\ \Omega$

Power factor, $\cos\theta = \frac{R}{Z} = \frac{100}{223.6} = 0.447$ (lead)

Current, $I = \frac{V}{Z} = \frac{50}{223.6} = 0.223\ A$

Apparent power, $S = VI = 50 \times 0.233 = 11.15\ VA$

$\boxed{S = 11.15\ VA}$

Real Power, $P = VI\cos\theta$

$= 50 \times 0.223 \times 0.447$

$\boxed{P = 4.984\ W}$

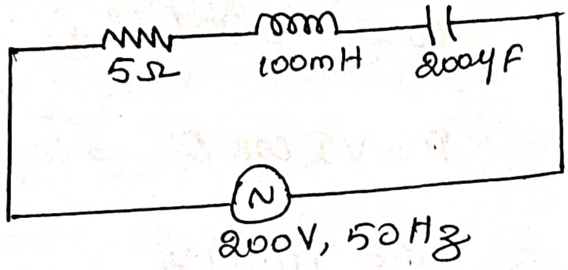
Reactive Power, $Q = VI\sin\theta$

$= 50 \times 0.223 \times \sin\left(\tan^{-1}\frac{200}{100}\right)$

$= 50 \times 0.223 \times 0.894$

$\boxed{Q = 9.96\ VAR}$

4. (31) In the given circuit calculate (a) inductive reactance (b) capacitive reactance (c) impedance of the whole ckt in complex form (d) current (e) power factor (f) total power (g) Voltage across coil and capacitor (h) draw the phasor diagram.



Solution:

gn: $R = 5\Omega$, $L = 100mH$, $C = 200\mu F$, $V = 200V$, $f = 50Hz$

(a) Inductive Reactance

$$X_L = 2\pi f L = 2\pi \times 50 \times 100 \times 10^{-3}$$

$$X_L = 31.415\Omega$$

(b) Capacitive Reactance

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 200 \times 10^{-6}}$$

$$X_C = 15.915\Omega$$

(c) Impedance, $Z = R + j(X_L - X_C)$

$$= 5 + j(31.415 - 15.915)$$

$$Z = 5 + j15.5\,\Omega$$

$$= \sqrt{5^2 + 15.5^2}$$

$$Z = 16.286\Omega$$

(d) current, $I = \frac{V}{Z} = \frac{220}{16.286}$

$I = 13.5 A$

(e) Power factor, $\cos\theta = \frac{R}{Z} = \frac{5}{16.286}$

$\cos\theta = 0.307$ (lag).

(f) Total Power, $P = VI\cos\theta = 200 \times 13.5 \times 0.307$

$P = 911.79 W$

(g) Voltage across coil,

$V_L = I X_L = 13.5 \times 31.415$

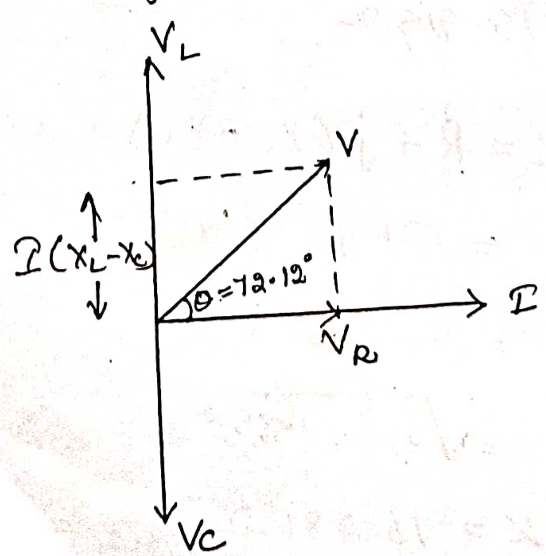
$V_L = 424.1 V$

Voltage across capacitor,

$V_C = I X_C = 13.5 \times 15.915$

$V_C = 214.85 V$

(h) Phasor diagram



SINGLE PHASE AND THREE PHASE BALANCED CIRCUITS

The three phase alternating supply is more common than the single-phase AC supply. There are several advantages of using polyphase supply systems as compared to single phase systems. Some of them are

1. In a three phase circuit, the total power is more nearly uniform unlike in a single-phase circuit, where the power varies widely.
2. For a given power rating, a three phase alternator is smaller in size leading to saving in copper and other material.
3. Polyphase motors are self starting unlike single-phase induction motors.
4. Polyphase machines have better power factor and efficiency.
5. For the same size, the capacity of a polyphase machine is higher.
6. Generation, transmission and utilization of power is more economical in polyphase systems compared to single-phase systems.

Hence a study of three phase system is important.

A three phase alternator has three separate windings in its stator. The three windings are displaced from one another by 120°. The three

Voltages then differ by 120°. If AA', BB', CC' are three windings, then the voltage in the windings $E_{AA'}$, $E_{BB'}$ and $E_{CC'}$ differ by 120° each.

$$e_{AA'} = E_m \sin \omega t$$

$$e_{BB'} = E_m \sin(\omega t - 120)$$

$$e_{CC'} = E_m \sin(\omega t + 120)$$

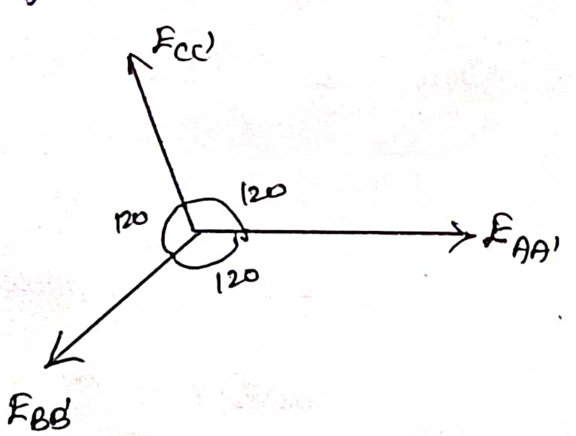
Also $|E_{AA'}| = |E_{BB'}| = |E_{CC'}| = (E_m / \sqrt{2}) = E$

In polar form we can write

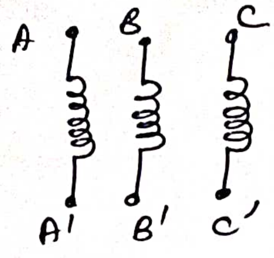
$$E_{AA'} = E\angle 0 \; ; \; E_{BB'} = E\angle -120 \; ; \; E_{CC'} = E\angle 120$$

Phase Sequence

From the phasor diagram and the equations it is clear that voltages are not in phase. There exists a phase difference of 120° between each of them. The B phase voltage follows the A phase voltage. The C phase voltage follows the B phase voltage.



Interconnection of windings



The three windings of a 3-phase alternator is as shown in the figure.

$$e_{AA'} = E_m \sin\omega t = E\angle 0$$

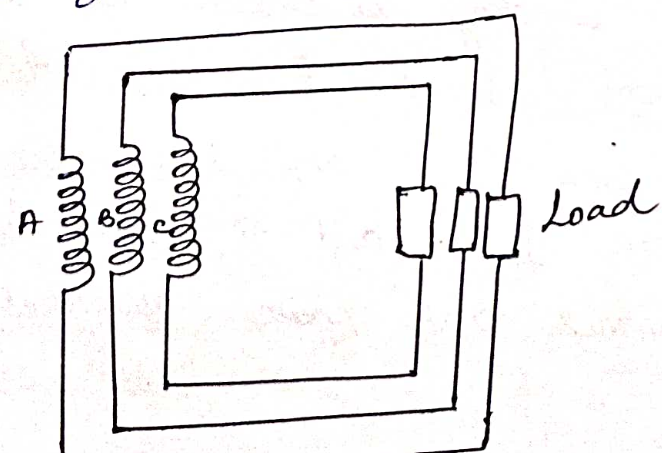
$$e_{BB'} = E_m \sin(\omega t - 120) = E\angle -120$$

$$e_{CC'} = E_m \sin(\omega t + 120) = E\angle 120$$

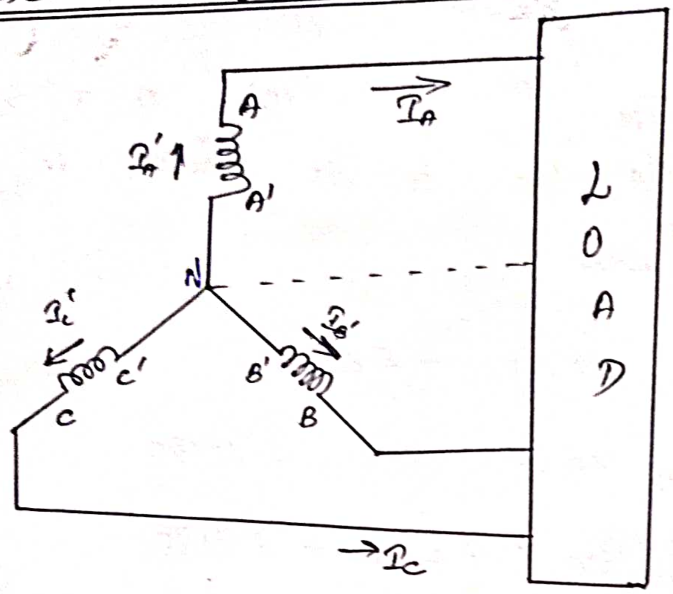
(a) Independent Connection
(b) Star (wye) Connection
(c) Mesh (or delta) Connection

(a) Independent Connection

The three windings are connected separately to the three loads. Each phase therefore supply its load separately. This is not a commonly used connection as in this we require six wires, a pair of wires for each phase.

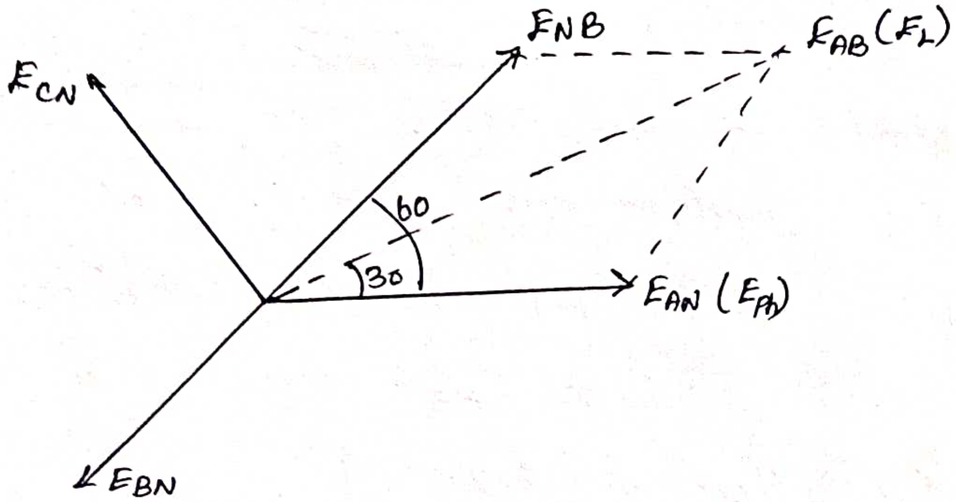


(b) Star (or wye) Connection



Here, the terminals A', B', C' are connected
together to form the star point, also called the
neutral (N). The lines A, B and C are connected
to the load. If the neutral is connected to
the neutral of the load, it becomes a 3-phase
wire system. Otherwise it is a 3-phase 3 wire s/m.

E_{AN}, E_{BN} and E_{CN} are called the phase
Voltages whereas the voltages E_{AB}, E_{BC} and E_{CA}
are called the line voltages. The current flowing
in any phase winding is called the phase current
and the current in a line is called the line
current. Thus $I_{A'A}$, $I_{B'B}$ and $I_{C'C}$ are all phase
currents whereas I_A, I_B and I_C are line currents.
The line quantities and phase quantities are as
shown below.



Hence, the line voltages in 3 phase star connected system is $\sqrt{3}$ times the phase voltage. But the phase current $I_{A'A}$ flows in the line A also, so that $I_A = I_{A'A}$. Hence in a star connected the system.

$$E_L = \sqrt{3}\, E_{ph} \text{ and } I_L = I_{ph}$$

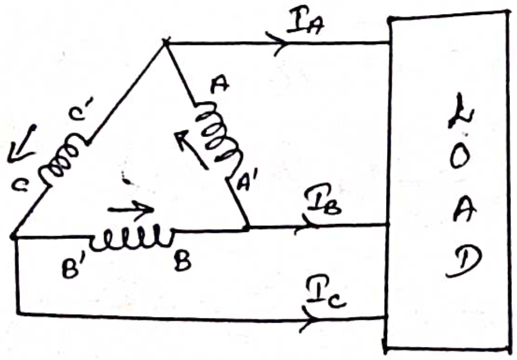
Power in a three phase circuit = 3 x phase power

$$= 3 E_{ph} I_{ph} \cos\phi$$

$$= \sqrt{3} \times E_L I_L \cos\phi$$

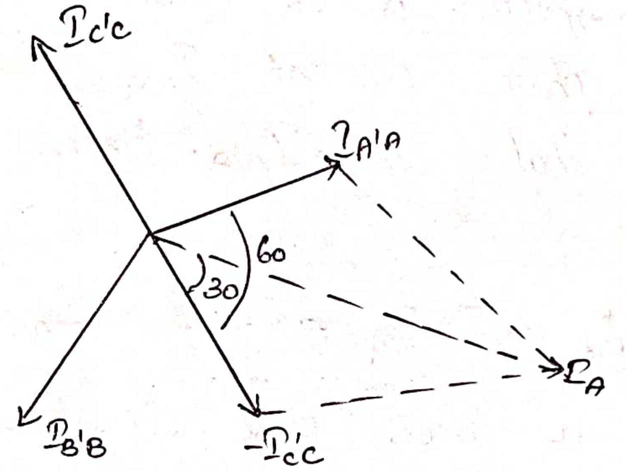
$$= \sqrt{3}\, E_L I_L \cos\phi$$

(a) Mesh (or delta) connection



The end of one winding A' is connected to the start of the next phase B' and so on. The three windings thus from a closed circuit.

It is clear that the phase voltage $E_{AA'}$, is also the line voltage E_{AB}. Hence, in a delta s/m, the line voltage is equal to the phase voltage. But the line current $I_A = I_{A'A} - I_{c'c}$.



Line current $I_A = \sqrt{3}\, I_{ph} \angle -30$

Hence in delta connection,

Line voltage E_L = Phase voltage E_{ph}

Line current $I_L = \sqrt{3}\, I_{ph}$

Power $= 3\, E_{ph}\, I_{ph} \cos\phi$

$= \sqrt{3}\, E_L\, I_L \cos\phi$

(1)

Unit-II : Magnetic Circuits & Electrical Installations

Magnetic circuits - definitions - MMF, flux, reluctance, magnetic field ~~theory~~ intensity, flux density, fringing, self and mutual inductances - simple problems.

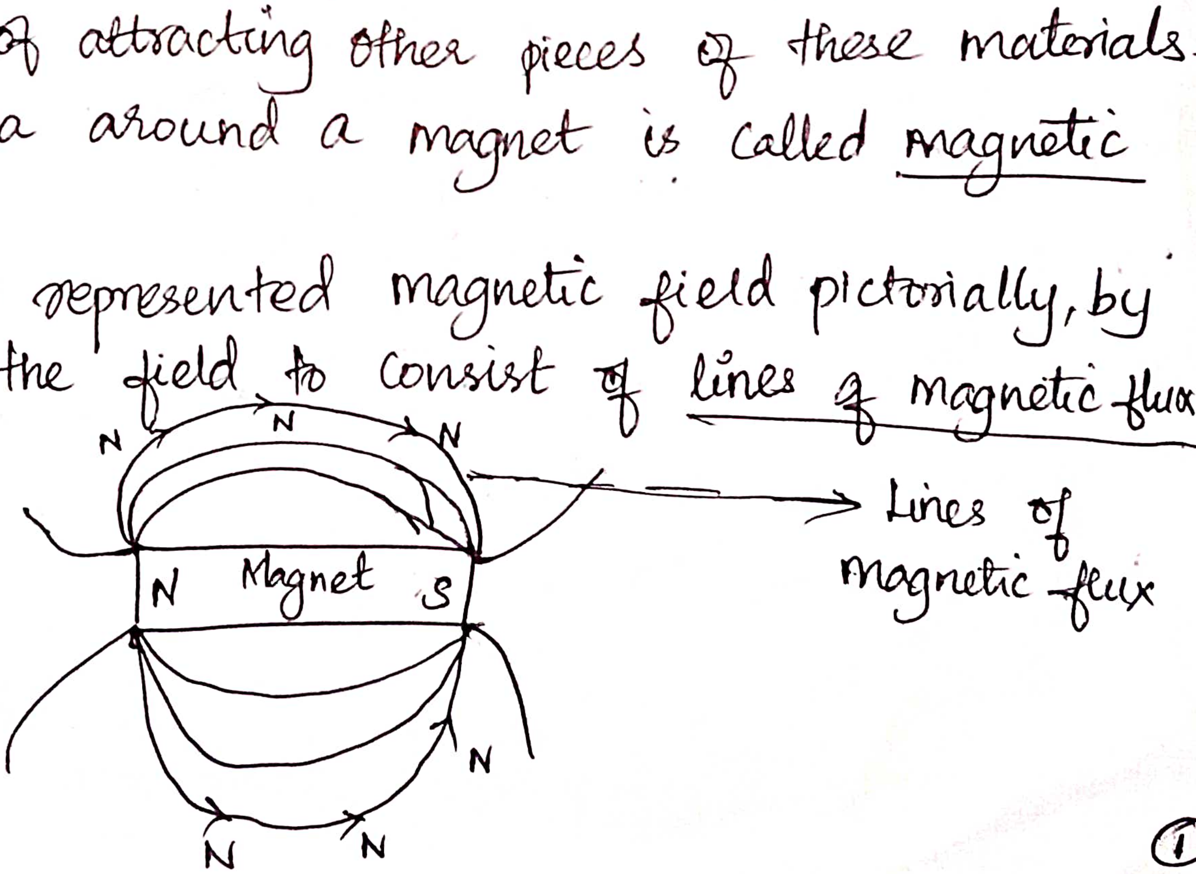
Domestic wiring, types of wires and cables, earthing, protective devices - switch fuse unit - Miniature circuit breaker - moulded case circuit breaker - earth leakage circuit breaker, safety precautions and first aid.

Magnetic Circuits

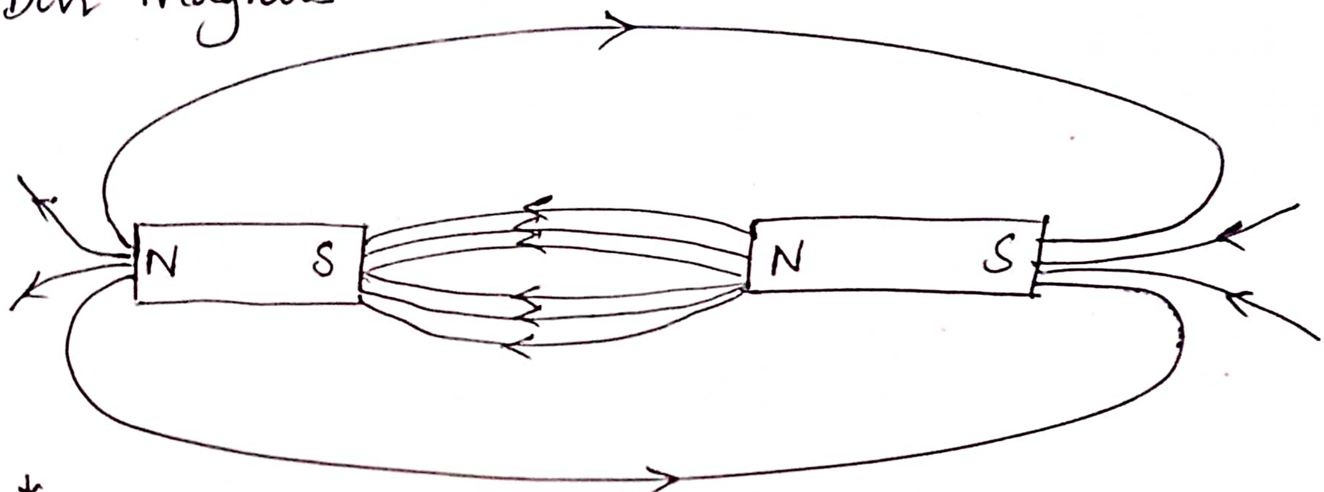
* Many common devices such as computer disk drives tape recorders, VCRs, transformers, motors, generators uses magnetic material for shaping and directing the magnetic fields which act as a medium for transferring and connecting energy.

Magnetic fields

* A permanent magnet is a piece of ferromagnetic material (such as iron, nickel or cobalt) which has properties of attracting other pieces of these materials.
* The area around a magnet is called magnetic field.
* Faraday represented magnetic field pictorially, by imagining the field to consist of lines of magnetic flux

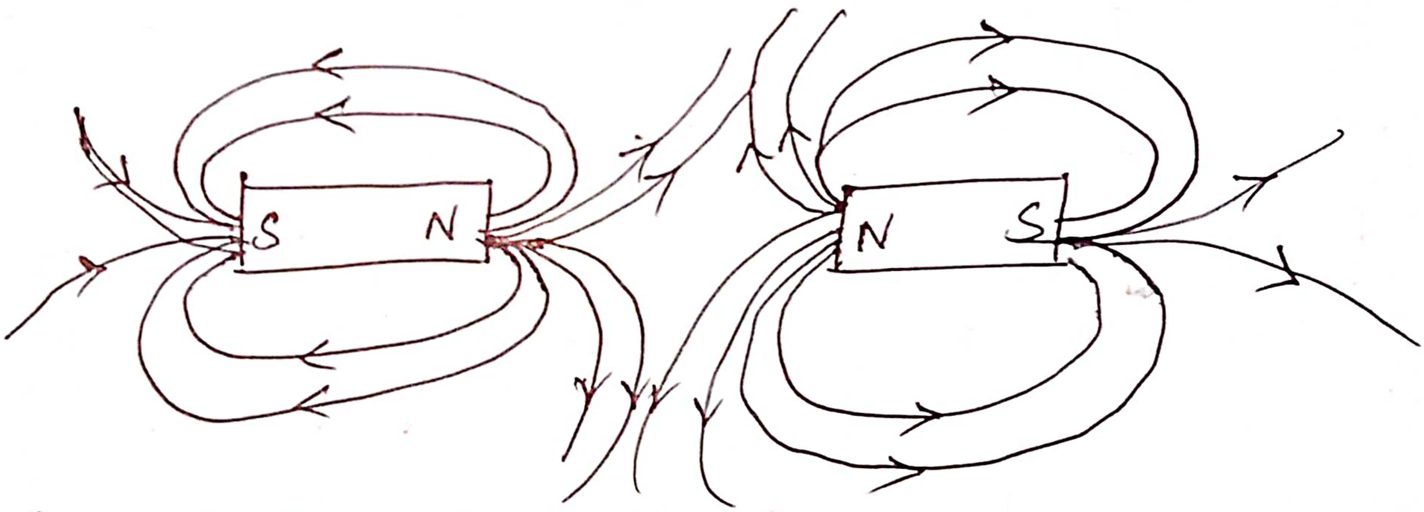


Laws of Magnetic Attraction and Repulsion with two bar magnets.



Fig

* with unlike poles adjacent, Attraction takes place.
* Lines of flux are contract and the magnets try to pull together.



Fig

* With Similar poles adjacent (i.e two North poles) repulsion occurs,
* The two North poles try to push each other apart. Since magnetic flux lines running side by side in the same direction repel.

Magnetic Flux and Flux Density

Magnetic flux is the amount of magnetic field (or the number of lines of force) produced by a magnetic source.

Symbol : ϕ unit : weber (Wb)

Magnetic flux density is the amount of flux passing through a defined area that is peripendicular to the direction of the flux.

$$\text{Magnetic flux density} = \frac{\text{Magnetic flux}}{\text{Area}}$$

Symbol : B unit : tesla (T)

$1T = 1 Wb/m^2$

$$B = \phi/A \text{ tesla}$$ where $A(m^2)$ is the area

Problems

(1) A magnetic pole face has a rectangular section having dimensions 200 mm by 100 mm. If the total flux emerging from the pole is 150 μWb. calculate flux density.

Soln: Gn. Flux $\phi = 150 \mu Wb = 150 \times 10^{-6} Wb$.

Area $A = 200 \times 100 = 20000 mm^2$.

$= 20000 \times 10^{-6} m^2$

Flux density (B) = $\frac{\phi}{A} = \frac{150 \times 10^{-6}}{20{,}000 \times 10^{-6}}$.

$$\boxed{B = 0.0075\,T \text{ (or) } 7.5\,mT}$$

(2) The maximum working flux density of a lifting electromagnet is 1.8T and the effective area of a pole face is circular in cross section. If the total magnetic flux produced is 353 mWb. Determine the radius of the pole face.

Soln

Gn. Flux density $B = 1.8\,T$

Flux $\phi = 353\,mWb = 353 \times 10^{-3}\,Wb$

$$B = \phi/A \Rightarrow A = \phi/B.$$

$$A = \frac{353 \times 10^{-3}}{1.8}\,m^2 = 0.1961\,m^2.$$

* The pole face is circular, hence area $= \pi r^2$, where r is the radius, Hence

$$\pi r^2 = 0.1961$$

$$r^2 = \frac{0.1961}{\pi} = \frac{0.1961}{3.14}.$$

$$r = \sqrt{0.06245} = 0.250\,m.$$

∴ The radius of the pole face is 250 mm.

Magnetomotive Force (MMF) & Magnetic field Intensity strength

* Magnetomotive force (MMF) is the cause of the existence of a magnetic flux in a magnetic circuit,

$$\boxed{\text{mmf } F_m = NI \text{ amperes.}}$$

N – No. of conductors (turns)
I – Current in amperes.

Unit: ampere_turns, turns has no dimensions.

SI unit : ampere.

* Magnetic field Intensity strength (Magnetizing force).

$$\boxed{H = NI/l} \text{ ampere per metre}$$

l – mean length of the flux path in metres.

Thus.

$$\boxed{\text{mmf} = NI = Hl \text{ amperes}}$$

Problems

(3) A magnetizing force of 8000 A/m is applied to a circular magnetic circuit of mean diameter 30 cm by passing a current through a coil wound on the circuit. If the coil is uniformly wound around the circuit and has 750 turns, find the current in the coil.

Soln

Gn $H = 8000$ A/m ; $l = \pi d = \pi \times 30 \times 10^{-2}$ m

$N = 750$ turns

$$H = \frac{NI}{l}, \quad I = \frac{Hl}{N} = \frac{8000 \times \pi \times 30 \times 10^{-2}}{750}$$

Current $\boxed{I = 10.05\ A}$.

Practice Problem

1. What is the flux density in a magnetic field of cross sectional area $20\ cm^2$ having a flux of 3 mWb?
2. Determine the total flux emerging form a magnetic pole face having dimensions 5cm by 6cm, if the flux density is 0.9 T.
3. The maximum working flux density of a lifting electromagnet is 1.9T and the effective area of a pole face is circular in cross section. If the total magnetic flux produced is 611 mWb determine the radius of the pole face.
4. A current of 5A is passed through a 1000 turn coil wound on a circular magnetic circuit of radius 120 mm. Calculate (a) the mmF and (b) the magnetic field strength.

Magnetic Field Intensity :-

* Magnetic field strength is also magnetic field intensity or magnetic intensity
* It is defined as the ratio of the MMF needed to create a certain flux density (B) within a particular material per unit length of the material.
* Represented as vector H, unit : Amperes/metre.

SI unit : Tesla (T)

$$\boxed{H = \frac{B}{\mu}} - M.$$

- B → Magnetic flux density, M - Magnetization
- μ → Magnetic permeability.

$\mu = \mu_r \mu_o$.

μ_r - relative permeability

$\mu_r = \frac{\text{Flux density in material}}{\text{Flux density in a vaccum}}$

$\mu_r = 1$ (Vaccum) [for air/non magnetic medium].

μ_o — Permeability of free space.

$\mu_o = 4\pi \times 10^{-7}$.

Problems :-

(4) A flux density of 1.2T is produced in a piece of cast steel by a magnetizing force of 1250 A/m. Find the relative permeability of the steel under these conditions.

Soln :-
For a magnetic material :

$$\boxed{B = \mu_o \mu_r H}$$

$$\mu_r = \frac{B}{\mu_o H} = \frac{1.2}{(4\pi \times 10^{-7})(1250)}$$

$$\boxed{\mu_r = 764}$$

Problem (5):- Determine the magnetic field strength & the mmf required to produce a flux density of 0.25T in an air gap of length 12mm.

Soln Gn: For air $B = \mu_0 H$ (since $\mu_r = 1$) $B = 0.25\,T$
$l = 12mm = 12 \times 10^{-3} m$

Magnetic field strength $\boxed{H = \frac{B}{\mu_0}} = \frac{0.25}{4\pi \times 10^{-7}}$

$\boxed{H = 198\,940\ A/m}$

$\boxed{mmf = Hl}$

$= 198\,940 \times 12 \times 10^{-3}$

$\boxed{mmf = 2387\ A}$

(6) A coil of 300 turns is wound uniformly on a ring of non-magnetic material. The ring has a mean circumference of 40 cm and a uniform cross-sectional area of 4 cm². If the current in the coil is 5A, Calculate (a) the magnetic field strength (b) the flux density and (c) the total magnetic flux in the ring.

Soln :- Gn - $N = 300$, $A = 4\ cm^2$, $l = 40\ cm$, $I = 5A$.

a) Magnetic field strength $\boxed{H = \frac{NI}{l}} = \frac{300 \times 5}{40 \times 10^{-2}}$

$H = 3750\ A/m$

(b) For a non-magnetic material $\mu_r = 1$, thus flux density $\boxed{B = \mu_0 H}$

$$B = 4\pi \times 10^{-7} \times 3750$$

$$\boxed{B = 4.712\ mT}$$

(c) Flux $\phi = BA$

$$= 4.712 \times 10^{-3} \times 4 \times 10^{-4}$$

$$\boxed{\phi = 1.885\ \mu Wb}$$

(7) An iron ring of mean diameter 10 cm is uniformly wound with 2000 turns of wire. When a current of 0.25A is passed through the coil a flux density of 0.4 T is set up in the iron. Find a) the magnetizing force and (b) the relative permeability of the iron under these conditions

Soln: Gn. $l = \pi d = \pi \times 10\ cm = \pi \times 10 \times 10^{-2}\ m$

$N = 2000$ turns ; $I = 0.25\ A$; $B = 0.4\ T$.

a) $H = \dfrac{NI}{l} = \dfrac{2000 \times 0.25}{\pi \times 10 \times 10^{-2}} = \dfrac{5000}{\pi} = 1592\ A/m$

b) $B = \mu_0 \mu_r H$

$\mu_r = \dfrac{B}{\mu_0 H} = \dfrac{0.4}{(4\pi \times 10^{-7})(1592)} = 200\ T$

Reluctance :-

* Reluctance S (R_M) is the 'magnetic resistance' of a magnetic circuit to the presence of magnetic flux.

