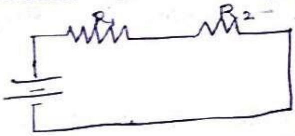
BE3251 BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT-I

ELECTRICAL CIRCUITS

DC Circuit:

* An electric circuit is a closed path consisting of active and passive elements all interconnected and the current flows in a closed path.



* The above circuit consists of one active and 2 passive elements.

* Active element - Supplies energy to the circuit

* Passive element - Receives energy from " "

* This energy is converted into heat (resistor) or stores it an electric (capacitor) or magnetic field (inductor). Battery is the active element.

BASIC CIRCUIT COMPONENTS:

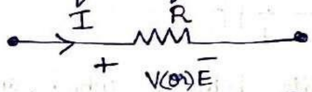
The three basic circuit components are

1. Resistor 2. Capacitor and 3. Inductor

Resistor:

* Resistor is made from material which opposes the flow of current through it.

Symbol



* It is denoted as R.

* Unit of resistance is Ohm (Ω).

* Relation between Voltage and Current is given by Ohm's Law.

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

* Energy is dissipated in the resistor in the form of heat. It is given as,

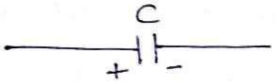
$$P = VI = (IR)\cdot I = I^2R = \frac{V^2}{R} \text{ watts}$$

* Energy is converted into heat during time, 't' and is given by,

$$W = P\,dt = \int_0^t I^2 R\,dt = I^2Rt = V\cdot I\cdot t \text{ Joules}$$

Capacitor :

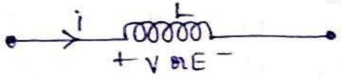
* Capacitor is a storage element which can store and deliver energy in an electric field.
* It is denoted as 'C'.
* Unit - Farad (F).
* Symbol



* Any 2 metal plates between which an electric field can be maintained constitute a capacitor

Inductor :

* Inductor is an element in which energy can be stored in the form of electromagnetic field.



* It is like a coil wound on a magnetic core or may be air core.

Ohm's Law :

When a voltage is applied to a closed circuit, it causes a flow of electrons and consequently there exists current in the circuit. The resistance of the circuit opposes the current flow.

Statement :

When the temperature remains constant, current flowing through a ~~directly~~ conductor is directly proportional to the potential difference across the conductor.

$V \propto I$ (At constant Temperature)

$V = IR$.

R → Proportionality constant.

V → Voltage in Volt. I → Current in ampere.

Limitations :

i) It is not applicable to non-metallic conductors.

ii) It is " " " non-linear devices like Zener diode, vacuum tubes etc.

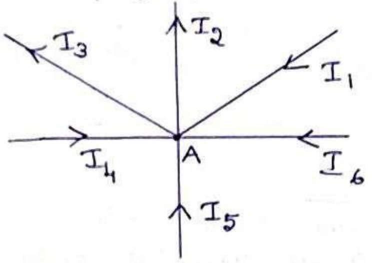
iii) It is not applicable, if the temperature changes.

KIRCHHOFF'S LAW

Kirchhoff's Current Law (I Law)

Statement :

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



A → Junction or node.

According to Kirchhoff's Law,

$$I_1 + I_4 + I_5 + I_6 = I_2 + I_3$$

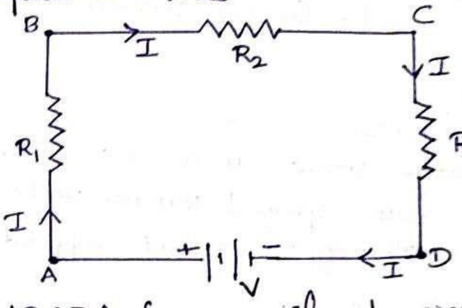
(flowing towards A) = (flowing away from A)

* Current at node A is equal to zero.

Kirchhoff's Voltage Law (II Law)

Statement :

In a closed circuit, the sum of the potential drops is equal to the sum of the potential rises.



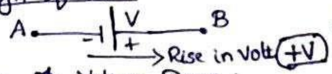
ABCDA forms a closed circuit. For the entire loop ABCDA,

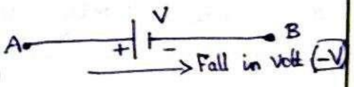
Sum of the potential drops = $IR_1 + IR_2 + IR_3$

Potential rise from D to A = V

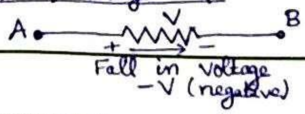
$$IR_1 + IR_2 + IR_3 = V$$

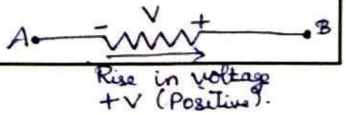
Sign of EMF





Sign of Voltage Drops :





Energy Sources :

Energy sources are devices which supply electric energy.

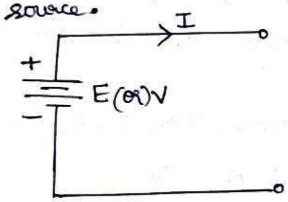
Independent Sources :

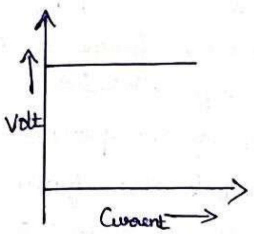
Classification
(i) Voltage Sources
(ii) Current Sources

Voltage Sources:

Ideal Voltage Source:

* Ideal voltage source is a source which delivers energy with specified terminal voltage, which is independent of the current supplied by the source.



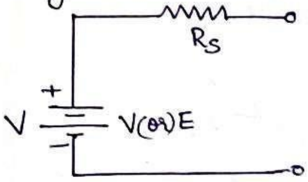


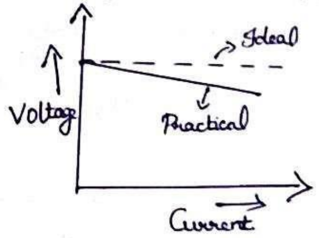
* For ideal voltage source, internal resistance or impedance is zero.

Practical Voltage Source :

* All practical voltage source fall short of an ideal source and the terminal voltage falls with increase in the current supplied by the source.

* Hence, a practical source is represented by voltage source in series with internal resist. Rs.

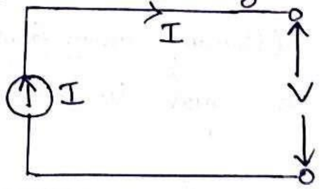


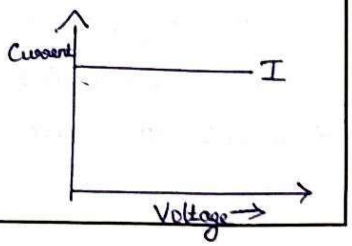


Current Sources :

* Ideal current source delivers energy with a specified current which is independent of the voltage at the terminals.

* The internal impedance or admittance of ideal current source is zero.

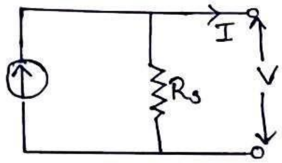


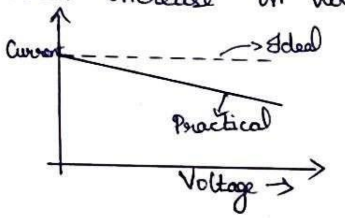


Practical Current Source:

* This is represented by the current source, I in parallel with internal impedance (or resistance)

* In this current is supplied by the source is decreased with increase in voltage



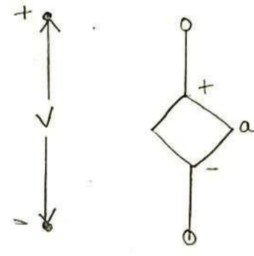


Dependent Sources:

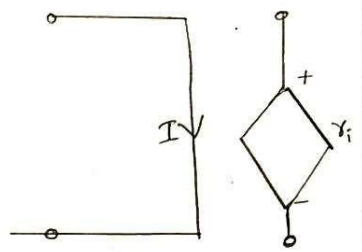
A dependent voltage or current source is one which depends on some other quantity, like voltage or current. Such a source is represented by a diamond shaped symbol.

4 types

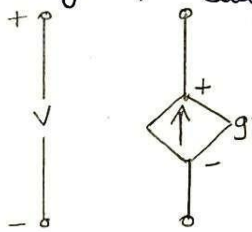
1. Voltage dependent Voltage Source
2. Current " " "
3. Voltage " Current "
4. " " " "



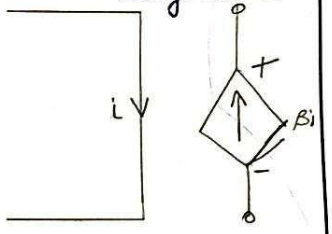
i) Voltage dependent Voltage Source



(ii) Current dependent Voltage source



(iii) Voltage dependent Current Source



(iv) Current dependent Current Source.

a, r, g, β → Proportionality Constant ~~(No Unit)~~

a, β → No Unit

r → Ω (ohm) Unit

g → ℧ (mho) Unit.

Simple Problems:

1) What will be the current drawn by a lamp rated at 250V, 40 watts connected to a 230 V supply?

Soln

Rated Power = 40 W ; Rated voltage = 250 V

We know $P = \frac{V^2}{R}$ ie $40 = \frac{(250)^2}{R}$

$$R = \frac{(250)^2}{40} = 1562.5\ \Omega$$

Current drawn from 230 V supply $= \frac{V}{R}$

$$= \frac{230}{1562.5} = 0.1472\ A$$

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

$$\text{Energy} = VIt$$

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

$$V = \frac{500}{3 \times 12} = 13.88\ V$$

3) Twenty lamps each of 60 W are used each for 4 hours / day in a building. Calculate (i) Current drawn when all the lamps are working and (ii) the monthly electricity charge at 55 paise per unit. Assume a supply of 240 V.

Soln:

Current drawn by 1 lamp $= \frac{P}{V} = \frac{60}{240} = 0.25A$

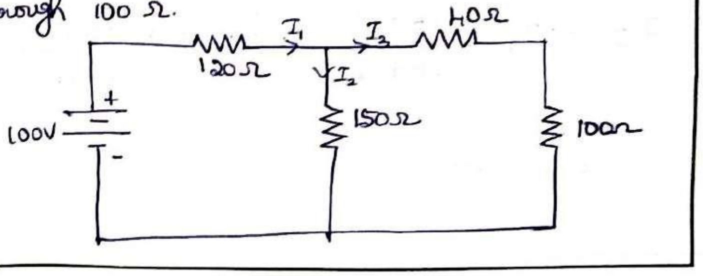
Tot Current drawn by 20 lamps $= 20 \times 0.25$
$= 5A$

Energy consumed in a month $= 30 \times 4 \times 20 \times 60\ Wh$

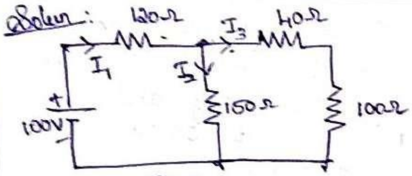
$$= \frac{30 \times 4 \times 20 \times 60}{1000}\ kWh = 144 \text{ units}$$

$$= 144 \times 0.55 = 79.20$$

4) From the circuit, find the value of current through 100 Ω.

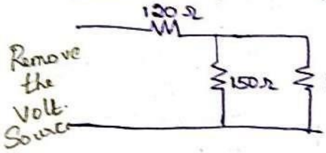


Solu:



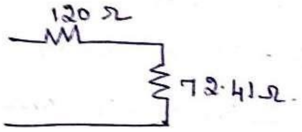
Since 40Ω and 100Ω are in series,

$40 + 100 = 140\ \Omega$



Since 150 Ω & 140 Ω are in parallel,

$$\frac{150 \times 140}{150 + 140} = 72.41\Omega$$



$120 + 72.41 = 192.41\Omega$

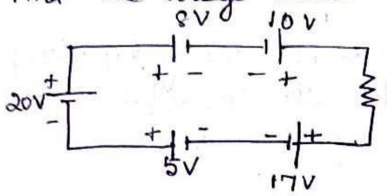
$$I_1 = \frac{V}{R_{eq.}} = \frac{100}{192.41} = 0.519\ A$$

Now, current through 100 Ω,

$$I_3 = I_1 \times \frac{150}{150 + 140} = 0.519 \times \frac{150}{290}$$

$$\therefore \boxed{I_3 = 0.268\ A}$$

5) Find the voltage across resistor 'R' in fig.



Apply KVL,

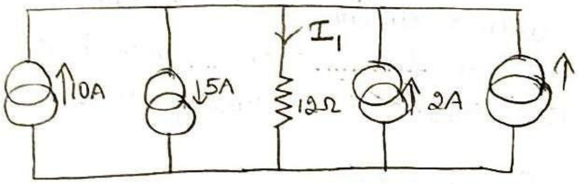
$$20 - 8 + 10 - 17 + 5 \cancel{20} - V_1 = 0$$

$$10 - V_1 = 0$$

$$\boxed{V_1 = 10V}$$

∴ Voltage across resistor, $\boxed{R = 10V}$

6) Find the current through 12Ω resistor in fig.



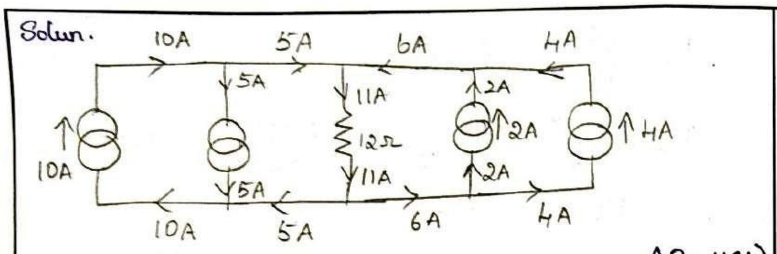
By KCL,

$$10A + 2A + 4A = 5A + I_1$$

$$16A = 5A + I_1$$

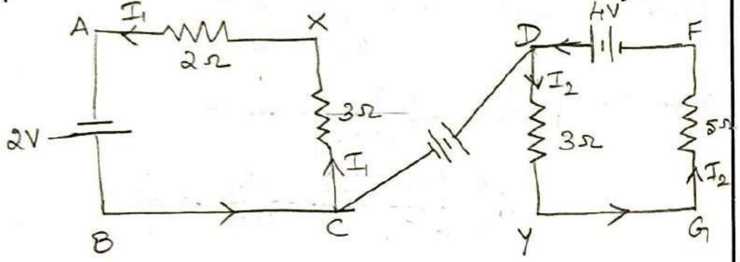
$$\boxed{11A = I_1}$$

Solun.



Here, incoming current is 5+6 = 11 A (By KCL)
This 11 A current flows through 12 Ω resistor.

7) What is the difference in potential between points x & y in the circuit shown in fig.



For Loop ABCXA,

$$2 - 3I_1 - 2I_1 = 0$$
$$2 - 5I_1 = 0$$
$$I_1 = \frac{2}{5} = 0.4A$$

For Loop DYGFD,

$$-3I_2 - 5I_2 + 4 = 0$$
$$-8I_2 = -4$$
$$8 I_2 = \frac{4}{8} = 0.5 A$$

Potential between x & y = $V_{xc} + V_{CD} + V_{DY}$

$V_{xc} = 3I_1$ (rise) $= 3 \times 0.4 = 1.2$ V

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

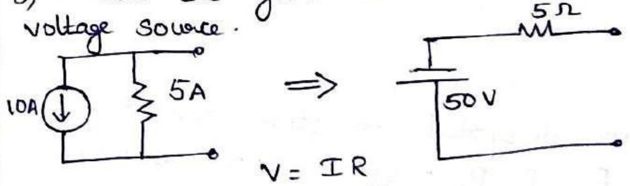
$V_{DY} = 3I_2$ (drop) $= 3 \times 0.5 = 1.5$ V

$V_{xy} = 1.2 + 4 - 1.5$ (since V_{DY} is a drop)

$= 3.7$ V (rise from x to Y).

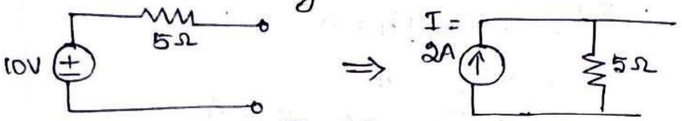
Source Transformation Problems:

8) Convert the given current source into a voltage source.



$V = IR$
$= 10 \times 5$
$V = 50$ V

9) Convert the voltage into current source.



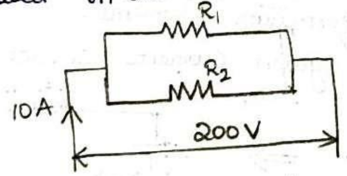
$$I = \frac{10}{5} = 2A$$

10) Two resistors connected in parallel across 200V supply take 10 A from the mains. If the power dissipated in one resistor is 800W, find the value of the other resistor.

Soln:

Total power taken, $P = V \cdot I = 200 \times 10 = 2000\,W$

Power dissipated in one resistor, $P_1 = 800\,W$



∴ Power dissipated in other resistor,

$$P_2 = P - P_1 = 2000 - 800 = 1200\,W$$

$$P_2 = \frac{V^2}{R_2} = 1200\,W$$

$$R_2 = \frac{V^2}{1200} = \frac{(200)^2}{1200} = \frac{40000}{1200} = 33.33\,\Omega$$

$$\boxed{R_2 = 33.33\,\Omega}$$

11) The effective resistance of two resistors connected in series is 100Ω When connected in parallel, the effective value is 24Ω. Determine the values of the two resistors.

Let the two resistors be R_1 & R_2.

When in series, $R_1 + R_2 = 100\,\Omega$.

$$R_2 = 100 - R_1$$

When in parallel, $\frac{R_1 R_2}{R_1 + R_2} = 24\,\Omega$

$$\cancel{\frac{R_1(100-R_1)}{R_1+R_1}} \quad \frac{R_1 R_2}{100} = 24$$

$$\frac{R_1(100-R_1)}{100} = 24$$

$R_1(100 - R_1) = 2400 \Rightarrow R_1 100 - R_1^2 = 2400$

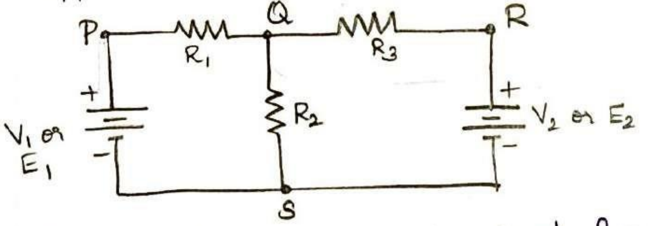
$R_1^2 - 100R_1 + 2400 = 0$ or $(R_1 - 60)(R_1 - 40) = 0$

Solving this equation, we get, $R_1 = 40\,\Omega$ or $60\,\Omega$

$$\boxed{R_1 = 60\,\Omega \text{ and } R_2 = 40\,\Omega}$$

MESH ANALYSIS

In Mesh method, Kirchhoff's Voltage Law (KVL) is applied to a network.



The branch current can be found by taking the algebraic sum of the mesh currents which are common to that branch.

Procedure:

Step 1: First, each mesh is assigned a separate mesh current. Assume all mesh current in clockwise direction.

Step 2: If two mesh currents (I_1 & I_2) are flowing through network elements, the actual current is the algebraic sum of two mesh currents (I_1 & I_2).

Q to S is $I_1 - I_2$; S to Q, is $I_2 - I_1$

Step 3: Rise in potential → + sign

Fall in " → - sign

Step 4: Suppose, if mesh current becomes negative, the actual direction becomes anticlockwise.

By applying KVL,

Mesh PQSP,

$$-I_1 R_1 - (I_1 - I_2) R_2 + V_1 = 0$$

$$I_1 (R_1 + R_2) - I_2 R_2 = V_1 \quad — ①$$

Mesh QRSQ

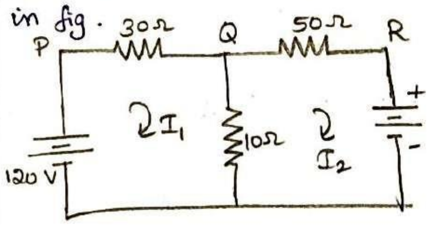
$$-I_2 R_3 - V_2 - (I_2 - I_1) R_2 = 0$$

$$+I_1 R_2 - I_2 (R_2 + R_3) = V_2 \quad — ②$$

Solving ① & ② I_1 & I_2 can be calculated.

Step 5: Branch current can be calculated from Mesh current I_1 & I_2.

Prob ① Solve the Mesh & branch currents shown in fig.