Reluctance,

$$S = \frac{F_M}{\phi} = \frac{NI}{\phi} = \frac{Hl}{BA} = \frac{l}{(B/H)A} = \frac{l}{\mu_0 \mu_r A}$$

Unit is $1/H$ (H^{-1}) or A/Wb.

* Ferromagnetic materials have a low reluctance & can be used as magnetic screens to prevent magnetic fields affecting materials within the screen.

Problems 8 : Determine the reluctance of a piece of mumetal of length 150mm and cross-sectional area 1800 mm². when the relative permeability is 4000. Find also the absolute permeability of the mumetal.

Soln Reluctance $S = l/\mu_0 \mu_r A$

$$= \frac{150 \times 10^{-3}}{4\pi \times 10^{-7} \times 4000 \times 1800 \times 10^{-6}}$$

$= 16580/H$ (or) 16580 A/Wb (or)

$$\boxed{S = 16.58\ kA/Wb}$$

Absolute permeability, $\mu = \mu_0 \mu_r$

$= 4\pi \times 10^{-7} \times 4000$

$$\boxed{\mu = 5.027 \times 10^{-3}\ H/m}$$

Problem 9 :- A mild steel ring has a radius of 50 mm & a cross-sectional area of 400 mm². A current of 0.5 A flows in a coil wound uniformly around the ring and the flux produced is 0.1 mWb. If the relative permeability at this value of current is 200, find (a) the reluctance of the mild steel and (b) the number of turns on the coil.

Soln:- Gn $l = 2\pi r = 2 \times \pi \times 50 \times 10^{-3}\ m$

$A = 400 \times 10^{-6}\ m^2$

$I = 0.5\ A$

$\phi = 0.1 \times 10^{-3}\ Wb$

$\mu_r = 200$

a) Reluctance $S = \frac{l}{\mu_0 \mu_r A}$

$$= \frac{2 \times \pi \times 50 \times 10^{-3}}{4\pi \times 10^{-7} \times 200 \times 400 \times 10^{-6}}$$

$S = 3.125 \times 10^{6}\ H$

b) $S = \frac{mmf}{\phi}$ (i.e) $mmf = S\phi$

$NI = S\phi$

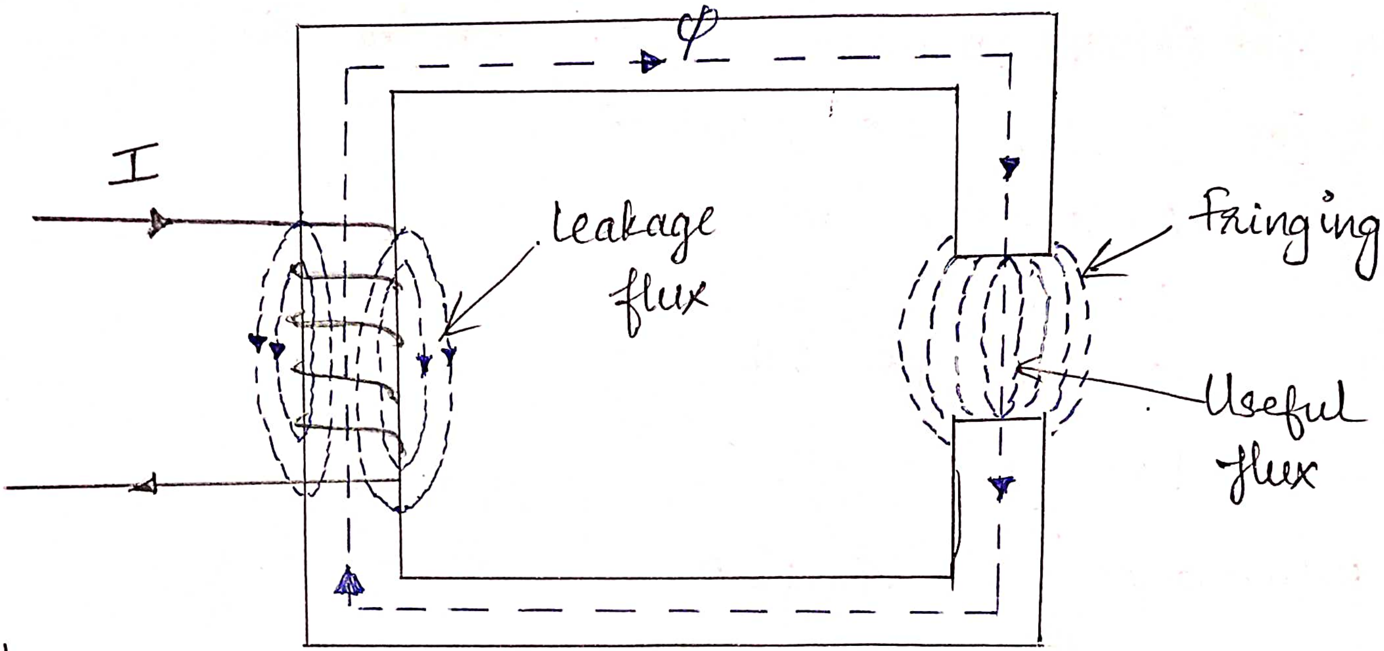
$N = \frac{S\phi}{I}$

$$= \frac{3.125 \times 10^{6} \times 0.1 \times 10^{-3}}{0.5}$$

$N = 625$ turns

Magnetic Leakage or Leakage Flux

* The part of magnetic flux that does not follow the desired path in a magnetic circuit is known as leakage flux.



Leakage Co-efficient or Hopkinson's co-efficient

* The ratio of the total flux (ϕ_T) to the useful flux (ϕ_u) is defined as the leakage co-efficient of Hopkinson's co-efficient or leakage factor of that magnetic circuit. It is denoted by λ.

$$\lambda = \frac{\text{Total Flux}}{\text{useful Flux}} = \frac{\phi_T}{\phi_u}.$$

Usually

λ is always greater than 1.

$\phi_T >> \phi_u$.

Magnetic Fringing :-

* When flux enters into the air gap, it passes through the air gap in terms of parallel flux lines.
* There exists a force of repulsion between the magnetic lines of force which are parallel and having same direction
* Due to this repulsive force there is tendency of the magnetic flux to bulge out (spread out) at the edge of the air gap
* This tendency of flux to bulge out at the edges of the air gap is called magnetic fringing.

It has two effects :-

1) It increases the effective cross-sectional area of the air gap.
2) It reduces the flux density in the air gap.

Inductance :-

- Inductance is a property of a circuit whereby there is an e.m.f induced into the circuit by the change of the flux linkages produced by a current change.
- When the emf is induced in the same circuit as that in which the current is changing, the property is called Self Inductance L
- When the emf is induced in a circuit by a change of flux due to current changing in an adjacent circuit, the property is called mutual Inductance M.

* The unit of Inductance is henry H.

'A circuit has an Inductance of one henry when an emf of one volt is induced in it by a current changing at the rate of one ampere per second.'

Induced emf in a coil of N-turns

$$E = -N\frac{d\phi}{dt} \text{ volts.}$$

where $d\phi$ is the change in flux in webers & dt is the time taken for the flux to change in seconds. $\frac{d\phi}{dt}$ is the rate of change of flux.

Induced emf in a coil of Inductance L henrys,

$$E = -L\frac{dI}{dt} \text{ volts.}$$

where dI is the change in current in amperes and dt is the time taken for the current to change in seconds. dI/dt is the rate of change of current.

Problems:-

1) Determine the emf induced in a coil of 200 turns when there is a change of flux of 25mWb linking with it in 50ms.

soln Induced emf $E = -N\frac{d\phi}{dt} = -(200)\left[\frac{25\times10^{-3}}{50\times10^{-3}}\right]$

$$\boxed{E = -100 \text{ Volts.}}$$

2) A flux of 400 μWb passing through a 150 turn coil is reversed in 40 ms. Find the average emf induced.

soln:- Flux is reversed, hence the flux changes from +400 μwb to −400 μwb, a total change of flux of 800 μwb.

Induced emf $E = -N\frac{d\phi}{dt}$

$$= -150\left[\frac{800 \times 10^{-6}}{40 \times 10^{-3}}\right]$$

The average induced emf $\boxed{E = -3 \text{ Volts}}$.

Self Inductance formula

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

$$L = N\frac{d\phi}{dI}.$$

$$\boxed{L = N\frac{\phi}{I}}$$

where

L - self Inductance in Henries ; I - current in Amperes

N - no. of turns ϕ - magnetic flux

Mutual Inductance

- when there is a change in the current or magnetic flux linked with the two coils, an opposing electromotive force (emf) is produced across each coil. This phenomenon is called mutual Inductance.

$$\phi = MI.$$

- The rate of change of magnetic flux in the coil is given as

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

$$e = -M\frac{dI}{dt}$$

Mutual Inductance formula

$$M = \frac{\mu_0 \mu_r N_1 N_2 A}{l}$$

μ_0 – permeability of free space
μ_r – relative permeability
N – Number of turns in coil
A – cross sectional area in m^2.
L – length of coil in m.

Problems (3):- Calculate the mutual inductance between two coils when a current changing at 200 A/s in one coil induces an emf of 1.5V in the other.

Soln:- Induced emf $|E_2| = M\frac{dI_1}{dt}$, i.e $1.5 = M(200)$

mutual inductance, $M = \frac{1.5}{200} = 0.0075H$ or $7.5mH$.

(4) The mutual inductance between two coils is 18 mH. Calculate the steady rate of change of current in one coil to induce an emf of 0.72 V in the other.

Induced emf., $|E_2| = M\frac{dI_1}{dt}$

Hence rate of change of current, $\frac{dI_1}{dt} = \frac{|E_2|}{M}$

$$= \frac{0.72}{0.018} = 40 \text{ A/s}.$$

(5) Two coils have a mutual inductance of 0.2 H. If the current in one coil is changed from 10 A to 4 A in 10 ms Calculate (a) the average induced emf in the second coil. (b) the change of flux linked with the second coil

Domestic Wiring

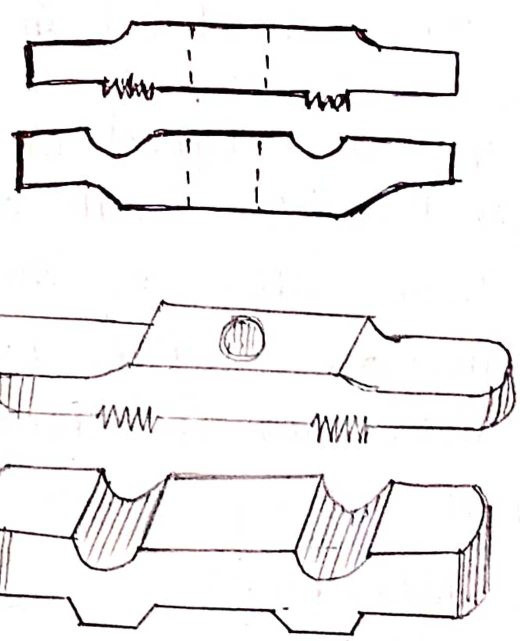
- Electrical wiring done in residential & commerical buildings to provide power for lights, fans, pumps and other domestic appliances is known as domestic wiring

Types of Wiring :-

- Cleat wiring
- CTS wiring (or) TRS wiring (or) Batten wiring
- Metal sheathed wiring (or) lead sheathed wiring
- Casing and Capping
- Conduit wiring.

Cleat Wiring :-

* In this type of wiring, insulated conductors (usually VIR, vulcanized Indian Rubber), PVC cables are supported on porcelain or wooden cleats
* These cleats have two halves : one base and the other cap.
* The lower part is grooved to accomdate, the cable & upper part is put over it.
* After the cable is put b/w the cleats, these are then screwed on wooden plugs also known as gutties.



Adv:- Installation & dismentling is simple & fast. Hence it is useful for temporary wiring.

Disadv:-
→ Appearance is not good
→ Cannot be used in damp places
→ As the wiring is exposed to atomsphere, its life span is short

2) Wooden/PVC Casing and Capping wiring

* Suitable for the voltages installations ~~and~~ using VIR or PVC Cables.
* The casing and capping form two parts of the wooden/PVC, Casing and Capping have grooves
* The cable is placed in the grooves of the casing and this is then covered by capping.
* The capping is fitted to the casing with the help of screws
* Casing & capping should be made of teak wood.
* The casing should be spaced from the wall by means of small porcelain blocks or disc insulators. ~~not less than~~ so that direct contact to the wall is avoided and it is protected against dampness of wall.

Adv :-
→ cheaper
→ Short circuit is avoided
→ economical
→ Simple to carry out any repair

Disadv :-
1) In case of a short circuit, there is risk of fire
2) Not recommended for damp places.

3) CTS (Cable Tyre Sheathed)/TRS (Tough Rough sheathed) Batten wiring

* Wires sheathed in tough rubber are used which are quite flexible.
* They are clipped on wooden battens with brass clips & fixed on to the walls or ceilings by flat head screws.
* These cables are moisture and chemical proof.
* They are suitable for damp climate but not suitable for outdoor use in sunlight.
* TRS wiring is suitable for lighting in low voltage installations.

(4) Metal sheathed or lead sheathed wiring

* Similar to that of CTS but the conductors are individually insulated & covered with a common outer lead-aluminium alloy sheatth.
* The sheath protects the cable against dampness, atomspheric extremities and mechanical damages.
* The sheath is earthed at every junction to provide a path to ground for the leakage current.
* They are fixed by means of metal clips on wooden battens.
* It is expensive & suitable for low voltage installations.

(5) Conduit Wiring :-

* In this System, PVC (Polyvinyl chloride) or VIR cables are run through metallic or PVC pipes providing good protection against mechanical injury and fire due to short circuit.
* They are either embedded inside the walls or supported over the walls, and are known as concealed wiring or surface conduit wiring respectively.
* The conduits are buried inside the walls on wooden gutties and the wires are drawn through them with fish (steel) wires.
* The system is best suited for public buildings, industries and workshops.

Earthing

The Process of sharing the charges with the earth is called earthing.

Grounding is also a safety process that protects the entire power s/m from malfunctioning & is mainly used to balance the load when the electric s/m overloads.

Earthing

* Earthing is used to protect ~~you~~ us from an electric shock.

* An earthing system or grounding system connects specific parts of an electric power system with the ground, typically the Earth's conductive surface, for safety and functional purposes.

Basic needs of Earthing

* To protect human lives as well as provide safety to electrical devices and appliances from leakage current.

* To keep voltage as constant in the healthy phase.

* To protect electric system and buildings from lighting.

* To serve as a return conductor in electric traction system and communication.

* To avoid the risk of fire in electrical installation systems.

Example

In a motor, if we have not earthed it and there is an electrical fault in this motor. will pass through the body and suppose this time someone touches the body even by mistake then he feels terrible grief.

But if we had earthed the body properly, this current would have easily gone into the ground with the help of earthing wire.

Methods of Earthing

1. Strip and wire Earthing
2. Rod Earthing
3. Pipe Earthing
4. Plate Earthing
5. Coil Earthing.

Strip and wire Earthing.

Strip and wire earthing, this etching is done in a place where the ground is rocky which means there is more rock in the ground. This earthing is widely used in long distance transmission lines.

Rod Earthing

This type of earthing is done by digging very deep in the sandy area as the moisture content is high across the sandy place. That's why we use Pipe earthing in this

Pipe Earthing

This is the most commonly used earthing in which we put a pipe 5 to 10 feet in the ground.

Plate Earthing

Plate earthing is considered to be the best earth. This is used in Substation and power station. Plate earthing nose. Such earthing is used in Places where a large number of current flows.

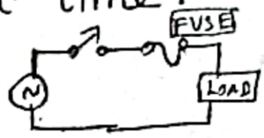
Coil Earthing

Coil earthing is used in the smallest amount. This earthing uses a coil made of G.I. wire. Such earthing is mostly used for electric poles.

Protective Devices.

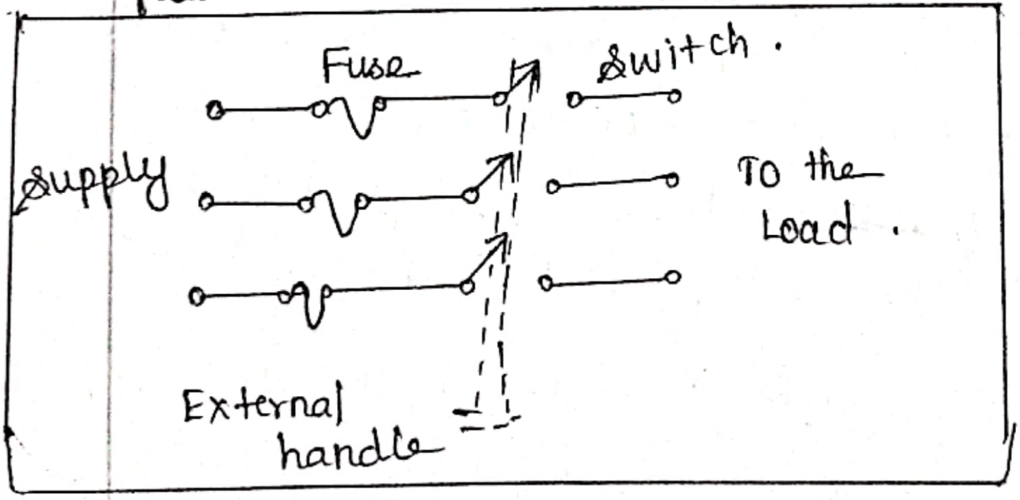
1. Switch Fuse Unit (SFU)
2. Miniature circuit Breaker (MCB)
3. Moulded case circuit Breaker (MCCB)
4. Earth Leakage circuit Breaker (ELCB)

Fuse ⇒ Short piece of wire which melts when excessive current flows through sufficient time.



1. Switch Fuse Unit (SFU)

* It has one swith unit & one fuse unit.
* SFU is a combination of metal enclosed of a switch & a fuse.
* It is widely used for low and medium voltages
* The ratings of switch fuse units are in the range of 30, 60, 100, 200, 400, 600 & 800 amperes.
* SFU are available as 3 pole & 4 Pole units
* It works as switch to connect or disconnect supply to the Load. & they can interrupt power supply by blowing fuse.



⑦ Miniature circuit Breaker (MCB)

* MCB guards an electrical circuit which automatically switches off electrical ciruit during abnormal condition of the network means in overload condition of the network as well as faulty condition.
* It is alternative to fuse.
* It is a small trip switch operated by overload and used to protect an electric circuit.
* To secure our household appliances to heavy electrical short circuit and overload current, MCB is used.
* In domestic usage appliances like lights, heaters and fans require MCB to constantly check and protect the connection.
* MCB operate on two principle:
  - Thermal Tripping [normal overload protection]
  - Magnetic tripping [Short circuit protection]

⑧ Moulded case circuit Breaker (MCCB)

* MCCB are a type of electrical protection device that is used when load currents exceed the capabilities of miniature circuit breaker.
* It can be used for a wide range of voltages & frequencies of both 50 Hz and 60 Hz.
* MCCB can have current rating upto 2500 amperes.
* Trip setting are normally adjustable.

* MCCBs are much Larger than MCBs
* MCCB has three Main functions,
  - (i) Protection Against Overload.
  - (ii) Protection against electrical faults.
  - (iii) Switching a circuit ON & OFF.

(4) Earth Leakage circuit Breaker. (ECLB)

* An ECLB is a safety device used for installing an electrical device with high earth Impedance to avoid shock.
* The main purpose of ELCB is to stop damage to humans and animals due to electric shock.
* There are <u>two</u> types of ELCB
  - Voltage operated ELCB
  - current operated ELCB
* this circuit breaker connects the phase, earthwire and Neutral.

Safety And Precautions:

There are simple way to reduce risks

⇒ check all equipments is in good working order.

⇒ If you find or suspect a fault, stop using the equipment, disconnect from the electrical supply and label not to use.

⇒ You should also avoid overloading sockets by providing enough socket-outlets

⇒ Switch off and unplug and unplug equipment before you clean it or make adjusments.

⇒ You should also ensure Controlled entry to electrical plant or switch gear

⇒ Choose electrical equipment that is intended for the specific working environment.

⇒ Seek specialist advice when choosing electrical equipment that is being used in flammable or explosive atmosphere.

⇒ Use lock off systems and correct signage to inform staff and prevent access.

⇒ Use plans and cable-avoiding tools to locate cables.

First aid :

The 911 emergency personnel may instruct you on the following.

1. Separate the person from current source
   ⇒ To turn off the power source

2. Do CPR, if necessary
   ⇒ When you can safely touch the person, do CPR if the person is not breathing or does not have a pulse.
   ⇒ For a child, start CPR for children
   For an adult, start adult CPR

3. Check for other injuries
   ⇒ There may be a fracture if the shock caused the person to fall.
   ⇒ For burns, see burn treatment

4. Wait for 911 to Arrive

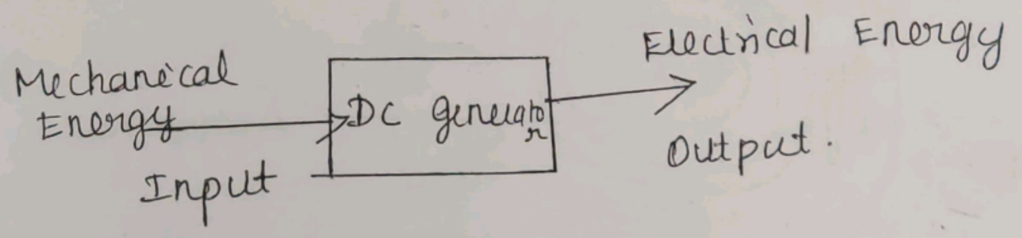
5. Follow up
   ⇒ A doctor will check the person for burns, fractures, dislocations and other injuries.

UNIT-2 Electrical Machines

Construction and working principle - DC seperately and self excited generators (EMF equation, Types and Applications), working principles of DC motors, Torque Equation, Types and Applications, construction, (Working principle and Applications of Transformer), (Three phase Alternator, (Synchronous motor) and (Three phase induction Motor.)

DC Generator

"An electrical generator is a rotating machine which converts mechenanical energy into electrical energy."



The energy conversion is based on the principle of electromagnetic induction.

* According to Faraday's Laws of electromagnetic induction, whenever a conductor is moved in a magnetic field,

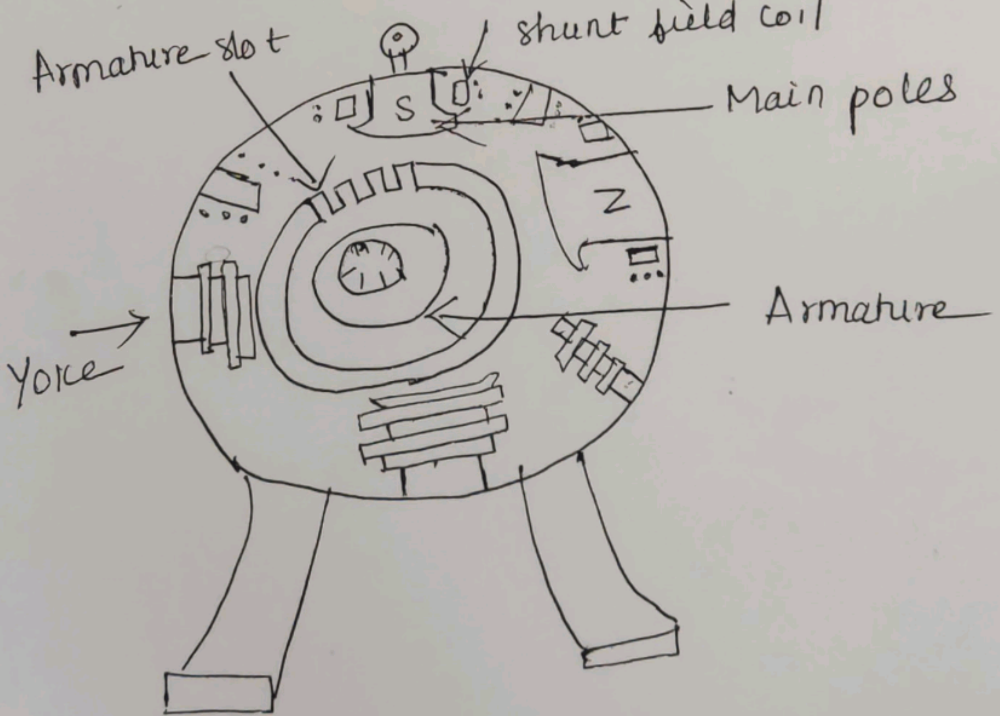
dynamically induced emf is produced in the conductor.

Construction of DC generator.

Parts of DC Generator

The major parts of DC generator are

1. Magnetic frame or yoke
2. Poles, interpoles, windings, pole shoes
3. Armature
4. Commutator
5. Brushes, Bearings and shaft.



Magnetic Frame.

It is used for two purpose.

* It acts as a protecting cover for the

whole machine and provides mechanical support for the poles.

* It carries the magnetic flux produced by the poles.

Poles

The pole consist of

(i) pole cores

(ii) pole shoes.

(iii) pole coils

* It acts as a protecting cover for whole Machine. and provides mechanical support for poles.

* It carries the magnetic flux produced by the poles.

Interpoles

* commutating poles (or) interpoles are provided to improve commutation.

* the commutating poles also have exciting coils which are connected in series with Armature

* The coils are made up of fewer turns of thicker conductor to reduce the resistance

Armature

* The armature consists of an armature core and Armature windings.
* the armature core houses the armature conductor or coils.

Commutator

* commutator converts alternating emf into Unidirectional emf or direct emf.
* It is made up of wedge shaped copper, insulated from each other by thin layers of built up-mica.

Brushes

* The brushes which are madeup of carbon or graphite.
* It collects the current from the commutator and to convey it to the external load resistance.
* They are rectangular in shape.

Bearings

* Ball Bearings are usually employed as they are reliable for light machines.

* For heavy duty machines roller bearings are used.

Working Principle of operation.

* Let us consider a single turn coil ABCD rotated on a shaft within a uniform magnetic field of flux density.

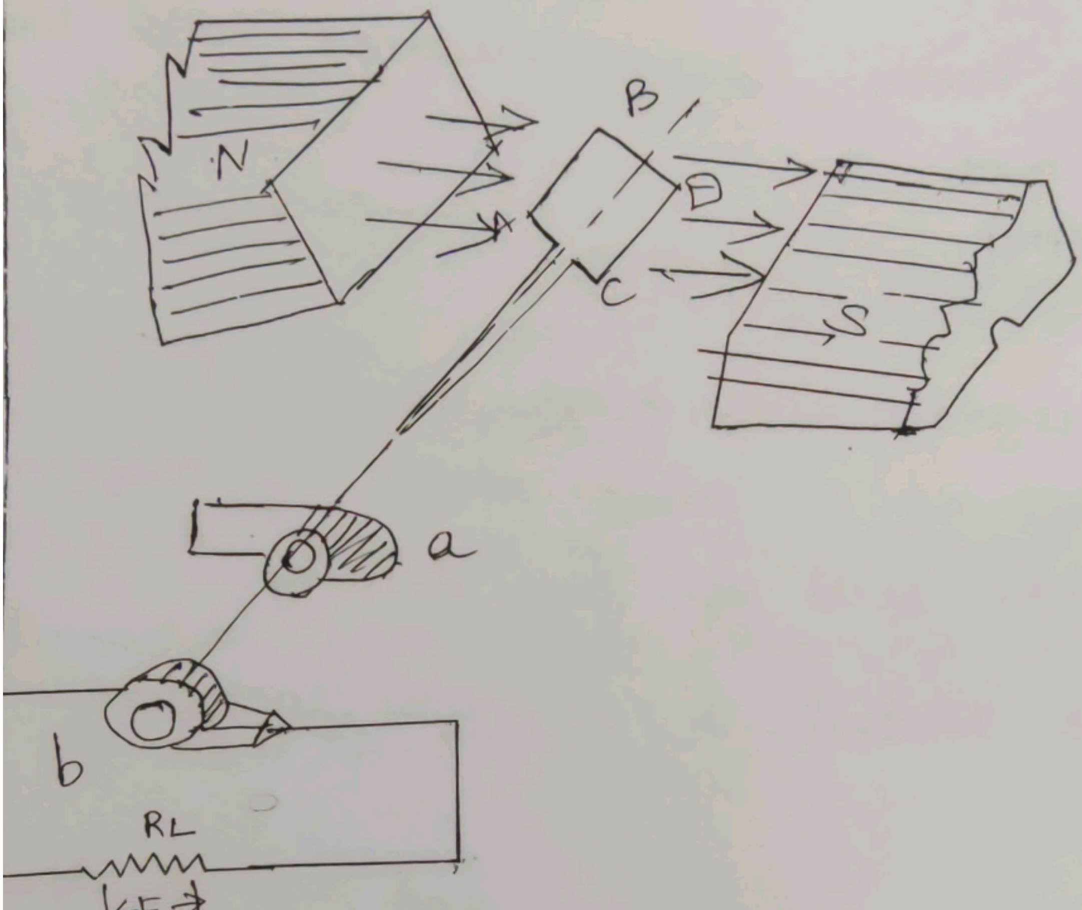
* It is rotated in an anti clockwise direction.

* Let 'L' be the length and 'b' be the breadth of coil in metres.

* When the coil sides AB and CD moving parallel to the magnetic field no flux linking the coil. hence no emf induced in it. ∴ $\frac{d\phi}{dt} = 0$ & $e = 0$.

* When the coil sides AB and CD

be Vertical to the magnetic field, flux linking the coil and an emf is induced in it. i.e $\phi = BLb\cos\omega t$



According to Faraday Law II, the emf induced is Proportional to rate of chang of flux linkages.

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

where N → No. of turns.
t → time in sec
ϕ → flux in weber

$$e = -\frac{d}{dt}(BLb\cos\omega t)$$

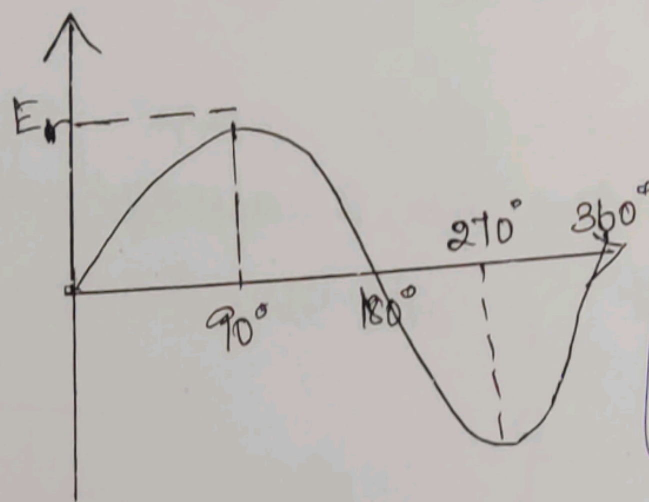
$\omega \sin\omega t$. ($\because N = 1$

$\phi = BLb\cos\omega t$)

$$\boxed{e = E_m \sin\omega t}$$

where $E_m = BLb\omega$ (maximum induced emf.

When $\omega t = 90°$, $e = E_m \sin 90°$ $\therefore$ $\boxed{e = E_m}$ the emf induced is maximum.



$\sin 90° - 1$

$\sin 180 - 0$

$\sin 270° - -1$

$\sin 360° - 0$.

When $\theta = 180°$, $e = E_m \sin 180°$ $\therefore$ $\boxed{e = 0}$ Now the emf induced is zero.

When $\theta = 270°$, $e = E_m \sin 270°$ $\boxed{e = -E_m}$

The coil sides again move at right angles to flux lines but with their position reversed. Hence the induced emf is maximum in the opposite direction.

when $\boxed{\theta = 360^\circ}$ $\boxed{e=0}$ the coil has now back to the starting point.

This alternating emf is made direction emf by using the commutator (split ring)

The ring is split into two equal segments P and Q. they insulated from each other.

The coil side AB is always attached to segment 'p' and likewise 'CD' to Q.

*

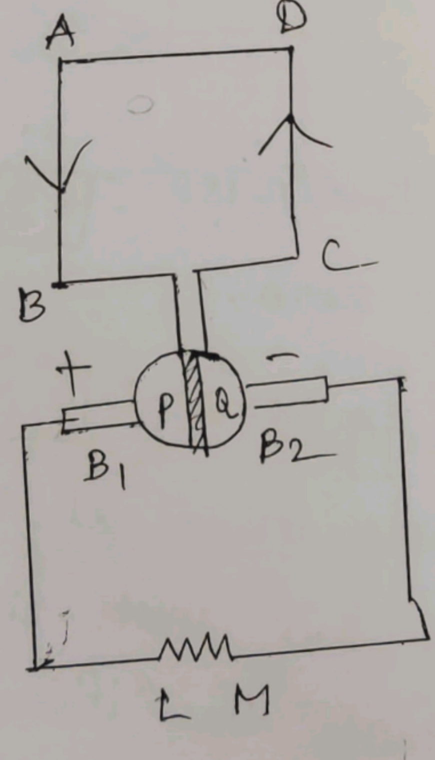


fig (a)

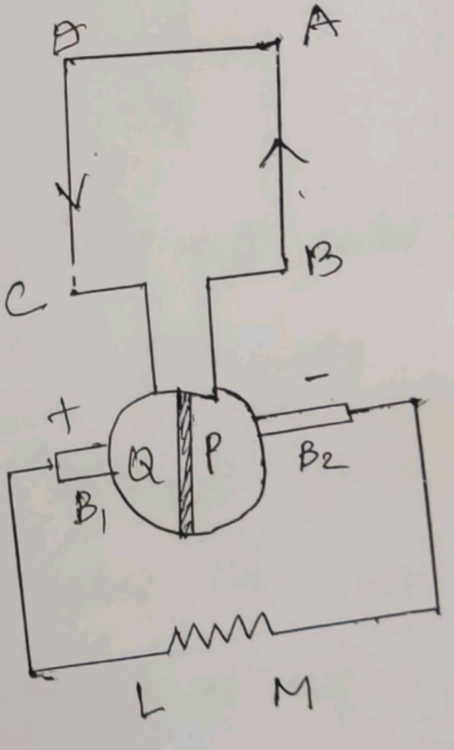


fig (b)

During the first half revolution current flows along ABLMCD through brush B_1 (positive) and into B_2 C (Negative) (fig a)

After a half cycle AB and CD exhaustes their position along with segments P and Q and now currents flow through DCLMBA B1 is new contact with Q and B_2 with 'P' (fig b)

This Process repeat again and again and new unidirectional emf fed to the external load resistance "R".

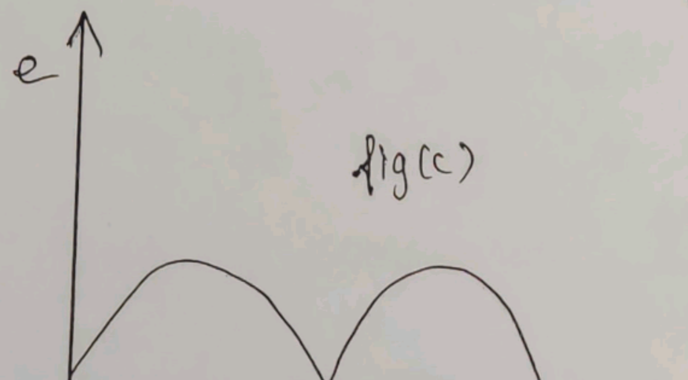


fig (c)

EMF equation of Generator & Motor

Let ϕ → flux in Web

P → No. of Poles

Z → Total no. of conductors.

A → No. of parallel path.

[Note $\boxed{A=2}$ for wave winding
$\boxed{A=P}$ for lap winding]

N → speed of rotation in rpm.

consider only one conductor on the periph of the armature.

As this conductor makes one complete revolution it cuts $P\phi$ (wb)

As speed is "N" rpm, the time taken for one revolution is "60/N" secs.

We know that $e \propto \frac{d\phi}{dt}$.

$$e = \frac{P\phi}{60/N} \qquad \therefore e = \frac{\phi P N}{60} \text{ volts}$$

since there are Z/A conductors in series in each parallel path the emf induced is

$$E_g = \frac{NP\phi}{60}\left(\frac{Z}{A}\right) \text{Volts}$$

where E_g → Generated Emf (for gener.

for motor

$$E_b = \frac{\phi ZN}{60}\left(\frac{P}{A}\right) \text{ Volts}$$

Where E_b = Back emf of motor in volts

Application of DC generator

1. Shunt generators are used for supplying nearly constant loads.

2. It is used for battery charging, for supplying the fields of synchronous machines.

3. DC series generators are used as booster for adding a voltage to the transmission lines and to compensate for line drop.

4. compound generator as a voltage regulator in self contained generator unit.

Types of DC Generator,

There are two types of DC generators.

They are,

(I) Seperately excited DC generator
(II) Self excited DC generator

(i) Seperately excited DC generator.

If the field winding is excited by a seperate DC supply, then the generator is called separately excited DC generator

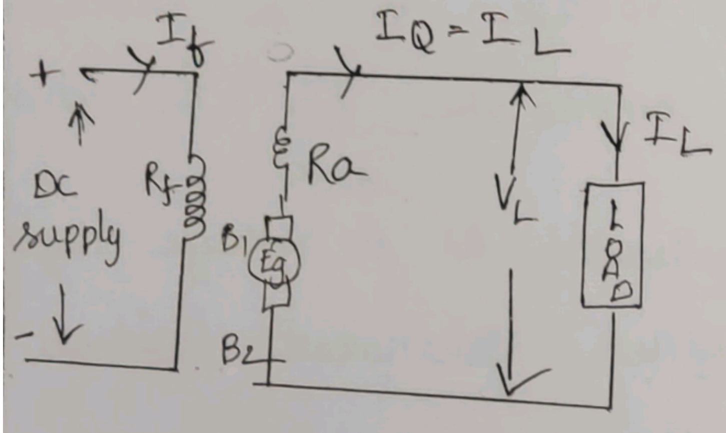


Fig: seperately exited DC generator

From this diagram,

Generated emf $E_g = V + I_a R_a + V_{brush}$

Where

$I_a \Rightarrow$ Armature current (A)
$R_a \Rightarrow$ Resistance of armature winding (Ω)

V_{brush} → voltage drop in brush (V)

E_g → Generated Emf.

Here $\boxed{I_a = I_L}$

I_L → Load current (A)

Electric power developed $\boxed{P_g = E_g I_a \ (W)}$

Power delivered to load $\boxed{P_L = V_L I_a \ (W)}$

where,

$\boxed{V_L = \text{Terminal voltage}}$.

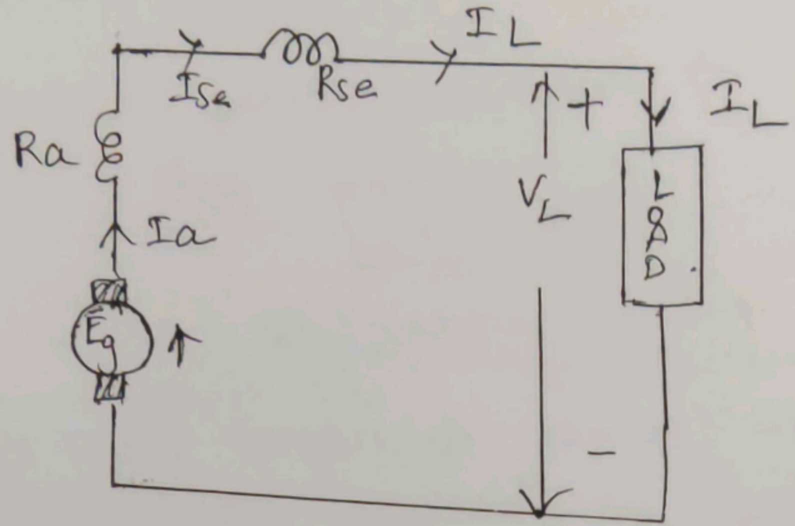
(ii) Self excited DC Generator

If in a DC Generator field winding is supplied from a armature of Generator itself then it is called Self excited DC Generator.

The self excited DC generators can be classified depending upon how the field winding is connected to the armature. There are three types

(a) series generator (b) shunt Generator (c) compound generator

Series Generator



The field winding is connected in series with the armature.

This type of DC generator is called DC Series generator.

*

Here the armature current flows through the field winding as well as the load.

The field winding has less no. of turns thick wire.

It has low resistance. It is denoted by Rse.

Here armature, field and load are all in series. So they carry the same current.

$$I_a = I_{se} = I_c$$

Generated Emf $E_g = V_L + I_a R_a + I_a R_{se} + V_{brush}$ (V)

where

V_L = Terminal Voltage (V)

I_a = Armature current.

R_a = Armature Resistance

R_{se} = field winding Resistance

V_{brush} = Brush drop.

Power developed in Armature $P_g = E_g I_a$

Power delivered to load $P_L = V_L I_a$ (Or) $V_L I_C$

$$E_g = V_L + I_a (R_a + R_{se}) + V_{brush}$$

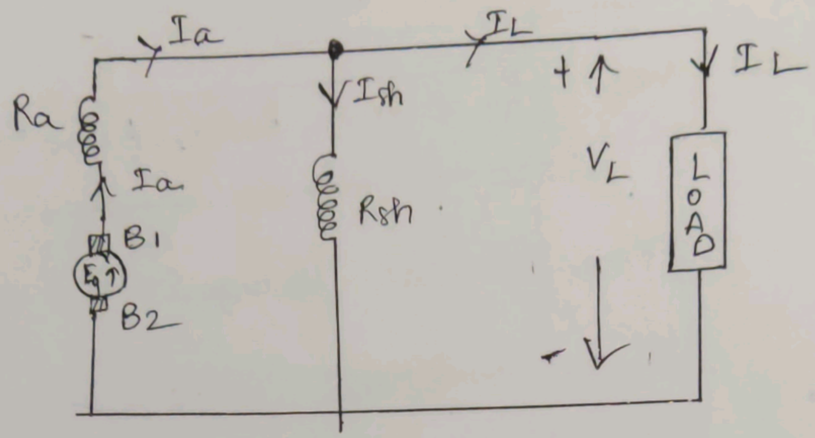
$[\because I_a = I_{se}]$

(b) Shunt Generator

* Here the field winding is connected in Parallel with Armature winding.

* The shunt field winding has more no. of

turns of thin wire. It has high resistance
The Load is connected across the armature



Generated Emf $E_g = V_L + I_a R_a + V_{brush}$ (V)

Armature current $I_a = I_{sh} + I_L$ (A)

* shunt field current $I_{sh} = \frac{V_L}{R_{sh}}$ (A)

Power developed by Armature $P_g = E_g I_a$

Power delivered to load $P_L = V_L I_L$ (W)

V_L → Terminal voltage.

(iii) Compound Generator

* It consits of both shunt field and series field windings

* One winding is in series and another winding is in parallel with armature

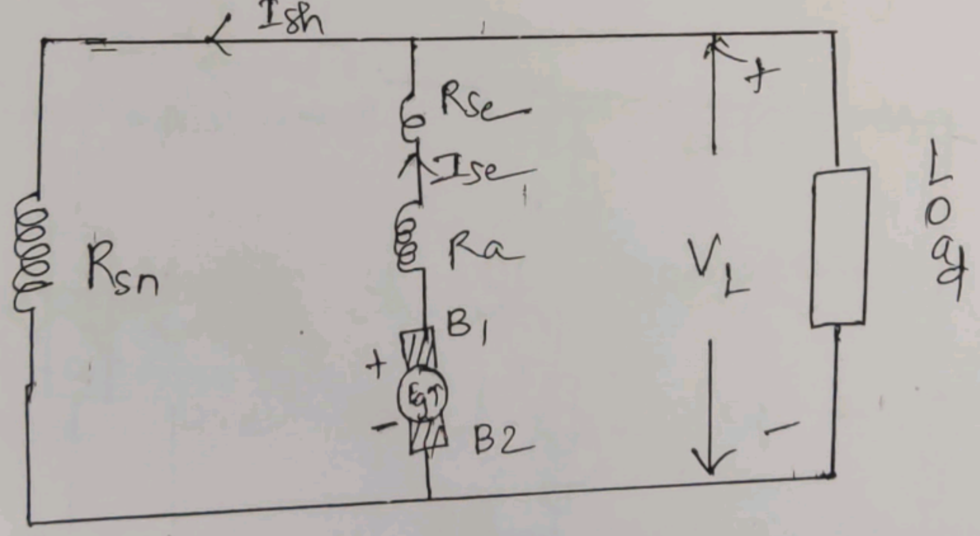
* This Generator can be classified as,

(a) Long shunt compound Generator

(b) short shunt compound Generator

(a) Long Shunt compound Generator

* Here shunt field winding is connected across both series field and armature windings



From the figure

$$I_a = I_{se} = I_L + I_{sh} \text{ (A)}$$

Shunt field current $$I_{sh} = \frac{V_L}{R_{sh}}$$

Generated Emf $E_g = V + I_a R_a + I_{se} R_{se} + V_{brush}$

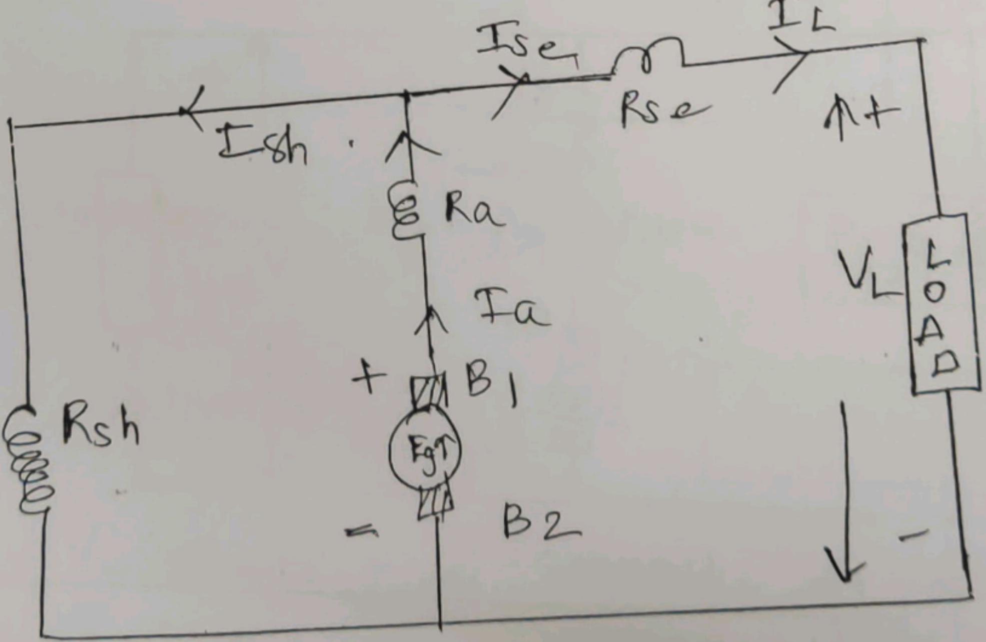
$$E_g = V + I_a(R_a + R_{se}) + V_{brush} \quad (V) \quad [\because I_a = I_{se}]$$

Power developed in armature $\boxed{P_g = E_g I_a}$ (W)

Power delivered to load $\boxed{P_L = V_L I_L}$ (W)

(b) short shunt compound Generator

* Here shunt field winding is connected in Parallel with armature and this combination is connected in series with series field winding.



Generated Emf $\boxed{E_g = V_L + I_a R_a + I_{se} R_{se} + V_{brush} \quad (V)}$

Series field current $\boxed{I_{se} = I_L}$

$I_L \rightarrow$ load current.

Armature current $I_a = I_{sh} + I_{se}$

Shunt field current

Apply KVL Across shunt field

$\therefore V_{sh} = V_L + I_{se} R_{se}$

$I_{sh} R_{sh} = V_L + I_{se} R_{se}$

$$\boxed{I_{sh} = \frac{V_L + I_{se} R_{se}}{R_{sh}} \ (A)}$$

Power developed in armature $P_g = E_g I_a (W)$

Power delivered to load $P_L = V_L I_L (W)$

Characteristics of DC Generator

There are three types of characteristics

(1). Open circuit characteristics (or) Magnetisation Characteristics (E_g Vs I_f)

2) Internal characteristics (or) total characteristics (E_g Vs I_a) (P.T.O.)

(3) External characteristics.

Seperately excited DC Generator characteri

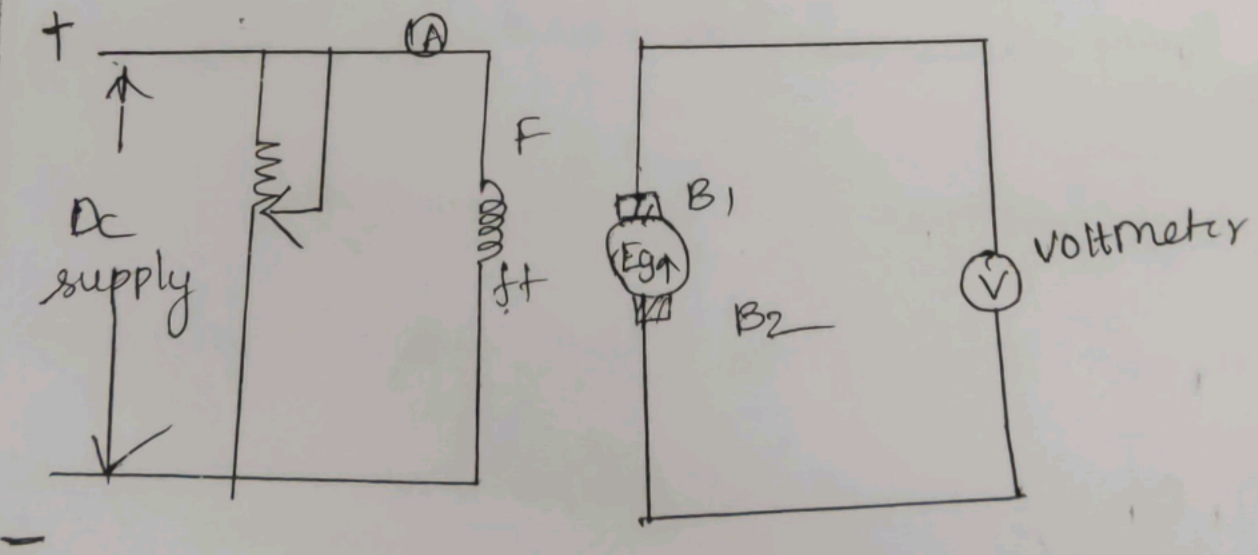
W.K.T Emf equation of Generator is *

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

$E_g \propto \phi N$ If N = constant

If $\phi\uparrow$ $E_g\uparrow$ i.e, if flux increases E_g increa

the variation of flux with the induce emf is called the open circuit charact (OCC) of the generator.

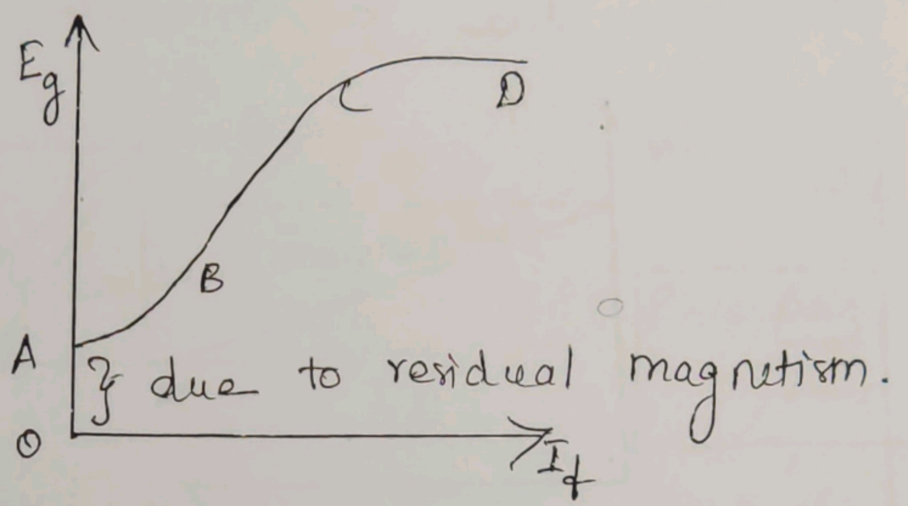


Open circuit characteristics (Eg Vs If)

As the field current is increased

the induced emf increases, increasing linearly from A to B.

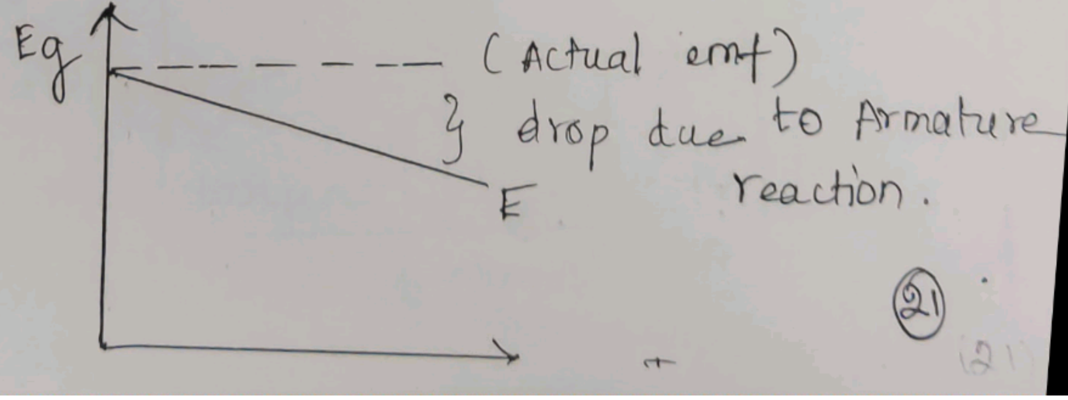
As the field current is further increased, the increase in flux is much smaller and hence the emf also increases slowly. At point D saturation has set in.



Internal Characteristics (Eg Vs Ia)

this curve is drawn between Emf induced and armature current (Ia)

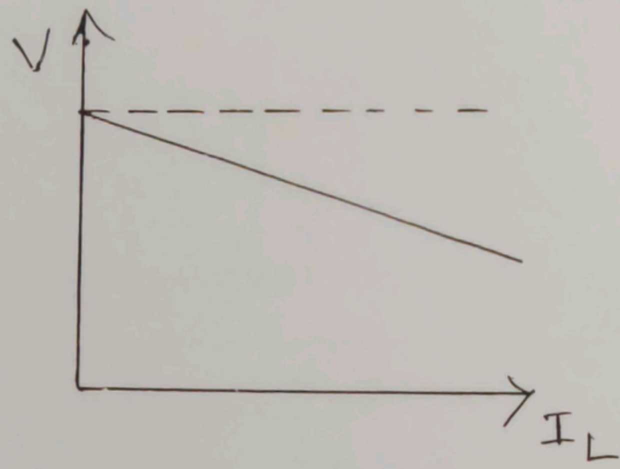
Here by increasing the Armature current induced emf (E) will decrease due to Armature reaction.



External characteristics (V Vs IL)

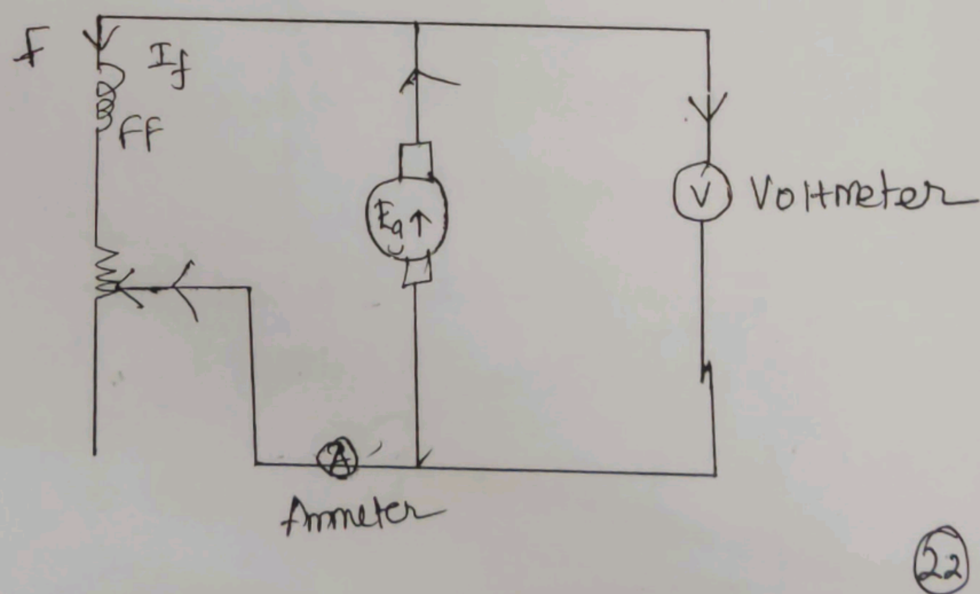
* This curve is drawn between the terminal voltage and armature current

* Here by increasing armature current (load current) then induced emf again decreases due to armature resistance.



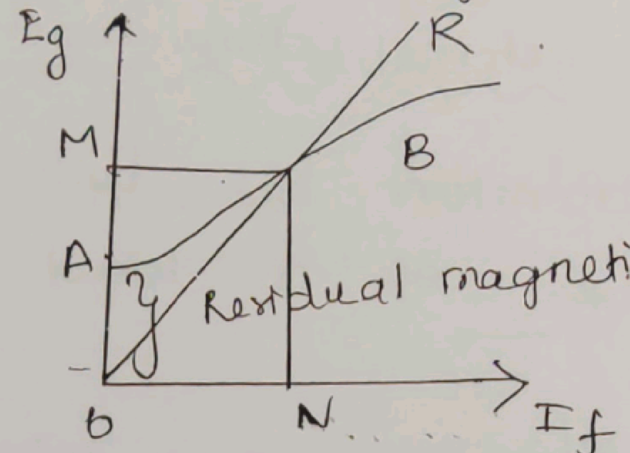
DC shunt Generator characteristics.

* Fig shows dc shunt generator



Open circuit characteristics

* This curve can be drawn between field Current and Induced emf.
* Initially the field current is zero, but emf (OA) is induced in the generator due to residual magnetism.



$$R_C = \frac{OM}{ON} = \frac{\Delta E_g}{\Delta I_f}$$

$$\boxed{R_C = \frac{\Delta E_g}{\Delta I_f}}$$

* Due to this voltage field current increases and emf also increases and it reaches Point B.
* There is no further increase in field current (or) induced emf.
* This curve is open circuit characteristic.

Critical Resistance (R_C)

* OR is the tangent drawn to the Portion of Occ from origin

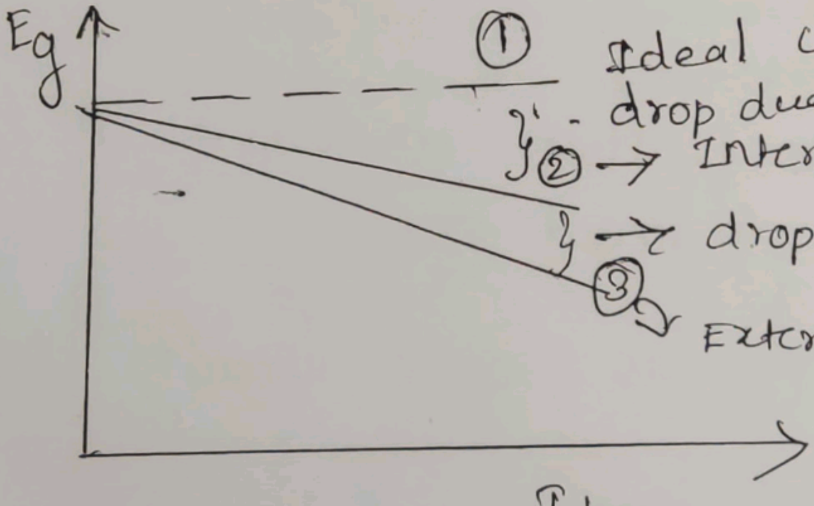
The slope of this tangent OM/ON gives the value of critical resistance, when the Generator just excites.

$$R_c = \frac{\Delta E_g}{\Delta I_f}$$

(ii) Internal and External characteristics.