Mesh PQSP,

$-30I_1 - 10(I_1 - I_2) + 120 = 0$

$40I_1 - 10I_2 = 120$ —— ①

Mesh QRSQ

$-50I_2 - 60 - 10(I_2 - I_1) = 0$

$-10I_1 + 60I_2 = -60$ —— ②

$$\Delta = \begin{vmatrix} 40 & -10 \\ -10 & 60 \end{vmatrix}$$

$= 2400 - 100 = 2300$

$$\Delta I_1 = \begin{vmatrix} 120 & -10 \\ -60 & 60 \end{vmatrix}$$

$= 7200 - 600 = 6600$

$$\Delta I_2 = \begin{vmatrix} 40 & 120 \\ -10 & -60 \end{vmatrix} = -2400 + 1200 = -1200$$

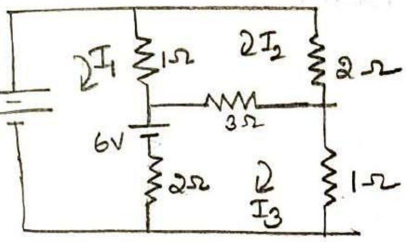
$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{6600}{2300} = 2.869\text{ A}$$

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{-1200}{2300} = -0.521\text{ A}$$

[Since '–'ive, current direction is opposite]

Problem ②

Use Mesh analysis, determine three Mesh currents in the below circuit.



~~Mesh~~ In Loop 1,

$-1(I_1 - I_2) - 6 - 2(I_1 - I_3) + 7 = 0$

$3I_1 - I_2 - 2I_3 = 1$ —— ①

In Loop 2,

$-2I_2 - 3(I_2 - I_3) - 1(I_2 - I_1) = 0$

$-I_1 + 6I_2 - 3I_3 = 0$ —— ②

In Loop 3,

$I_3 + 2(I_3 - I_1) + 6 - 3(I_3 - I_2) = 0$

$-2I_1 - 3I_2 + 6I_3 = 6$ —— ③

Matrix representation of ①, ② & ③ is

$$\begin{bmatrix} 3 & -1 & -2 \\ -1 & 6 & -3 \\ -2 & -3 & 6 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 6 \end{bmatrix}$$

By Cramer's rule,

$$\Delta = \begin{vmatrix} 3 & -1 & -2 \\ -1 & 6 & -3 \\ -2 & -3 & 6 \end{vmatrix} = 3(36-9)+1(-6-6)-2(3+12)$$

$$= 81-12-30$$

$$= 39$$

$$\Delta_1 = \begin{vmatrix} 1 & -1 & -2 \\ 0 & 6 & -3 \\ 6 & -3 & 6 \end{vmatrix} = 1(36-9)-(-1)(0+18)-2(0-36)$$

$$= 27+18+72$$

$$= 117$$

$$\Delta_2 = \begin{vmatrix} 3 & +1 & -2 \\ -1 & 0 & -3 \\ -2 & 6 & 6 \end{vmatrix} = 3(0+18)-1(-6-6)-2(-6)$$

$$= 54+12+12$$

$$= 78$$

$$\Delta_3 = \begin{vmatrix} 3 & -1 & 1 \\ -1 & 6 & 0 \\ -2 & -3 & 6 \end{vmatrix} = 3(36)-(-1)(-6)+(3+12)$$

$$= 108-6+15$$

$$= 117$$

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{117}{39} = \underline{\underline{3A}}$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{78}{39} = \underline{\underline{2A}}$$

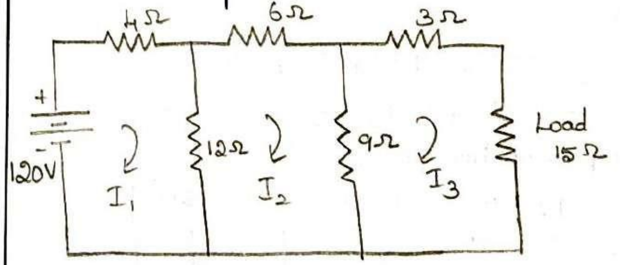
$$I_3 = \frac{\Delta_3}{\Delta} = \frac{117}{39} = \underline{\underline{3A}}$$

The three mesh currents are

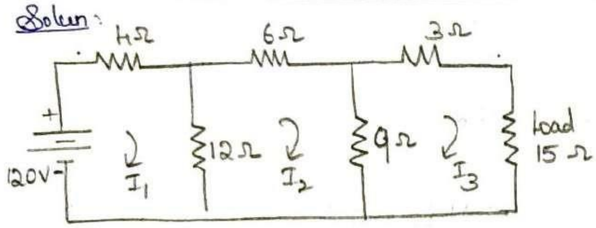
$$\boxed{I_1 = 3A \;;\; I_2 = 2A \;;\; I_3 = 3A}$$

Problem 2

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



Soln:



In Loop 1,

$$-4I_1 - 12(I_1 - I_2) + 120 = 0$$

$$-4I_1 - 12I_1 + 12I_2 = -120$$

$$16I_1 - 12I_2 = 120 \quad \text{——} ①$$

In Loop 2,

$$-6I_2 - 9(I_2 - I_3) - 12(I_2 - I_1) = 0$$

~~+6~~ $12I_1 - 27I_2 + 9I_3 = 0$ —— ②

In Loop 3,

$$-3I_3 - 15I_3 - 9(I_3 - I_2) = 0$$

$$-27I_3 + 9I_2 = 0 \quad \text{——} ③$$

Matrix representation is,

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

By Cramer's rule, we can find current through load (15Ω) Mesh current I_3 through 15Ω resis

$$\Delta = \begin{vmatrix} 16 & -12 & 0 \\ 12 & -27 & 9 \\ 0 & 9 & -27 \end{vmatrix} = 16(729-81)+12(-324$$

$$= 6480$$

$$\Delta I_3 = \begin{vmatrix} 16 & -12 & 120 \\ 12 & -27 & 0 \\ 0 & 9 & 0 \end{vmatrix} = 16(0-0)+12(0-0) +120(108-0)$$

$$= 0+0+120(108)$$

$$= 12960$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{12960}{6480} = 2A //$$

Current through load resistor (15Ω) is 2A.

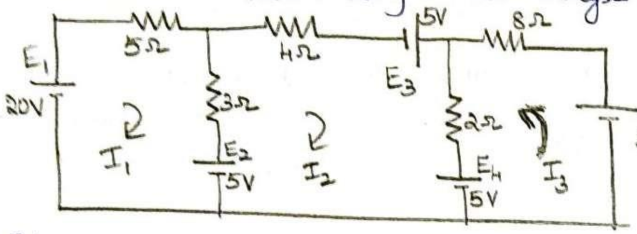
$\therefore$ Power delivered to the load $= I^2 R$

$$= 2^2 \times 15$$

$$= 60\,W //$$

Prob.

③ Determine the current supplied by each battery in the circuit shown using Mesh analysis.



Soln :

The three loop currents are,

Loop 1:

$$-5I_1 - 3(I_1 - I_2) - 5 + 20 = 0$$

$$-5I_1 - 3I_1 + 3I_2 + 15 = 0$$

$$8I_1 - 3I_2 = 15 \quad \text{——} ①$$

Loop 2

$$-4I_2 + 5 - 2(I_2 - I_3) - \cancel{5} + \cancel{5} - 3(I_2 - I_1) = 0$$

$$-4I_2 - 2I_2 + 2I_3 - 3I_2 + 3I_1 + 5 = 0$$

$$-3I_1 + 9I_2 + 2I_3 = -5$$

$$3I_1 - 9I_2 - 2I_3 = 5 \quad \text{——} ②$$

Loop 3

$$30 - 8I_3 - 2(I_3 + I_2) - 5 = 0$$

$$-8I_3 - 2I_3 + 2I_2 + 25 = 0$$

$$2I_2 + 10I_3 = 25 \quad \text{——} ③$$

Matrix representation of 1, 2, 3 is

$$\begin{bmatrix} 8 & -3 & 0 \\ 3 & -9 & -2 \\ 0 & 2 & 10 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 15 \\ 5 \\ 25 \end{bmatrix}$$

$$\Delta = \begin{bmatrix} 8 & -3 & 0 \\ 3 & -9 & -2 \\ 0 & 2 & 10 \end{bmatrix} = 8(-90+4) + 3(30-0) + 0$$

$$= -688 + 90 = -598$$

$$\Delta I_1 = \begin{vmatrix} 15 & -3 & 0 \\ 5 & -9 & -2 \\ 25 & 2 & 10 \end{vmatrix} = 15(-90+4) + 3(50+50)$$

$$= -1290 + 300 = -990$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{-990}{-598} = 1.655\ A$$

$$\Delta I_2 = \begin{vmatrix} 8 & 15 & 0 \\ 3 & 5 & -2 \\ 0 & 25 & 10 \end{vmatrix} = 8(50+50) - 15(30)$$

$$= 800 - 450 = 350$$

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{350}{-598} = 0.5852\ A$$

$$\Delta I_3 = \begin{vmatrix} 8 & -3 & 15 \\ 3 & -9 & 5 \\ 0 & 2 & 25 \end{vmatrix} = 8(-225-10) + 3(75) + 15(6)$$

$$= -1880 + 225 + 90$$

$$= -1565$$

$$I_3 = \frac{\Delta I_3}{\Delta} = \frac{-1565}{-598} = 2.617A$$

Current supplied by battery E_1 is $I_1 = 1.655$ A

" " " " E_2 is $I_1 - I_2 = 1.655 - (-0.5852)$
$= 2.2402$ A

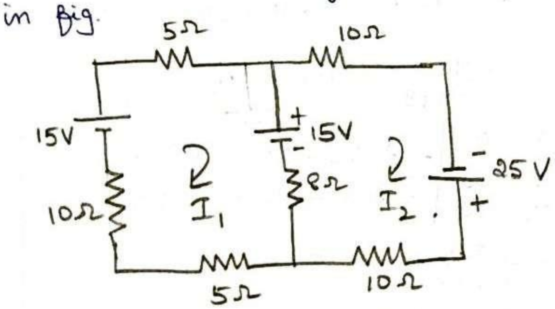
Current supplied by E_3 is $I_2 = -0.5852$ A

" " E_4 is $I_3 + I_2 = 2.617 - 0.5852$
$= 2.0318$ A

Current supplied by E_5 is $I_3 = 2.617$ A

Prob ④

Find the current through the 8Ω resistor shown in fig.



By using Mesh inspection method,

$$\begin{bmatrix} 5+8+5+10 & -8 \\ -8 & 10+10+8 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 15-15 \\ 25+15 \end{bmatrix}$$

ie $$\begin{bmatrix} 28 & -8 \\ -8 & 28 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 40 \end{bmatrix}$$

Apply Cramer's rule, to find current through 8Ω resistor.

$$\Delta = \begin{vmatrix} 28 & -8 \\ -8 & 28 \end{vmatrix} = 784 - 64 = 720$$

$$\Delta I_1 = \begin{vmatrix} 0 & -8 \\ 40 & 28 \end{vmatrix} = 0 - (-320) = 320$$

$$I_1 = \frac{\Delta I_1}{\Delta} = \frac{320}{720} = 0.44 \text{ A}$$

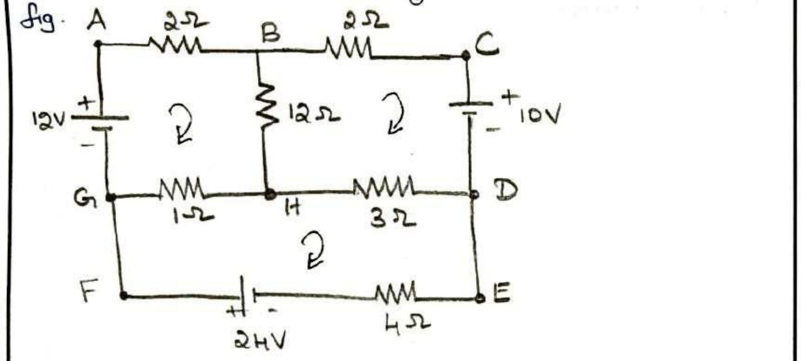
$$\Delta I_2 = \begin{vmatrix} 28 & 0 \\ -8 & 40 \end{vmatrix} = 1120$$

$$I_2 = \frac{\Delta I_2}{\Delta} = \frac{1120}{720} = 1.55 \text{ A}$$

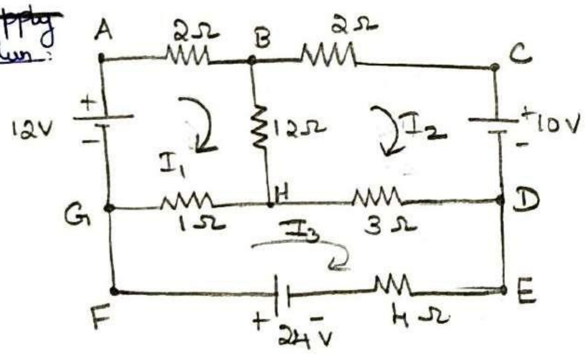
Current through 8Ω resistor $= I_2 - I_1$
$= 1.55 - 0.44$
$= 1.11$ A //

Problem ⑤

Determine the current through 4Ω resistor shown in fig.



~~Applg~~ Soln:



In Loop 1, ABHGA;

$$-2I_1 - 12(I_1 - I_2) - 1(I_1 - I_3) + 12 = 0$$

$$-2I_1 - 12I_1 + 12I_2 - I_1 + I_3 + 12 = 0$$

$$-15I_1 + 12I_2 + I_3 \pm 12 = 0$$

$$\Rightarrow 15I_1 - 12I_2 - I_3 - 12 = 0$$

$$\rightarrow \boxed{15I_1 - 12I_2 - I_3 = 12} \quad \text{—— ①}$$

In Loop 2, BCDHB:

$$-2I_2 - 10 - 3(I_2 - I_3) - 12(I_2 - I_1) = 0$$

$$-2I_2 - 3I_2 + 3I_3 - 12I_2 + 12I_1 = 10$$

$$-17I_2 + 12I_1 + 3I_3 = 10$$

$$\Rightarrow 12I_1 - 17I_2 + 3I_3 = 10 \quad \text{—— ②}$$

In Loop 3, GHDEFG

$$-1(I_3 - I_1) - 3(I_3 - I_2) - 4I_3 + 24 = 0$$

$$-I_3 - 3I_3 - 4I_3 + I_1 + 3I_2 + 24 = 0$$

$$8I_3 + I_1 + 3I_2 + 24 = 0$$

$$I_1 + 3I_2 + 8I_3 = -24 \quad \text{—— ③}$$

Matrix form,

$$\begin{vmatrix} 15 & -12 & -1 \\ +12 & +17 & -3 \\ -1 & -3 & 8 \end{vmatrix} \begin{vmatrix} I_1 \\ I_2 \\ I_3 \end{vmatrix} = \begin{vmatrix} 12 \\ -10 \\ +24 \end{vmatrix}$$

$$\Delta = \begin{vmatrix} 15 & -12 & -1 \\ 12 & -17 & 3 \\ 1 & 3 & 8 \end{vmatrix}$$

$$= 15(+136 - 9) + 12(-96 - 3) - 1(36 + 17)$$

$$= \cancel{-2175+12}\ 15(127) + 12(-99) - 53$$

$$= 664$$

$$\Delta_1 = \begin{vmatrix} 12 & -12 & -1 \\ -10 & 17 & -3 \\ 24 & -3 & 8 \end{vmatrix}$$

$$= 12(136-9) + 12(-80+72) - 1(30-408)$$

$$= 1806$$

$$\Delta_2 = \begin{vmatrix} 15 & 12 & -1 \\ -12 & -10 & -3 \\ -1 & 24 & 8 \end{vmatrix}$$

$$= 15(-80+72) - 12(-96-3) - 1(-288-10)$$

$$= 1366$$

$$\Delta_3 = \begin{vmatrix} 15 & -12 & 12 \\ -12 & 17 & -10 \\ -1 & -3 & 24 \end{vmatrix}$$

$$= 15(408-30) + 12(-288+10) + 12(36+17)$$

$$= 2730$$

To find,

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{1806}{664} = 2.71\ A$$

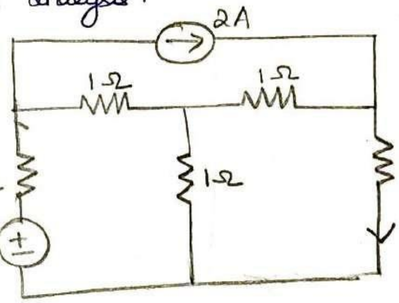
$$I_2 = \frac{\Delta_2}{\Delta} = \frac{1366}{664} = 2.05\ A$$

$$I_3 = \frac{\Delta_3}{\Delta} = \frac{2730}{664} = 4.11\ A$$

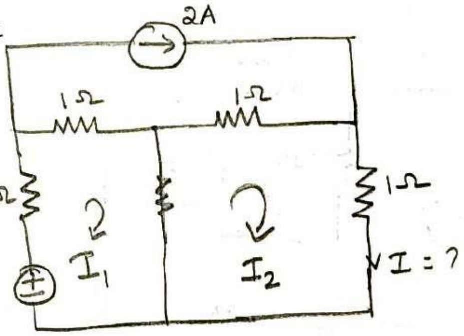
Current through 4Ω resistor is

$$\boxed{I_{4\Omega} = I_3 = 4.11\ A}$$

Prob ⑥ Find the value of current I using Mesh analysis.



Soln:



NODAL ANALYSIS:

Meaning of Node:

A junction point in an electrical circuit is called a node.

Note:

- * A potential (V) drop can be measured w.r.t. this point and another node acting as a reference point.
- * Generally grounded node is taken as reference point.
- * For 'n' no of nodes, (n-1) - KCL equations are formed.

Steps involved in Nodal Analysis:

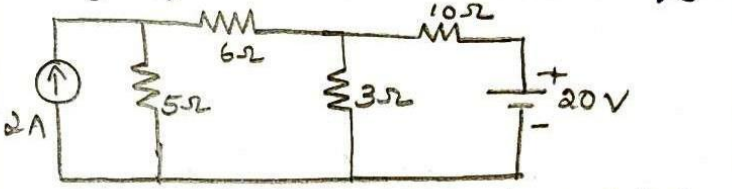
1. Identify all independent nodes wherever the current branches out and select a reference node.
2. Write the nodal equation using KCL for all nodes except the reference node.

2. Write the nodal equation using KCL for all nodes except the reference node.

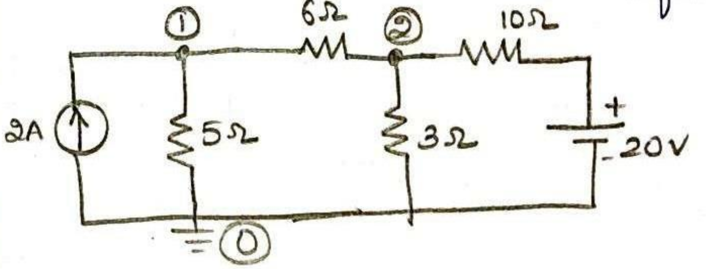
3. Nodal equations are then solved to find nodal voltages and branch currents.

PROBLEMS:

1. Using nodal analysis, determine nodal voltages for the circuit shown in fig.



Soln: Step 1: Identify all nodes & assign reference.



Step 2: Write nodal equation using KCL.

At node ①,

$$\frac{V_1}{5} + \frac{V_1 - V_2}{6} = 2\,A$$

$$\frac{V_1}{5} + \frac{V_1}{6} - \frac{V_2}{6} = 2$$

$$V_1\left[\frac{1}{5} + \frac{1}{6}\right] - V_2\left[\frac{1}{6}\right] = 2$$

$$\boxed{0.367V_1 - 0.167V_2 = 2} \quad — ①$$

At nod ②:

$$\frac{V_2 - V_1}{6} + \frac{V_2}{3} + \frac{V_2 - 20}{10} = 0$$

$$-\frac{V_1}{6} + V_2\left(\frac{1}{3} + \frac{1}{6} + \frac{1}{10}\right) - 2 = 0$$

$$-\frac{V_1}{6} + V_2\left(\frac{1}{3} + \frac{1}{6} + \frac{1}{10}\right) = 2$$

$$\boxed{-0.167V_1 + 0.597V_2 = 2} \quad — ②$$

Step: 3
Solve ① & ②, we get

$$0.367V_1 - 0.167V_2 = 2$$

$$-0.167V_1 + 0.597V_2 = 2$$

$$\Delta = \begin{vmatrix} 0.367 & -0.167 \\ -0.167 & 0.59 \end{vmatrix}$$

$$= 0.216 - 0.027 = 0.188$$

$$\Delta_1 = \begin{vmatrix} 2 & -0.167 \\ 2 & 0.59 \end{vmatrix}$$

$$= (1.18 + 0.334) = 1.514$$

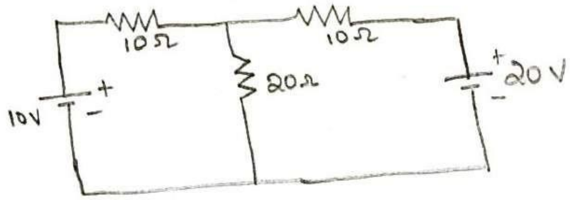
$$\Delta_2 = \begin{vmatrix} 0.367 & 2 \\ -0.167 & 2 \end{vmatrix}$$

$$= 0.734 + 0.334 = 1.068$$

$$V_1 = \frac{1.514}{0.188} = 8.053\,V ✓$$

$$V_2 = \frac{1.068}{0.188} = 5.680\,V ✓$$

2) Using Nodal analysis, determine the current in the 20Ω resistor.