Once the generator has built up to the specified voltage on no load it may be loaded.

If we increase the load on the generator, the voltage drop also increases.



the curve (1) shows the ideal dc generator. There is no drop in the armature i.e. $E_g = V$

The curve (2) shows the internal characteristics Here the drop is due to armature reaction.

The curve can be drawn for load current Versus (E).

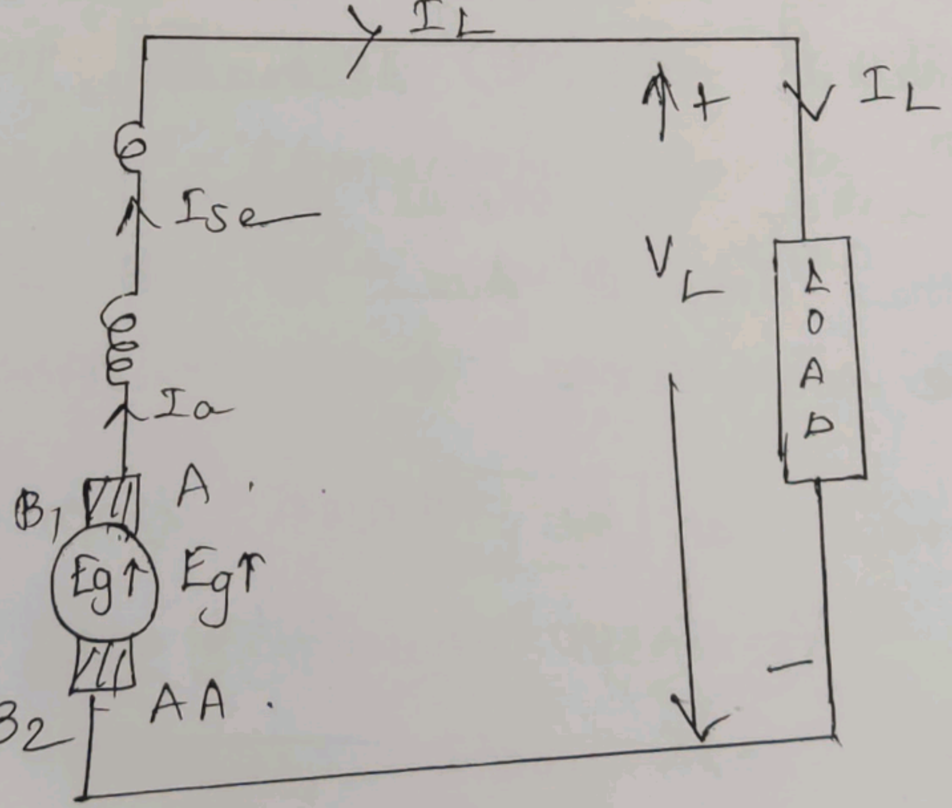
The curve (3) shows external characteristic Here drop is due to Armature Resistance (R_a)

By increasing the load current terminal Voltage decreases.

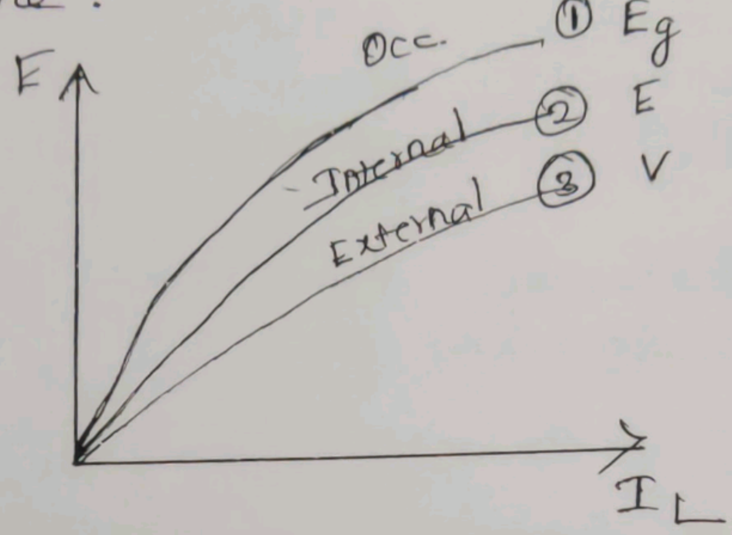
———— × ———— × ————

DC Series Generator characteristics

The connection for the dc series generator is shown in fig



The curve (1) shows Open circuit characteristics. This curve can be obtain by disconnecting the field winding fro *
the machine and excited by seperate dc source.



The curve (2) shows internal character Here the drop is due to armature reaction. By increasing the load curr the induced emf (E) decreases.

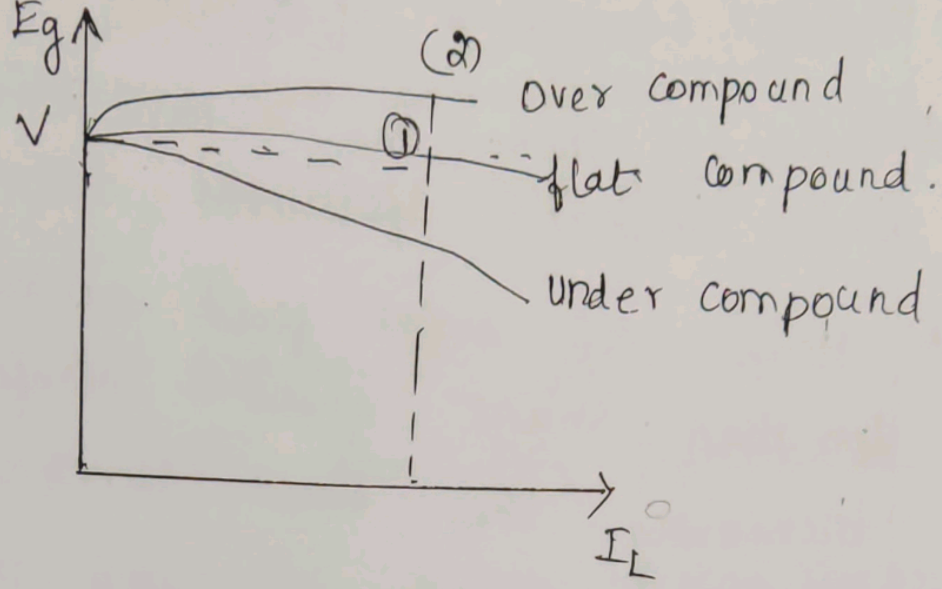
The curve (3) shows external Charact Here the drop is due to the armat resistance and series field resistance.

The curve can be drawn from load current Vs terminal voltage

—— X ——

Compound Generator characteristics.

It consists of series field and shunt field windings. Fig shows external characteristics of compound generator.



(a) Flat compound Generator

* A compound generator has both shunt and series field and if the drop in flux in the shunt field is exactly compensated for by the rise in flux in series feild then it is possible to have constant voltage characteristics

i.e $\boxed{E_g = V}$

(b) Over compound Generator

* Curve (2) shows the characteristics of over compound Generator.

Here the series field excitation is more than shunt field.

i.e $\boxed{V > E_g}$

c) Under compound Generator

curve (3) shows the characteristics of under compound Generator.

Here the series field exitation is less than shunt field. Therefore by increasing the load current the terminal voltage decreases.

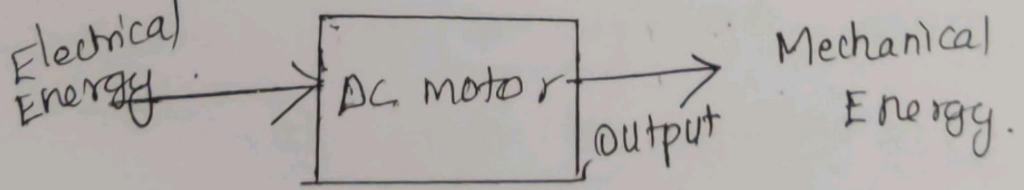
$\boxed{V < E_g}$

—— x —— x

DC Motors.

"The DC motor converts Electrical Energy into Mechanical Energy".

It is shown in fig.



Construction

The DC motor has the following part

(i) Magnetic Frame (or) yoke
(ii) poles, Interpoles, windings, pole shoes
(iii) Armature (iv) commutator
(v) Brushes, Bearings and shafts.

(i) Magnetic frame (or) yoke

It is used for two purpose

* It acts as a protecting cover for whole machine and provides mechanical support for poles.

* It carries the magnetic flux produced by the poles.

(ii) Poles

The pole consists of (i) pole cores
(ii) pole shoes
(iii) pole coils

* The pole core and pole shoes form the field magnet.

* A field winding is wound over the Pole core.

* The Pole coils are madeup of copper or strip.)

Interpoles

* Commutating poles (or) interpoles are Provided to improve commutation.

* the commutating poles also have exciting coils which are connected in series with Armature.

* the coils are madeup of fewer tu of thicker conductor to reduce the resistance.

Armature

* the armature consists of an armature core and Armature winding

* the armature core houses the armature conductors or coils.

Commutator

* The commutator converts the alternating emf into unidirectional (or) direct emf.

* It is made up of wedged shape copper, insulated from each other by thin layers of built-up-mica

Brushes

* The brushes which are made up of carbon or graphite

* It collects the current from the commutator and to convey it to the external load resistance.

* They are rectangular in shape.

Bearings

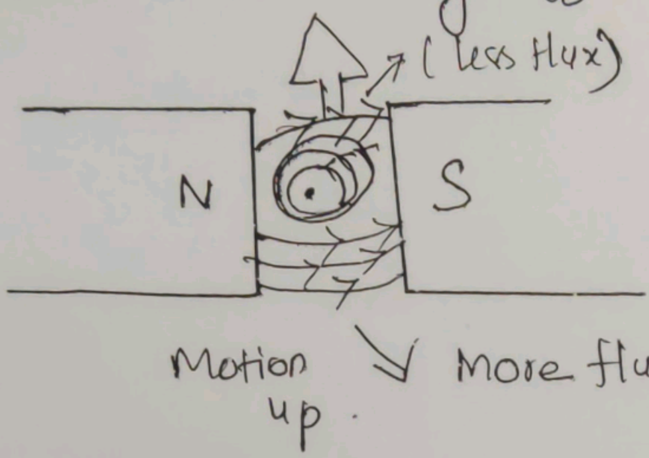
* Ball bearings are usually employed as they are reliable for light machines.

* For heavy duty machines roller bearings are used.

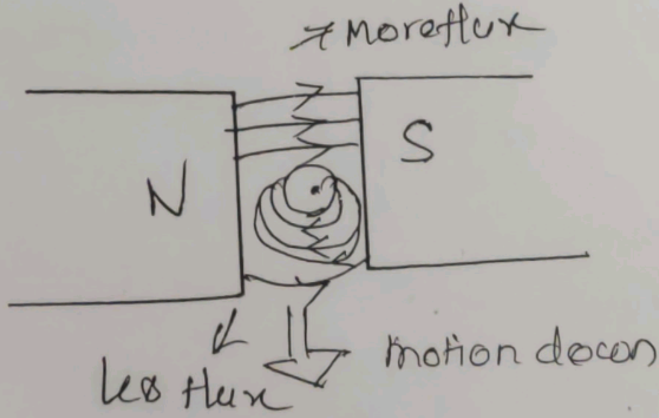
Working

Principle of operation

* the basic principle of operation of DC motor is that "whenever a current carrying conductor is placed in a magnetic field, it experiences a force tending to move it".



* Above the conductor the flux is less and below the conductor, the field is more causes the motor to move upward



* then the direction of current through the conductor is reversed as shown in fig. Here the field below the

conductor is less and field above conductor is more.

* then the conductor tends to move downwards.

* The magnitude of force experienced by the conductor in a motor is given by

$$F = BIL \text{ newtons}$$

where B = magnetic field intensity

I = current in Amperes.

L = Length of conductors in metres.

* The direction of motion is given by Fleming's left hand rule

——— X ———

Types of DC Motors

The types of DC motors are

(i) separately excited DC motor

(ii) self excited DC motor

(a) series motor

(b) shunt motor

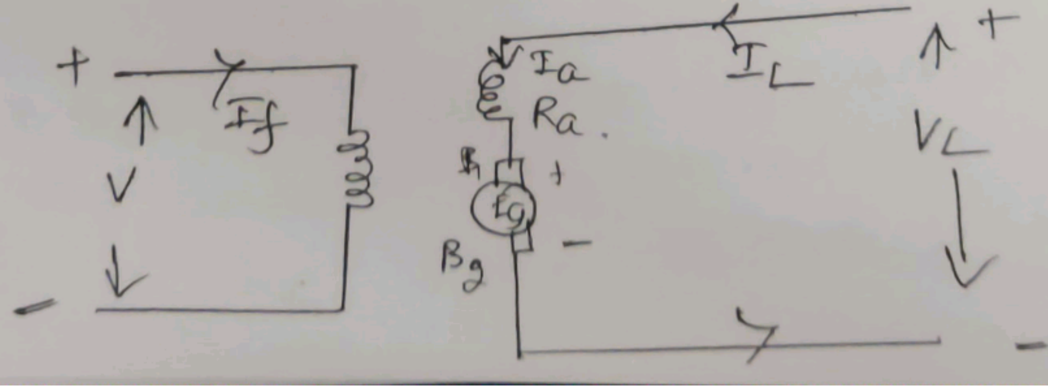
(c) compound motor.

- long shunt compound motor
- Short shunt compound motor

Separately excited DC Motor.

* Here the field winding and armature are seperated. The field winding is excited by seperate dc source.

* That is why it is called as separate excited DC motor.



* From the diagram

Armature current I_a = line current I_L

$$\boxed{I_a = I_L} \quad (A)$$

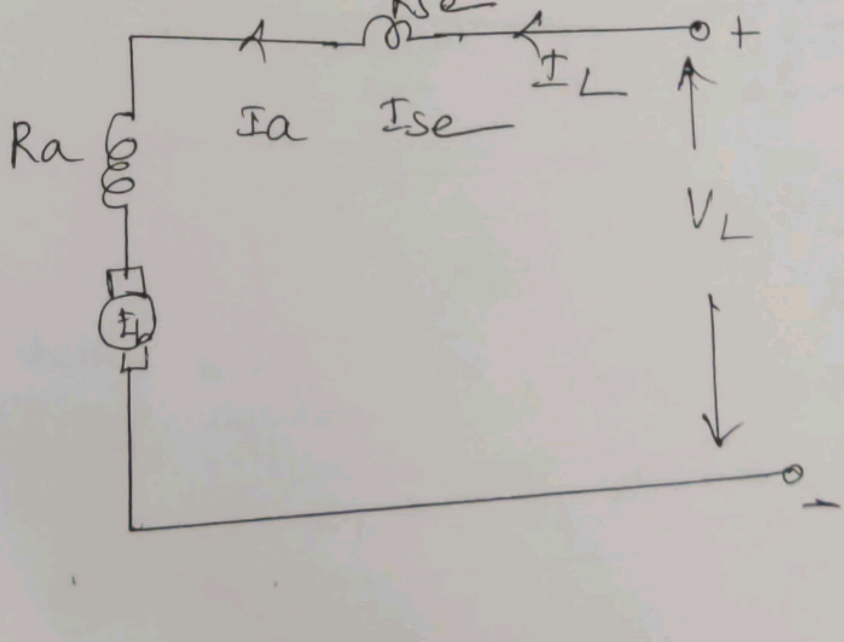
$$\boxed{V_L = I_a R_a + E_b + V_{brush}} \quad (V)$$

(ii) Self Excited DC motor

(a) DC series motor.

* Here the field winding is connected in series with Armature winding.

* Here the field winding has less no. of turns of thick wire "R_{se}" is resistance of series field winding. Its value is very small.



The voltage equation is given by,

$$V = I_{se}R_{se} + I_a R_a + E_b + V_{brush}$$

In DC series motor

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

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

where

I_L → Line current

V_{brush} → Brush drop

E_b → back emf.

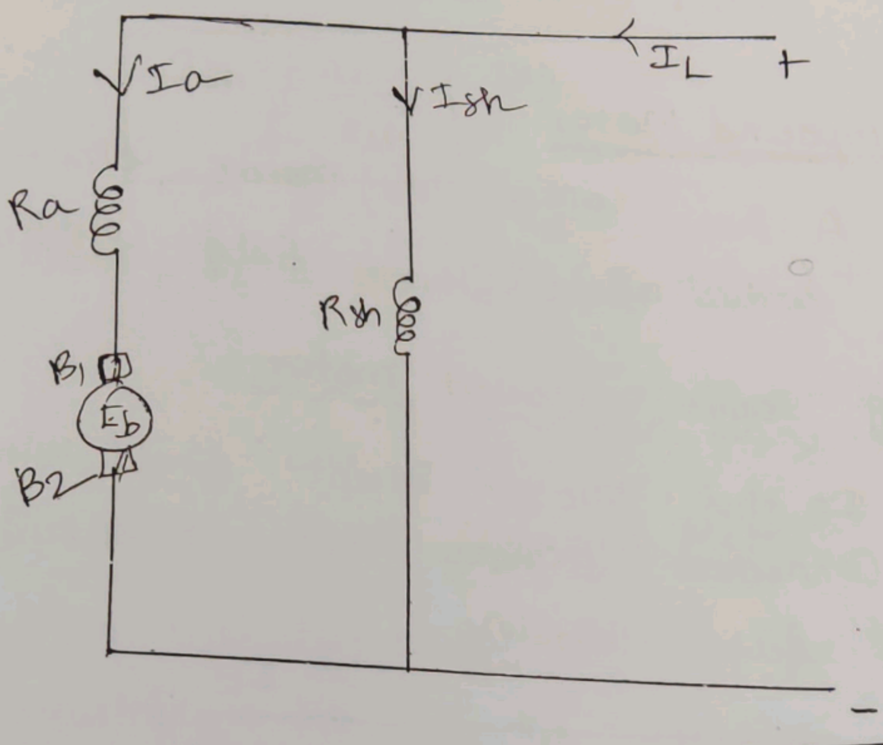
* In series motor flux produced is directly proportional to armature current

ie $$\phi \propto I_{se} \propto I_a$$

(ii) DC shunt Motor.

* In this motor the feild winding is connected in parallel with armature winding.

* It has more no. of turn with this wire.
* Ra → Armature Resistance
* Rsh → Shunt field Winding Resistance
* I_L → Line current drawn from the supply



from the diagram $I_L = I_a + I_{sh}$ A)

$$I_{sh} = \frac{V_L}{R_{sh}} (A)$$

voltage equation of DC shunt motor is

$$V = E_b + I_a R_a + V_{brush} (V)$$

In shunt motor flux produced by field winding is proportional to field current (I_{sh})

i.e $\boxed{\phi \propto I_{sh}}$

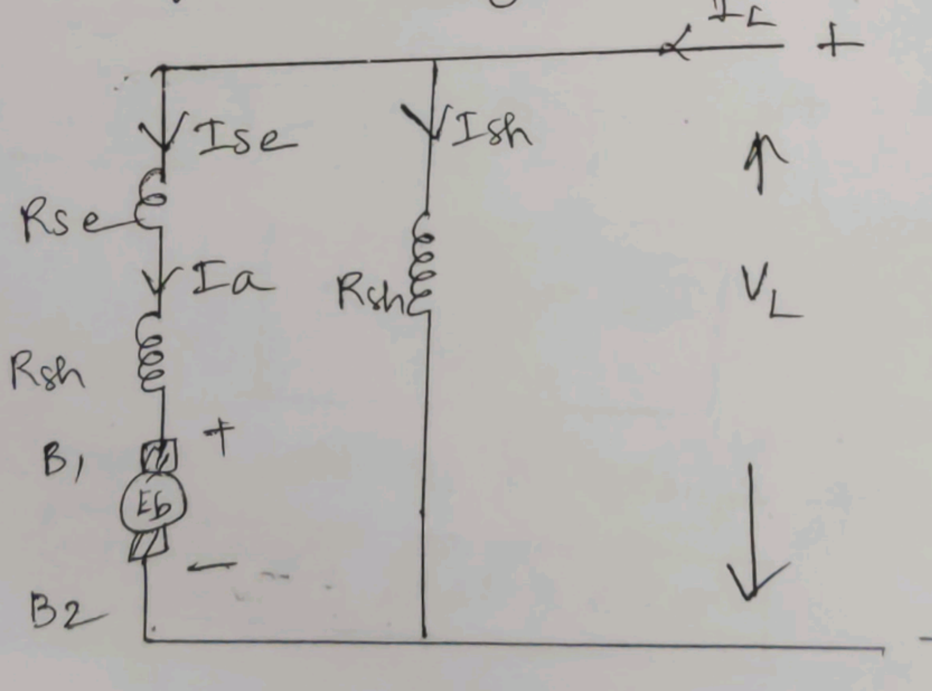
DC shunt motor also called a constant flux motor (or) constant speed motor.

DC Compound Motor

A DC compound motor consists of both series and shunt field windings.

(a) Long shunt compound motor.

In this motor shunt field winding is connected across both armature and series field winding



* From the diagram.

$$V_L = E_b + I_a R_a + I_{se} R_{se} + V_{brush} \ (V)$$

$$I_a = I_{se} \quad (A)$$

$$I_L = I_{sh} + I_{se} \quad (A)$$

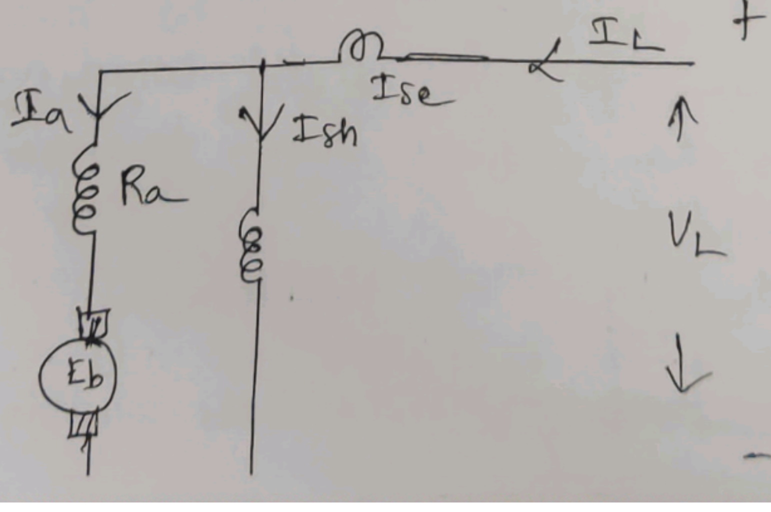
$$I_{sh} = \frac{V_L}{R_{sh}} \quad (A)$$

Now, $V_L = E_b + I_a(R_a + R_{se}) + V_{brush}$

$[\because I_{se} = I_a]$

(b) Short Shunt Compound Motor:

* In this type of motor, the shunt field winding is across the armature and series field winding is connected in series with this Combination.



From the diagram.

$$V_L = E_b + I_a R_a + I_{se} R_{se} + V_{brush}.$$

$$I_{se} = I_L$$

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

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

Voltage drop across shunt field winding.

$$I_{se} R_{se} + V_{sh} = V_L$$

$$\therefore V_{sh} = V_L - I_{se} R_{se}$$

$$I_{sh} R_{sh} = V_L - I_{se} R_{se}$$

$$I_{sh} = \frac{V_L - I_{se}R_{se}}{R_{sh}}$$

The compound motor again classified two types

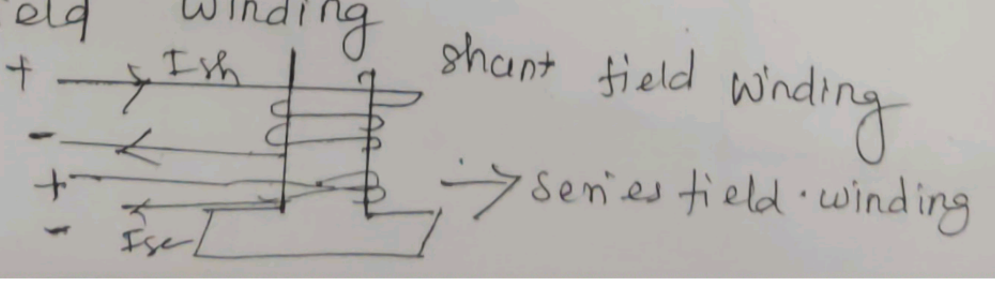
(i) cumulative compound motor

(ii) Differential compound motor.

Cumulative compound motor

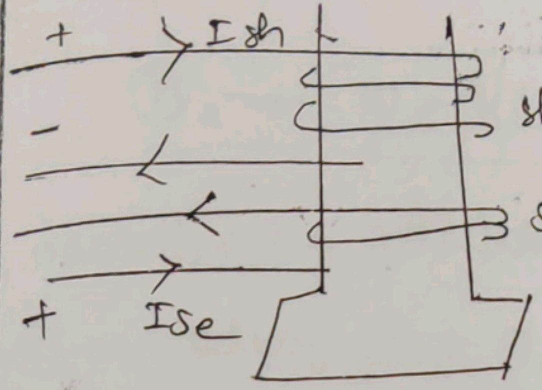
* In this type of motor the two field winding fluxes and each other.

* Flux due to series field winding strengthens the flux due to shunt field winding



Differential Compound motor.

In this type of motor the two field winding fluxes oppose each other. i.e field due to series field winding reduces the field due to shunt field winding



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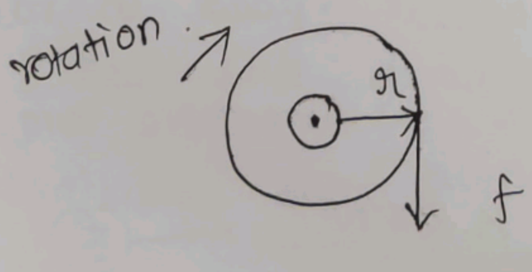
Torque Equation.

"Torque is nothing but turning (or) twisting force about an axis.

* Torque is measured by product of force and the radius at which the force acts.

* consider a wheel of radius "r" metres acted on by a circumferential force 'F' newton as shown in fig.



(41)

Let the force 'F' cause the wheel to rotate at 'N' rpm. The angular velocity of wheel is

$$\omega = \frac{2\pi N}{60} \text{ rad/sec}$$ [N rpm = 60 sec
1 rpm = $\frac{60}{N}$ sec

Torque $\boxed{T = f \times r}$ N-m —— ①

Work done per revolution = F × distance moved

= F × 2πr joules —— ②

Power developed p = workdone / time

$$= \frac{f \times 2\pi r}{\text{time for 1 rev}} = \frac{F \times 2\pi r}{60/N} \quad \text{—— ③}$$

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

$$\boxed{P = T\omega \text{ (watts)}} \quad \text{—— ④}$$

where T = Torque in N-m
ω = Angular speed in rad/sec

Power in Armature = Armature torque × ω

$$E_b I_a = T_a \times \frac{2\pi N}{60} \quad \text{—— ⑤}$$

[∵ P = $E_b I$

W.K.T, $E_b = \frac{\phi Z N P}{60 A}$ —— (6)

sub (6) in (5)

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

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

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

$$\therefore T_a = 0.159 \phi I_a \frac{PZ}{A} \text{ N-m}$$ —— (7)

The above equation is torque equation of DC motor

$\therefore T_a = K \phi I_a$ where $K = 0.159 \phi \frac{Z}{A}$

$\therefore$ $T_a \propto \phi I_a$

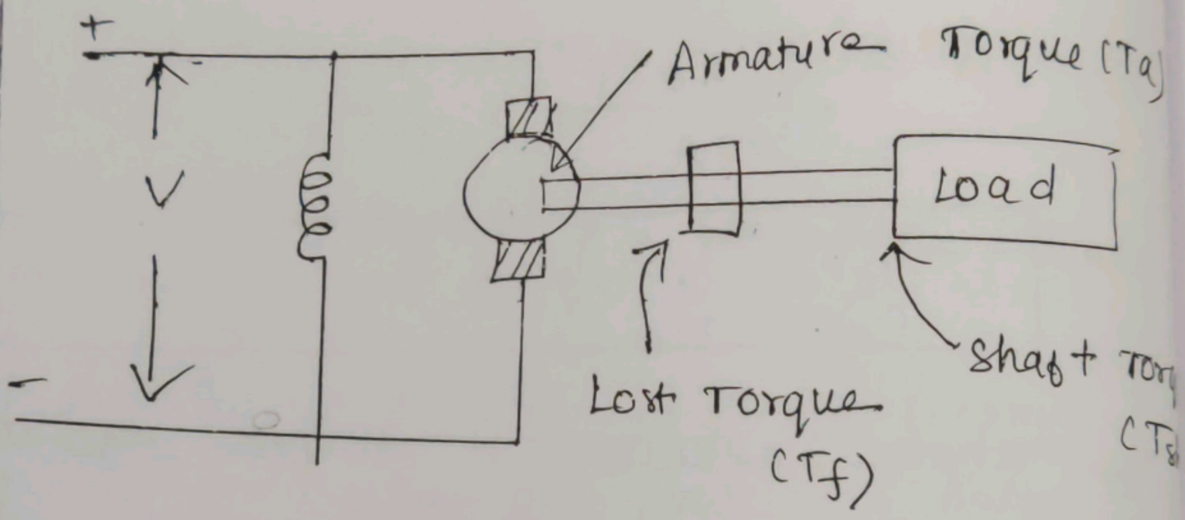
Shaft Torque

* The full armature torque is not available for doing useful work.

(43)

some amount of torque is used to supplying iron loss and friction loss in the motor.

* This torque is called lost Torque (T_f)
* The remaining torque is available for doing useful work. This torque is known as shaft torque (or) useful Torque (T_{sh})



* The armature torque is sum of lost torque and shaft torque

$$\therefore \boxed{T_a = T_f + T_{sh}}$$

The o/p power of motor is

$$P_{out} = T_{sh} \times \frac{2\pi N}{60} \text{ watts}$$

$$T_{sh} = \frac{P_{out}}{2\pi N} \times 60$$

$$\boxed{T_{sh} = 9.55 \frac{P_{out}}{N} \text{ N-m}}$$

Speed and Torque Equation

For DC motor the speed equation is obtained as follows

W.K.T $V = E_b + I_a R_a$ — (1)

$$E_b = \frac{\phi Z N P}{60 A} \quad — (2)$$

sub (2) in (1)

$$V = \frac{\phi Z N p}{60A} + I_a R_a$$

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

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

the values A, Z and P are constant

$$N = \frac{K(V - I_a R_a)}{\phi} \qquad \left[K = \frac{60A}{Zp}\right]$$

where $K \rightarrow$ constant.

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

(or) $N \propto \frac{E_b}{\phi}$ ——— (3)

Hence speed of the motor is directly Proportional to back emf (E_b) and inversely Proportional to flux ϕ.

Torque equation

Torque equation of DC motor is given by

$T \propto \phi I_a$ ——— (4)

Hence the flux ϕ is proportional to the current flowing through the field winding

$\phi \propto I_f$ ——— (5)

DC shunt motor

For DC shunt motor, the shunt field current (I_{sh}) is constant. Therefore flux ϕ is constant.

$T \propto \phi I_a$ becomes

$T \propto I_a$ ——— (6)

DC series motor

The series field current is equal to Armature current I_a. Therefore flux $\phi \propto I_a$

Hence $T \propto \phi I_a$ becomes

$$\boxed{T \propto I_a^2}$$

The speed and torque equations are mainly used for analyzing the characteristics of DC motors.

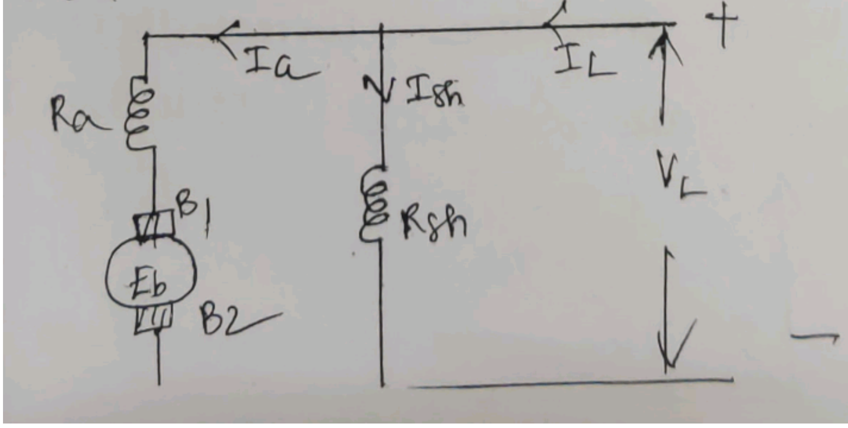
— x —

Characteristics of DC motor.

There are three types of characteristics.

1. Speed - armature current characteristics.
2. Torque - armature current characteristics.
3. Speed Torque characteristics.

DC shunt motor characteristics.

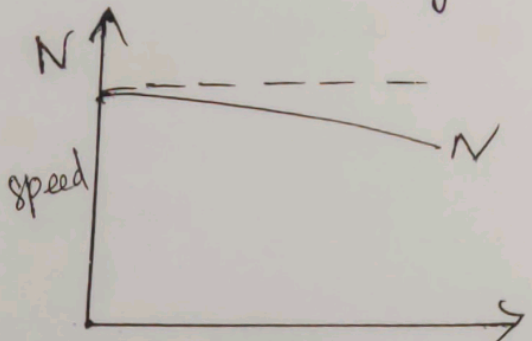


(i) Speed armature current characteristics

W.K.T $N \propto \frac{E_b}{\phi}$

In this m/c flux is constant $\therefore N \propto E_b$

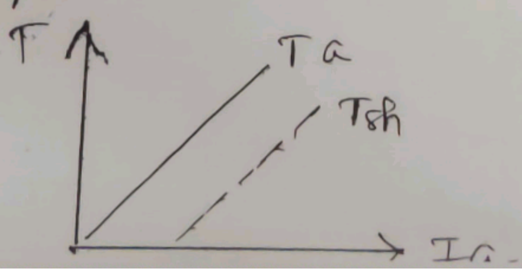
$\therefore N \propto V - I_a R_a$ This implies that speed is nearly constant except for a small drop. This is shown in fig



(ii) Torque - armature characteristics (T Vs Ia)

* In Dc shunt motor Torque is directly proportional to armature current i.e $T \propto I_a$.

* So, when armature current increases the torque also increases. It is shown in

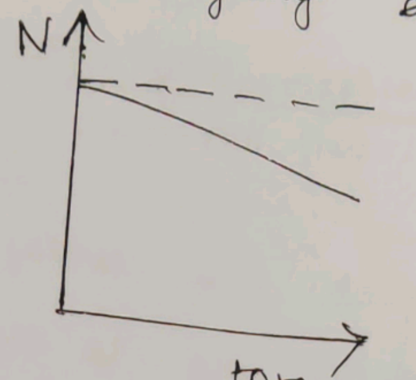


(iii) Speed - Torque characteristics (N Vs T)

* It is also called mechanical characteristic

* This characteristics can be got from the above two characteristics.

* Here when the load torque increases, the speed slightly decreases.



(b) D.C. series motor characteristics.

* In D.C series motor the field winding and armature winding in series.

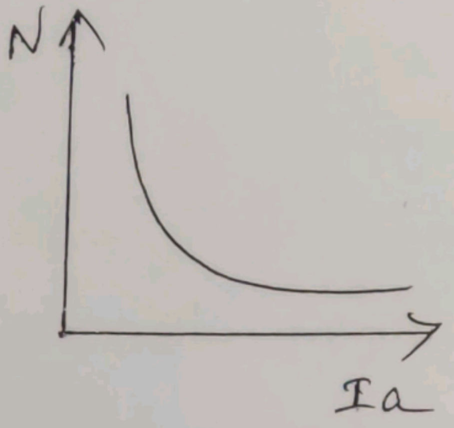
$$I_L = I_a = I_{se}$$

(i) Speed - Armature current characteristics

* In this machine field flux (ϕ) depends field current through it. i.e $\phi \propto I_{se} \propto I_a$

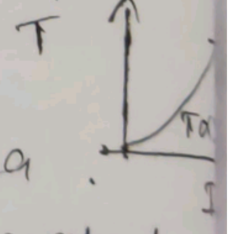
$\therefore \phi \propto I_a$

* $N \propto \frac{E_b}{I_a}$. From this equation, it is clear that by increasing the armature current speed will increase.



(ii) Torque Armature current characteristics

* In DC series motor $T \propto I_a^2$. As I_a increases T_a increases as the square of the current.



* This characteristics is a parabola.
* After saturation the flux is constant.

(iii) Speed - Torque characteristics

Here the DC series motor speed is high, the torque is low and viceversa. It is shown in fig.

Transformer

Working Principle and Application of Transformer

Introduction.

* A transformer is a device that changes ac electric power at one voltage level to ac electric power at another voltage level through the action of a magnetic field.

* Transformer works on the principle of electromagnetic induction.

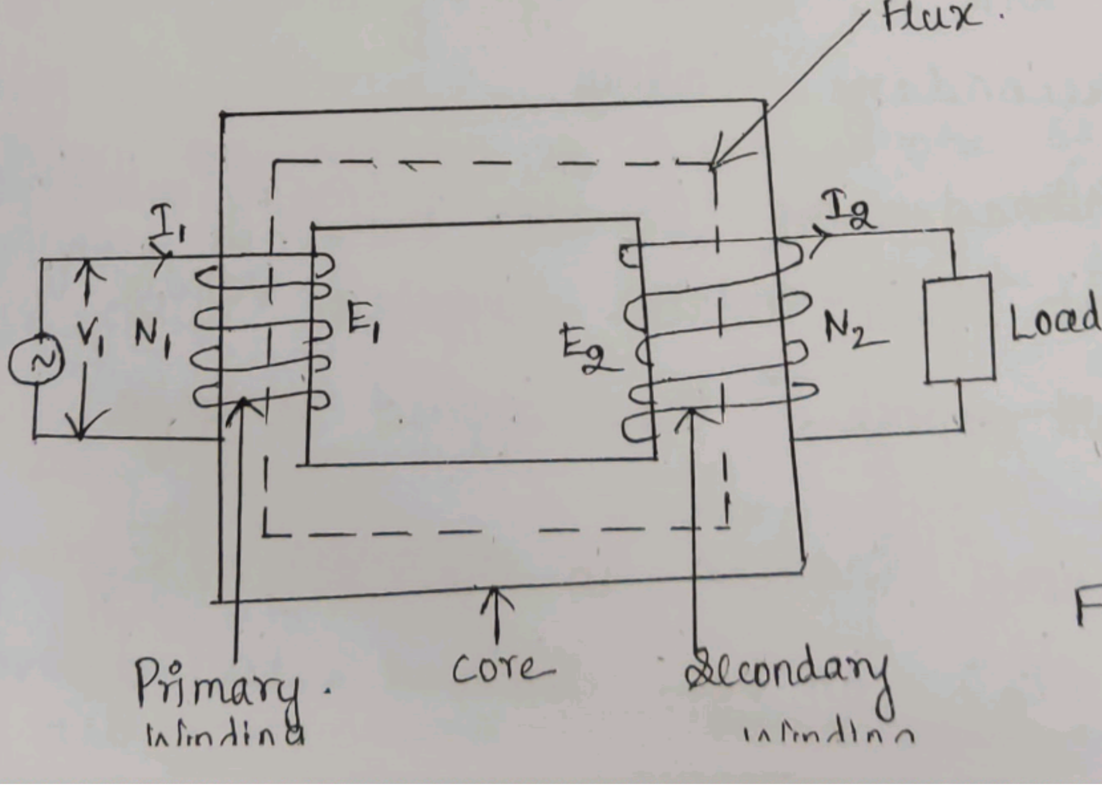


Figure 1.1

Working Principle of a Transformer.

* From the Figure 1.1, Transformer consists of two windings insulated from eachother and wound on a common core made up of magnetic material.

* Alternating voltage is connected across one of the windings called the primary winding. In both the windings emf is induced by the electromagnetic induction. The second winding is called secondary winding.

* When the primary winding is connected to a ac source an exciting current flows throu[gh] the winding. As the current is alternating, i[t] will produce an alternating flux in the cor[e] which will be linked by both the primary and secondary windings.

* The induced emf in the primary winding (is almost equal to the applied voltage V_1 and will appose the applied voltage.

* The emf induced in the secondary winding (E_2) can be utilised to deliv[er]

Power to any load connected across the secondary.

Thus power is transferred from the primary to the secondary circuit by the electromagnetic Induction.

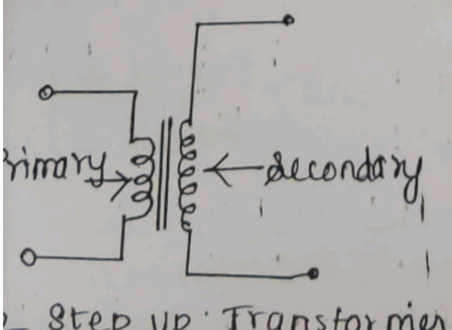
The flux in the core will alternate at the same frequency as the frequency of the supply voltage.

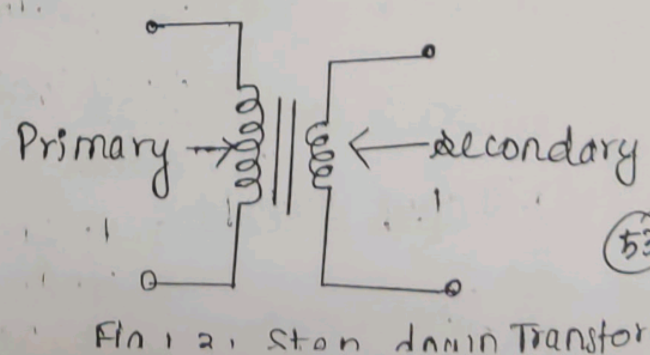
The Frequency of induced emf in the secondary is same as that of the supply voltage.

The magnitude of the emf induced in the secondary winding will depend upon its number of turns.

In a Transformer, if the number of turns in the secondary winding is less than that in the Primary winding, it is called a step-down Transformer fig 1.3

When the number of turns in the secondary winding is higher than the primary winding, it is called a step-up transformer. Fig 1.2





2 Step up Transformer

Fig 1.3 Step down Transformer

Classification of Transformers

(i) Duty they perform.

1. Power Transformer - for transmission and distribution purposes.
2. Current Transformer - instrument transformers.
3. Potential Transformer - instrument transformers

(ii) Construction.

1. Core Type Transformer
2. Shell Type Transformer
3. Berry Type Transformer

(iii) Voltage Output.

1. Step down Transformer (Higher to Lower)
2. Step up transformer (lower to Higher)
3. Auto Transformer (variable from '0' to rated value)

(iv) Application

1. Welding Transformer
2. Furnace Transformer.

(v) Cooling

1. Duct type Transformer (Air natural (or) Air blast)
2. Oil immersed.
   - a. Self cooled
   - b. Forced air cooled
   - c. Water cooled
   - d. Forced oil cooled

(vi) Input supply

1. Single phase Transformer
2. Three phase Transformer
   - a). Star - star
   - b) Star Delta
   - c) Delta - Delta

starting by providing a special winding on the rotor poles, known as damper winding or squirrel cage winding.

* The damper winding consists of short circuited copper bars embedded in the face of the field poles.

* AC supply given to the stator produces a rotating magnetic field which causes the rotor to rotate, therefore in the begining synchronous motor provided with damper winding starts as a squirrel cage induction motor.

* The exciter moves along the rotor- when the motor attains about 95% of synchronous speed, the rotor winding is connected to exciter terminals and the rotor is magnetically locked by the rotating field of the stator and the motor runs as a synchronous motor.

(2) By Means of AC Motor

* A small direct coupled induction motor called the pony motor, may be used for starting the synchronous motor unless the motor is required to start against full load Torque.

* The induction Motor frequently has two poles less than the synchronous motor and so is capable of raising the speed of the latter to synchronous speed.

* Before switching on the AC supply to the synchronous motor, it must be synchronised with the bus bars.

* After normal operation is established, the pony motor is some times de-coupled from the synchronous motor.

(3) By means of Damper Grids in the Pole faces.

* The synchronous motor is made self

Three phase Alternator

Alternator

* The machine which produces 3 phase power from mechanical power is called an alternator or synchronous generator.

* An alternator works on the same fundamental principle of electromagnetic induction as a d.c. generator. i.e when the flux linking a conductor changes, an emf is induced in the conductor.

Working of Alternator.

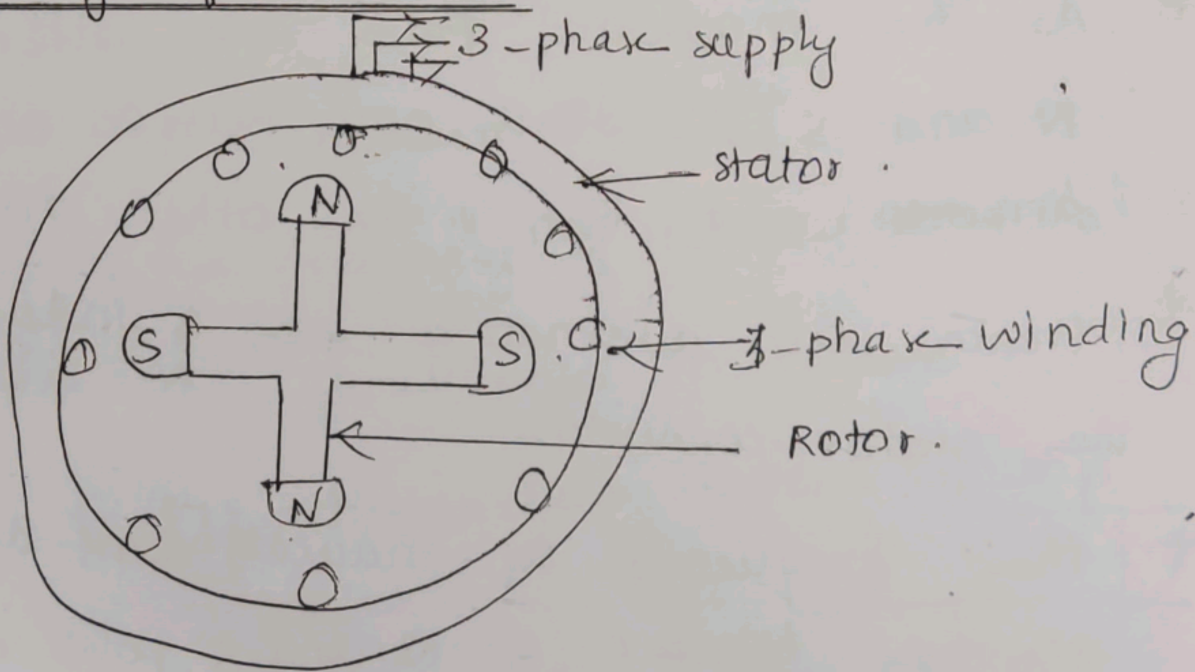


Fig: sectional view of a salient pole alternator.

* The field magnets are magnetized by applying 125 volts or 250 volts through slip rings.
* The field windings are connected such that, alternate N and S poles are produced.
* The rotor and 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 and S pole, this emf acts in one direction and then in the other direction.
* Hence an alternating emf is induced in the stator conductors.
* The frequency of induced emf depends on the Number of N and S poles moving past an armature conductor in one second.
* The direction of induced emf can be found by fleming's right hand rule and

frequency is given by

$$f = \frac{PN}{120}$$

where N → speed of the rotor in r.p.m

P → Number of rotor poles.

Equation of Induced EMf

Let Z = number of conductors or coil sides in series/phase

Z = 2T where T is the number of coils or turns per phase

P = number of poles.

f = frequency of induced emf in Hz

ϕ = flux/pole in webers

$$K_d = \text{distribution factor} = \frac{\sin \frac{m\beta}{2}}{m \sin \frac{\beta}{2}}$$

K_c or K_p = pitch factor (or) coil span factor

$= \cos \alpha/2$

k_f = form factor = 1.11 - if emf is assumed sinusoidal

N = rotor speed in r.p.m.

* For one revolution of the rotor each stator conductor is cut by a flux of ϕP webers.

$$d\phi = \phi P \quad \text{and} \quad dt = \frac{60}{N} \text{ second.}$$

Average emf induced per conductor

$$= \frac{d\phi}{dt} = \frac{\phi P}{60/N} = \frac{\phi PN}{60}$$

W.K.T, $f = \frac{PN}{120}$ (or) $N = \frac{120f}{P}$

sub value of N, we get average emf per conductor

$$= \frac{\phi P}{60} \times \frac{120 f}{P} = 2f\phi \text{ volt.}$$

If there are Z conductors in series/phase then, Average e.m.f / phase = $2f\phi Z$ volts = $4f\phi T$ Volts.

RMS value of e.m.f / phase = $1.11 \times 4f\phi T$

$= 4.44 f\phi T$ volts

The above equation is true only, if the winding is concentrated in one slot.

* But practically it is not true, as the winding for each phase under each pole is distributed and for such cases k_p and k_d must be considered.

∴ Actually available voltage / phase

$= 4.44 k_p k_d f\phi T$ volts.

If the alternator is star connected, then the line voltage is $\sqrt{3}$ times the phase voltage.

Voltage Regulation.

Voltage Regulation of an alternator is defined as the increase in terminal voltage when full Load is thrown off, assuming field current and (61) speed remaining the same. The percentage regulation is defined as the ratio of change in terminal voltage from full load to no load to rated terminal voltage.

$$\text{Percentage regulation} = \frac{E_0 - V}{V} \times 100$$

where

E_0 = No load terminal voltage

V = Full Load terminal voltage

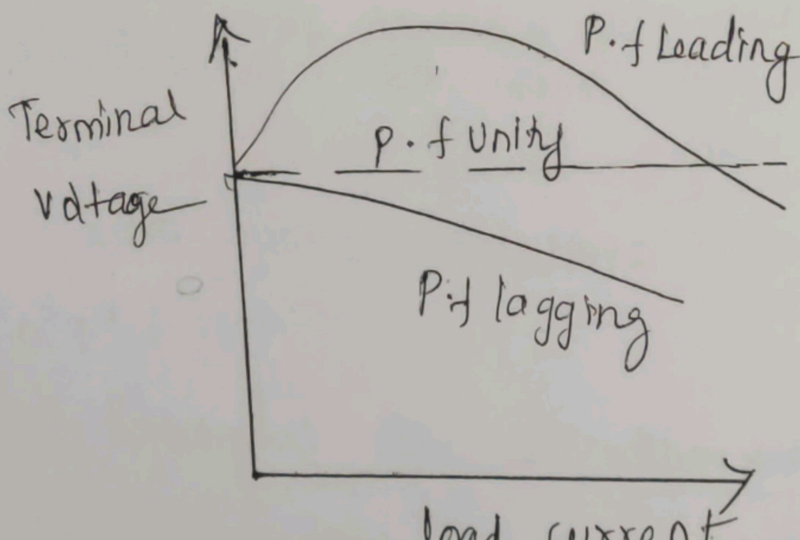


fig: voltage characteristics of an alternator

Synchronous Motor

* The synchronous motor is one type of 3 phase A.C motors which operate at a constant speed from no load to full load.

* It is similar in construction to 3 phase A.C generator in that it has a revolving field which must be separately excited from a D.C source.

* By changing the D.C field excitation, the power factor of this type of motor can be varied over a wide range of lagging and leading values.

* This motor is used in many applications because of its fixed speed from no load to full load, its high efficiency and low initial cost.

* It is also used to improve the power factor of 3-phase AC industrial circuits.

Working Principle

* When a sinusoidal (single phase) voltage is applied to a winding, the magnetic

field produced by the resultant current flow will also be sinusoidally varying with respect to time.

* This means that the field is pulsating.

* Now when a three-phase 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

$$N_s = \frac{120 \times f}{P}$$

where f is the frequency of supply
P is the Number of poles.

$N_s \Rightarrow$ synchronous speed.

* When a three-phase supply is given to a three-phase winding a magnetic field of constant magnitude but rotating

* N_S and S_R and similarly S_S and N_R get attracted and the rotor tries to rotate in the 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 and cannot start by itself.

* If the rotor is now rotated seperately by a prime moven 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 N_S and S_R and similarly S_S and N_R get attracted and locked to one another.

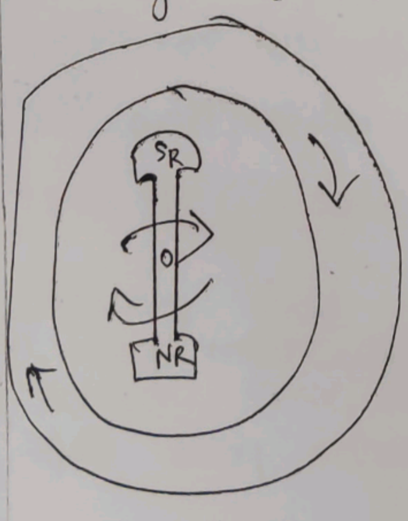


fig (a)

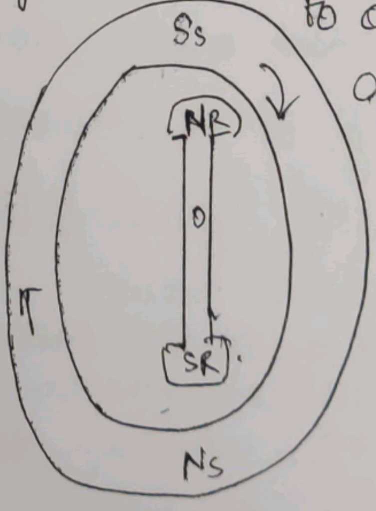
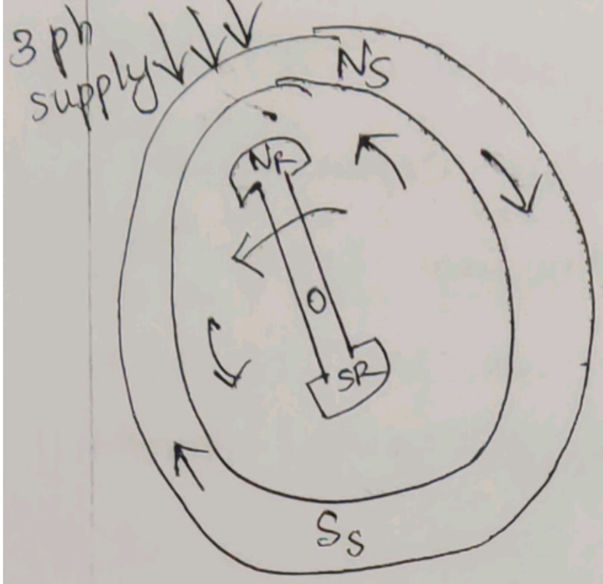
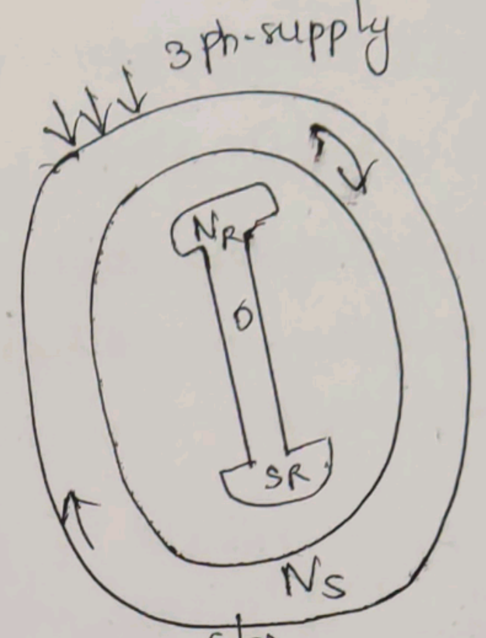


fig (b).

at a constant speed, N_S is produced.



(a)



(b)

* Diagram above shows the two fictitious assumed stator poles marked N_S and S_S to rotate clockwise at a synchronous speed N_S.

* The rotor poles N_R and S_R are formed by the d.c excitation.

* When N_S and N_R are together likes poles repel each other, since N_S and S_S are moving in the clockwise direction, N_R and S_R tend to figure (a).

* Half a cycle later, the stator poles have moved, whereas the rotor poles have moved significantly is shown fig (b).

starting by providing a special winding on the rotor poles, known as damper winding or squirrel cage winding.

* The damper winding consists of short circuited copper bars embedded in the face of the field poles.

* AC supply given to the stator produces a rotating magnetic field which causes the rotor to rotate, therefore in the begining synchronous motor provided with damper winding starts as a squirrel cage induction motor.

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② By Means of AC Motor

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* The induction Motor frequently has two poles less than the synchronous motor and so is capable of raising the speed of the latter to synchronous speed.

* Before switching on the AC supply to the synchronous motor, it must be synchronised with the bus bars.

* After normal operation is established, the pony motor is some times de-coupled from the synchronous motor.

③ By means of Damper Grids in the Pole faces.

* The synchronous motor is made self

* Hence a synchronous motor, though not self starting, starts working as a motor if it is started up by some means.

* It needs two seperate supplies — one a d.c source for excitation of the rotor and other, a three phase supply for the stator.

* Because of the interlocking between the stator and rotor poles, the motor runs only at one speed, the synchronous speed.

Starting Methods of synchronous Motor.

① From DC source

* When DC supply and dc compound motor are available, the synchronous motor is coupled and started by means of a dc compound motor.

* The speed of dc motor is adjusted by the speed regulator

* The synchronous motor is then excited and synchronised with AC supply mains.

* At the moment of synchronising, the synchronous motor is switched on with the Ac mains and either the dc motor is disconnected from the dc supply mains.

* Now the synchronous machine is operating as a motor, from ac supply mains and dc machine acts as load on it.

* The synchronous motor can also be started by the exciter mounted on an overhung synchronous motor bracket and shaft extension.

* An available dc source operates the exciter as a motor during the starting period then after the synchronous machine is brought up to speed and synchronised, the exciter assumes its normal function.

Torque of a Synchronous Motor.

① Starting Torque

* It indicates the ability of the motor to accelerate the load. It is also sometimes called "break away Torque"

* It may be as low as 10% in case of centrifugal pumps and as high as '200 or 250% of full load Torque". as in case of loaded reciprocating two-cylinder compressors.

* The synchronous motor possesses no self starting torque, in modern synchronous motors, by making changes in the design of damper windings, torque can be developed.

② Running Torque.

* Running Torque is the torque developed by the motor under running condition.

* It is determined by the o/p power and speed of the driven machine.

* Peak output power determines the maximum torque that would be required (71)

by the driven machine.

* The breakdown or maximum running Torque of a motor must be greater than this value in order to avoid stalling of the machine.

③ Pull in Torque

* It pertains to the ability of the machine to pull in to synchronism when changing from induction to synchronous motor operation.

④ Pullout Torque.

* It is the maximum Torque that the synchronous motor will develop without pulling out of synchronism.

* Its value ranges from 1.25 to 3.5 times the full load torque.

Three phase Induction Motor.

* Three phase Induction Motors are extensively used for electric drives

Advantages

* It is simple and extremely rugged construction
* High reliability.
* Low cost
* High efficiency.
* It requires little maintenance.
* Its ability to start off from rest unlike synchronous motors which have to be started and run up by seperate prime movers.

Disadvantages

(i) The speed is not constant, when load is varied.