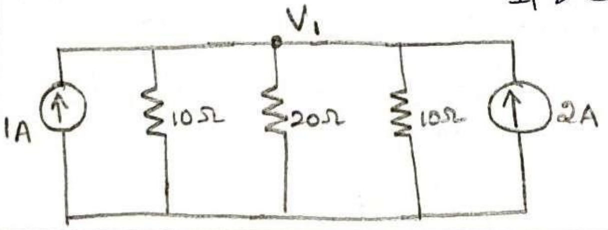
Soln:

Convert all voltage sources into their equivalent current sources.

$$I_1 = \frac{10\,V}{10\Omega} = \frac{10}{10} = 1\,A$$

$$I_2 = \frac{V}{R} = \frac{20}{10} = 2\,A$$

ie, Now redraw the above ckt with I_1 & I_2.



$$\frac{V_1}{10} + \frac{V_1}{20} + \frac{V_1}{10} = 2 + 1$$

$$V_1\left(\frac{1}{10} + \frac{1}{20} + \frac{1}{10}\right) = 3$$

$$0.25\,V_1 = 3$$

$$V_1 = \frac{3}{0.25} = 12$$

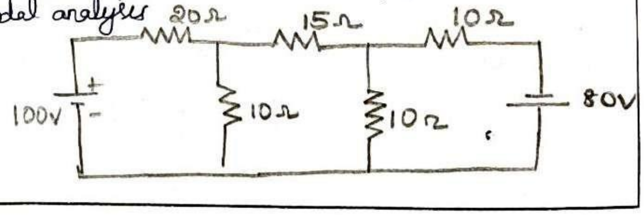
$$\boxed{V_1 = 12}$$

So, current flows through 20Ω resisto is,

$$I_{20\Omega} = \frac{V}{R} = \frac{12}{20} = 0.6\,A$$

$$\boxed{I_{20\Omega} = 0.6\,A}$$

3) Calculate the voltage across 15Ω resisto in the network shown in fig. below using Nodal analysis

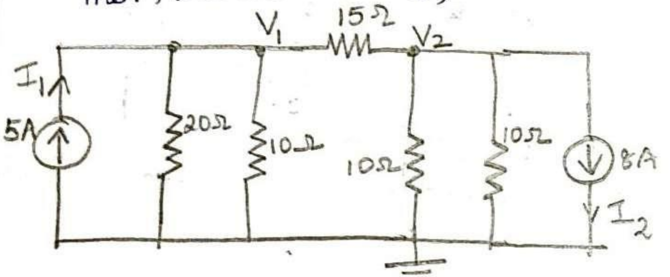


2) Soln:

Convert all the volt source into their equivalent current source.

$I_1 = \frac{100}{20} = 5A$; $I_2 = \frac{80}{10} = 8A$

Then, the ckt becomes,



At node 1, the current is 5A.

At node 2, the current is -8A.

Node equation in matrix form by inspection method.

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

$0.216 V_1 - 0.066 V_2 = 5$ —— ①

$-0.066 V_1 + 0.266 V_2 = -8$ —— ②

Solve V_1 & V_2 by Cramer's rule,

$$\Delta = \begin{vmatrix} 0.216 & -0.066 \\ -0.066 & 0.266 \end{vmatrix} = 0.0574 - 0.0043$$
$$= 0.0531$$

$$\Delta V_1 = \begin{vmatrix} 5 & -0.066 \\ -8 & 0.266 \end{vmatrix} = 1.33 - 0.528$$
$$= 0.802$$

$$V_1 = \frac{\Delta V_1}{\Delta} = \frac{0.802}{0.0531} = 15.1V$$

$$\Delta V_2 = \begin{vmatrix} 0.216 & \cancel{-0.066}\ 5 \\ -0.066 & -8 \end{vmatrix}$$

$$= -1.728 + 0.33 = -1.398$$

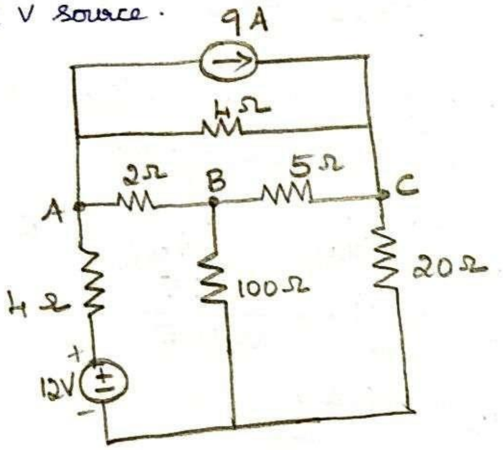
$$V_2 = \frac{\Delta V_2}{\Delta} = \frac{-1.398}{0.0531} = -26.327V$$

Current through 15Ω resistor is,

$$I_{15} = \frac{V_1 - V_2}{15} = \frac{15.1 - (-26.327)}{15}$$

$$\boxed{I_{15} = 2.76A}$$

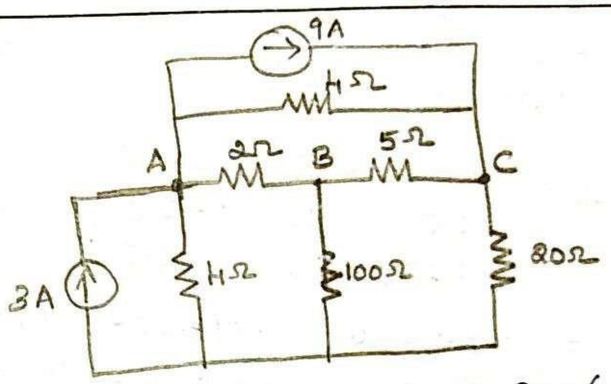
4) Use nodal analysis to determine the voltage across 5 Ω resistance and the current in the 12 V source.



Soln:

First convert voltage source into current source.

$$I = \frac{12}{4} = 3\,A$$



At node A, the current is 3 − 9 = −6 A

At node C, the current is 9 A

At node B, the current is zero.

By inspection method,

$$\begin{bmatrix} \frac{1}{4}+\frac{1}{2}+\frac{1}{4} & -\frac{1}{2} & -\frac{1}{4} \\ -\frac{1}{2} & \frac{1}{2}+\frac{1}{100}+\frac{1}{5} & -\frac{1}{5} \\ -\frac{1}{4} & -\frac{1}{5} & \frac{1}{5}+\frac{1}{20}+\frac{1}{4} \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} -6 \\ 0 \\ 9 \end{bmatrix}$$

$$\begin{bmatrix} 1 & -0.5 & -0.25 \\ -0.5 & 0.71 & -0.2 \\ -0.25 & -0.2 & 0.5 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} -6 \\ 0 \\ 9 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 1 & -0.5 & -0.25 \\ -0.5 & 0.71 & -0.2 \\ -0.25 & -0.2 & 0.5 \end{vmatrix}$$

$$= 1(0.355 - 0.04) + 0.5(-0.25 - 0.05) - 0.25(0.1 + 0.1775)$$

$$= 0.0956$$

$$\Delta V_B = \begin{vmatrix} 1 & -6 & -0.25 \\ -0.5 & 0 & -0.2 \\ -0.25 & 9 & 0.5 \end{vmatrix}$$

$$= 1(1.8) + 6(-0.25 - 0.05) - 0.25(-4.5)$$

$$= 1.125$$

$$V_B = \frac{\Delta V_B}{\Delta} = \frac{1.125}{0.0956} = 11.76\,V$$

$$\Delta V_C = \begin{vmatrix} 1 & -0.5 & -6 \\ -0.5 & 0.71 & 0 \\ -0.25 & -0.2 & 9 \end{vmatrix}$$

$$= 1(6.39 - 0) + 0.5(-4.5 - 0) - 6(0.1 + 0.178)$$

$$= 6.39 - 2.25 - 1.668$$

$$= 2.472$$

$$V_A = \frac{\Delta V_A}{\Delta} = \frac{0.61}{0.096} = 6.35\,V$$

$$V_B = \frac{\Delta V_B}{\Delta} = \frac{1.125}{0.095}$$

$$\boxed{V_B = 11.72\,V}$$

$$V_C = \frac{\Delta V_C}{\Delta} = \frac{2.472}{0.095}$$

$$\boxed{V_C = 25.83\,V}$$

Voltage across 5 Ω resistance is,

$$V_{5\,\Omega} = V_C - V_B$$

$$= 14.11\,V$$

Current from 12 V source, $I = \frac{12 - V_A}{4}$

$$\boxed{I = 1.41\,A}$$

DEPARTMENT OF SCIENCE AND HUMANITIES

INTRODUCTION to AC CIRCUITS & PARAMETERS:

Rotary electro mechanical generators produce voltage alternating in polarity and reversing positive and negative over time.

Either as a voltage switching polarity or as a current switching direction back and forth, this kind of electricity is known as Alternating Current (AC).

AC	DC
1) Symbol: (~) AC voltage Source	Symbol: (±) DC Voltage Source
2) Voltage can be raised or decreased with use of transformer.	In DC raising & decreasing of voltage is not easy.
3) AC Voltage generators are easy to construct and cost is less.	It is not possible in DC circuits.

Note: When necessary AC supply can be converted to obtain DC supply.

When two or more coils of wire are placed, a changing magnetic field created by one induces a voltage in the other. This is known as mutual induction.

AC Waveforms:

When an alternator produces AC voltage, the voltage switches polarity over time. When graphed over time, the wave is traced.

The shape obtained by plotting the instantaneous values of an alternating quantity such as voltage & current along the y-axis and time, (t) along the x-axis is called a waveform.

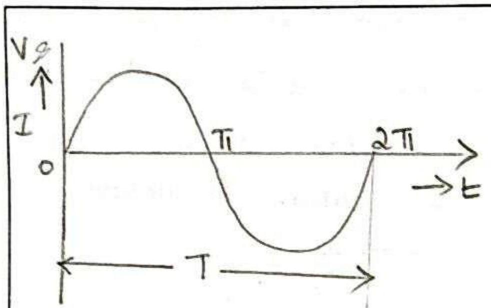


Fig: Graph of AC voltage over time (Sine Waveform).

Amplitude:

The maximum positive or negative value attained by an alternating quantity in one complete cycle is called Amplitude or peak value or Maximum value. The maximum value of voltage and current is represented by Em or Vm and Im respectively.

Cycle:

When one set of positive and negative values completes by an alternating quantity or it goes through 360 degrees electrical, it is said to have one complete cycle.

Frequency (f):

The number of cycles made per second by an alternating quantity is called frequency. It is measured in cycle per second (c/s) or hertz (Hz).

Time Period (T):

The time taken in seconds by a voltage or a current to complete one cycle is called Time Period.

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

The Average Value of a Waveform :

* The average value of a waveform can be found for any wave like sinusoidal, triangular trapezoidal or any other shape.

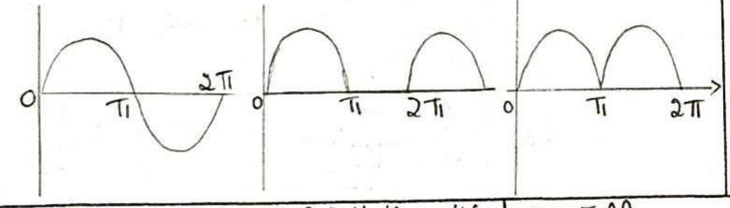
* The average value of a cycle of a waveform is the area under the waveform divided by the length one cycle.

Mathematically

$$V_{av} = \frac{1}{T}\int_0^T v\,dt = \frac{1}{2\pi}\int_0^{2\pi} v\,dt$$

where $T \rightarrow$ length of one cycle.

Consider the following shapes.



a) Full Sine Wave (b) Half-rectified Wave (c) Full-rectified wave

In fig.(a),

The total area under the curve = 0

[∵ ~~As~~ half of its is above wt axis and equal half is below wt-axis.]

Hence the $\boxed{\text{Average value of full sine wave} = 0}$

In fig(b)

The average value is,

$$V_{av} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin \omega t \, d\omega t$$

$$= \frac{1}{2\pi}\left[-V_m \cos \omega t\right]_0^{\pi} \quad \left[\because \int \sin t = -\cos t\right]$$

$$= -\frac{V_m}{2\pi}\left[\cos \omega t\right]_0^{\pi}$$

$$= -\frac{V_m}{2\pi}\left[\cos \pi - \cos 0\right] \quad \overset{\text{We know}}{\left[\begin{array}{l}\cos \pi = -1 \\ \cos 0 = 1\end{array}\right]}$$

$$= -\frac{V_m}{2\pi}\left[-1 - 1\right] = +\frac{\cancel{2}V_m}{\cancel{2}\pi}$$

$$\boxed{V_{av} = \frac{V_m}{\pi}}$$

In fig(c)

The average value of full rectified wave will be double of half wave rectified wave over the same period 2π.

ie For full rectified wave,

$$\boxed{\text{Average value} = \frac{2V_m}{\pi}}$$

The effective or RMS value of a wave.

The rms or effective value of a wave is Root Mean of Squared values. It is represented mathematically as.

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

We have to take the square of various ordinates and find the area of the squared wave over the period, T. Also find the mean value and then obtain its square root. This is the effective value.

For fig.(a)

The instantaneous value of the wave is,

$$\boxed{i = I_m \sin \omega t}$$

The rms value of the ~~cos~~ full sine wave is,

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2\,d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2 \omega t\,d\omega t}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{2\pi} \frac{1-\cos 2\omega t}{2}\,d\omega t}$$

$$= I_m\sqrt{\frac{1}{4\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{2\pi}}$$

$$= I_m\sqrt{\frac{1}{4\pi}\left[2\pi - 0 - \frac{\sin \cancel{4\pi}}{\cancel{2}} - \frac{\cancel{\sin 0}}{2}\right]} \quad = 0$$

$$= I_m\sqrt{\frac{1}{4\pi}[2\pi - 0]} = I_m\sqrt{\frac{\cancel{2\pi}}{2\cancel{4\pi}}}$$

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

For fig.(b), For a half rectified sine wave, the rms value is,

$$I_{rms} = \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d\omega t}$$

$$= \frac{I_m}{\sqrt{2\pi\times 2}}\sqrt{\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{\pi}}$$

$$= \frac{I_m}{2\sqrt{\pi}}\left[\sqrt{\cancel{\phi}(\pi - 0) - \sin 2\pi + \sin 0}\right]$$

$$= \frac{I_m}{2\sqrt{\pi}}\left[\sqrt{\pi - 0 - 0 + 0}\right]$$

$$= \frac{I_m}{2\cancel{\sqrt{\pi}}}\cancel{\sqrt{\pi}}$$

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

ie rms of half recitified sine wave is $\frac{1}{2}$ of its peak value.

For fig.(c),

The rms value will be same as the full rectified wave.

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

Form Factor:

It is defined as the ratio of rms value of a wave and the average value of the wave.

$$\boxed{\text{Form factor} = \frac{\text{rms value of the wave}}{\text{Average value of the wave}}}$$

For a sinusoidal wave,

$$\text{Form factor} = \frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}}$$

$$= \frac{\cancel{V_m}}{\sqrt{2}} \times \frac{\pi}{2\cancel{V_m}}$$

$$\boxed{\text{Form factor} = 1.11}$$

Peak Factor or Crest factor :

It is the ratio of the peak value of the wave to its rms value.

$$\text{Peak factor} = \frac{\text{Peak value}}{\text{RMS value}}$$

$$= \frac{\cancel{V_m}}{\frac{\cancel{V_m}}{\sqrt{2}}} = \sqrt{2}$$

$$\boxed{\text{Peak factor} = 1.414}$$

Power Analysis in AC Circuits :

Instantaneous Power :

* In purely resistive circuit, all energy delivered by the source is dissipated in the form of heat by resistance.

* In a reactive circuit, all the energy delivered by the source is inductor or capacitor in its magnetic or electric field during a portion of voltage cycle and returned to another cycle so that net energy is transferred.

Average Power (Watts)

Average power is defined as; $P = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} p(t)dt$

Avg. value after one cycle is

$$P_{av} = \frac{1}{T} \int_0^t p(t)\, dt$$

$$= \frac{1}{T} \int_0^T \left\{ \frac{V_m I_m}{2} \left[\cos(2\omega t + \theta) + \cos\theta \right] dt \right\}$$

$$= \frac{1}{T} \int_0^T \frac{V_m I_m}{2} . \cos(2\omega t + \theta) dt + \frac{1}{T} \int_0^T \frac{V_m I_m}{2} \cos\theta\, dt$$

First term is zero,

Instantaneous Power, $P = V \cdot i$

$$p = V_m \sin \omega t \cdot I_m \sin \omega t$$

$$= V_m I_m \sin^2 \omega t$$

$$= V_m I_m \left(\frac{1 - \cos 2\omega t}{2} \right)$$

$$P = \frac{V_m I_m}{2} - \frac{V_m I_m}{2} \cos 2\omega t$$

Average Power, $P_{avg} = \frac{V_m I_m}{2}$ [since P_{avg} of cosine wave is zero

$$= \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$

$$\boxed{P_{avg} = V_{rms} \cdot I_{rms}}$$

~~Also $P_{avg} = VI$~~ In a purely resistive circuit, the phase angle between voltage and current is ~~90°~~ 0°. ∴ The average power is ,

$$P_{avg} = \frac{V_m I_m}{2} = \frac{I_m^2 R}{2}$$

In a purely reactive circuit, the phase angle between voltage and current is 90°. Hence, the average power is zero.

Apparent Power (Volt ampere)

The apparent power is defined as the product of RMS value of voltage and current.

Apparent Power = $V_{rms} I_{rms}$

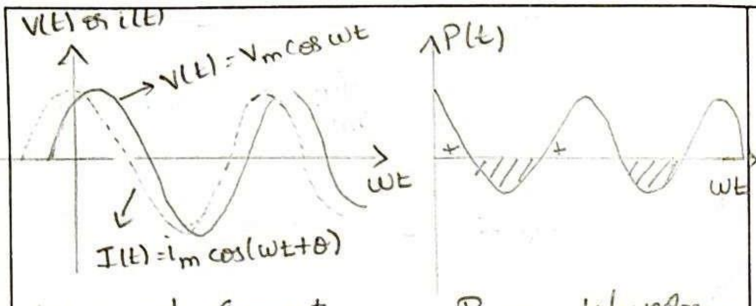
Consider $v(t) = V_m \cos \omega t$

Current through the circuit $i(t) = I_m \cos(\omega t \div \theta)$

Power at any instant of time $p(t) = v(t) \cdot i(t)$

$$P(t) = V_m \cos \omega t \cdot I_m \cos(\omega t + \theta)$$

$$P(t) = \frac{V_m I_m}{2} \left[\cos(2\omega t + \theta) + \cos \theta \right]$$



Voltage and Current Waveform

Power Waveform

Fig: Voltage, Current and Power Waveform.

Power Factor (PF) (cos θ)

$$\text{Power Factor} = \frac{\text{True Power (Average Power)}}{\text{Apparent Power}}$$

$$= \frac{V_{rms} \cdot I_{rms} \cos\theta}{V_{rms} \cdot I_{rms}}$$

$$= \cos\theta$$

Reactive Power :

Average Power $P_{av} = V_{eff}\, I_{eff} \cos\theta$ —①

Impedance triangle

$\cos\theta = \frac{R}{|Z|}$ —②

[∵ $\cos\theta = \frac{adj}{hyp}$

and $V_{eff} = I_{eff} \cdot Z$ —③

Sub ② & ③ in ①

$P_{av} = I_{eff} \cdot \cancel{Z} \cdot I_{eff} \cdot \frac{R}{\cancel{Z}}$

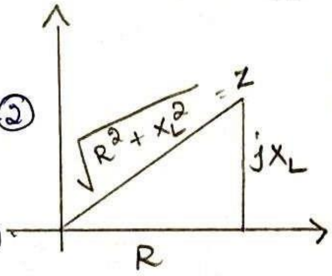


Fig: Impedance Triangle

$P_{av} = I_{eff}^2 \cdot R$ Watts.

This is the average power dissipated in resistive circuit only.

For pure inductor,

The instantaneous power is

$P = v \times i$

$$P = V_m \sin \omega t \times I_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$= V_m I_m \sin \omega t \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$P = V_m I_m \sin\omega t \ (-\cos \omega t)$$

$$\boxed{\because \sin(\theta - 90) = -\cos\theta}$$

$$P = -\frac{V_m I_m}{2} \sin(2\omega t)$$

$$\boxed{\because \sin 2\theta = 2 \sin\theta \cos\theta}$$

$$\therefore P_{avg} = 0$$

The average power of one complete cycle is zero.