(ii) Low starting torque compared to DC shunt motor

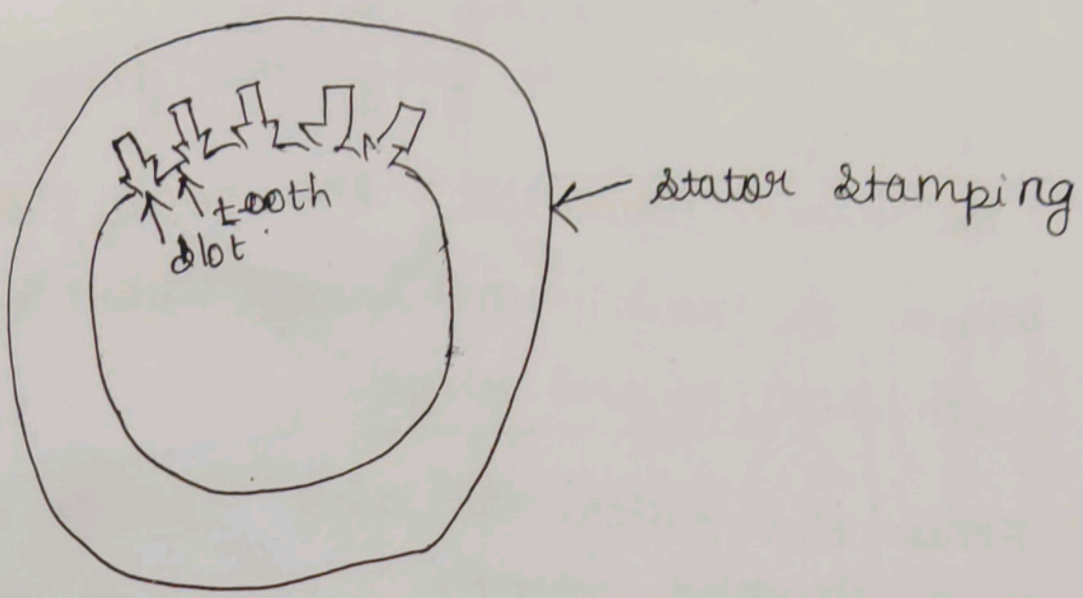
(iii) Reduction in efficieny when speed is varied.

construction

The induction motor consists of two main Parts. Viz (a) Stator
(b) rotor.

Stator

* The stator is made up of a number of stampings with alternate slot and tooth.
* Stampings are insulated from each other
* Each stamping is 0.4 and 0.5 mm thick.
* Number of stampings are stamped together to build the stator core.
* The stator core is then fitted in a casted or fabricated steel frame.
* Three-phase winding is called stator winding
* It may be connected either in star or delta.



Rotor

There are two types of rotors used in induction motors.

They are 1. squirrel cage rotor
2. slip ring or wound rotor.

① squirrel cage rotor

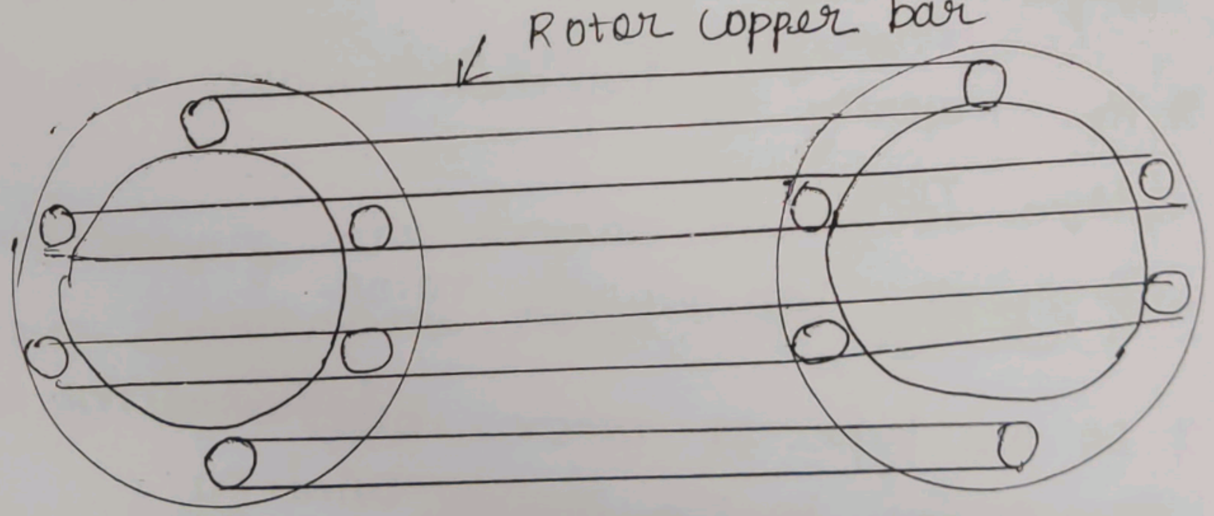


Fig : squirrel cage rotor.

15

* 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.

* The majority of induction motors are cage rotors.

② 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.

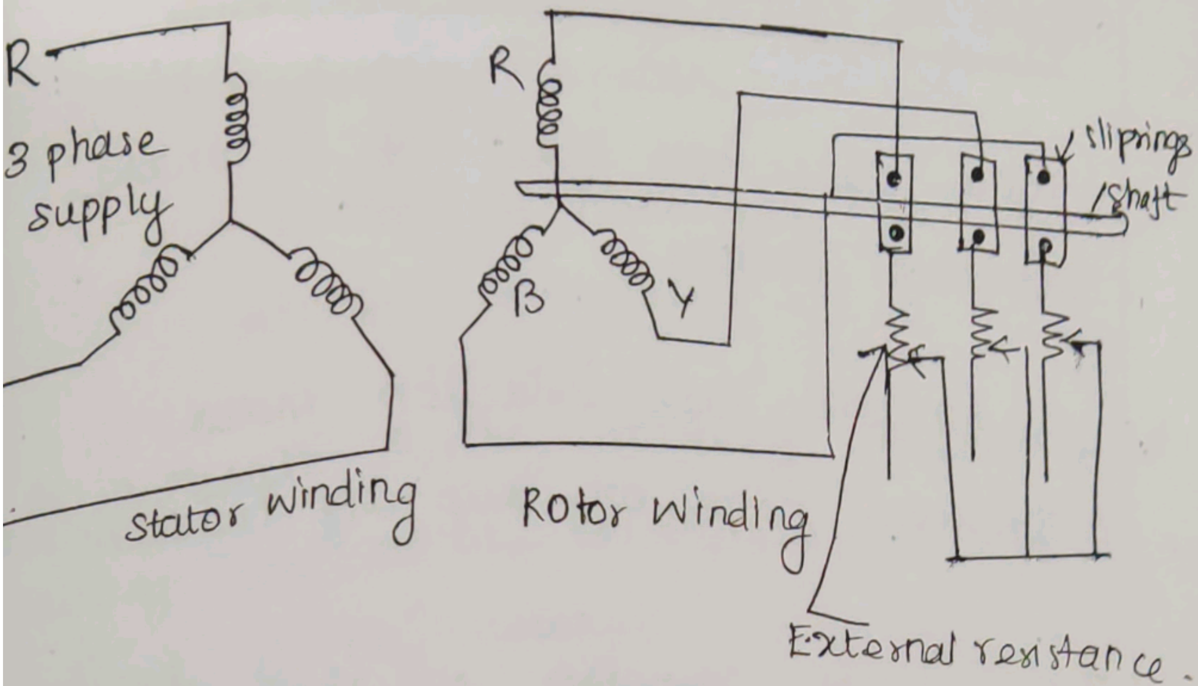


Fig: slipRing (or) wound Rotor

The three phases are 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 slipring induction motor or wound rotor induction motor.

Types of 3-Phase induction motors.

There are two types of 3-phase induction motors.

1. squirrel cage induction motor
2. wound rotor or slip ring induction motor.

Principle of operation of three phase Induction motor

* Three-phase 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.
* This magnetic field rotates at synchronous speed given by

$$N_s = \frac{120f}{P}$$

N_s = synchronous speed

f = supply Frequency

P = number of Poles for which the stator is wound.

* 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 and 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 synchronous 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 synchronous speed.

In an induction motor, the rotor speed is always less than the synchronous speed.

Therefore this machine is called an asynchronous machine.

The difference between synchronous speed and rotor speed is called the slip speed.

$$\text{Slipspeed} = N_S - N$$

$$\text{Slip}, s = \frac{N_S - N}{N_S}$$

(8).

$$N = N_S(1-S)$$

$$\% \text{ slip} = \frac{N_S - N}{N_S} \times 100$$

* At <u>no load</u>, the difference between synchronous speed and rotor speed is only about 1%.

* At <u>loaded condition</u>, 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.

* The variation of speed from no load to full load is very small.

* Thus a three phase induction motor is also called a constant speed motor.

Advantages of squirrel cage induction motor.

1. cheaper
2. Light weight.
3. Rugged construction.
4. More efficient.
5. Requires less maintenance
6. It can be operated in dirty & explosive environment

Disadvantages of squirrel cage induction Motor

1. Moderate starting torque.
2. External resistance cannot be connected to rotor circuit. So starting torque cannot be controlled.

Applications of squirrel cage induction Motor

Lathes, drilling machines, fans, blowers, water pumps, grinders, printing machines.

Advantages of slip ring induction motor.

1. the starting torque can be controlled by varying the rotor circuit resistance.
2. The speed of the motor can be controlled.

Disadvantages of slip ring induction motor

1. Highcost
2. High rotor inertia.
3. High speed limitation.

Application

Lifts, hoists, cranes, elevators,

UNIT - III

ANALOG ELECTRONICS

Resistor, Inductor and Capacitor in Electronic circuits - Semiconductor materials: Silicon & Germanium - PN Junction Diode, Zener Diode - Characteristics Applications - Bipolar Junction Transistor - Biasing - JFET, SCR, MOSFET, IGBT - Types I-V characteristics and Applications, Rectifier and Inverters.

Resitor, Inductor and capacitor in Electronic circuits.

DC circuits - Basic circuit components.

* Resistor
* capacitor
* Inductor

Conductor

* Some materials allow electric charges to pass through them easily, these materials are called conductors.

* Materials that do not allow electric charges to pass through them easily are called Insulators.

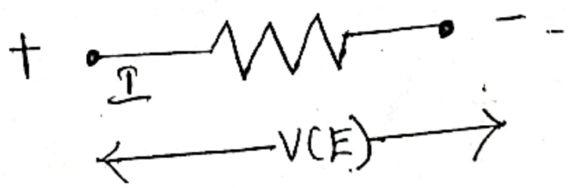
Network (Electrical circuit).

Active Elements.	Passive elements
① which supply power or energy to the network.	- Elements which either store energy or dissipate energy in the form of heat.
② Ex: Voltage source & Current source	- Ex: Resistor, capacitor Inductors.

Resistor

* Electrical component which opposes the flow of current through it. Unit of Resistance is ohm (Ω). It is denoted by R.

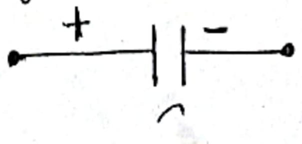
$$R = \frac{V}{I} \text{ ohm}$$



Capacitor

* Capacitor is a storage element which can store & deliver energy in a electric field.

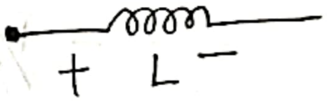
* It is denoted by C.
* The unit of capacitence is Farad (F).



Inductor

Inductor is the element in which energy is stored in the form of electromagnetic field. It is a device that resists change in current.

The inductance is denoted by 'L' and its unit is Henry (H).



V-I Relation:

For inductance the voltage is proportional to rate of change of current.

$$V \propto \frac{di}{dt}$$

$$V = L \frac{di(t)}{dt}$$

$$\Rightarrow I = \frac{1}{L} \int V dt$$

Assuming that initially zero current flows through the inductance, if a current i is made to follow flow through a coil, the energy stored in time t is

$$W = \int_0^t V.I\,dt$$

$$= \int_0^t \left(L \frac{di}{dt}\right) i\,dt$$

$$= L \int_0^t i.di$$

$$W = \frac{1}{2} i^2 L \quad \text{Joules}.$$

⇓

Energy stored in inductor.

Henry is the unit of inductance in which an induced electromotive force of one volt is produced when current is varied at the rate of one ampere per second.

SEMICONDUCTOR MATERIALS : Silicon & Germanium

Basics of Semiconductor

Materials are classified according to the Resistivity/conductivity

- Insulator (Resistance ↑, conductance ↓)
- conductor (Resistance ↓, conductance ↑)
- semiconductor. (Conductance ↓, Resistance moderate)

Semiconductor.

* The small electric field is required to push the electrons from the Valence Bond to Conduction Band. At low temperature, Valence band is completely filled and conduction band is empty. It acts like insulator at low temperature.

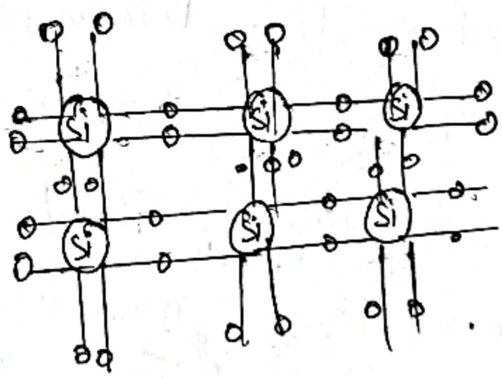
* As the temperature increases, number of electrons crossing over to the conduction band from valence Band increases and electrical conductivity increases. Thus semiconductor has negative temperature Coefficient of Resistance.

Types of semiconductor.

1) Intrinsic semiconductor	2) Extrinsic semiconductor
* Pure form of Semiconductor or (No doping)	* Due to the poor Conduction of current at Room temperature,

	the Intrinsic semiconductor is not useful.
* Electron hole pairs are created by applying electric field at room temperature. Thus Produces current in lower manner Eg: Silicon, Germanium.	* Extrinsic semiconductor is adding impurities to the intrinsic semiconductor [Doping]

Silicon A silicon crystal lattice has a diamond cubic crystal structure in a repeating pattern of eight atoms. Each silicon atom is combined with four neighbouring silicon atoms by four bonds. silicon, a very common element, is used as the raw material of semiconductors because of its stable structure

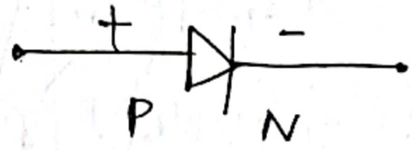


Germanium.

Germanium is a chemical element with the symbol Ge and atomic number 32. It is a lustrous, hard brittle, grayish-white metalloid in the carbon group, chemically similar to its group neighbours silicon and tin. Pure Germanium is a semiconductor with an appearance similar to elemental silicon. Like silicon, Germanium naturally reacts and forms complexes with oxygen in nature.

P-N Junction Diode.

* The PN Junction diode is formed by simply bringing P-type and n-type materials together.



Depletion Region.

* At the instant, two materials are "joined", the electrons and holes in the region of the Junction will combine, results in lack of carriers in the carrier near the Junction.

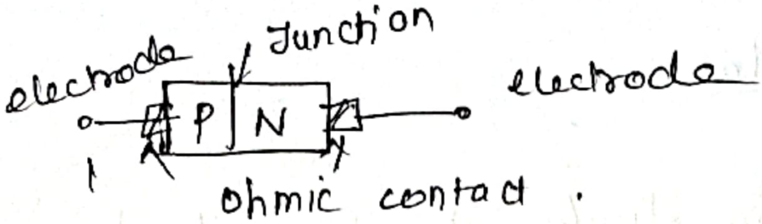
* This region of uncovered positive and negative ions is called the depletion region, due to the depletion of carriers in this region.

* Diode will operate in three Biases.

  (i) No Bias/ Zero Bias ($V_D = 0V$)

  (ii) Forward Bias ($V_D > 0V$)

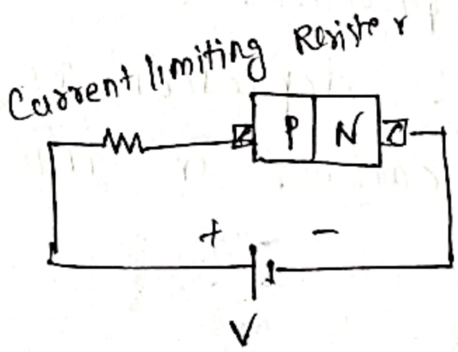
  (iii) Reverse Bias ($V_D < 0V$)



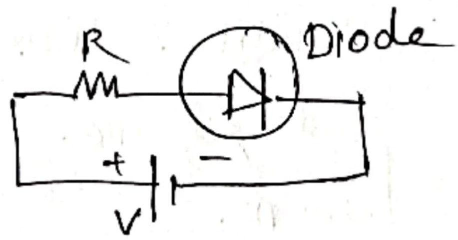
Forward Biased PN junction.

If an external DC - voltage is connected in such a way that the p-region terminal is connected to the positive of the DC - Voltage and n region is connected to the negative of the DC - voltage, this biasing condition is called "forward biasing".

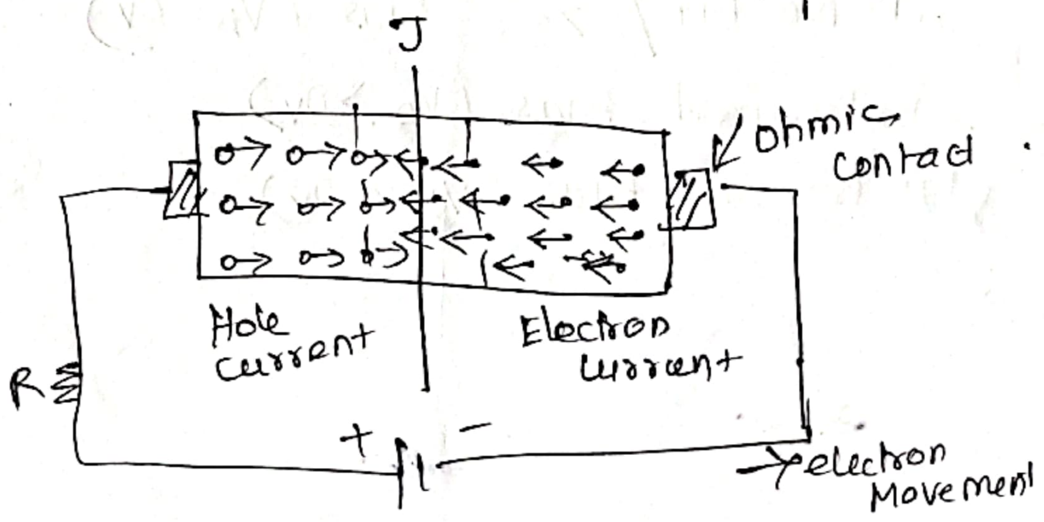
Operation of forward biased diode.



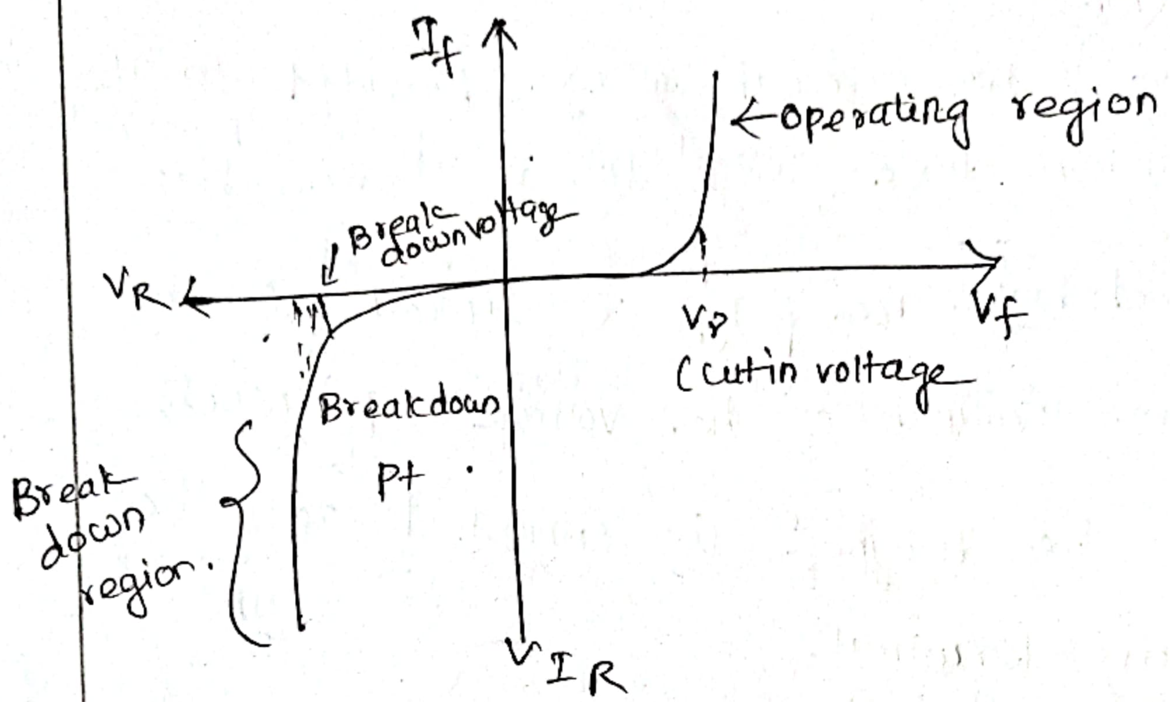
(a) forward biasing.



(b) symbolic representation.



VI Characteracteristics of PN Diode



The response of a diode when connected in an electrical circuit can be judged from its characteristics known as volt-ampere commonly called VI-characteristics.

Biasing conditions for the p-n Junction Diode.

In a p-n junction diode, there are two operational regions.

1. p-type
2. n-type.

The voltage applied determines one of three biasing conditions for p-n junction diode.

* There is no external voltage provided to the P-n junction diode while it is at <u>zero bias</u>.

* <u>Forward bias</u>: The p-type is linked to the positive terminal of the voltage potential, while the n-type is connected to the negative terminal.

* <u>Reverse bias</u>: This p type is linked to the negative terminal of the voltage potential, while the n-type is connected to the positive terminal.

Applications

* Diode may be utilised as a photodiode.
* It has the potential to be utilised as a solar cell.
* The diode can be utilised in LED lighting applications when it is forward-biased.
* Many electric circuits utilise it as a rectifier, while varactors employ it as a voltage-controlled oscillator

Zener Diode

* In a general purpose PN diode, the doping is light. As a result of this, the breakdown voltage is high. If P and N region are heavily doped, then the breakdown voltage can be reduced.

* When the doping is heavy, even if the reverse voltage is low, the electric field at barrier will be so strong and thus the electrons in the covalent bonds can break away from the bonds. This effect is known as zener effect.

* A diode which exhibits the zener effect is called as zener diode.

* Hence, It is defined as a reverse biased heavily doped PN Junction diode which Operates in breakdown region.

* Zener breakdown occurs in Junction which is heavily doped and have narrow depletion layers.

* The breakdown voltages sets up a very strong electric field.

* This field is strong enough to break or

rupture the covalent bonds thereby generating electron hole pairs

* Even a small reverse voltage is capable of Producing large number of current carrier.

* When a zener diode is operated in the breakdown region, care must be taken to notice that the Power dissipation across the junction is within the power rating of the diode.

* otherwise heavy current will flow through the diode and may destroy it.

Equivalent circuit of zenerdiode

The schematic symbol of zener diode and its equivalent circuit is shown in figure. It is similar to that of normal diode except the line representing cathode is bent at both end.

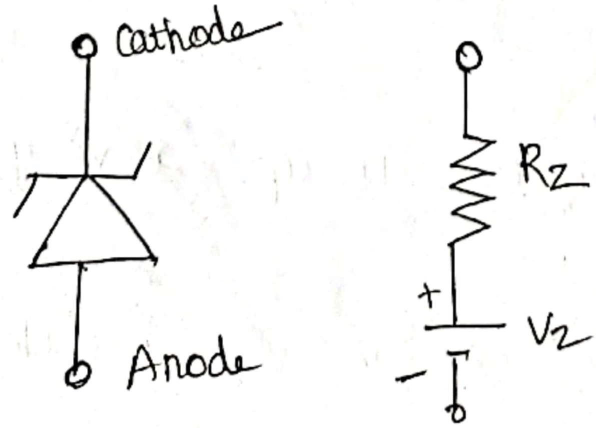


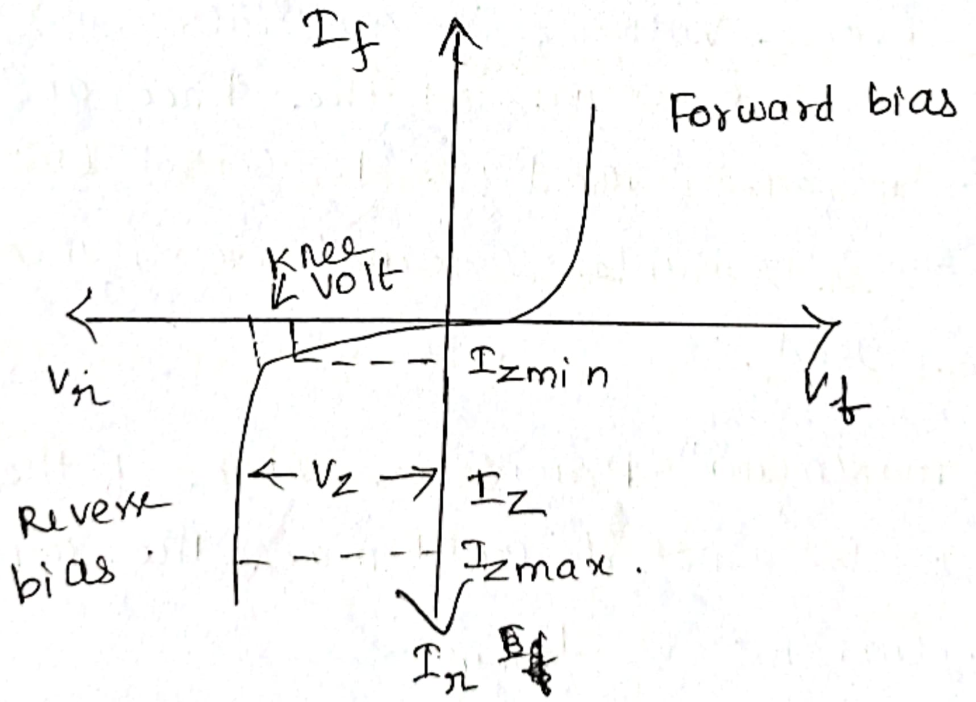
fig: symbolic representation of zener diode and its equivalent circuit.

* When the reverse bias voltage across zener diode exceeds the breakdown voltage V_Z, the current increases very sharply.

* It means that voltage across zener diode is constant at V_Z even though the current through it changes.

* Therefore in breakdown region, a zenerdiode may be represented by a battery of voltage V_Z in series with the zener resistance as shown in diagram.

V-I characteristics of Zener Diode



* Figure shows the V-I characteristics of zener diode.

* The forward characteristics of a zener diode is similar to that of a P-N junction diode.

* The reverse characteristics of zener diode is obtained as follows.

* the reverse current that is present at the Origin and the knee of the curve is due to the reverse leakage current due to the minority carriers. this current is specified by stating its value at 80% of the zener voltage V_Z.

* As the reverse voltage is gradually increased, the breakdown occurs at the knee and the current increases rapidly. To control this current, a suitable external resistance has to be used.

* The maximum permissible value of the current is denoted by I_{zmax}. The minimum usable current is I_{zmin}.

* The voltage across the terminals of the diode for a current I_Z which is the approximate midpoint of the linear

Linear range of the reverse characteristics is called a zener voltage V_Z. At the knee point, the breakdown voltage remains constant between I_{Zmax} and I_{Zmin}. This ability of a diode is called the regulating ability and is an important feature of a zener diode.

Application of zener Diode.

It can be used as

a) as voltage regulators.
b) as peak clippers
c) for reshaping waveforms
d) Protection of meter against damage from accidental application of excessive voltage.

Bipolar Junction Transistors

* A Bipolar Junction transistor is a three layer, two Junction and three terminal semiconductor device.

* Its operation depends on the interaction of majority and minority carriers.

* Therefore, it is named as bipolar device.

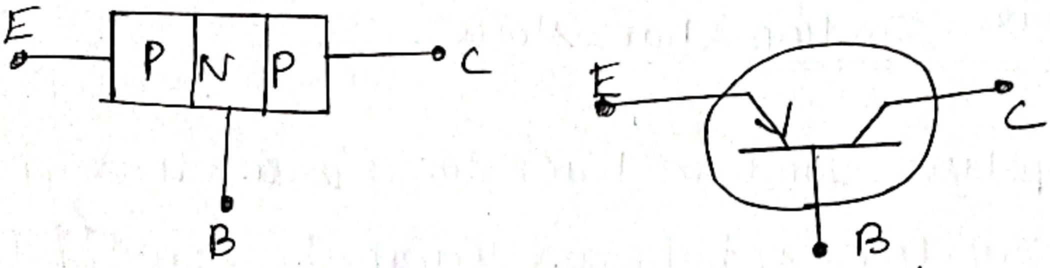
* The word transistor was derived from the two word combination, (TRANsfer + reSISTOR = TRANSISTOR)

* Transistor means, signals are transferred from low resistance circuit (input) into high resistance (output) circuit.

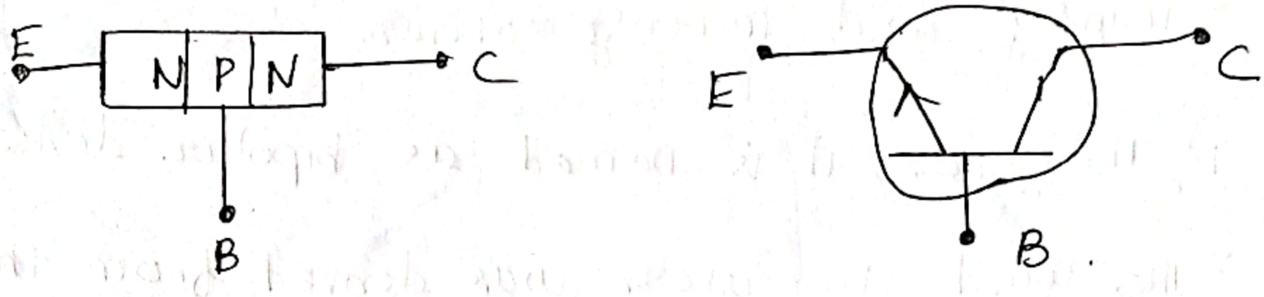
* Transistor consists of two back to back PN junction joined together to form single piece of semiconductor device.

* The two Junctions gives three region named as emitter, base and collector.

* There are two types of transistors such as NPN Type or PNP type.



(a) PNP Transistor and its symbol.



(b) NPN transistor and its symbol.

* The arrow on the emitter specifies whether the transistor is NPN Type or PNP Type.

* This arrow also indicates the direction of current flow, when the emitter base Junction is forward biased.

* The diagram above shows the circuit representation and symbols of NPN and PNP Transistor.

Emitter

* It is more heavily doped than any of other regions because, its main function is to supply majority charge carriers (either electrons or holes) to the base.

* The current through the emitter is emitter current. It is noted as I_E.

Base

* Base is the middle section of the transistor. It seperates the emitter and collector.

* It is very lightly doped.

* It is very thin as compared to either emitter or collector.

* The current flows through the base section is base current. It is denoted as I_B.

Collector

* It forms the right hand side section of the transistor.

* It is shown in diagram.

* The main function of the collector is to collect the majority charge carriers coming from the emitter and passing through the base.

* Generally, collector region is made physically larger than the emitter region, because it has to dissipate much greater power.

* Collector is moderately doped. The current flows through the collector section is collector current.

* It is denoted as I_C.

PNP and NPN Transistors.

To understand the basic operation of transistor, the followings points are need to be kept in mind.

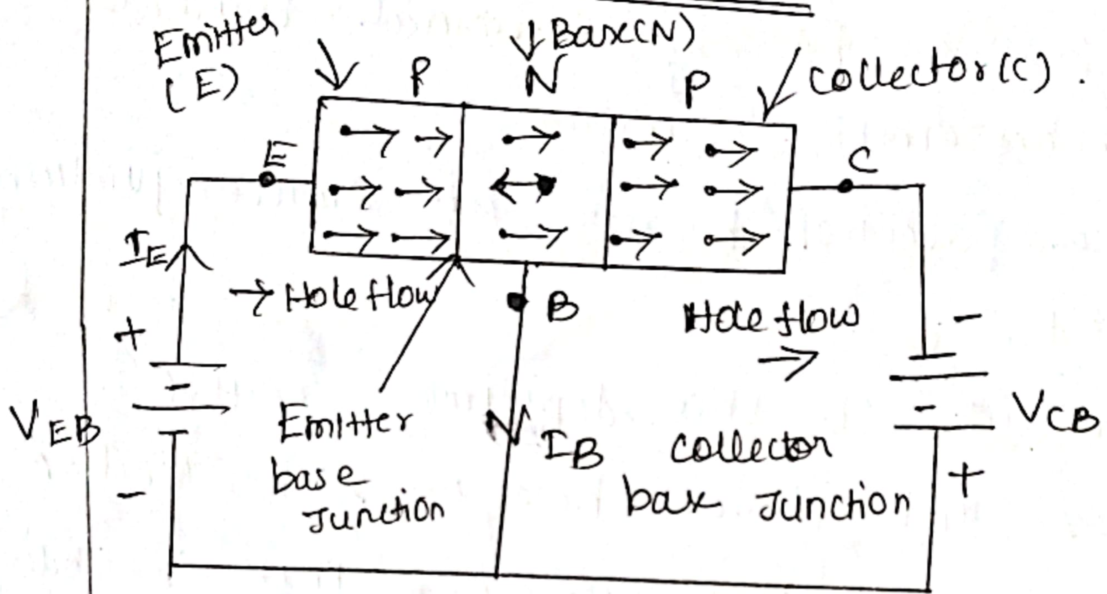
① Emitter section is meant to provide charge carriers, therefore, It is always forward biased.

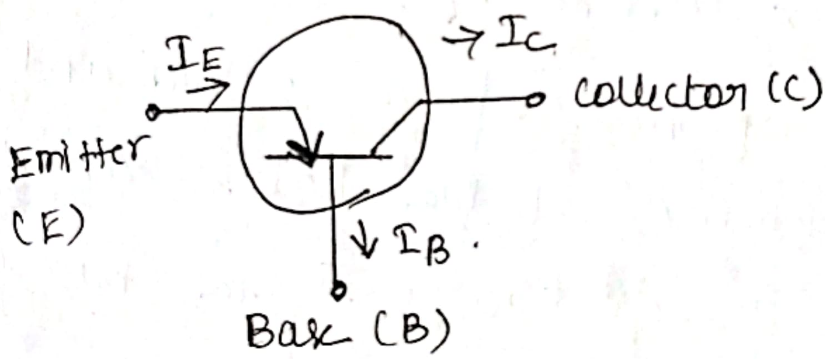
② First letter of transistor type indicates the polarity of the emitter voltage with respect to base.

③ the main function of collector is to collect or attract those carriers through

4) Second letter of transistor type indicates the polarity of collector voltage with respect to the base.

Working of PNP Transistor





* Figure shows the connection diagram of PNP Transistor.

* In this circuit diagram, the emitter base junction is forward ~~diagra~~ biased (i.e, positive polarity of the battery is connected with 'p' type semiconductor and negative polarity

of the battery is connected with 'p' type semiconductor. and negative polarity of the battery is connected with 'N' type semiconductor and collector base junction is reverse biased.

* The holes in the emitter are repelled by the positive battery terminal towards the PN or emitter junction.

* Then the potential barrier at emitter junction is reduced.

* As a result of this, depletion region disappears and hence holes cross the junction and enter in to N-region (base). This constitutes the emitter current I_E.

* Because of base region is thin and lightly doped, majority of the holes (about 97.5%) are able to drift across the base without meeting electrons.

* Only 2.5% of the holes recombine with the free electrons of N-region.

* This constitutes the base current I_B which is very small.

The following points about transistor circuits are,

1. In a PNP transistor, majority charge carriers are holes.

2. Emitter arrow shows the direction of flow of conventional current. But electrons flows will be in the opposite direction.

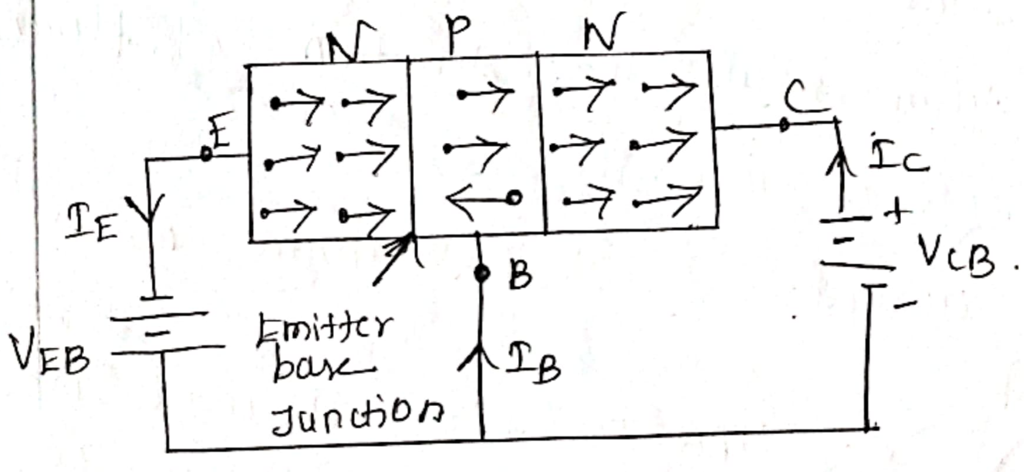
3. Emitter base Junction is always forward biased and collector base Junction is always reverse biased.

4. The collector current is always less than the emitter current because same recombination of holes and electrons takes place.

$$I_C = I_E - I_B.$$

$$\boxed{I_E = I_B + I_C}$$

Working of NPN Transistor



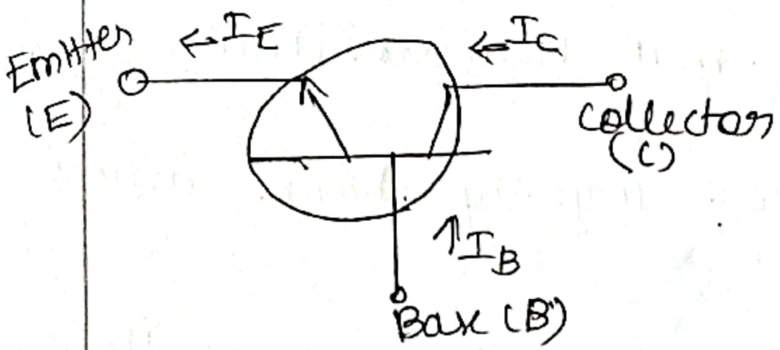


Figure shows the connection diagram of NPN Transistor. In this circuit diagram, the emitter base Junction is forward biased. (ie, Negative polarity of the battery is connected with the 'N' type semiconductor and positive polarity of the battery is connected to with P type semi conductor) and collector base Junction is reverse biased.

→ The following points about transistor circuits are.

① In a NPN Transistor, majority charge carriers are electrons

② Emitter arrow shows the direction of flow of conventional current.

③ collector current I_C is less than emitter current I_E

The choice of NPN Transistor is made more often because majority charge carriers are electrons whose mobility is much more than that of holes.

SCR - Silicon controlled Rectifier

* SCR is a four layered PNPN device and a member of thyristor family

* It consists of three diodes connected back to back with gate connection or two complementary transistors connected back to back.

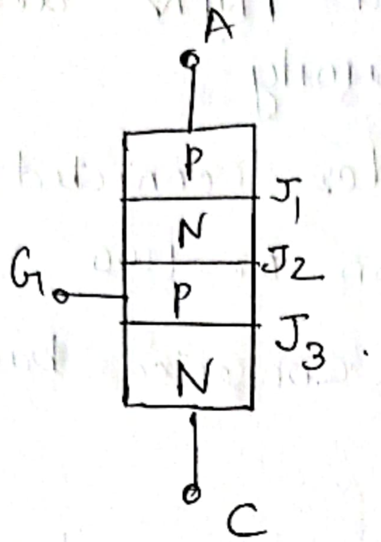
* It is widely used as switching device in power control applications.

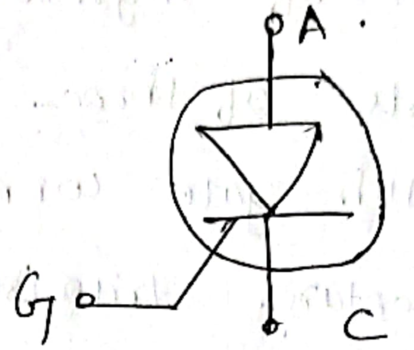
* It can switch ON for variable length of time and delivers selected amount of power to load.

* It can control loads, by switching the current OFF and ON up to many thousand times a second.

* Hence it posses advantage of RHEOSTAT and a switch with none of their disadvantages.

Symbol of SCR.





Construction

→ It is a four layered three terminal device layers being alternately p-type and n-type silicon.

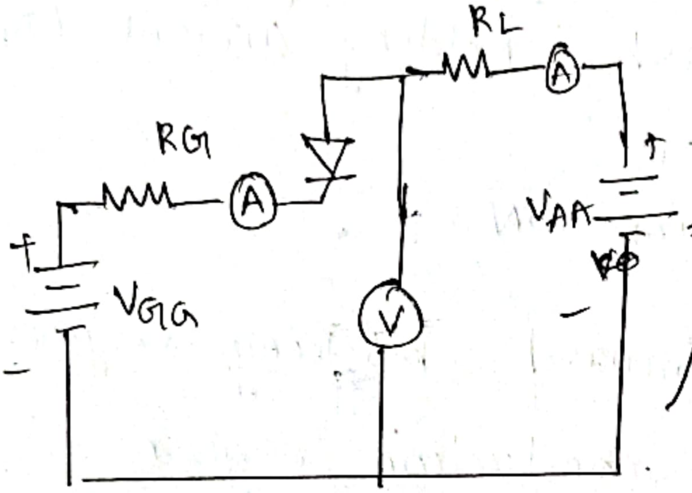
→ Junctions are marked J_1, J_2, J_3.

→ where as terminals are anode (A), Cathode (C) and Gate (G).

→ The gate terminal is connected to inner p-type layer and it controls the firing or switching of SCR

VI characteristics of SCR

* The forward characteristics of SCR may be obtained using the fig (a).
* The volt ampere characteristics of a SCR for $I_G = 0$ is shown in fig (b)



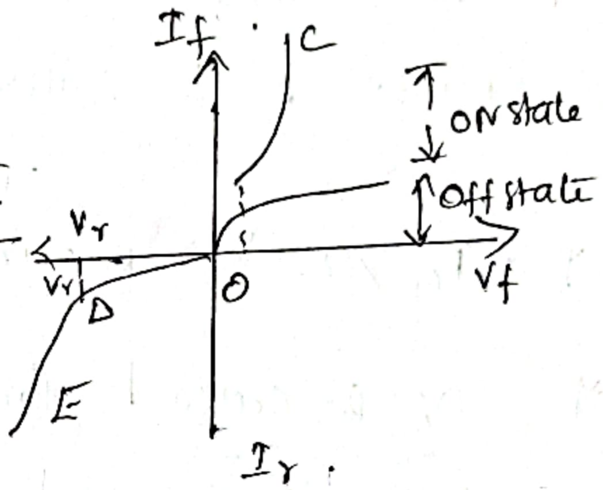


fig (b)
VI characteristics of SCR.

* As the applied anode to cathode voltage is increased above zero, a very small current flows through the device, under this condition the SCR is off. It will be continued until, the applied voltage reaches the forward breakover voltage (point A).

* If the anode -cathode voltage exceeds the breakover voltage it conducts heavily the SCR turns ON and anode to cathode voltage decreases quickly to a point B.

* The current corresponding to the point 'B' is called 'holding current (I_H)".

* $I_G > 0 \Rightarrow$ SCR turn ON.

* OA is called forward blocking region.

BC $\Rightarrow$ forward conduction region.

<u>Application</u>

- relay controls.
- phase controls.
- static switches.
- regulated power supplies.
- heater controls.
- inverters
- motor controls.

JFET

FET - Field Effect Transistor

* FET is a three terminal unipolar semiconductor device.

* In FET, current is controlled by an electric field and so called field effect Transistor.

* There are two types of FET,

1. Junction field effect Transistor (JFET)
2. Metal oxide semiconductor FET (MOSFET) or Insulated Gate FET (IGFET).

JFET

* Junction field Effect Transistor (JFET) is one of the simplest types of FET.

* JFETs are three-terminal semiconductor devices that can be used as electronically controlled switches or resistors or to build amplifiers.

Types of JFET

① N-channel JFET
② P-channel JFET.

JFET has the following Notation,

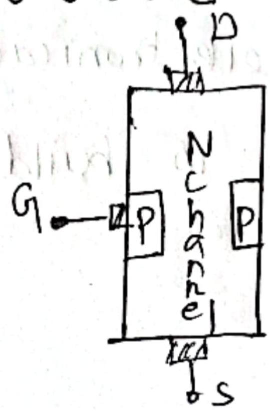
Source : The source S is a terminal through which the majority carriers enter the bar.

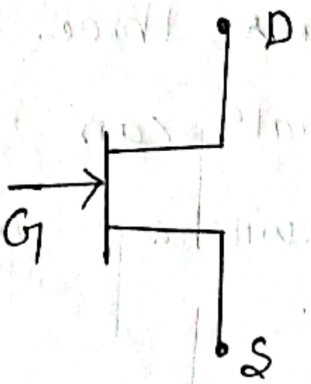
Drain : The drain D is a terminal through which the majority carriers leave the bar.

Gate : These are two internally connected heavily doped impurity regions which form two P-N Junctions.

Channel : The space b/w gate through which majority carriers pass.

N-channel JFET :





Construction of N-channel JFET

* N-channel JFET consists of an N-Type semiconductor bar.

* On both the ends of the bar metal contacts are made, they are called source and drain.

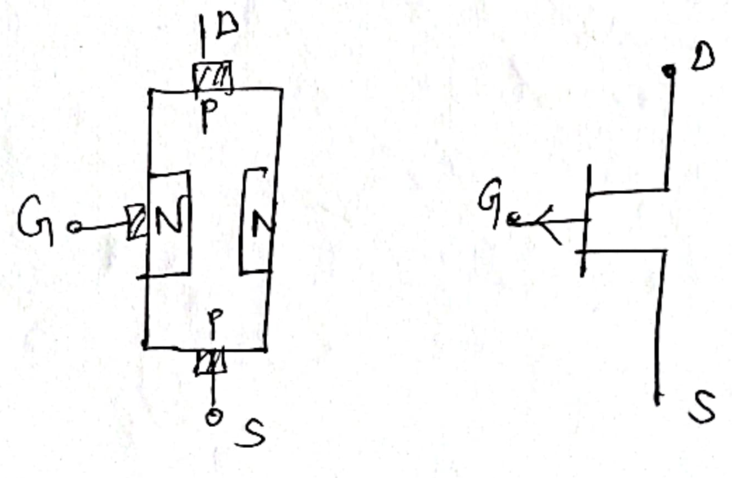
* Electrons are the majority carriers in N-channel JFET.

P-channel JFET.

* P channel JFET consists of a P-type semiconconductor bar.

* on both the ends of the bar metals contacts are made they are called source and drain.

* Holes are the majority carriers.



IGBT

IGBT - Insulated Gate Bipolar Transistor.

* IGBT is a minority - carrier device with high input impedance and Large bipolar Current - carrying capability.
* Combination of BJT & MOSFET.
* High i/p impedance like a PMOSFET
* Low on state power loss like a BJT
* In IGBT second breakdown problem is not present.
* Voltage controlled device.
* Three terminal device.

Symbol of IGBT.

* The IGT device has undergone many improvements cycles to result in the modern insulated gate bipolar Transistor (IGBT)

* These devices have near ideal characteristics for high voltage (>100 V) medium frequency (<20kHz) applications.

* This device along with the MOSFET have the potential to replace the BJT completely.

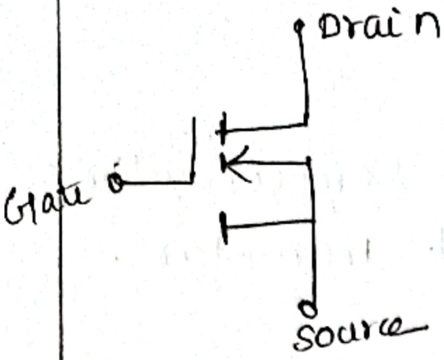


fig: Nchannel MOSFET.

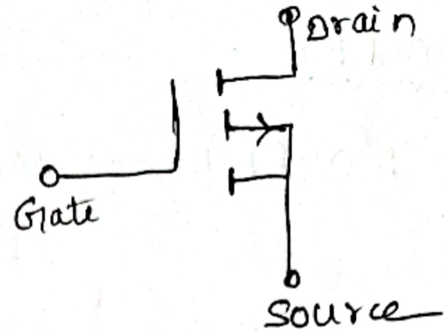
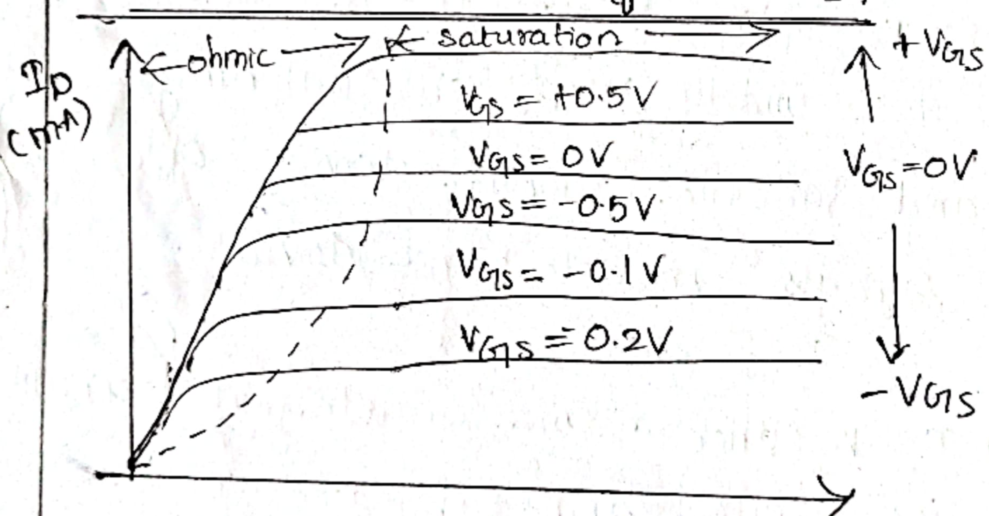


fig: P channel MOSFET.

and a Body (B) / substrate terminals. The body terminal will always be connected to the source terminal hence the MOSFET will operate as a three-terminal device.

VI characteristics of MOSFET.



Applications of MOSFET.

* MOSFET amplifiers are extensively used in radio frequency applications.
* It acts as a passive element like resistor, capacitor and inductor.
* DC motors can be regulated by power MOSFETs.
* High switching speed of MOSFETS make it an ideal choice in designing chopper circuits.

MOSFET

MOSFET – Metal oxide semiconductor field Effect Transistor.

* MOSFET is the common term for Insulated Gate field Effect Transistor (IGFET).

* There are two basic forms of MOSFET,

(i) enhancement MOSFET

(ii) Depletion MOSFET.

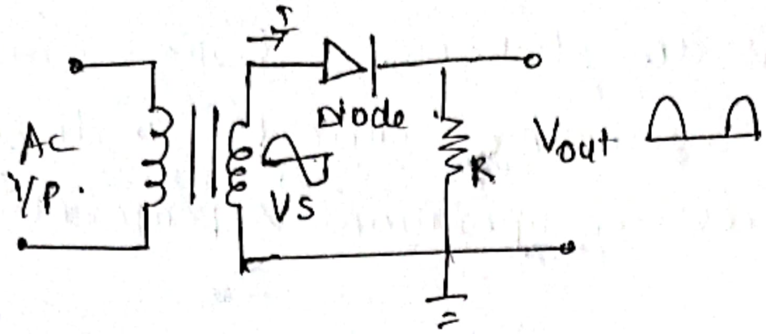
* The MOSFET transistor is a semiconductor device that is widely used for switching purposes and for the amplification of electronic signals in electronic devices.

* A MOSFET is either a core or integrated circuit where it is designed and fabricated in a single chip because the device is available in very small sizes.

Symbol of MOSFET.

In general, the MOSFET is a four terminal device with a Drain (D), Source (S), Gate (G)

* For small power levels this type of Rectifier circuit is commonly used.

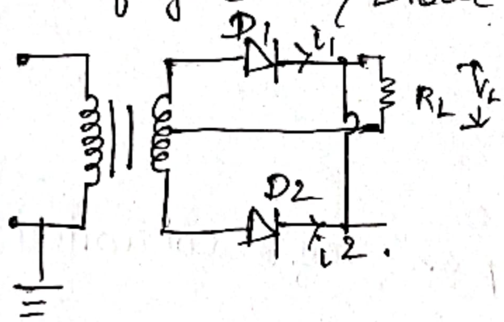


+ive half cycle → diode ⇒ becomes ⇒ Forward Biased.
-ive half cycle → diode ⇒ becomes ⇒ Reverse Biased.

Full Wave Rectifier

* This type of rectifier uses two diodes and a transformer with centre tapped secondary winding.

+ive half cycle ⇒ Diode D_1 ⇒ forward Biased.
-ive half cycle → Diode D_2 ⇒ Reverse Biased.



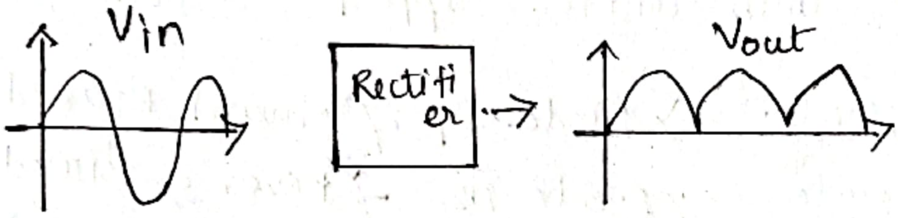
Applications of Rectifiers

* Rectifiers are used in electric Welding to Provide Polarized Voltage.
* Half wave rectifiers are used as a mosquito repellent.
* Half-Wave rectifiers are used as a signal Peak detector in AM radio.
* Rectifiers are used in modulation, demodulation and Voltage Multipliers.

Rectifiers

Rectifier is an electronic device or circuit that converts alternating current to direct current. The reverse operation is performed by the inverter.

* These bridge rectifiers are available in different packages as modules ranging from few amperes to several hundred amperes.



Types of Rectifiers

There are two types of controlled Rectifiers

* Half wave Rectifier
* Full wave Rectifier

Half wave Rectifier

* It is a simple Type of rectifier made with single diode which is connected in Series with load.

Inverters

* Inverters are also called AC Drives (or) VFD (Variable Frequency Drive).
* They are electronic devices that can turn DC (Direct current) to AC (Alternating current)
* It is also responsible for controlling speed and torque for electric motors.
* Basically, Inverter is a kind of oscillator.
* Transistors are the key components of inverter, which convert DC power into AC power.
* In otherwords, the inverter is a static device.
* It can convert one form of electrical energy into other forms of electrical energy. But it cannot generate electrical power.

Applications of Inverter.

* When the AC main power supply is not available, an uninterruptible power supply (UPS) uses battery and inverter.
* Power inverters are basically used in the HVDC transmission line. It is also used to connect two Asynchronous AC systems.

* The output of the solar panel is DC power. The solar inverter used to convert DC Power into AC power.

Unit-5 - Sensors and Transducers

Sensors, Solenoids, pneumatic Controls with electrical actuators mechatronics, types of valves and its applications, electro-pneumatic systems, proximity sensors, limit switches, piezoelectric, hall effect, photo sensors, strain guage, LVDT differential pressure transducer, optical & digital transducers Smart sensors, Thermal Imagers.

Sensors:-

* A sensor is a device that measures a physical quantity and converts it into a signal which can read by an observer or by an instrument.
* Exa: A thermocouple converts temperature to an o/p voltage which can be read by a voltmeter.
* For accuracy, all sensors need to be calibrated against known standards.
* Applications
  - touch sensitive mobile phones
  - Used in the field of medicine, machines Cars, aerospace, robotics
  - Laptop's touch pad
  - touch controller light

Transducers:-

- A transducers is a device, usually electrical electronic, electro-mechanical, electromagnetic, photonic or photovoltaic that converts one type of energy or physical attribute to another (generally electrical or mechanical) for various measurement purposes including measurement or information transfer (exa: pressure sensors)
- The term transducer is commonly used in two senses; the sensor, used to detect a parameter in one form and report it in another (usually an electrical or digital signal) and the audio load speaker, which converts electrical voltage variations representing music or speech to mechanical cone vibration and hence vibrates air molecules creating sound.

Solenoid:-

* A solenoid is a long piece of wire which is wound in the shape of a coil. when the electric current passes through the coil it creates a relatively uniform magnetic field inside the coil.
* The solenoid can create a magnetic field from electric current and this magnetic field

can be used to generate a linear motion with the help of a metal core.

* This simple device can be used as an electromagnet, as an inductor or as a miniature wireless receiving antenna in a circuit.

Working Principle :-

- It works on the principle of "Electromagnetism."
- when the current flow through the coil magnetic field is generated in it, if you place a metal core inside the coil the magnetic lines of flux is concentrated on the core which increases the induction of the coil compared to the air core. This concept of electro-magnetic induction

- Most of the flux is concentrated only on the core, while some of the flux appears at the ends of the coil and a small amount of flux appears outside the coil.
- The magnetic field strength of the solenoid can be increased by increasing the density of the turns or by increasing the current flow in the coil.

Types of solenoid :-

* Ac Laminated solenoid
* DC - C Frame solenoid
* DC - D Frame solenoid
* Linear solenoid
* Rotary solenoid

Application :-

* The main use of solenoid is as a switch for power.
* They are used in inductors, valves, antennas etc.
* Its application is in varied fields like medical, Industrial use, Locking systems, automotic etc.
* It is used to control a valve electrically.
* It is used in computer Printers.
* They are used in fuel injection gears in car
* they are used

Advantages :-

* By using in Automobiles, there is zero pollution in the air
* Solenoid Engine can work efficiently with less torque
* Solenoid Engines can be used as a substitute for fossil fuel.

Actuators

* An **actuator** is a mechanical device, that takes energy (created by air, electricity, or liquid) converts it into motion
* It is used in manufacturing or industrial applications and used in devices such as motors, pumps, switches and valves.

Electrical Actuator:-

* It is an electromechanical device that converts electrical energy into mechanical energy
* Most electric actuators operate through the interaction of magnetic fields and current carrying conductors to generate force

Pneumatic Actuators:

* Pneumatic actuators are the devices used for converting pressure energy of compressed air into the mechanical energy
* Pnematic actuators operate by using ~~The~~ pressurised air from the compressor is supplied to reservoir to convert energy into a rotary or linear motion. As a result of this, pneumatic actuators are often selected for use in the repeated opening and closing of valves or other Industrial applications.

Electro-pneumatic Actuators

* Electro pneumatic is a pneumatic control s/m where air pressure and direction of valve are controlled by an electrical current.

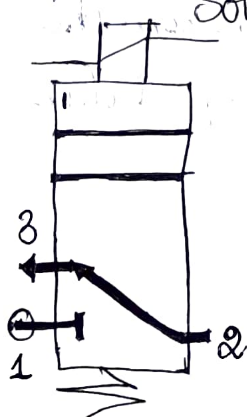
Electro-Pneumatic S/m :-

* Pneumatic S/m's can be controlled by electric circuits. The interface b/w these two circuits is a solenoid valve.
* Solenoid valves perform the same function as normal pneumatic valves but these are operated electrically.
* Inside the solenoid valve, there is a coil of wire through which an electric current is passed.
* It produces a magnetic field which attracts an iron armature. The movement of the armature operates the valve.

Solenoid operation OFF

* when the electric current is not flowing, a spring pushes the iron armature out of the coil.
* A seal connected to the armature blocks port 1. Air can flow b/w ports 2 and 3.