From fig (Impedance triangle)

$$\sin\theta = \frac{opp}{hyp} = \frac{jX_L}{Z}$$

ie $jX_L = Z \sin\theta$

P_L, Reactive Power $= I_{rms}^2 \cdot X_L$

$$P_L = I_{rms}^2 \cdot Z \sin\theta$$

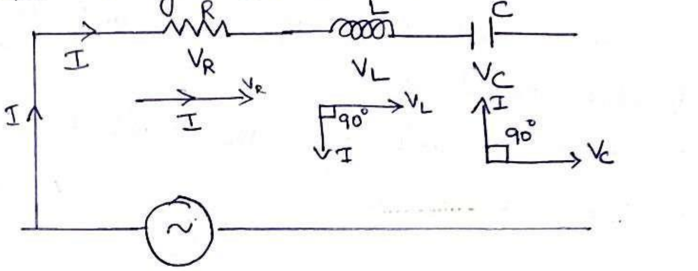
$$= (I_{rms} \cdot Z)\, I_{rms} \sin\theta$$

$$\boxed{P_L = (V_{rms}\, I_{rms} \sin\theta)\ VAR}$$

VAR → Volt Amphere Reactive - Unit of Reactive Power.

STEADY STATE ANALYSIS OF RLC CIRCUITS

AC through Series R-L-C Circuit :



$V = V_m \sin \omega t$

The voltage, $V = V_m \sin \omega t$ is applied to series RLC circuit.

$$\overline{V} = \overline{V_R} + \overline{V_L} + \overline{V_C}$$

$$\overline{V} = \overline{RI} + \overline{IX_L} + \overline{IX_C}$$

$V_R = IR$ = Drop across resistance which is inphase with I.

$V_L = IX_L$ = Drop across Inductance which leads the current by 90°.

$V_C = IX_C$ = Drop across Capacitance which lags the current by 90°.

Case (1) $X_L > X_C$

When $X_L > X_C$, the volt, $V_L > V_C$.

* ∴ The resultant of V_L & V_C will be directed towards V_L.
* Current I will lag the resultant of V_L & V_C ie $V_L - V_C$.

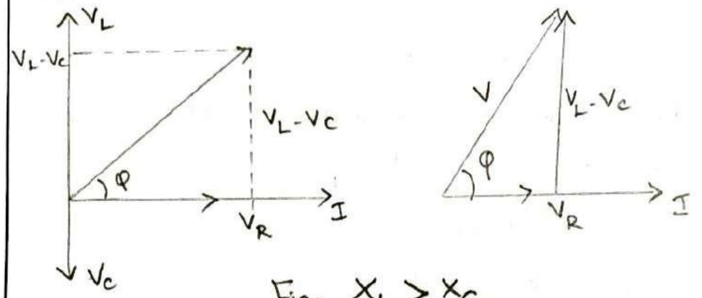


Fig: $X_L > X_C$

From voltage triangle,

$$V = \sqrt{V_R^2 + (V_L - V_C)^2} = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

$$V = I\sqrt{R^2 + (X_L - X_C)^2}$$

$$V = IZ$$

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

Case 2 : $X_L < X_C$

When $X_L < X_C$, the voltage, $V_L < V_C$

∴ The resultant volt of V_L & V_C will be directed towards V_C. The circuit will be capacitive in nature.

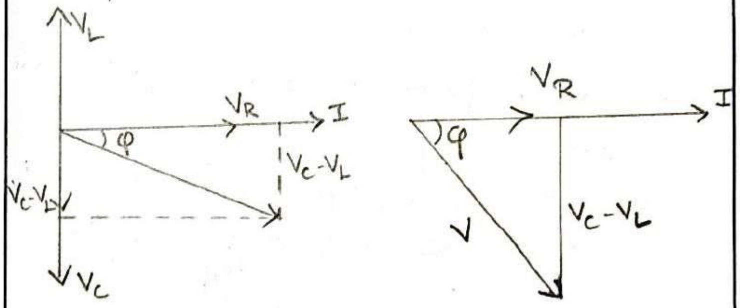


Fig: $X_C > X_L$

From voltage triangle,

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

$$= \sqrt{(IR)^2 + (IX_C - IX_L)^2}$$

$$V = IZ$$

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

Case 3 : $X_L = X_C$

When $X_L = X_C$, the voltage $V_L = V_C$.

$\therefore V_L$ & V_C will cancel each other & the resultant is zero.

Hence $V_R = V$ in this case, and the circuit is resistive in nature.

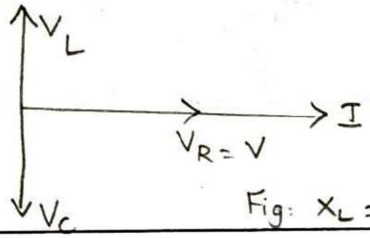


Fig: $X_L = X_C$

Impedance

For series RLC circuit,

$$Z = R + jX_L - jX_C$$

$$Z = R + j(X_L - X_C)$$

$$Z = R + jX$$

where, $X = X_L = X_C \Rightarrow$ Total reactance of the circuit.

If $X_L > X_C$, X is positive & the circuit is inductive

If $X_L < X_C$, X is negative " , , , " Capacitive

If $X_L = X_C$, X is Zero , " " " resistive

$$\tan\varphi = \left[\frac{X_L - X_C}{R}\right]$$

$$\cos\varphi = \frac{R}{Z}$$

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

Power ;

P_{av} = Avg. Power consumed by R, L, C.

$P_{av} = I^2 R$ [∵ Avg. power consumed by L & C is zero]

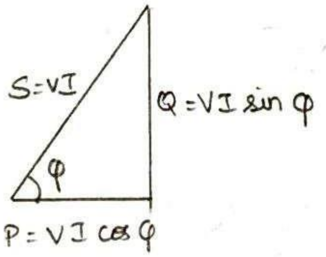
$P_{av} = I(IR)$

$P = I V_R$

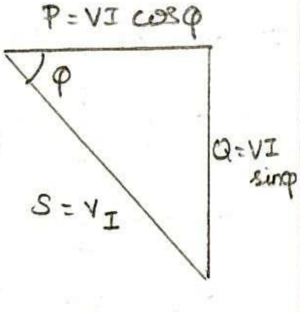
$= IV\cos\varphi$

$P = VI\cos\varphi$ W

Power triangle:



$X_L > X_C$

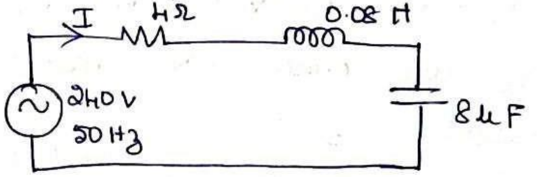


$X_C > X_L$

Problem

A 240 V, 50 Hz AC supply is applied a coil of 0.08 H inductance & 4 Ω resist connected in series with a capacitor of 8 uF. Calculate i) Impedance (ii) Circuit current (iii) Phase angle between Volt & Current iv) Power factor v) Power consumed vi) Q factor of the ckt at resonant freq.

Given R = 4 Ω, L = 0.08 H, C = 8 uF,
V = 240 v, f = 50 Hz



Here,

$X_L = L\omega = 2\pi f_L = 2\pi \times 50 \times 0.08 = 25.12\,\Omega$

$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f_C} = \frac{1}{2\times 50\times 8\times 10^{-6}} = 398.09\,\Omega$

Impedance of the circuit :

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

$$= \sqrt{(4)^2 + (25.12 - 398.09)^2}$$

$$= 376.97\,\Omega$$

Circuit Current, $I = \frac{V}{Z} = \frac{240}{376.97} = 0.636$

Phase angle b/w volt & Current

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

$$= \tan^{1}\left(\frac{25.12 - 398.09}{4}\right)$$

$\varphi = -89.38°$ (The -ive sign shows Current is leading)

Power Factor :

$$\cos\varphi = \frac{R}{Z} = \frac{4}{372.99} = 0.01072 \text{ (leading)}$$

Power Consumed :

$$P = VI\cos\varphi = 240 \times 0.636 \times 0.01072$$

$$= 1.636\text{ W}$$

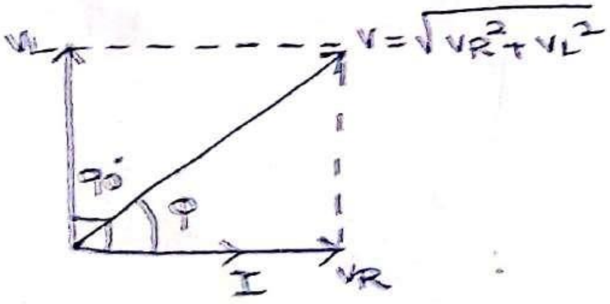
$$Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

$$= \frac{1}{4}\sqrt{\frac{0.08}{8\times10^{-6}}}$$

$$= 25$$

RL Circuit

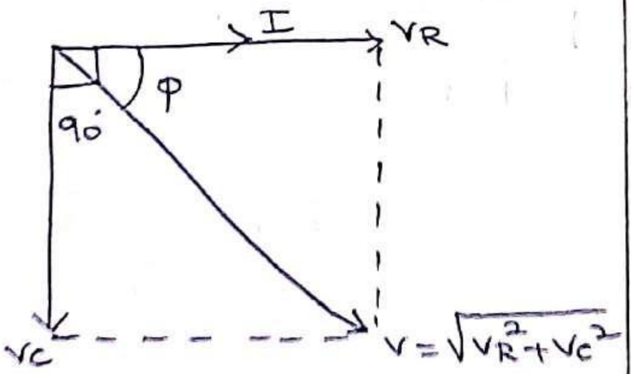
1. Impedance $Z = \sqrt{R^2 + X_L^2}$
(or)
$Z = R + jX_L$ $X_L = \omega L$
2. phase angle $\phi = \tan^{-1} \frac{X_L}{R}$
3. Power factor $= \cos\phi = \frac{R}{Z}$
4. Real power $P = VI\cos\phi$
5. Reactive power $Q = VI\sin\phi$
6. Apparent power $S = VI$
7. Current $I = \frac{V}{Z}$
8. Admittance $Y = \frac{1}{Z}$
9. voltage across Resistor $V_R = IR$
10. voltage across Inductor $V_L = I.X_L$



(phasor diagram)

RC Circuit

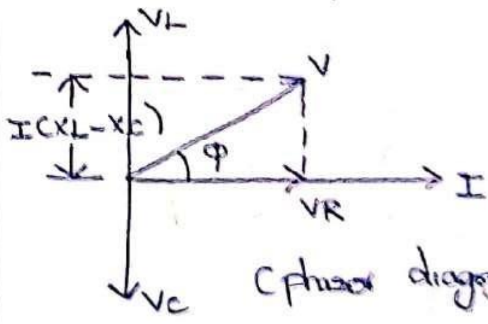
1. Impedance $Z = \sqrt{R^2 + X_c^2}$
(or)
$Z = R + (-jX_c)$ $X_c = \frac{1}{\omega C}$
2. phase angle $\phi = \tan^{-1} \frac{X_c}{R}$
3. power factor $= \cos\phi = \frac{R}{Z}$
4. Real power $P = VI\cos\phi$
5. Reactive power $Q = VI\sin\phi$
6. Apparent power $S = VI$
7. Current $I = \frac{V}{Z}$
8. Admittance $Y = \frac{1}{Z}$
9. voltage across Resistor $V_R = IR$
10. voltage across Capacitor $V_C = I.X_C$



(phasor diagram)

RLC Circuit

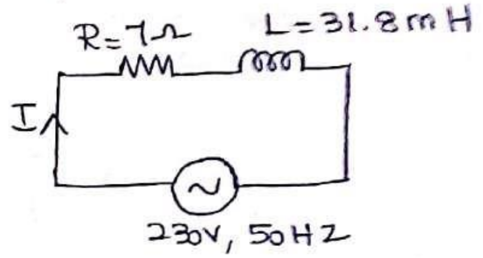
1. Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$
(or)
$Z = R + j(X_L - X_C)\ \Omega$
2. phase angle $\phi = \tan^{-1} \frac{(X_L - X_C)}{R}$
3. power factor $= \cos\phi = \frac{R}{Z}$
4. Real power $P = VI\cos\phi$
5. Reactive power $Q = VI\sin\phi$
6. Apparent power $S = VI$
7. Current $I = \frac{V}{Z}$
8. Admittance $Y = \frac{1}{Z}$
9. voltage across the Coil
$V_{coil} = I.X_{coil}$
$= I.\sqrt{R^2 + X_L^2}$
10. voltage across Resistor $V_R = IR$
11. voltage across Inductor $V_L = I.X_L$
12. voltage across Capacitor $V_C = I.X_C$



(phasor diagram)

Problem based on RL Circuit

① A coil having a resistance of 7Ω and an inductance of 31.8 mH is connected to 230V 50HZ supply. Calculate the circuit current, phase angle, power factor and power consumed.



Solution :

(i) Current $I = \frac{V}{Z} = \frac{230}{?}$

$= \frac{230}{12.2} = 18.85A$

$\boxed{I = 18.85A}$

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

$= \sqrt{7^2 + ?}$

$= \sqrt{7^2 + 10^2} = 12.2\Omega$

$X_L = \omega L$

$= 2\pi f L$

$= 2 \times \pi \times 50 \times 31.8 \times 10^{-3}$

$X_L = 10\Omega$

(ii) phase angle :

$\varphi = \tan^{-1} \frac{X_L}{R}$

$= \tan^{-1}\left(\frac{10}{7}\right)$

$\boxed{\varphi = 55^\circ}$

(iii) power factor

$= \cos\varphi$

$= \cos 55$

$= 0.573$ (lag)

(iv) power consumed

$P = VI\cos\varphi$

$= 230 \times 18.85 \times 0.573$

$\boxed{P = 2484.24 \text{ W}}$

Result :

circuit current = 18.85 A

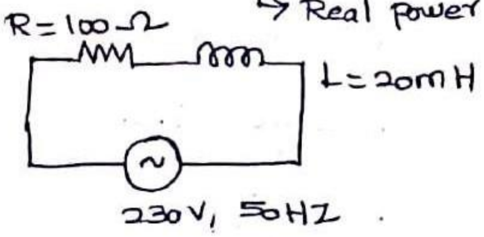
phase angle = 55°

power factor = 0.573 (lag)

power consumed = 2484.24 W

②. A 100Ω resistor and a 20mH inductor are connected in series across a 230V, 50HZ supply. Find circuit impedance, Admittance, current, voltage across resistance, voltage across inductor, apparent power, Active power and power factor.

↳ Real power



Solution:

(i) Circuit impedance:

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

$= \sqrt{100^2+6.283^2}$

$\boxed{Z = 100.197 \Omega}$

$X_L = \omega L$

$= 2\pi f L$

$= 2 \times \pi \times 50 \times 20 \times 10^{-3}$

$X_L = 6.283 \Omega$

(ii) Admittance $Y = \frac{1}{Z} = \frac{1}{100.197}$

$\boxed{Y = 9.98 \times 10^{-3}}$

(iii) Current $I = \frac{V}{Z} = \frac{230}{100.197} = 2.295A$

$\boxed{I = 2.295A}$

(iv) Voltage across resistor

$V_R = IR$

$= 2.295 \times 100$

$\boxed{V_R = 229.5V}$

(v) Voltage across Inductor

$V_L = I X_L$

$= 2.295 \times 6.283$

$\boxed{V_L = 14.42 V}$

(vi) Apparent power

$S = VI$

$= 230 \times 2.295$

$\boxed{S = 527.85 VA}$

$VI\cos\phi$
↑
→ Real power

(vii) Active power

$P = I^2 R$

$= (2.295)^2 \times 100$

$\boxed{P = 526.7 W}$

(viii) power Factor

$\cos\phi = \frac{R}{Z}$

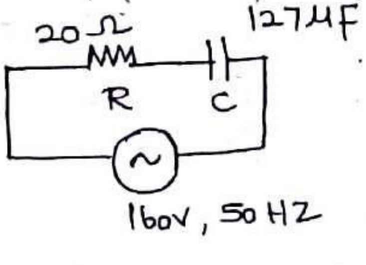
$= \frac{100}{100.197}$

$= 0.998(lag)$

$\boxed{\cos\phi = 0.998 \text{ lag}}$

Problem based on RC circuit

(1.) A series RC circuit with R = 20Ω and C = 127 μF has 160V, 50HZ supply connected to it. Find (a) the impedance (b) current (c) power factor (d) power. Draw the phasor diagram.



Solution

(1) Impedance

$Z = R - jX_C$

$= R - j\,?$

$= 20 - j25$

$\boxed{Z = 32 \angle -51.3^\circ\ \Omega}$

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

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

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

$\boxed{X_C = 25\ \Omega}$

(11) Current $I = \frac{V}{Z} = \frac{160 \angle 0^\circ}{32 \angle -51.3^\circ} = 5 \angle 51.3^\circ\ A$

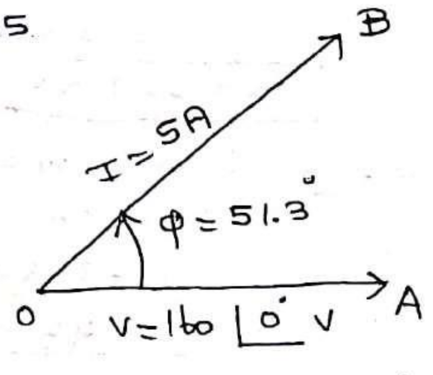
$\boxed{I = 5 \angle 51.3^\circ\ A}$

(111) Power factor $= \frac{R}{Z} = \frac{20}{32} = 0.625$

(1V) Power $= V I \cos\phi$

$= 160 \times 5 \times 0.625$

$\boxed{P = 500\ W}$

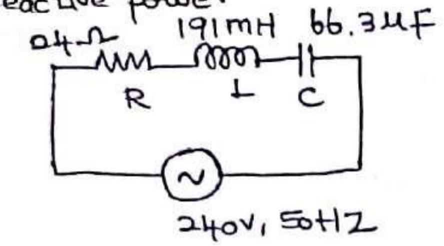


(phasor diagram)

Problem based on RLC circuit

① In a series RLC circuit $R = 24\Omega$, $L = 191\text{ mH}$ and $C = 66.3\mu F$ given that the supply voltage is 240V, 60HZ. find (i) Equivalent impedance (ii) power factor (iii) current (iv) power and (v) Reactive power

Solution



(i) Equivalent Impedance

$$Z = R + j(X_L - X_C)$$
$$= 24 + j(72 - 40)$$
$$= 24 + j32$$
$$\boxed{Z = 40 \angle 53.13^\circ \ \Omega}$$

$$X_L = \omega L$$
$$= 2\pi f L$$
$$= 2 \times \pi \times 60 \times 191 \times 10^{-3}$$
$$\boxed{X_L = 72\Omega}$$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$
$$= \frac{1}{2\pi \times 60 \times 66.3 \times 10^{-6}}$$
$$\boxed{X_C = 40\Omega}$$

(ii) power factor

$$\cos\phi = \cos(59.0334)$$
$$= 0.6 \text{ lag}$$
$$\phi = \tan^{-1}\left[\frac{X_L - X_C}{R}\right]$$
$$= \tan^{-1}\left[\frac{72 - 40}{24}\right]$$
$$= 59.0334$$

(iii) Current

$$I = \frac{V}{Z} = \frac{240\angle 0^\circ}{40\angle 53.13^\circ}$$
$$= 6\angle -53.13^\circ \text{ A}$$
$$\boxed{I = 6\text{ A}}$$

(iv) power (Real power)

$$P = VI\cos\phi$$
$$= 240 \times 6 \times 0.6$$
$$\boxed{P = 864\text{ W}}$$

(v) Reactive power

$$Q = VI\sin\phi$$
$$= 240 \times 6 \times 0.8$$
$$\boxed{Q = 1152 \text{ VAR}}$$

↓

Volt ampere Reactive

(2) A Coil of resistance 5Ω and inductance 100mH is Connected in Series with a 200μF Capacitor across a 220V, 50HZ Supply

Calculate (i) the inductive reactance

(ii) the capacitive reactance

(iii) Impedance of the whole circuit in Complex form

(iv) the Current

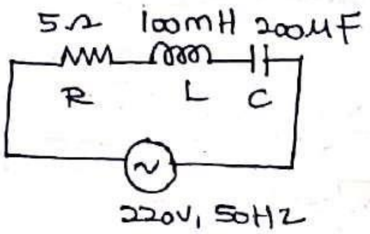
(v) the power factor

(vi) total power

(vii) Voltage across the Coil and the Capacitor.

Draw the illustrative phasor diagram, depicting the voltage and current.

Solution



(i) Inductive reactance

$$X_L = \omega L$$

$$= 2\pi f L$$

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

$$\boxed{X_L = 31.415\,\Omega}$$

(ii) Capacitive Reactance

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

$$= 15.915\,\Omega$$

$$\boxed{X_C = 15.915\,\Omega}$$

(iii) Impedance

$$Z = R + j(X_L - X_C)$$
$$= 5 + j(31.415 - 15.915)$$
$$= 5 + j(15.5\,\Omega)$$

$$\boxed{Z = 16.286 \angle 72.121}$$

(iv) Current $I = \frac{V}{Z} = \frac{220\angle 0^\circ}{16.286\angle 72.121}$

$$\boxed{I = 13.5\angle -72.121 \text{ A}}$$

(v) Power factor

$$\cos\varphi = \frac{R}{Z} = \frac{5}{16.286} = 0.307 \text{ (lagging)}$$

$$\boxed{\cos\varphi = 0.307 \text{ (lag)}}$$

(vi) Total power

$$P = V I \cos\varphi$$
$$= 220 \times 13.5 \times 0.307$$

$$\boxed{P = 911.79\,W}$$

(vii) Voltage across the coil

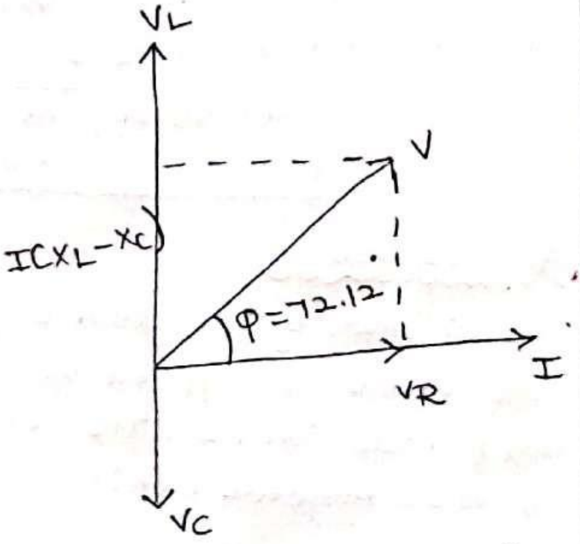
$$V_{coil} = I \cdot X_{coil}$$
$$= I \cdot \sqrt{R^2 + X_L^2}$$
$$= 13.5 \times \sqrt{5^2 + 31.415^2}$$

$$\boxed{V_{coil} = 429.4\,V}$$

Voltage across the capacitor

$$V_C = I X_C$$
$$= 13.5 \times 15.915$$

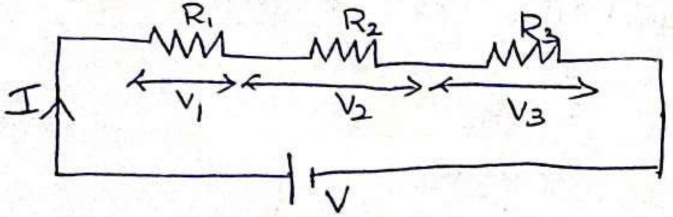
$$\boxed{V_C = 214.85\,V}$$



(phasor diagram)

Resistors in Series

When resistors are connected in series, such that the same current passes through all of them.



Each resistor has a voltage drop across and it is given by Ohm's law.

$V_1 = IR_1$; $V_2 = IR_2$; $V_3 = IR_3$.

∴ Total drop in 3 resistors ~~are~~ is,

$V = V_1 + V_2 + V_3$

$= IR_1 + IR_2 + IR_3$.

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

If ckt behaves as a single resistor, R equal to $R_1 + R_2 + R_3$ is connected across the battery.

The power dissipated in R_1 is

$P_1 = V_1 \cdot I = (I \cdot R_1) \cdot I = I^2 R_1$

$P_1 = I^2 R_1 = \frac{V_1^2}{R_1^2} \cdot R_1$

$\Rightarrow P_1 = \frac{V_1^2}{R_1}$

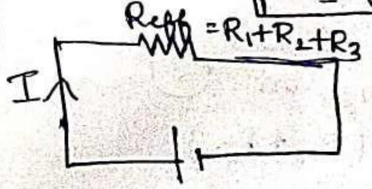
Similarly $P_2 = \frac{V_2^2}{R_2}$; $P_3 = \frac{V_3^2}{R_3}$

Total Power, $P = P_1 + P_2 + P_3$

$= \frac{V_1^2}{R_1} + \frac{V_2^2}{R_2} + \frac{V_3^2}{R_3}$

$= \frac{V^2}{R_1 + R_2 + R_3} = \frac{V^2}{R_{eff}}$

$$\boxed{P = VI}$$



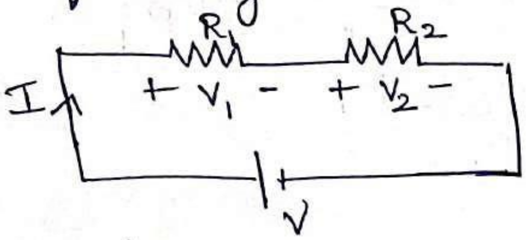
In a series ckt,

1. The same current flows through all the resistors.

~~2. Sum of~~ 2. For each resistors, there will be a voltage drop.

3. Sum of voltage drop will be equal to the applied voltage.

Division of Voltage in Series Circuit :



* Two resistors R_1 & R_2 in series connected to a DC source, V.

* I is the current flowing through resistors R_1 & R_2.

* V_1 & V_2 are voltage drop across R_1 & R_2 respectively.

By applying Ohm's Law,

$$V_1 = IR_1 \text{ —— (1a)} \quad ; \quad V_2 = IR_2 \text{ —— (1b)}$$

By applying KVL,

$$V = V_1 + V_2 \text{ —— (2)}$$

Sub values of V_1 & V_2 in (2)

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

$$I = \frac{V}{R_1 + R_2} \text{ —— (3)}$$

On substituting for I from ~~f~~ equation (3) in (1a) we get

$$V_1 = \frac{V}{R_1 + R_2} \times R_1$$

$$\boxed{V_1 = V \times \frac{R_1}{R_1 + R_2}}$$

On substituting (3) in (1b) we get,

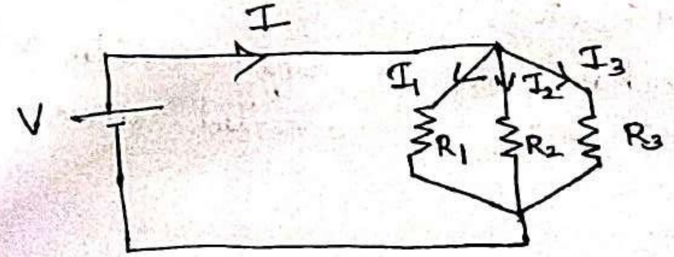
$$V_2 = \frac{V}{R_1 + R_2} \times R_2$$

$$\boxed{V_2 = V \times \frac{R_2}{R_1 + R_2}}$$

Resistors in Parallel :

When resistors are connected across one another such that the same voltage is applied to each, then they are said to be in parallel.

Current in each resistor is different.



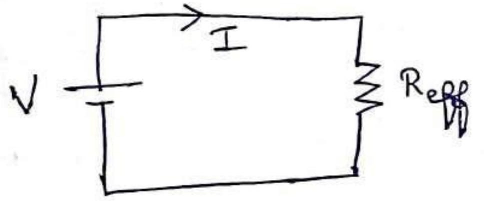
$I_1 = \frac{V}{R_1}$; $I_2 = \frac{V}{R_2}$; $I_3 = \frac{V}{R_3}$

$$I = I_1 + I_2 + I_3$$

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

$$\boxed{I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)} \text{ — ①}$$

If we replace three resistors in parallel by a single equivalent resistor, R, it will draw same current I.



$V = I R_{eff}$ [Ohms law] — ②

Comparing ① & ②,

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

If only two resistors in parallel, then R_{eff} given by,

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

or

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

If two resistors R_1 & R_2 are equal then

$$R_{eff} = \frac{R_1^2}{2R_1} = \frac{R_1}{2}$$

In parallel circuit,

1. The voltage across each resistor of the parallel circuit is the same.
2. The current in each branch is different.
3. The total current is equal to the sum of branch current.

Division of Current in Parallel Circuit:

Two resistors R_1 & R_2 connected in parallel, we get

$I = I_1 + I_2$ & $V = I_1 R_1 = I_2 R_2$

From the above,

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

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

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

$$= \frac{I_1 (R_2 + R_1)}{R_2}$$

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

Similarly

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

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

$$I = \frac{I_2 (R_1 + R_2)}{R_1} \Rightarrow \boxed{I_2 = I \frac{R_1}{R_1 + R_2}}$$

So current in a branch is equal to total current multiplied by other branch resistance and divideded by sum of branch resistanc

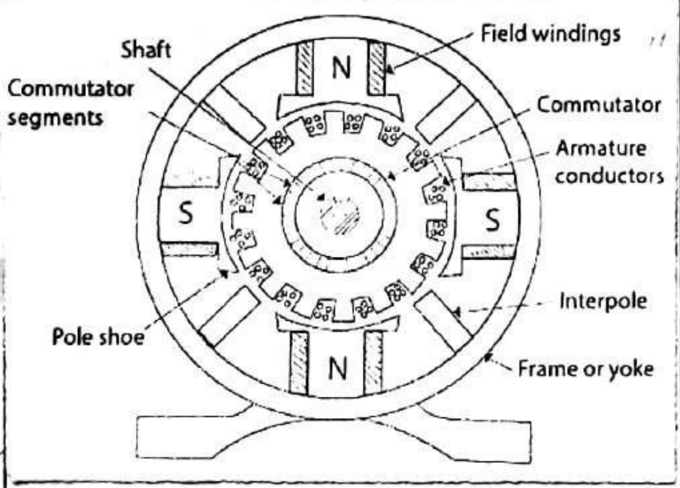
DC Generator

Whenever a conductor is moved in a magnetic field dynamically induced emf is produced in the conductor.

Construction

1. Magnetic frame (or) Yoke

- protecting cover for the machine, provides Mechanical support for the poles.
- Small machines yoke made up of cast Iron. Large machines yoke made up of cast steel.



2. poles

- pole core and pole shoes form the electromagnet.
- Field winding is wound over the pole core. pole coils are made up of copper wire
- Small machines, poles are made up of cast Iron, Large machines poles are made up of cast steel.

3. Armature

- Consists of armature core and armature windings.
- Armature core houses the armature conductors.
- Conductors rotates, they alternatively come under influence of north and south poles. It causes hysteresis loss.
- To reduce losses, steel containing a few percentage of silicon is used in the armature
- To minimize the eddy current losses the armature core is laminated.
- Losses produce heat in armature, to remove the heat ventilating ducts are used.

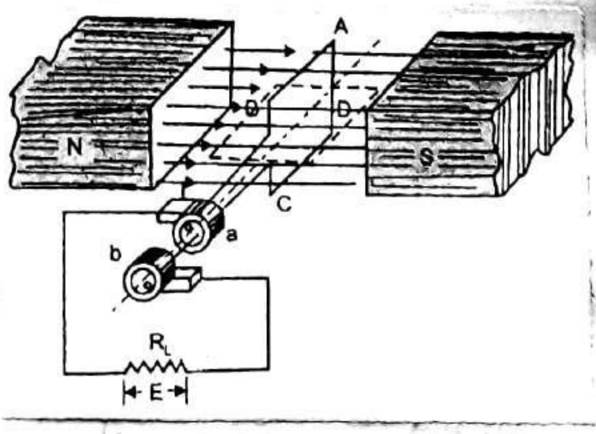
4. Commutator

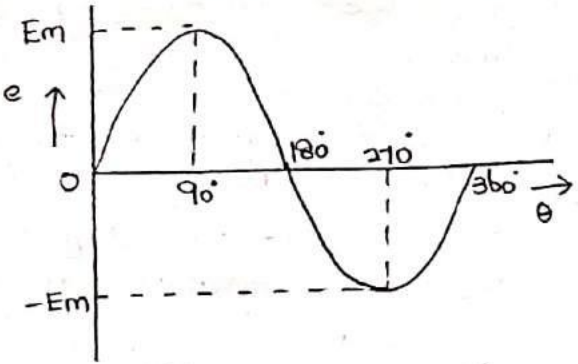
- It converts the alternating emf into unidirectional emf.
- Made up of wedge shaped segments insulated from each other by thin layer of built-up mica.

5. Brushes and Bearings

- Brushes made up of carbon (or) graphite, to collect current from the commutator.
- Brushes are rectangular in shape
- Brushes are housed in brush holders
- Ball bearings are employed for light machines, Roller bearings are employed for heavy duty machines
- Ball bearings for reliable operation

Principle of operation





- Consider a single turn coil ABCD rotated on a shaft within a uniform magnetic field, It is rotated in an anticlockwise direction.

- 'l' be the length and 'b' be the breadth of the coil in meters.

- When the coil sides AB and CD are moving parallel to the magnetic field, the flux lines are not being cut and no emf is induced in the coil.

- At this position, we assume the angle of rotation 'θ' as zero.

According to Faraday's II Law, the emf induced is proportional to the rate of change of flux

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

N - no. of turns

φ - flux

t - time

- when θ = 90° coil sides are moving at right angles to the flux lines, The flux lines are cut at the maximum rate and the emf induced is maximum.

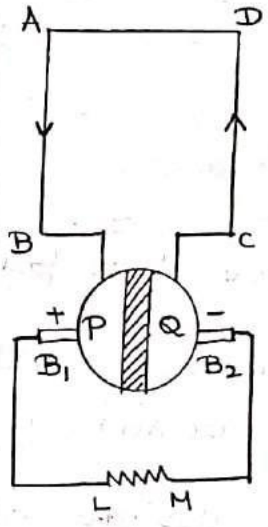
- when θ = 180°, the coil sides are again moving parallel to the fluxlines (AB and CD have exchanged positions) and the emf induced is zero.

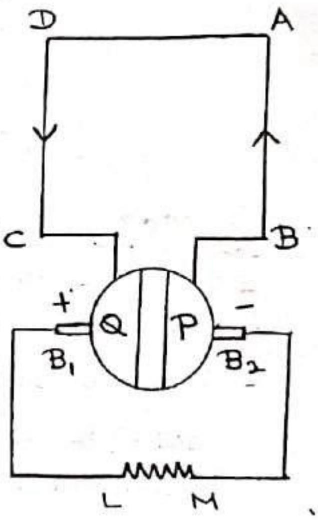
- when θ = 270°, the coil sides again move at right angles to flux lines to the flux lines, but their position reversed when compared with θ = 90°. Hence emf induced is maximum in the opposite direction.

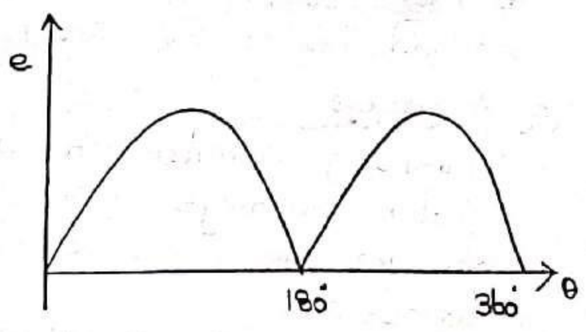
when θ = 360° the coil sides once again move parallel to the magnetic field making the induced emf equal to zero. The coil has now come back to the starting point.

- DC generators is made unidirectional by replacing the slip rings by a split ring.

- The split ring is split into two equal segments P and Q and the segments are insulated from each others and also from shaft.







- The coil side AB is always attached to the segment P and likewise CD to Q.

- The Brushes B_1 and B_2 touch these segments and are meant to collect the current.

- During the first half revolution, current flows along, ABLMCD through brush B1. which is positive and into B2 (Negative brush)

- After half a cycle AB and CD exchanged position along with the segment P and Q and current now flows through DcLMBA. B1 is now in contact with Q.

- For each half revolution, the positions of segments P and Q also reverse

- Hence the current in the load is always unidirectional. In a generator the split rings are called Commutator.

Emf Induced in a Dc generator

ϕ - Flux per pole in webers

P - no. of poles

Z - Total no. of conductors in the armature

- All the 'Z' conductors are not connected in series. they are divided into group.

- Let 'A' be the no. of parallel path.

- Each parallel path will have Z/A Conductors in Series.

- 'N' - Speed of rotation in rpm

- Consider one conductor in the armature. As this conductor makes one complete revolution it cuts Pϕ webers.

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

Emf induced in the Conductor = rate of change of flux cut

$$e \propto \frac{d\phi}{dt} = \frac{P\phi}{60/N}$$

$$e = \frac{NP\phi}{60} \text{ volts}$$

There are Z/A conductors in series in each parallel paths the emf induced

$$Eg = \frac{NP\phi}{60} \cdot \frac{Z}{A}$$

$$\boxed{Eg = \frac{P\phi NZ}{60A}} \text{ volts}$$

For lap winding A = P

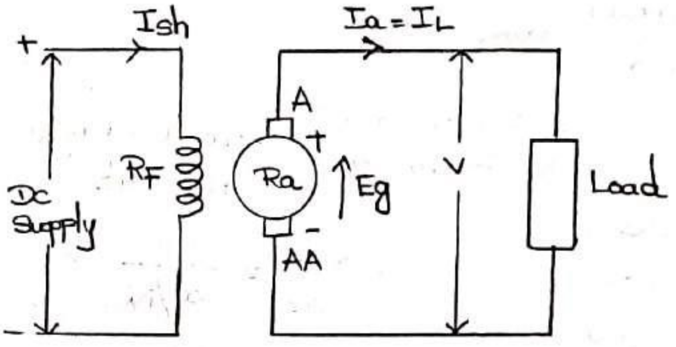
For wave winding A = 2

Types of DC generators

1. Separately excited DC generators
2. Self excited DC generators

1. Separately excited DC generators

- The field winding is excited by a separate DC supply.



- Armature current I_a = Load current I_L

  R_a = Resistance of armature winding

- Terminal voltage $V = E_g - I_aR_a - V_{brush}$
- Generated emf $E_g = V + I_aR_a + V_{brush}$
- Electric power developed $= E_gI_a$
- power delivered to load $= V I_a$

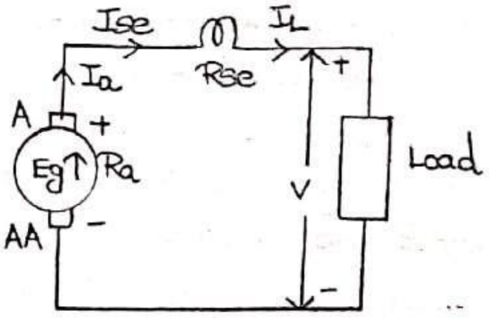
2. Self excited DC generators

- the field winding is supplied from the armature of the generator itself.
- Residual flux is present in the poles

Types :-

(i) Series generator
(ii) Shunt generator
(iii) Compound generator

(i) Series generator



- Field winding is connected in series with the armature
- Armature current flows through the field winding as well as the load.
- field winding has low resistance

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

Generated Emf

$E_g = V + I_aR_a + I_aR_{se} + V_{brush}$

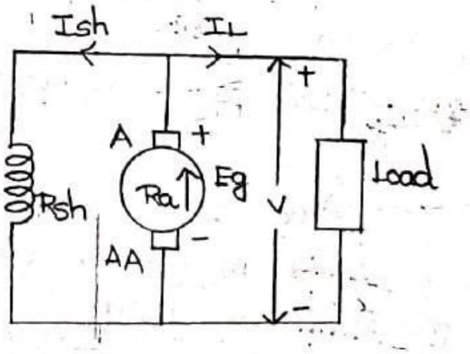
Terminal voltage

$V = E_g - I_aR_a - I_aR_{se} - V_{brush}$

Electric power developed $= E_gI_a$

Power delivered to load $= V I_a$ (or) $V I_L$.

(iii) shunt generator



- Field wing is connected across the armature

- Field winding has more no. of turns of thin wire
- It has high resistance.

Terminal voltage $V = E_g - I_aR_a$

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

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

Electric power developed $= E_g I_a$

Power delivered to load $= V I_L$.

(iii) Compound generator

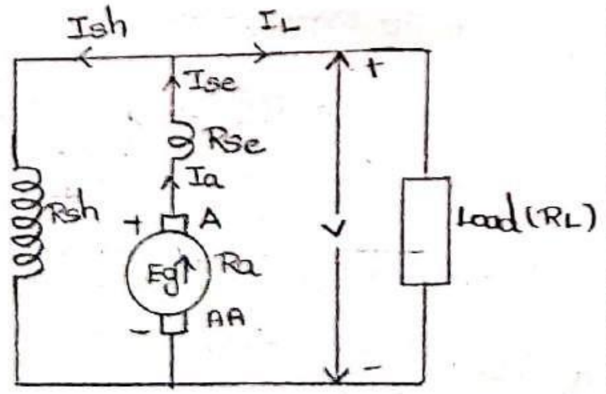
- Compound generator consists of both shunt field and series field windings - one winding is in series and other winding is in parallel with the armature

Types are

(a) Long shunt Compound generator

(b) Short shunt Compound generator

(a) Long shunt Compound generator



- shunt field is connected across both series field and armature windings

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

shunt field current $I_{sh} = \frac{V}{R_{sh}}$

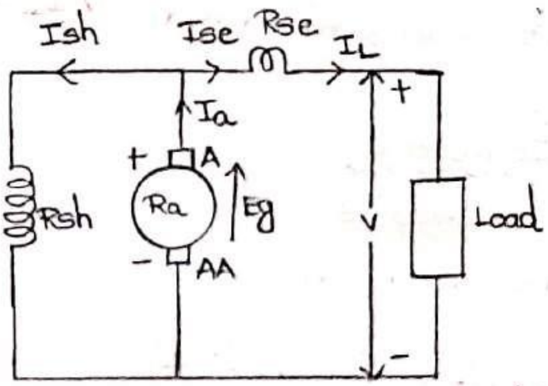
Generated EMF $E_g = V + I_a(R_a + R_{se}) + V_{brush}$

Terminal voltage $V = E_g - I_a(R_a + R_{se}) - V_{brush}$

Electric power developed $= E_g I_a$

Power delivered to load $= V I_L$.