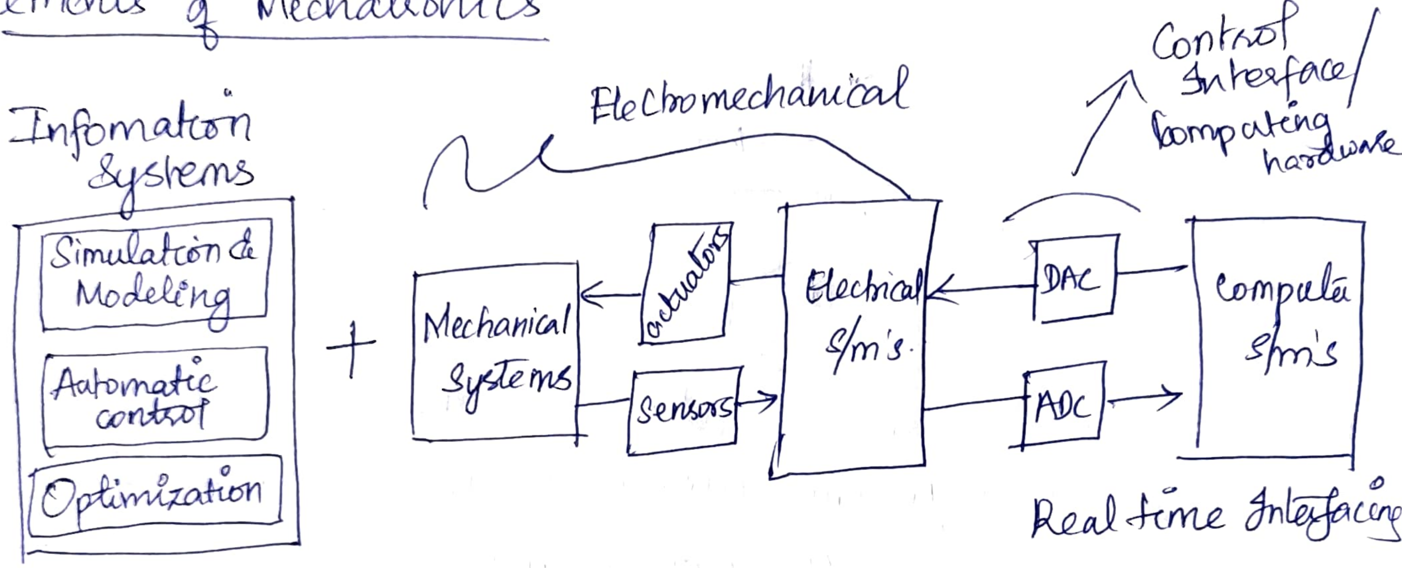
Solenoid valve OFF



Mechatronics

- It is the synergistic integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms and Computer hardware and Software to mange complexity, uncertainity and communication in engineered S/m.

Elements of Mechatronics



* Electromechanical elements refer to sensors and actuators

Sensors - A variety of physical variables can be measured using sensors.

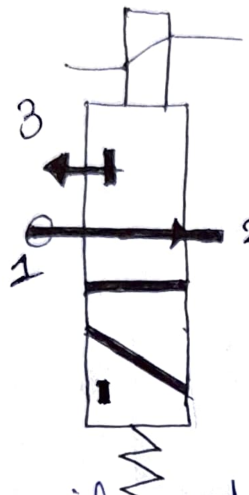
* eg: Stress & Pressure using strain guage, light using photo-resistor.

Actuators:-

- DC servomotor, stepper motor, relay, solenoid, LED Shape memory alloy, electromagnet and pump apply commanded action on the physical process

Solenoid Operation ON

* when current flows, the iron armature is attracted into the coil by a magnetic field. The Spring pressure is overcome and the seal moves to block port 3. Air can flow b/w port 1 and 2.



Solenoid Valve ON

* when the solenoid valve is ON, an electric current will flow through the coil. when the current flows through the coil, the iron armature is attracted by magnetism
* The solenoid has control of the valve Port 1 is connected to port 2 and air flows to inflate the Soft robot.
* when the solenoid valve is off, the coil is de-energised and the Spring has control of the Valve. Port 2 is connected to port 3 and air flows out of the Soft robot.

* IC based sensors and actuators (digital compass, potentiometer etc):
* The electrical/electronic elements are used to interface electro mechanical sensors and actuators to the control interface/computing hardware elements.

- Control computing hardware implements a control algorithm which use sensor measurements, to compute control actions to be applied by the actuator.
- Computer elements refer to hardware/software utilized to perform.
  * computer aided dynamic, s/m analysis, optimization design & simulation
  * virtual implementation
  * PC based data acquisition & control.

Applications:-

→ Smart consumer products: home security, camera microwave oven, dish washer, climate control units etc.

→ Medical - Implant devices, assisted surgery, etc.

→ Denfense - Unmanned air, ground & underwater vehicles jet engines etc.

→ Manufacturing: Robotics, machines, etc.

→ Automotive: climate control, antelock brake, air bags etc

→ Network-centric, distributed s/m's: distributed robotics, tele robotics, intelligent highways, etc.

Types of Values and its Applications

* Values are mechanical or electro-mechanical devices that are used to control the movement of liquids, gases powders etc., through pipes or tubes or from tanks or other containers.

* Valves rely on some form of mechanical barrier - a plate, a ball, a diaphragm, for example - that can be inserted and removed from the flow stream of the material passing by.

Types of Value:

1) Gate Valve:

* It is a type of multi-turn linear motion valve used to completely open or close the fluid flow.
* Applications: * Control the flow of air, water, steam, petroleum

② Plug Valve:

* Plug valves are type of quarter turn valve consisting of a cylindrical or conical shape plug used to control high density fluid flow with suspended solids.
* It consists of a slit in the valve plug. When the valve is in open condition, this slit remains in line with the flow direction
* When the valve is closed, the slit in the valve plug is turned by 90°.

3) Globe Valve

* Globe valves are multi-turn linear motion types of valves used for on, off, throttling & non-return applications. But they have the disadvantages of high pressure drops.
* The Globe valve consists of a convex disk-shaped plug. They work by restricting fluid flow by changing the distance between the plug & the stationary seat.

4) Ball Valve :-

* Ball valve are quater turn, rotatory valves consisting of a ball-shaped disk sandwiched between two cup-shaped seats to turn on and off fluid flow
* Advantage: low-pressure drop, two way flow and easy to operate
* Disadvantage – Cannot use them for high temperature applications.

5) Diaphragm Valve

* It utilizes a flexible membrane known as a diaphragm to control the liquid flow
* It has applications in the pharmaceutical, food and semiconductor industry.
* The diaphragm valves consist of a valve body, inlet outlet port, diaphragm and a saddle/seat. The diaphragm sit upon the saddle to close the valve.

Proximity Sensor

- It is a sensor able to detect the presence of nearby objects without any physical contact.

* A proximity sensor often emits an electromagnetic field or a beam of electromagnetic radiation & looks for changes in the field or return signal.

* Capacitive proximity sensor/photo electric sensor is suitable for a plastic target.

* Inductive proximity sensor always requires a metal target

* Proximity sensors can have a high reliability & long functional life because of the absence of mechanical parts and lack of physical contact between the sensor and the sensed object.

* Proximity sensors are also used in machine vibration monitoring to measure the variation in distance between a shaft and its support bearing. This is common in large steam turbines, compressors and motors that use sleeve-type bearings.

* A proximity sensor adjusted to a very short range is often used as a touch switch.

Limit Switches

* A limit switch is an electromechanical device operated by a physical force applied to it by an object.
* Limit switches are used to detect the presence or absence of an object.
* These switches were used to define the limit of travel of an object
* Limit switches are electromechanical devices consisting of an actuator mechanically linked to an electrical switch.
* When an object contacts the actuator, the switch will operate causing an electrical connection to make or break.

Limit switch Vs Proximity Sensor

- Limit switches are replaced by Proximity sensors from many industrial applications.
- Unlike a limit switch, a proximity sensor has no mechanical moving parts.
- A proximity sensor performs the switching action with electronic switches.
- Limit switches provide rugged and reliable operation in different environments.
- Limit switches are capable of handling much higher current values than proximity sensors.

PiezoElectric

* Piezoelectricity also called the piezoelectric effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress.
* The piezoelectric effect is a reversible process: the materials exhibiting the piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibits the reverse piezoelectric effect, the internal generation of a mechanical strain resulting from an applied electrical field.
* A piezoelectric sensor is a device that uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain or force by converting them to an electrical charge.

Hall Effect :-

* Hall effect is a process in which a transverse electric field is developed in a solid material when the material carrying an electric current is placed in a magnetic field that is peripendicular to the current.

Principle of Hall Effect :-

* It states that when a current carrying conductor or a semiconductor is introduced to a perpendicular magnetic field, a voltage can be measured at the right angle to the current path. This effect of obtaining a measurable voltage is known as the Hall effect.

Theory:-

* when a conductive plate is connected to a circuit with a battery, then a current starts flowing. The charge carriers will follow a linear path from one end of the plate to the other end.
* The motion of charge carriers results in the production of magnetic fields
* when a magnet is placed near the plate, the magnetic field of the charge carriers is distorted. this upsets the straight flow of the charge carriers.
* The force which upsets the direction of flow of charge carriers is known as Lorentz force.
* Due to the distortion in the magnetic field of the charge carriers, the negatively charged electrons will be deflected to one side of the plate and positively charged holes to the other side.
* A potential difference, known as the Hall voltage will be generated between both sides of the plate which can be measured using a meter.
* The Hall voltage represented as V_H is given by the formula

$$V_H = \frac{IB}{qnd}$$

I - current flowing through the sensor
B - Magnetic Field strength
q - charge
n - no. of. charge carriers per unit volume.
d - thickness of the sensor.

Applications

* Magnetic field sensing equipment
* used in phase angle measurement
* Hall effect Sensors.
* For detecting wheel Speed and accordingly assist the anti-lock braking system.

Photo Electric Sensors :-

* Photo electric sensors are used to determine the presence of the object by transmitting the light.
* A photoelectric sensor is used to detect the object with change of level of light receiving as compared to the light emitting.
* Light emitted by the photoelectric sensors may be infrared or visible
* A photo electric sensor consists primarily of an emitter for emitting light and a receiver for receiving light
* when emitted light is interrupted or reflected by the sensing object, It changes the amount of light that arrives at the receiver.
* The receiver detects this change and converts it to electrical o/p.

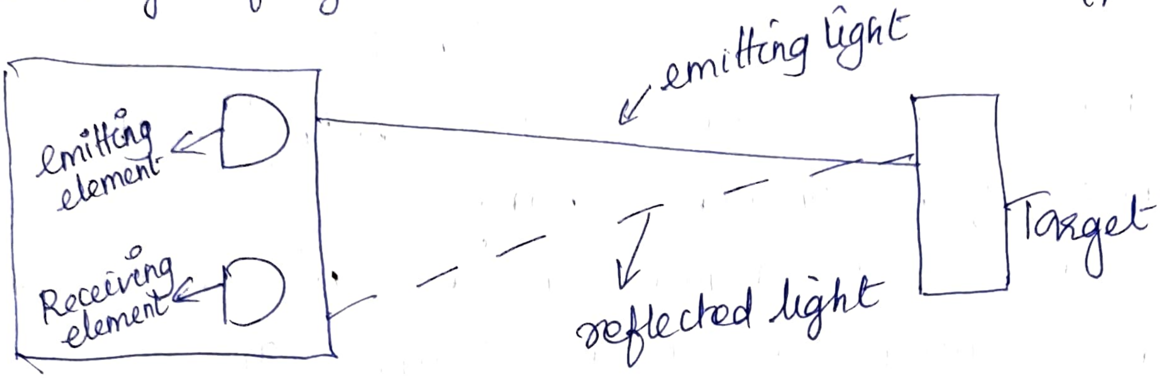
Types:-

→ Reflective photo electric sensor
→ Thrubeam photoelectric sensor
→ Retroreflective photoelectric sensor.

Reflective photoelectric sensor:-

* The emitter & receiver is installed in the same housing
* when the sensor emits the light
* light strikes the sensing object and reflect to the receiver

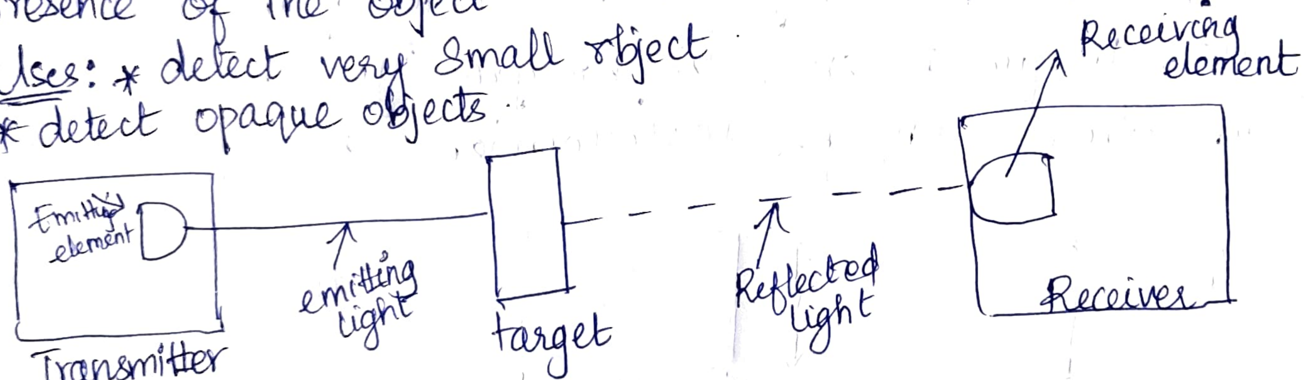
* This causes changes the amount of the light at the receiv[er]. This change of light is used to create electrical o/p.



Thrubeam photoelectric sensor

- Emitter and receiver are installed opposite to each other
- when an object passes between beam causes interruption into the beam. These interruption are used to detect the presence of the object

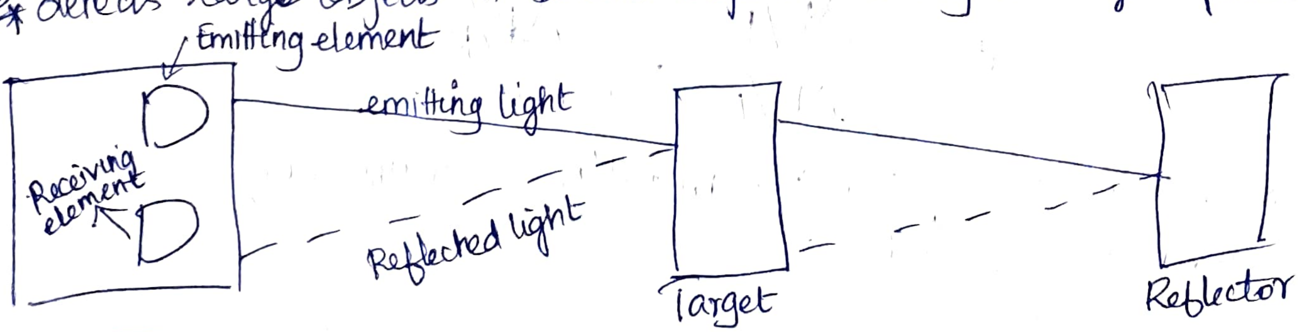
Uses: * detect very small object
* detect opaque objects.



Retro-reflective photoelectric sensors

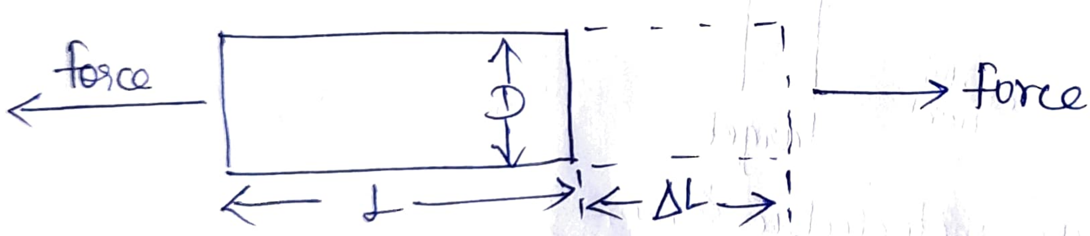
* The emitter and receiver are installed in the same housing and light from the emitter is normally reflected back to the receiver by a reflector installed on the opposite side
* when the sensing object interrupts the light, it reduces the amount of light received.
* This ~~light~~ reduction in light intensity is used to detect the object

Uses * detects large objects * Detects objects moving at high speed.



Strain Gauge:

* If a metal conductor is stretched or compressed its resistance changes ~~on account~~ both the length and diameter of the conductor changes.
* Also there is a change in the value of resistivity of the conductor when it is strained and this property is called piezo-resistive effect.
* Therefore resistance strain guages are also known as piezo resistive guage
* The strain guages are used for measurement of strain and in many detectors notably the ~~node~~ load cells, Torque meters, diaphragm type pressure guage temperature sensors, accelerometers and flow meters.



$$\boxed{\varepsilon = \frac{\Delta L}{L}}$$

ΔL - fractional change in length.

* Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length.

$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

* The guage factor for metallic strain guages is typically around 2.

Semiconductor Strain Guage

- Semiconducting materials such as sillicon and germanium are used as resistive material for semiconductor strain guage.
- In metallic guages, the change in resistance is mainly due to change in dimensions when strained, the semi conductor strain guage depends upon for the action upon photoresistive effect i.e the change in the value of the resistance due to change in resistivity.

Advantages

* It has high guage factor
* Hystersis characteristics are excellent.
* Small in size.

Disadvantages

* Very sensistive to changes in temperature
* Linearity is very poor
* more expensive

Uses

* It is the fundumental sensing element for many types of sensors, including pressure sensors load cells, torque sensors, position sensors etc.

LVDT

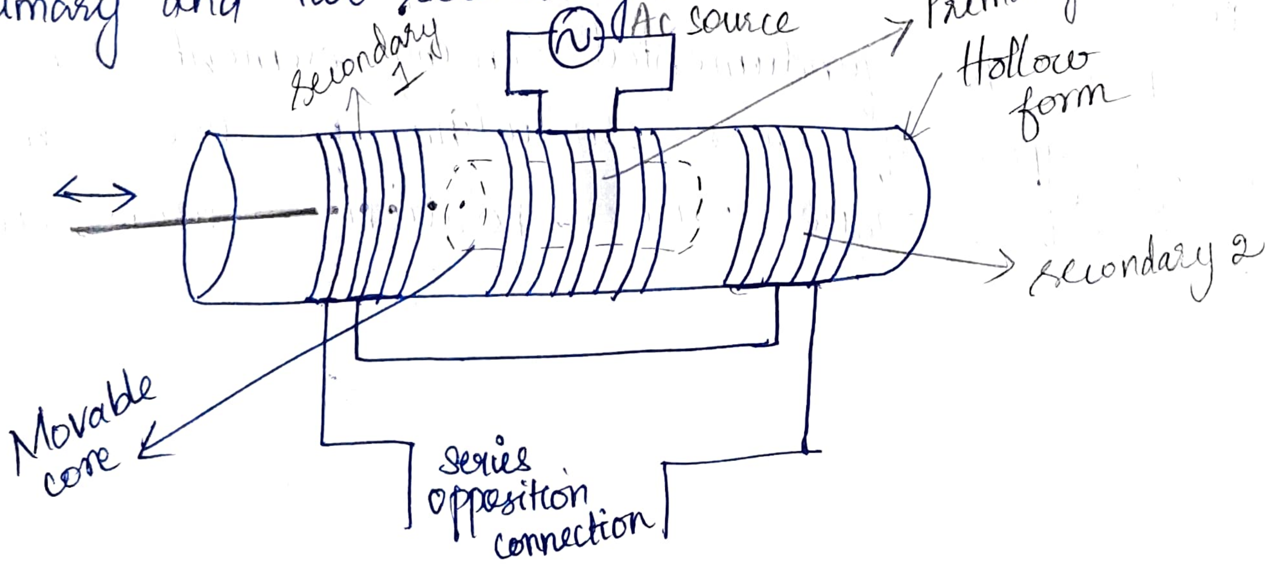
- Linear Variable Differential Transformer (Transducer)

* Inductive type passive transducer.
* Measures force in terms of displacement of ferromagnetic core of a transformer.
* Its converts translational or linear displacement into electrical voltage

Principle:- Electromagnetic Induction

Construction:-

* It consists of Cylindrical transformer, where core is surrounded by one primary winding in the centre and 2 secondary windings at the sides.
* The no. of windingturns are similar in both secondary windings, but they are opposite to each other.
* Primary winding is connected to the ac source
* The soft iron core affects magnetic coupling between primary and two secondary



Operation :-

* when the iron core lies at the centre of both secondary the o/p differential voltage remains unaffected and has zero magnitude
* when the core move towards secondary-1, it induces more emf across it and less emf across secondary-2 lets assume that it is positive displacement.
* This is due to more flux links with the secondary 1 than secondary 2.
* when the core moves towards secondary-2, it induces more emf across it and less emf across secondary-1 lets assume that it is negative displacement.
* This is due to more flux links with the secondary 2 with secondary 1.
* The o/p differential voltage is proportional to the displacement of the iron core

Output voltage Differential o/p voltage $E_o = E_{s1} - E_{s2}$.

Advantages:-

* High range
* No frictional loss
* High input & high sensitivity
* Low Hysteresis
* Low power consumption

Disadvantage:-

* Sensitive to stray magnetic fields
* Affected by vibrations & temperature

Differential Pressure Transducer :-

* A pressure transducer is a device that measures the pressure of a (liquid) fluid, indicating the force the fluid is exerting on surface in contact with it.
* Pressure transducers are used in many control and monitoring applications such as flow, air, speed, level, pump systems or altitude.
* To calculate pressure, the pressure transducer contains a force collector such as flexible diaphragm which deforms when pressurized and a transduction element that transforms this deformation into an electrical signal
* A pressure transducer measures pressure. It uses a sensor capable of converting the pressure acting on it into electrical signals.
* These electrical signals are then relayed to controllers or PLC's where they are then processed and recorded.
* Pressure transducers use strain guages to measure the force acting on them. The strain guages undergo deformation and this creates a change in voltage produced by it.
* The pressure measurement is based on the degree of change seen in the voltage.

Static Pressure Transmitter

- It measure the pressure of a fluid when it is at rest
- when a fluid exerts pressure on the pressure transducer the strain guage within it gets deformed.
- This deformation results in voltage variations
- The magnitude of variation corresponds to the intensity of the pressure
- Once the pressure releases, the strain guage gets back to its original form.

* Piezoelectric pressure transducers are an example of non-static or dynamic pressure transducers. They measure pressure variance in real time.

Differential Pressure

* Measures the difference between two pressures on each side of the sensor
* exa: A liquid pressure transducer where the fluid levels above and below the liquid are measured.

Optical Transducer:-

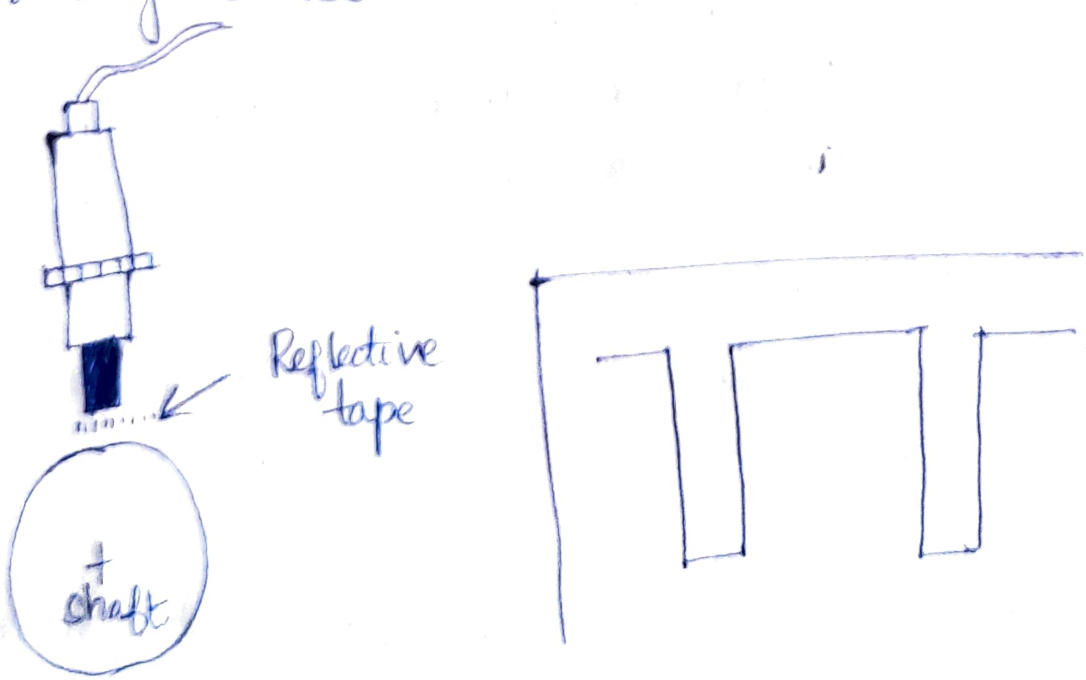
* The optical transducer convert light into electrical quantity. They are also called as photoelectric transducers
* The optical transducers can be classified as photo emissive, photo conductive and photovoltaic transducers
* The photo emissive devices operate on the principle

that radiation falling on a Cathode causes electrons to be emitted from the Cathode surface.

* The photoconductive devices operate on the principle that whenever a material is illuminated, its resistance changes.

* The photovoltaic cells generate an output voltage that is proportional to the radiation intensity. The radiation that is incident may be X-rays, gamma rays, ultraviolet, infrared or visible light.

* An optical transducer converts light rays into an electronic signal. The purpose of an optical transducer is to measure a physical quantity of light and depending on the type of transducer, then translates it into a form that is readable by an integrated measuring device.



Optical Transducer

Digital transducer

* Any transducer that presents information as discrete samples and that does not introduce a quantization error when the reading is represented in the digital form may be classified as a digital transducer.

Adv:-

* Digital signals are less susceptible to noise, disturbance or parameter variations because data can be processed as binary words.
* High reliability
* Large amount of data can be stored using compact high density data storage methods.
* Fast data transmission over long distance.
* Digital signals use low voltages and low power
* Digital devices typically have low overall cost.

Shaft Encoders:-

- Encoder is a transducer that generates a coded (digital) reading of a measurement.
- Shaft encoders are digital transducers used for angular velocity measures.

Applications

* Robotics
* Manipulators
* Machine tools
* Data storage systems
* plotters
* printers
* other rotating machinery

Advantages

* High Resolution.
* High accuracy
* Noise immunity with reduction in cost.

Smart Sensors

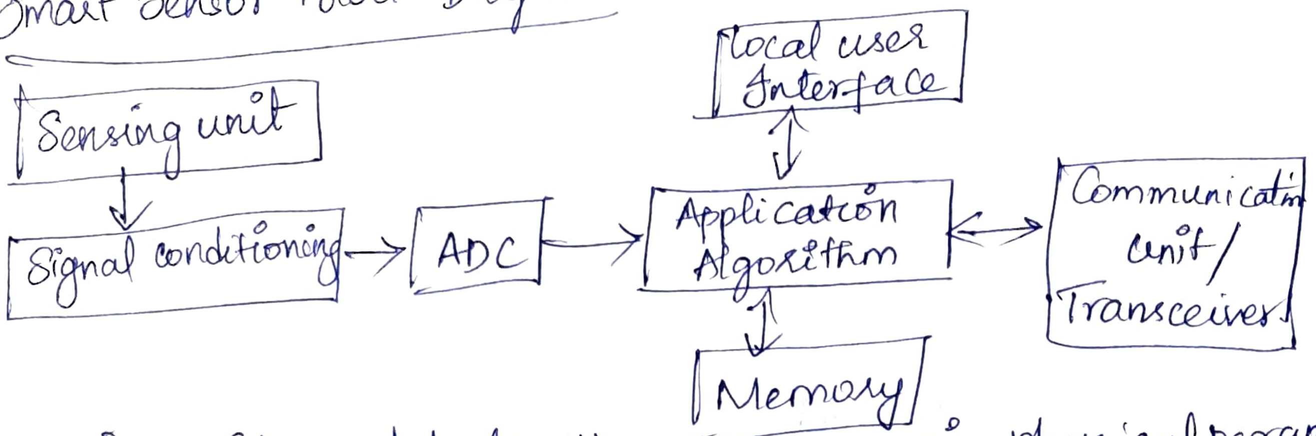
* The Integration of electronics and sensors on a single chip to make an intelligent sensor is known as a smart sensor.
* These sensors have higher S/N ratio, fast signal conditioning, auto calibration, self testing, high reliability small physical size, detection & prevention of failure
* A smart sensor is a device that uses a transducer to gather particular data from a physical environment to perform a predefined & programmed function on the particular type of gathered data then it transmits the data through a networked connection.

Working Principle:-

- Smart sensors work by capturing data from physical environments & changing their physical properties like speed, temperature, pressure, mass or presence of humans into calculable electrical signals.

* These sensors include a Digital Motion Processor (DMP) to perform onboard processing data like filtering noise
* These sensors have 4 main functions, They are measurement, configuration, verification & communication

Smart Sensor Block Diagram



Sensing unit - detects the changes in physical parameter and generates electrical signals equivalent to it.

Signal conditioning unit - controls the signal to meet the necessities of next-level operations without losing data.

Analog to Digital Converter - ADC converts the signal from analog to digital format and sends it to the µp.

Local user Interface - It is a panel-mounted device used to allow building operators to monitor and control system equipment.

Application Algorithm - The signals from smart sensors reach here and process the received data based on the application programs previously loaded here and generate output signals.

Memory - It is used to store media for saving received and processed data.

Communication Unit - The o/p s/l's from the application algorithm or µp are transmitted to the main station through the communication unit. This unit also gets command requirements from the key station to execute specific tasks.

Types

* Level Sensor
* Temperature sensors
* Pressure sensors
* Infrared sensors
* Proximity sensors
* Air Quality detection sensors
* motion sensors
* Smart-plant sensors
* Smart climate sensor

Thermal Imagers

* A Thermographic camera (also called an infrared camera or thermal imaging camera, thermal camera or thermal imager) is a device that creates an image using infrared radiations, similar to a normal camera that forms an image using visible light.
* Thermal imaging is based upon the science of infrared energy (ow known as 'Heat') which is emitted from all objects
* The quantity of radiation emitted tends to be proportional to the overall heat of the object.
* thermal cameras or thermal imagers are sophisticated devices comprised of a sensistive heat sensor with the capacity to pick up minute difference in temperature
* As they gather the infrared radiation from objects in a particular environment, they can start to map out an image based on the differences & inflexions of the temperature measurements.

Uses:-

* Temperature measurements of components used in industrial applications, building inspections, Surveillance for security, police and fire applications and robotic vision.
* It helps to know the leaking, plumbing and electrical issues to ensure use safety.