(b) Short shunt Compound generator



- shunt field winding is connected in parallel with armature and this combination is connected in series with series field winding.

$I_{se} = I_L$

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

$E_g = V + I_aR_a + I_{se}R_{se} + v_{brush}$

Voltage across shunt field winding $= I_{sh}R_{sh}$

$I_{sh}R_{sh} = E_g - I_aR_a - v_{brush}$

$= V + I_aR_a + I_{se}R_{se} + V_{brush} - I_aR_a - V_{brush}$

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

shunt field current $I_{sh} = \frac{V + I_{se}R_{se}}{R_{sh}}$

Terminal voltage $V = E_g - I_aR_a - I_{se}R_{se} - V_{brush}$

Electric power developed $= E_g I_a$

Power delivered to load $= V I_L$

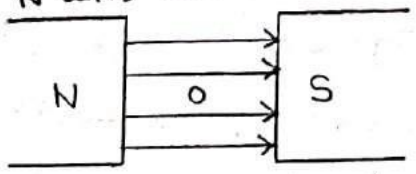
Dc motors

Converts Electrical energy into Mechanical energy

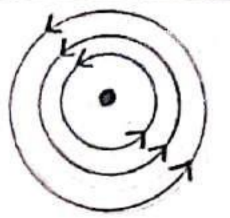
Principle of operation

"Whenever a current carrying conductor is placed in a magnetic field, the conductor experiences a force tending to move it".

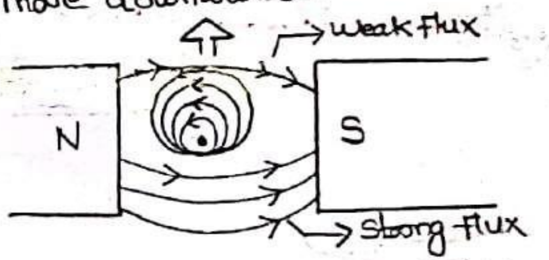
- the magnetic field between two poles N and S

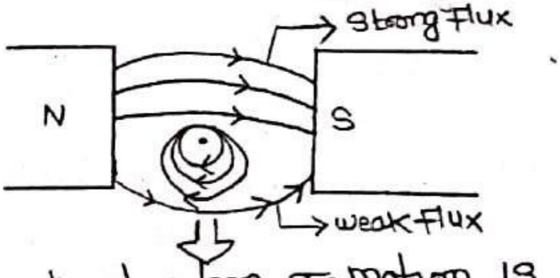


- A current carrying conductor is shown along with the direction of the flux loop around it.



- If a current carrying conductor is placed between two magnetic poles. Both the fields will be distorted.
- Above the conductor, the field is weakened (less flux) and below the conductor, the field is strengthened.
- ∴ the conductor tends to move upwards.
- Then the direction of the current through the conductor is reversed. Here the field below the conductor is less (week) and field above the conductor is more (strong)
- Then the conductor tends to move downwoords.





- The direction of motion is given by Fleming's left hand rule

Thumb - direction of motion of the Conductor

Forefinger - direction of the field

Middle finger - direction of the Current

- The magnitude of the force experienced by the Conductor in a motor is given by

$$F = BIl \text{ newtons}$$

where, B - Magnetic field density wb/m²

I - Current in Amperes

l - length of the Conductor in metres.

Back EMF :-

The Conductors are cutting flux and that is exactly what is for generator action to take place

This means that even when the machine is working as a motor, voltages are induced in the Conductors This emf is called as the back emf (or) Counter emf.

According to lenz's law, the direction of the back emf opposes the supply voltage

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

Torque Equation of DC motor

- Torque is nothing but turning or twisting force about an axis.

- Torque is measured by the 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.

- Let force 'F' cause the wheel to rotate at 'N' rpm.

- The angular velocity of the wheel is

$$\omega = \frac{2\pi N}{60} \text{ rad/sec}$$

$$\text{Torque } T = F \times r \text{ N-m}$$

$$\left.\begin{matrix}\text{workdone per}\\ \text{revolution}\end{matrix}\right\} = F \times \text{distance moved}$$

$$= F \times 2\pi r \text{ Joules}$$

$$\text{power developed } P = \frac{\text{workdone}}{\text{Time}}$$

$$= \frac{F \times 2\pi r}{\text{Time for 1 rev}}$$

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

$$\left[\because \text{time for 1 rev} = \frac{60}{N}\right]$$

$$P = (F \times r) \cdot \frac{2\pi N}{60}$$

$$P = T \cdot \omega \text{ watts}$$

where

T = torque in N-m

w = Angular speed in rad/sec

The torque developed by a DC motor is obtained by looking at the electrical power supplied to it and Mechanical power produced by it. It is also called as Armature torque.

power in Armature = Armature torque x w

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

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

$$T_a = \frac{\phi I_a}{2\pi} \times \frac{PZ}{A}$$

$$T_a = 0.159\, \phi . I_a \frac{PZ}{A} \text{ N-m}$$

Speed and Torque equation:-

w.k.T $E_b = V - I_a R_a$

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

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

For a given machine Z, A and P are constants

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

K is a constant

∴ speed equation becomes

$$N \propto \frac{V - I_a R_a}{\phi} \quad (or) \quad N \propto \frac{E_b}{\phi}$$

Torque equation of DC motor given by

w.k.T $\boxed{T \propto \phi I_a}$

Flux ϕ proportional to the current flowing through the field winding

$$\boxed{\phi \propto I_F}$$

For DC shunt motor, shunt field current Ish is constant as long as Input voltage is constant

$T \propto \phi I_a$ becomes

$$\boxed{T \propto I_a}$$

For DC series motor, series field current is equal to the armature current Ia

$$\phi \propto I_a$$

Hence $T \propto \phi I_a$ becomes

$$T \propto I_a I_a$$

$$T \propto I_a^2$$

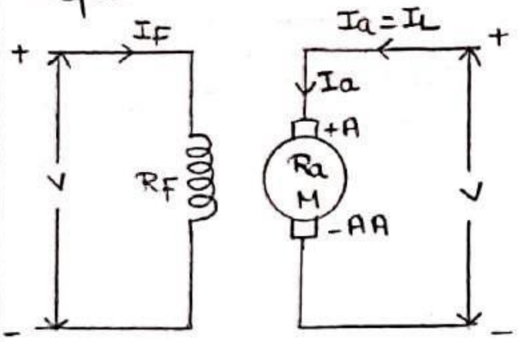
Types of Dc motors

(1) Separately excited Dc motor

(2) Self excited Dc motor

(1) Separately excited Dc motor

- Field winding is excited by a separate Source.



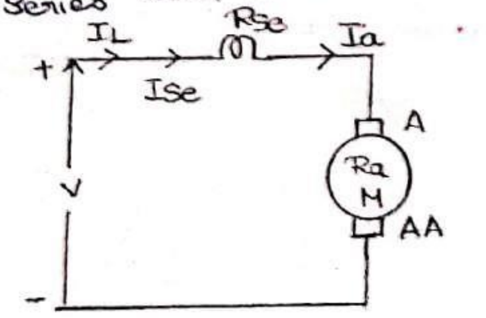
$$I_a = I_L$$

$$E_b = V - I_a R_a - V_{brush}$$

(2) Self excited Dc motor

(a) Dc Series motor

- Field winding is Connected in Series with armature.



- Field winding should have less no. of turns

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

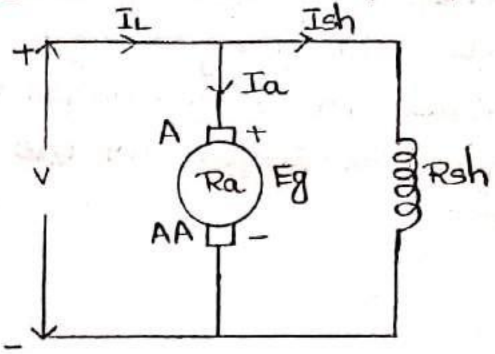
$$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$$

$$\therefore I_a = I_{se}$$

$$V = E_b + I_a (R_a + R_{se}) + V_{brush}$$

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

(b) Dc shunt motor



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

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

$$V = E_b + I_a R_a + V_{brush}$$

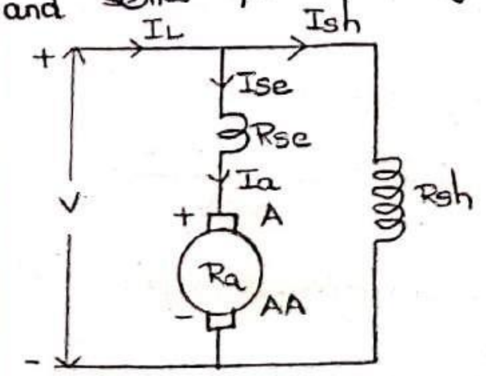
$$\phi \propto I_{sh}$$

- Fielding winding has more no. of turns.

(c) Dc Compound motor

(i) Long shunt Compound motor

The shunt field winding is Connected across both armature and series field winding.



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

$$I_{se} = I_a$$

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

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

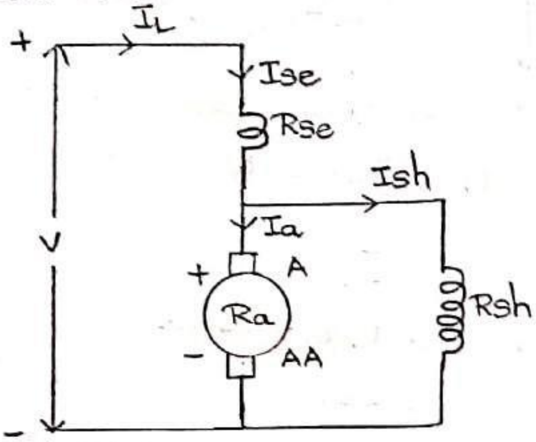
$$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$$

$$I_a = I_{se}$$

$$V = E_b + I_a (R_a + R_{se}) + V_{brush}$$

(iii) short shunt Compound Motor

- shunt field winding is across the armature and series field winding is connected in series with this combination.



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

$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$

$I_{se} = I_L$

$V = E_b + I_a R_a + I_L R_{se} + V_{brush}$

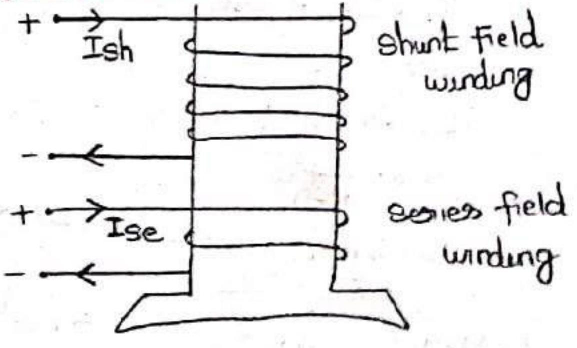
voltage drop across shunt field winding $\Big\}$ $= V - I_L R_{se}$

$V_{sh} = E_b + I_a R_a + V_{brush}$

$\therefore I_{sh} = \frac{V - I_L R_{se}}{R_{sh}}$

The compound motor again into two types.

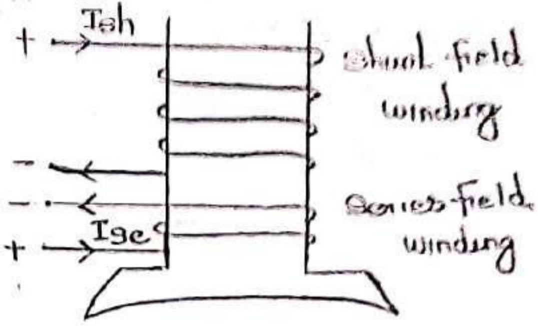
(i) Cummulative Compound motor



- The two field winding fluxes aid each other (strong flux)

(ii) Differential Compound motor

- The two field winding fluxes oppose each other. (weak flux)

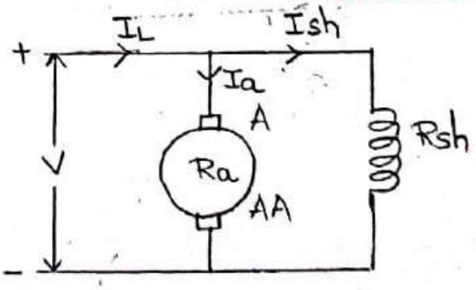


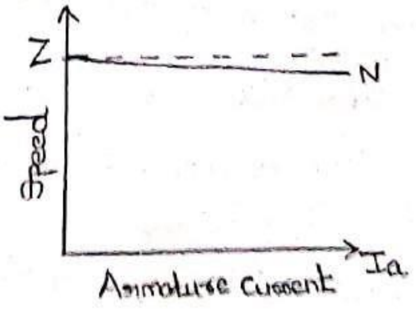
Characteristics of DC motors

(i) shunt motor characteristics

- Field is connected across the supply. Supply voltage is constant the field current and hence the flux are also constant.

(i) Speed - Armature current characteristics.





Speed equation of the DC motor

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

I_{sh} and ϕ are nearly Constant.

$$N = K(V - I_a R_a)$$

K is Constant. This implies that speed is nearly Constant except for a small droop.

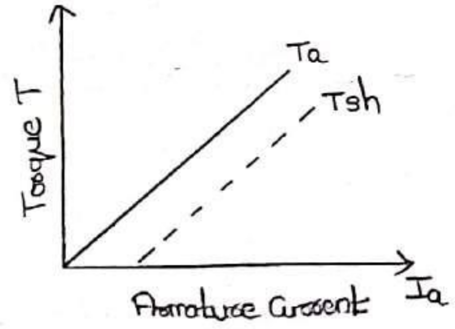
(ii) Torque – armature characteristics

$T \propto \phi I_a$

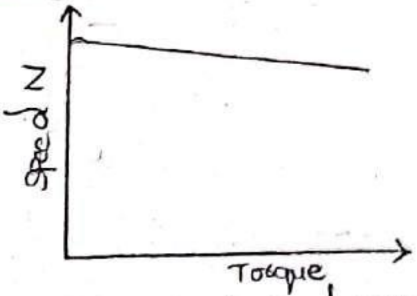
ϕ – constant

$T \propto I_a$

Armature current increases, the torque also increases.

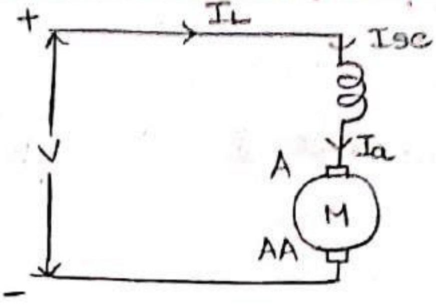


(iii) Speed – torque characteristics



- It is called mechanical characteristics.
- When the load torque increases the speed slightly decreases.

(2) DC Series motor characteristics



$I_L = I_a = I_{se}$

(i) Speed – Armature characteristics

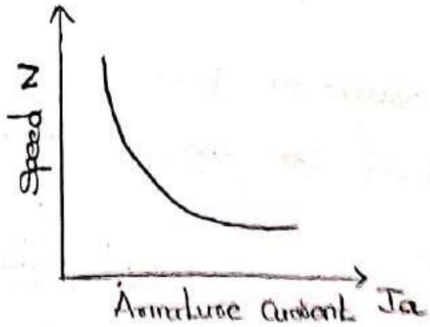
- Flux is not constant with loads

the speed equation – $N = \frac{K(V - I_a R_a)}{\phi}$ becomes

$$N = \frac{K(V - I_a R_a)}{I_a} \quad [\because \phi \propto I_a]$$

$$N \propto \frac{E_b}{I_a}$$

Increasing the armature Current speed will be decreased



- DC Series motor should never be started without some load. Otherwise the motor speed will rise to a dangerous value and gets damaged.

(ii) Torque- Armature Current

W.K.T $T \alpha \phi Ia$

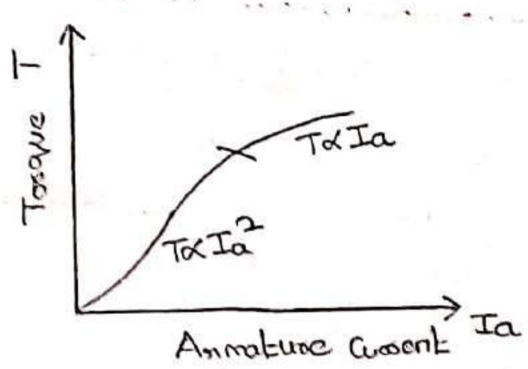
In series motor $\phi \alpha Ia$

$T \alpha \phi Ia$

$T \alpha Ia Ia$

$T \alpha Ia^2$ before saturation

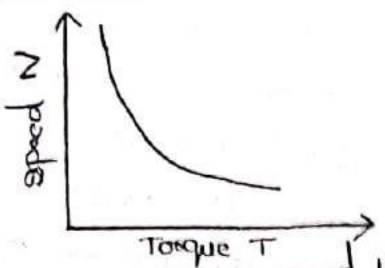
$T \alpha Ia$ after saturation



At light load, armature current Ia, and hence ϕ is small. But Ia increases Ta increases as the square of the current.

After saturation flux is constant ∴ $T \alpha Ia$ so curve becomes straight line.

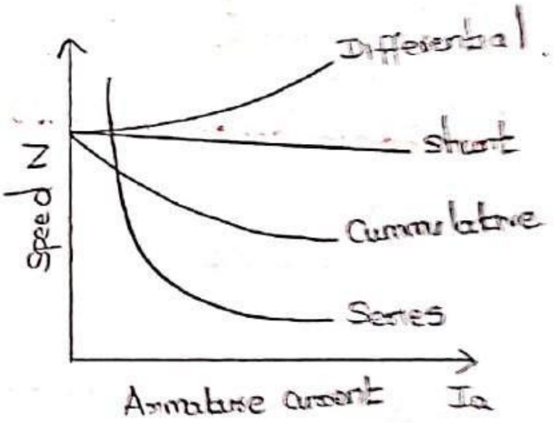
(iii) Speed-torque characteristics

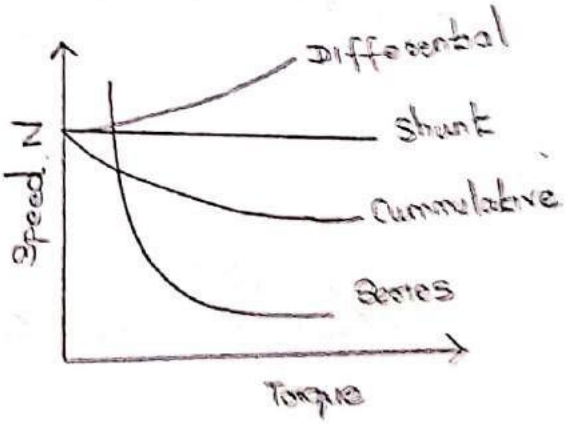


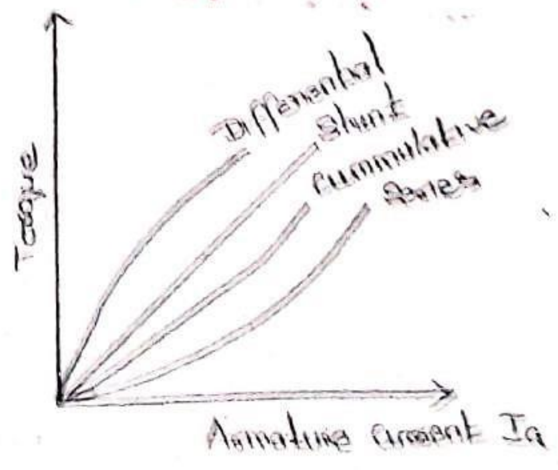
- DC series motor, speed is high, the torque is low and vice-versa.
- the characteristics got from the above two characteristics.

(3) Compound characteristics

- the characteristics will be depend on the whether the series field windings are assisting each other (cummulative) or opposing each other (Differential)







Applications of DC motors

DC shunt motors:

Driving Centrifugal pumps and light machine tools, wood working, lathe etc...

DC series motors:

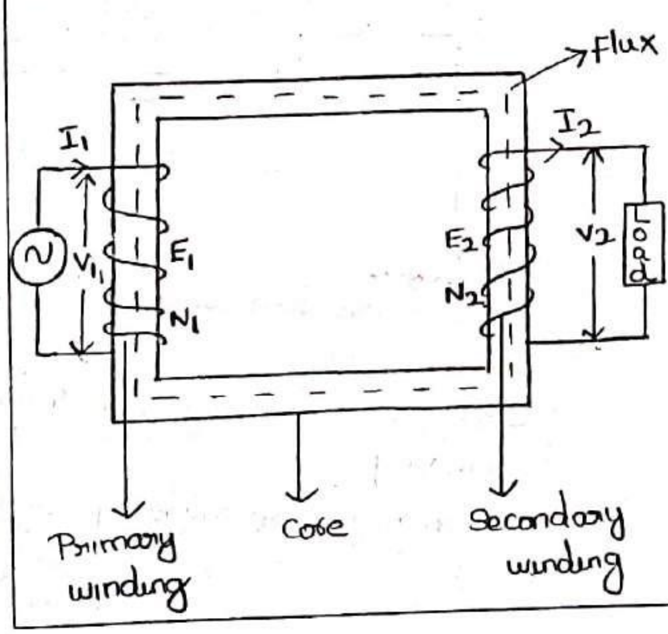
Cranes, hoists, fans, blowers, conveyers, lifts etc.

DC Compound motors:

Driving heavy machine tools, Punching machines etc...

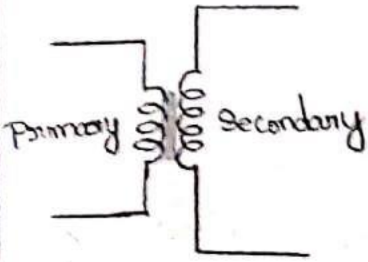
Transformers

- The transformer works on the principle of electromagnetic Induction
- It is an Electrical device, no moving parts, by mutual Induction transfer electrical energy from one ckt to another ckt at the Same frequency
- It Consists of two windings insulated from each other and wound on a Common core made up of magnetic material.

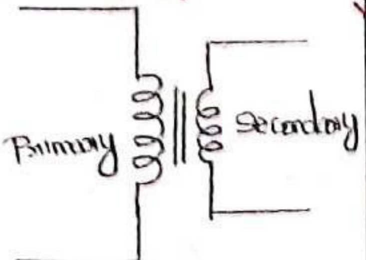


Working Principle of a transformer

- When the primary winding is Connected to an Ac Source an exciting Current flows through the winding.
- As the Current is alternating it will produce an alternating flux in the Core which will be linked by both the primary and secondary windings.
- The Induced emf in the primary winding (E_1) is almost equal to the applied Voltage V_1 and will oppose the applied voltage.
- The emf induced in the secondary winding (E_2) Can be utilised to deliver power to any load Connected across the Secondary. Thus power is transferred from the primary to the Secondary ckt by Electro-magnetic Induction
- The magnitude of the emf induced in the secondary winding will depend upon its number of turns
- Transformer is a constant flux machine. Because flux in the transformer Core is Constant.
- If the number of turns in the secondary winding is less than those in the Primary winding It is called a step-down transformer
- If the number of turns in the Secondary winding is higher than the primary winding. It is called a step-up transformer



Step up transformer



Step down Transformer

Constructional Details:

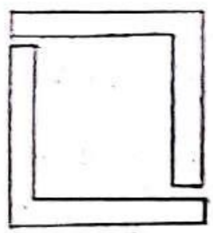
A transformer is a static device, no moving parts.

The main components of a transformer

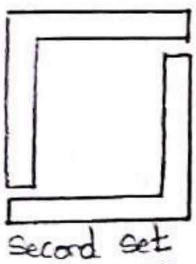
(i) Magnetic core

- Transformer core is generally laminated and is made up of good magnetic material like silicon steel.
- Thickness of laminations varies from 0.35mm to 0.5mm.
- Laminations are insulated from each other by coating with thin coat of varnish

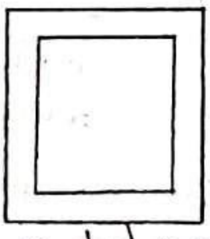
Various types of stampings (or) laminations



First set of stamping



Second set of stamping



Finished core

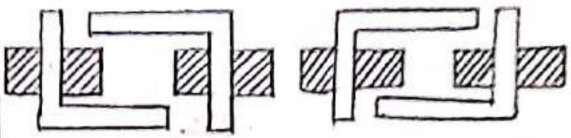
Two types of transformer cores are

(a) Core type

(b) Shell type

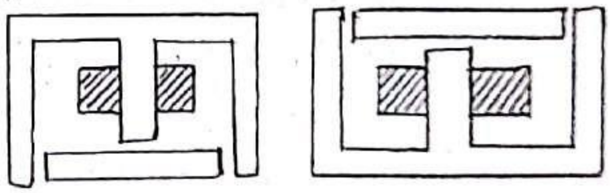
(a) Core type transformer

- Windings surround a considerable part of core
- It has two limbs for two windings made up of two L-type stampings.
- It has only one magnetic path.



(b) Shell type transformer

- The core surrounds the considerable parts of windings.
- The two windings are carried by central limb.
- The core is made up of E and I stampings and has three limbs.
- It has two parallel path of magnetic flux.



Winding

- There are two windings in a transformer.
- They are primary and secondary winding
- Windings are made of copper

Insulation

- Paper is still used as the basic conductor Insulation.

For Low voltage transformers - Enamel Insulation used

For power transformers - Enamelled Copper with paper insulation used

Insulating oil:

- oil used in transformer protects the paper from dirt and moisture and removes the heat produced in the Core and Coils.

Expansion tank:

- A small auxillary oil tank may be mounted above the transformer.
- Its function is to keep the transformer tank full of oil.

Temperature gauge

- Every transformer is provided with a temperature gauge to indicate hot oil or hottest spot temperature.
- It is a self contained, weather proof unit made of alarm contacts

oil gauge

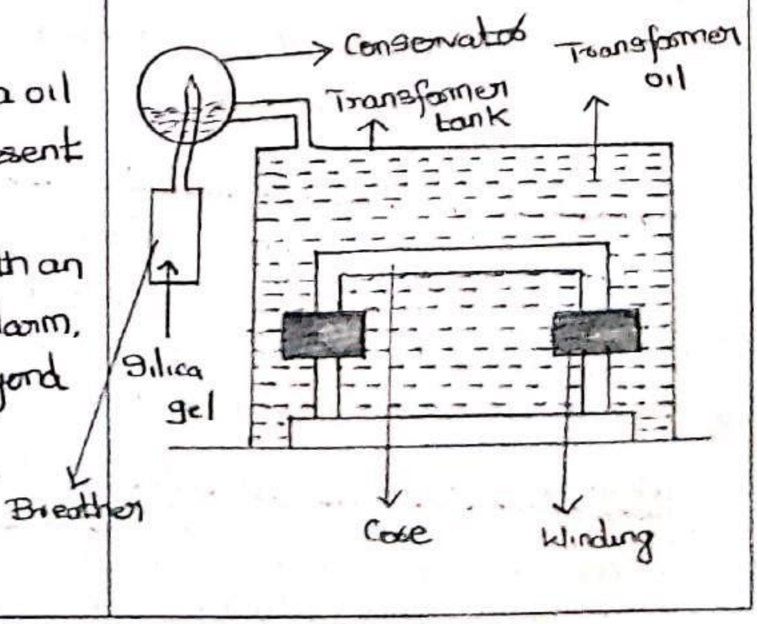
- Every transformer is fitted with a oil gauge to indicate the oil level present inside the tank.
- oil gauge may be provided with an alarm contact which gives an alarm, when the oil level has dropped beyond permissible height

Buchholz relay

- the first warning for occurance of fault is given by the presence of bubbles in the oil.
- the gas bubbles will rise up the pipe joining the conservator to the tank.
- It is possible to mount gas operated relay in this pipe to give an alarm in case of minor fault and to disconnect the transformer from the supply mains in case of severe faults.

Breather

- Method to prevent the entry of the moisture inside the transformer tank.
- the breather is filled with some drying agent, such as calcium chloride (or) silica gel.
- silica gel (or) calcium chloride absorbs moisture and allows dry air to enter the transformer tank



Bushings

- Connections from the transformer are bought out by means of bushing.
- ordinary porcelain Insulators can be used upto a voltage of 33KV.
- Above 33KV, capacitor and oil filled type of bushings are used.
- Bushings are fixed on the transformer tank.

Cooling Arrangement in transformers

(a) oil Immersed natural Cooled transformer

- the core and coils are immersed in an insulating oil contained in an iron tank
- the heat produced in the core and windings is conducted by the circulation of oil to the surface which dissipates heat to surroundings.

(b) oil Immersed forced Air Cooled transformer

- the core and windings are immersed in the oil and cooling is increased by forced air over the cooling surfaces.
- The air is forced over external surfaces by means of fan mounted externally to the transformer

(c) Oil immersed water Cooled transformer

- The core and windings are immersed in an oil and cooling is increased by circulation of cold water through the tubes immersed in oil.

(d) oil immersed forced oil cooled transformers

- The core and windings are immersed in an oil and cooling is achieved by forced oil circulation.
- In this method, forced oil circulation is obtained by a centrifugal pump which is located at either the oil inlet or outlet

(e) Air blast transformers

- Transformers is cooled by a forced circulation of air through core and windings.
- It is used in substations located in thickly populated places where oil is considered a fire hazard.

EMF equation of a transformer

N_1 - No. of primary winding turns

N_2 - No. of Secondary winding turns

ϕ_m - Maximum value of flux in the core in wb.

B_m - maximum value of flux density in the core wb/m^2

A - Area of the core in m^2

f - frequency of the AC supply (Hz)

V_1 - Supply voltage across primary. (volts)

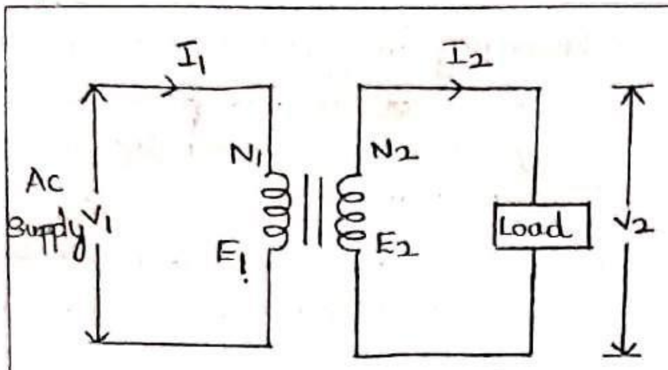
V_2 - supply voltage across secondary (volts)

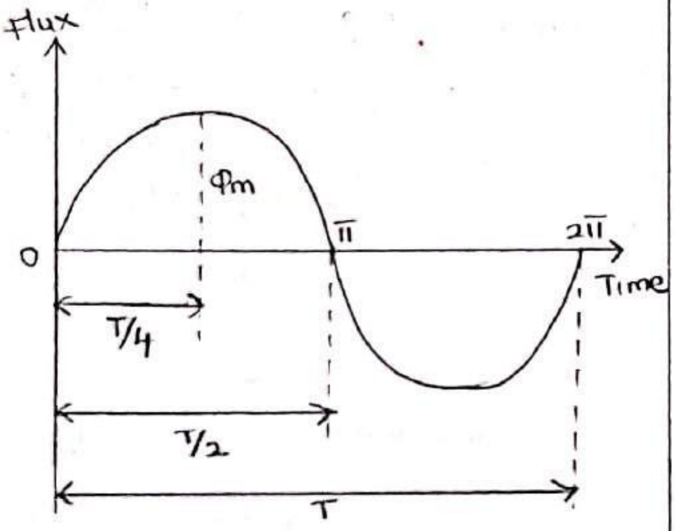
I_1 - full load primary current (Amperes)

I_2 - full load secondary current (Amperes)

E_1 - EMF induced in primary winding (volts)

E_2 - EMF induced in secondary winding (volts)





Flux is maximum at T/4 second where 'T' is the time period in sec

w.k.T $T = \frac{1}{f}$ where 'f' is the Frequency

∴ Average rate of Change of flux $= \frac{\phi_m}{\frac{1}{4f}}$ wb/sec

If we assume single turn coil, the According to faradays law of electromagnetic Induction

Average value of emf Induced/turn

$= 4f \times \phi_m$ volt

$$\text{Form factor} = \frac{\text{Rms value}}{\text{Average value}} = 1.11$$

Rms value = Form factor × Average value

∴ Rms value of emf induced/turn

$= 1.11 \times (4f \times \phi_m)$

$= 4.44 f\phi_m$ volts.

∴ Rms value of emf induced in the entire primary winding

$E_1 = 4.44 f\phi_m \times N_1$

$E_1 = 4.44 f B_m A \times N_1$ volts — ①

∴ $[\phi_m = B_m A]$

Similarly Rms value of emf induced in the entire secondary winding

$E_2 = 4.44 f\phi_m \times N_2$

$E_2 = 4.44 f B_m A \times N_2$ volts — ②

Transformation ratio:

For Ideal transformer

$V_1 = E_1 \quad V_2 = E_2$

$V_1 I_1 = V_2 I_2$

$\frac{V_2}{V_1} = \frac{I_1}{I_2}$; $\frac{E_2}{E_1} = \frac{I_1}{I_2}$ — ③

From Equation ② and ①

$\frac{E_2}{E_1} = \frac{N_2}{N_1}$ — ④

From Equation ④ and ③

$\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = k$ — ⑤

where 'k' is called transformation ratio

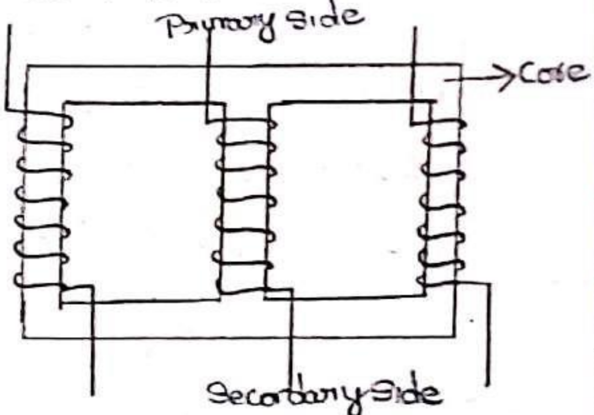
Three phase transformers

- Three phase transformer Construction is similar to single phase transformer

- Generated voltage is 13.2KV, 22KV or higher

- Before transmission, it is required to step up the voltage for this a three phase step-up transformer is required.

- At the distribution sub-station the voltage must be stepped down and it is necessary to reduce the voltage upto 6000V, 400V, 230V



- Three phase shell type transformer has three limb. Here we use only 'I' core. Around each limb, the primary and secondary windings are placed

- operation of three phase transformer is similar to single phase transformer

- Three phase supply is given to the primary winding, due to this three phase flux is produced in the primary winding.

- The flux is linked with secondary winding

- Depending upon the numbers of turns in the secondary the secondary voltage will be stepped up (or) stepped down.

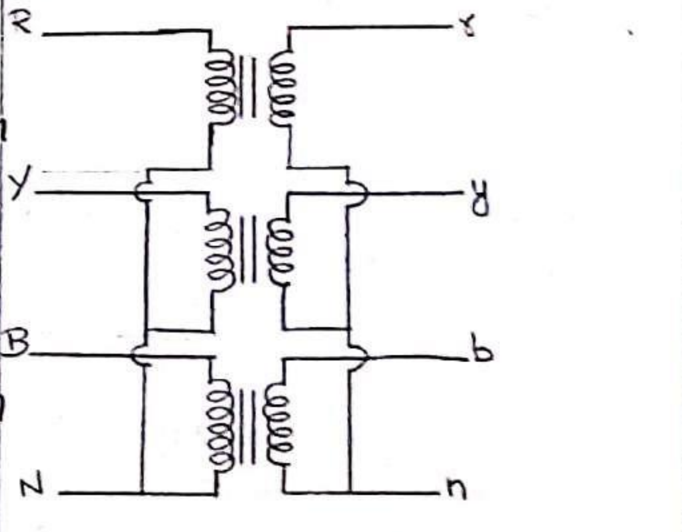
- primary and the secondary windings can be connected either in star or Delta.

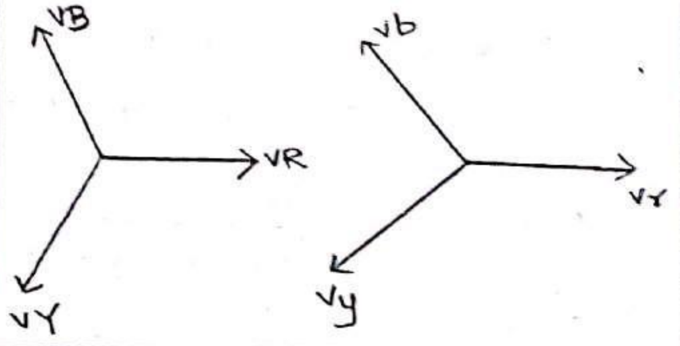
Advantages of Three phase transformer

1. It occupies less space for same rating, compared to a bank of three 1φ transformer.
2. It has less weight
3. Cost is also low
4. Easy to handle
5. Transported very easily

Three phase transformer Connections

① star-star Connection.





- It is most economical for small current rating, high voltage transformers
- the numbers of turns perphase and quantity of insulation required is minimum.
- There is a phase shift of 30° between the phase voltage and line voltages on both primary and secondary
- The star-star Connection works well for balanced load.

star-star Connection Advantages:-

1. Less no. of turns and less quantity of Insulation required

$$v_{ph} = \frac{V_L}{\sqrt{3}}$$

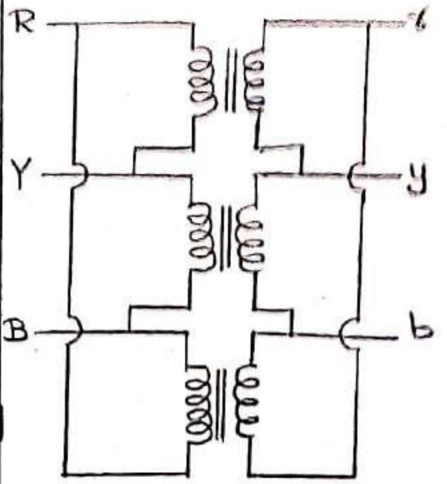
2. $I_{ph} = I_L$ the current through the windings is high.
3. suitable for 3φ-4 wire system because of presence of neutral point.

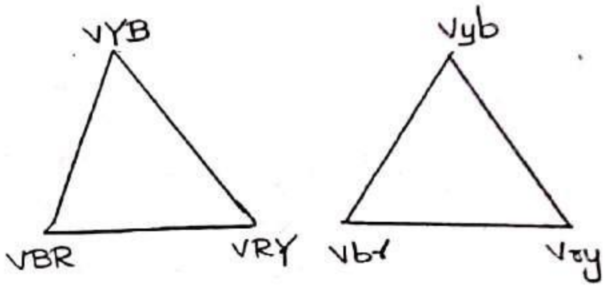
star-star Disadvantages:-

1. Neutral point shifts due to unbalanced load and performance is not satisfactory.
2. Connecting neutral point to earth, third harmonic present may cause distortion in secondary voltage.

② Delta-Delta Connection

- This arrangement for carry large currents on low voltages and when continuity of service must be maintained, even though one of the phase developed fault.





Advantages:

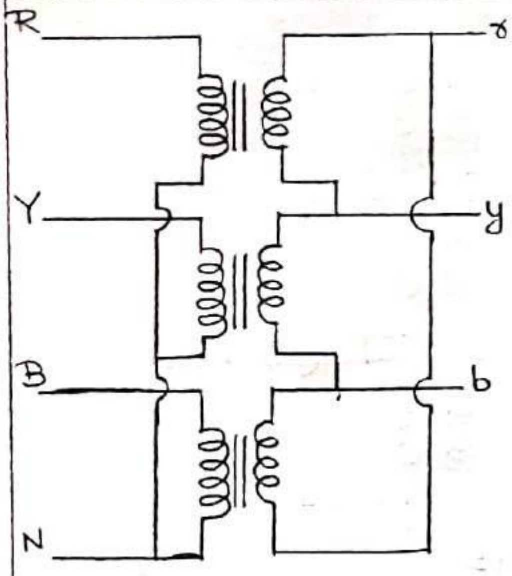
1. This connection permits unbalanced loading
2. No distortion in secondary voltage
3. For Delta $I_p = \frac{I_L}{\sqrt{3}}$ cross section of the winding low, which economical for low voltage transformers.

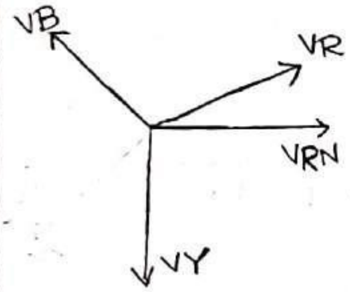
Disadvantages:

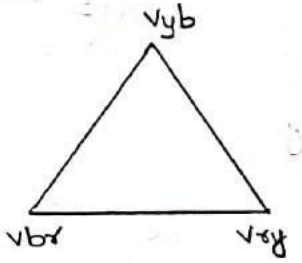
1. Not suitable for 3φ four wire system because neutral absent.
2. This Connection is used for low Voltage transformers.

③ star-Delta Connection

- This Connection used in transformer to step-down voltages and hence it is used at the distribution side that is at the Receiving side.







Advantages:

1. Primary is star connected, fewer number of turns are required in primary.
2. possible to handle large unbalanced load
3. Neutral point on primary side can be earthed to avoid distortion

Disadvantages:

1. Secondary voltage is not inphase with the primary, it not possible to make it parallel with star-star and delta-delta transformers.

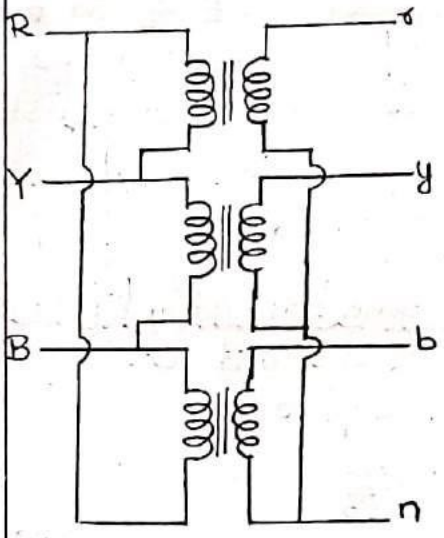
④ Delta-star connection

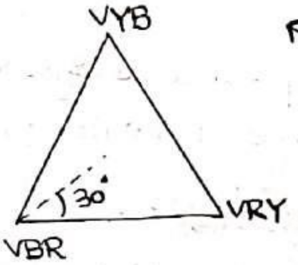
- It is used to step up the voltage and hence it is used at the beginning of transmission

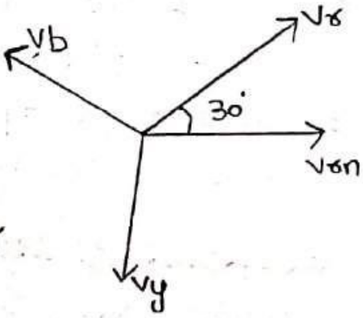
- The neutral point is available on the secondary side.

For star connection $V_{ph_1} = \frac{V_{L1}}{\sqrt{3}}$

For Delta connection $V_{ph_2} = V_{L2}$







Advantages:

1. primary is delta connected, the winding cross-section is small.
2. Neutral is available on the secondary side, three phase four wire supply can be carried out.
3. Saving in cost of Insulation because of star connection on secondary side

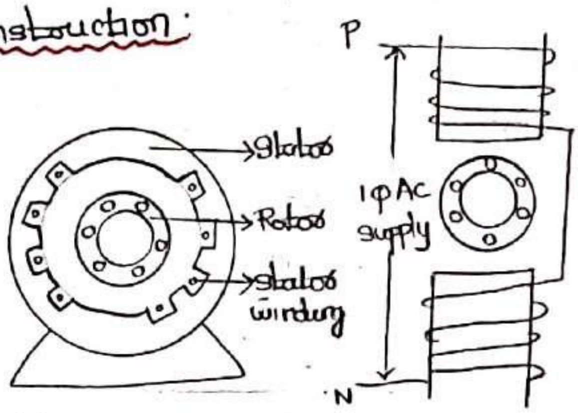
Disadvantages:

1. Secondary voltage is not inphase with the primary it is not possible to make it parallel with star-star and Delta-Delta transformer

2. Secondary is Connected in star, this type of transformer affected by unbalanced load.

Single phase Induction motor

Construction:



- A 1φ Induction motor Construction is similar to a three phase Induction motor (squirrel)
- The rotor is the same as that in a three phase induction motor. But the stator has only a single distributed phase winding.

It Consists of two parts

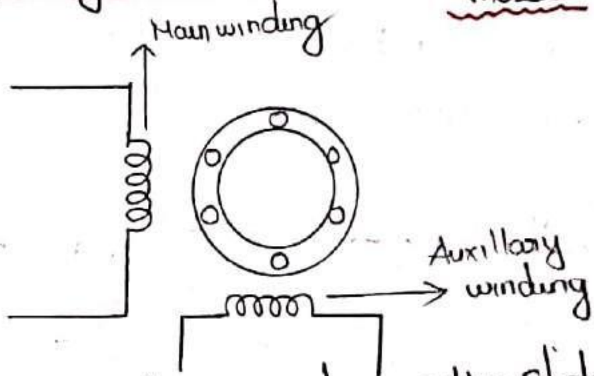
ⓐ Stator ⓑ Rotor

- There is no external connection between stator and rotor.

Operation of single phase Induction motor:

- The single phase Induction motor stator winding is connected to single phase Ac supply. Then a magnetic field developed in stator.
- Due to the transformer action, the currents are induced in the rotor conductors.
- The axis of rotor mmf wave Coincides with the axis of stator mmf wave.
- Therefore the torque angle is zero and no starting torque is developed in this motor.
- However if rotor is initially given a starting torque by some means the motor will pick up the speed and continue to rotate in the same direction.
- thus the 1φ Induction motor is not self starting motor. The starting torque can be provided by some arrangement required.

Starting of single phase Induction motor.



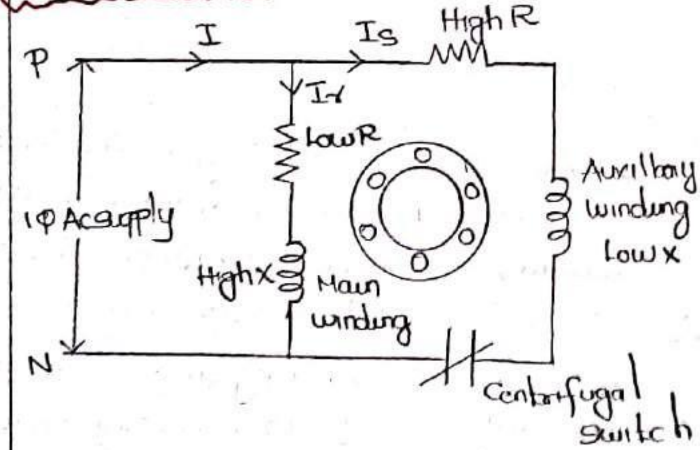
- An auxiliary winding in the stator is provided in addition with main winding. Then the induction motor starts as a two phase motor.
- The main winding and Auxillary are displaced by 90° electrical degrees
- The current in the main and auxillary winding are phase shifted from each other. The result of this rotating field is produced. Then the motor rotates

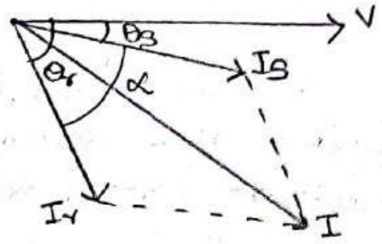
- The motor speed is about 75% of synchronous speed, the auxillary winding is disconnect from the circuit.
- This is done by connecting a centrifugal switch in the auxillary winding which is only used for starting purpose.
- Under Running condition, a single phase induction motor can develop torque with only the mainwinding.

Types of single phase Induction motor

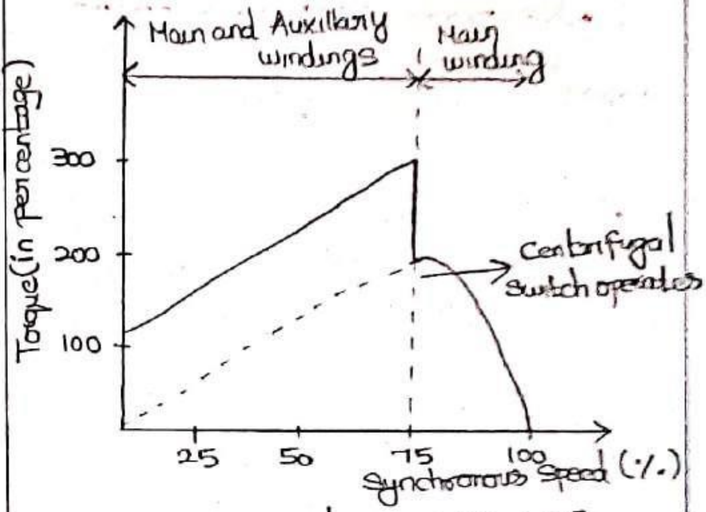
a. split-phase motors
b. Capacitor-start motors
c. capacitor-run motors
d. capacitor-start capacitor-run motors

(a) split phase motors





- It consists of two stators windings one is main winding (or) Running winding other one is auxillary winding (or) starting winding



- These two winding axis are displaced by 90° electrical degrees.
- The auxillary winding has high resistance and low reactance.
- Main winding has low resistance and high reactance.
- These two currents are out of phase
- The motor speed is about 75% of synchronous speed, the auxillary winding is disconnected from the ckt
- This is done by connecting a centrifugal switch in the auxillary circuit after 75% of speed the motor is running only because of main winding.
- The starting torque of the motor can be increased by connecting a resistance in series with auxillary winding.

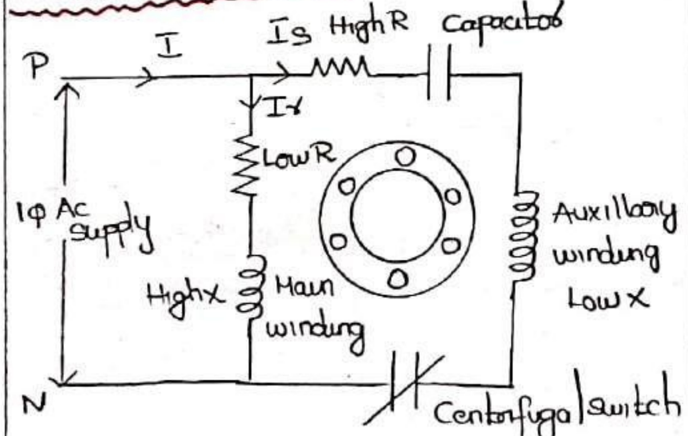
Applications

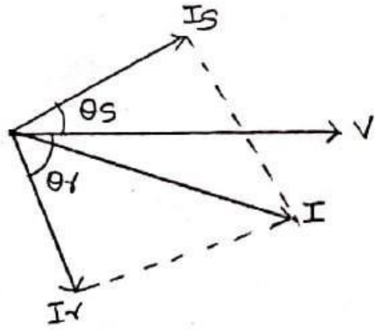
1. Fans, 2. Blowers 3. washing Machines.

Characteristics:

1. starting torque is 100% to 250% of the rated value
2. power factor is 0.5 to 0.65
3. Efficiency 55% to 65%.
4. Power rating of the motor ½ to 1Hp.

⑥ Capacitor start single phase Induction motor





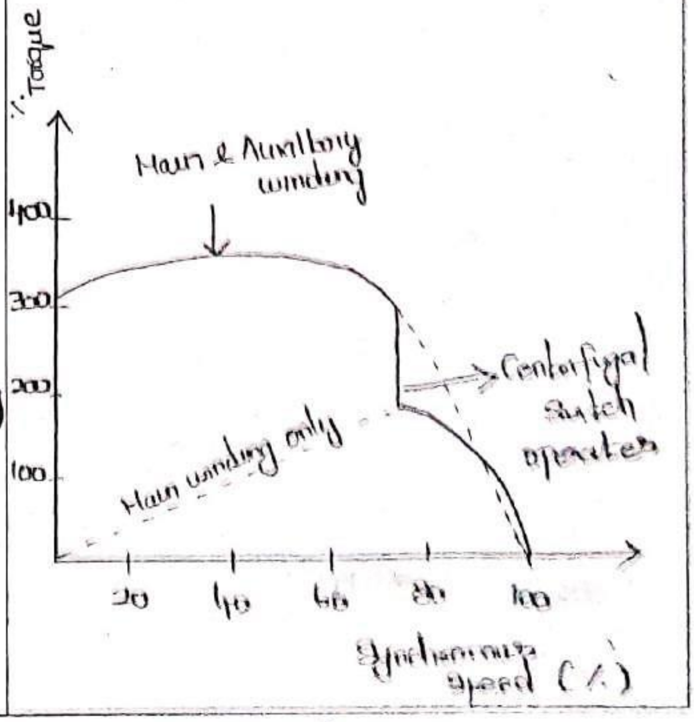
- The capacitor is connected in series with the auxillary winding used to get higher starting torque
- The starting current Is leads the line voltage, because of the capacitor present in auxillary winding
- The running current Ir lags the line voltage
- The phase displacement between the two current approximate equal to 90° on starting
- Again the auxillary winding is disconnected from the circuit by centrifugal switch at 75% of the synchronous speed.
- The capacitor is only used for during starting period.

Applications

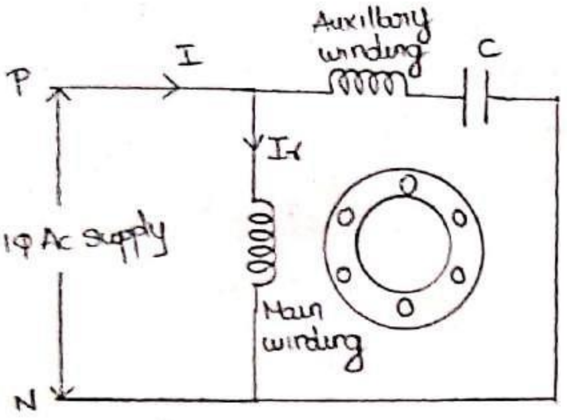
1. Compressors 2. pumps.
3. Conveyors 4. washing machines.

Characteristics of motors.

1. starting torque is 250% to 400% of rated value
2. power factor is 0.5 to 0.65
3. power rating of the motor 1/8 to 1Hp.
4. Efficiency 55% to 65%.



(c) Capacitor – Run motors

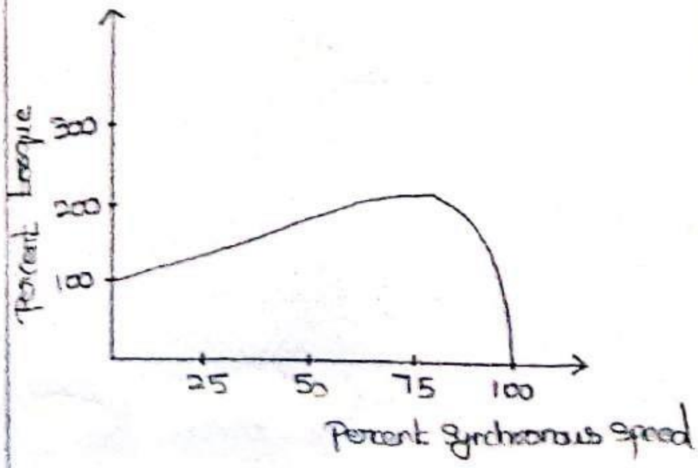


- In this motor, a capacitor is Permanently Connected in series with auxillary winding.

- Here the centrifugal switch is not needed, therefore the cost of the motor is less.

- Capacitor value is between the range of 20 – 50 MF.

- starting torque has to be Sacrified because of capacitor chosen is a compromise between the best starting and running conditions.



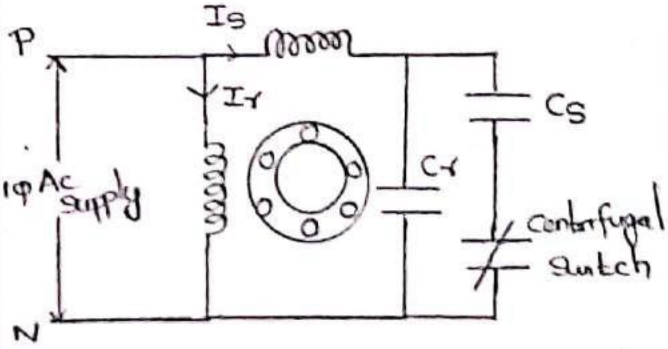
Applications:

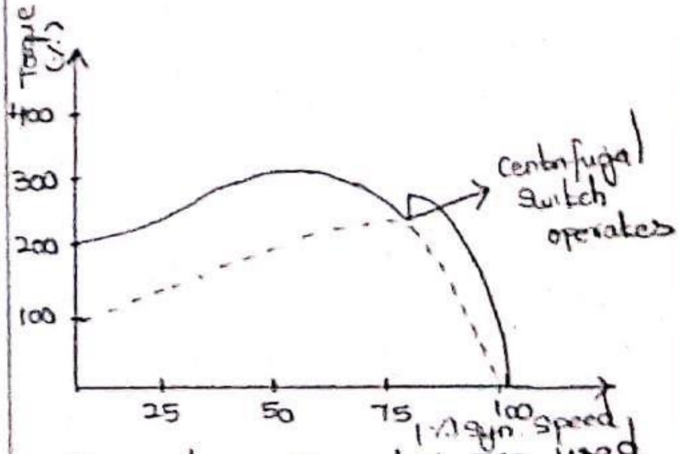
1. Fans 2. Blowers 3. Centrifugal pumps.

Characteristics of the motors.

1. starting torque is 100% to 200% of rated value
2. power factor of the motor is range 0.75 to 0.9
3. power rating of the motor is 1/8 to 1 Hp.
4. Efficiency of the motor is 60 to 70%.

(d) Capacitor – start Capacitor – run motor.





- Here two Capacitor are used
- one capacitor Cs is used for starting Purpose and another one Capacitor Cr is used for running Purpose

- In this motor, we can get high starting torque, because of two capacitors.
- The starting capacitor Cs value large and running capacitor Cr value is less.
- Running capacitor Cr is permanently connected in series with Auxillary winding.
- when the motor speed picks upto 75% of synchronous speed, the centrifugal switch is open & the starting capacitor Cs is disconnected from the ckt.
- The capacitor Cs is used for developing high starting torque and capacitor Cr is used for improve the power factor.

Applications:-

1. pumps
2. conveyors.

Characteristics:

1. starting torque 200% to 300%.
2. power factor 0.75 to 0.9
3. power rating 1/8 to 1Hp.
4. Efficiency 60% to 70%.

Three phase Induction motor

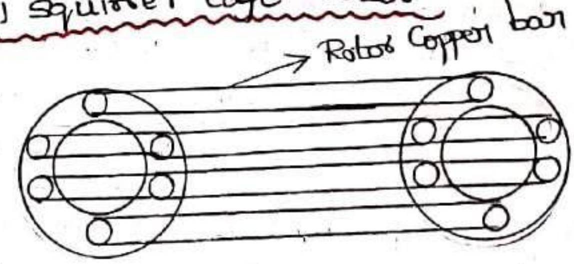
Construction:-

Stator

- stator is made up of a number of stampings with alternate slot and tooth.
- stamping are insulated from each other. Each stamping is 0.4 to 0.5mm thick.
- Number of stampings are stamped together to build the stator core
- stator winding is made of fixed no. of poles.

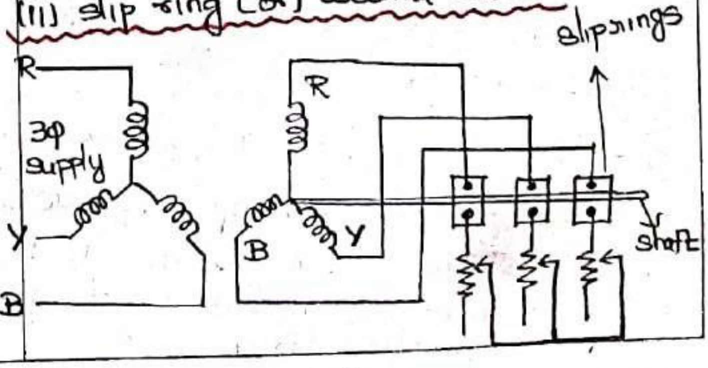
Rotor

(i) squirrel cage rotor



- Made up of a cylindrical laminated core with slots to carry the rotor conductors.
- Rotor conductors are heavy bars of copper or aluminium short circuited at both ends by end rings.
- External resistance cannot be connected in rotor circuit.

(ii) slip ring (or) wound rotor



- This type rotor windings are similar to the stator winding.
- Rotor winding may be star or Delta connected
- Three phases are bought out and connected to slip rings mounted on the rotor shaft.
- Variable External resistance can be connected in the rotor circuit with help of brushes and slip rings.

Three phase Induction motors [principle of operation]

- Three phase is given to the stator winding. Due to this current flows through the stator winding
- This current is called stator current. It produces rotating magnetic field

Magnetic field rotates at synchronous speed

$$N_s = \frac{120f}{P}$$

Ns - Syn. speed

N - supply frequency

P - no. of poles.

- 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
- The rotor tries to catch up 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 becomes 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. therefore this machine is called an Asynchronous machine.
- Difference b/w synchronous speed and rotor speed is called the slip speed.

$$\text{slip speed} = N_s - N$$

$$\text{slip } s = \frac{N_s - N}{N_s}$$

$$N = N_s(1 - s)$$

$$\%\text{ slip} = \frac{N_s - N}{N_s} \times 100$$

Advantages:

1. cheaper
2. Light weight
3. More efficient
4. Require less maintenance.

Disadvantages:

1. Moderate starting torque
2. External resistance cannot be connected to rotor circuit. so starting torque cannot be controlled.

Applications:

Laths, drilling machines, Fans, blowers, grinders etc...

Torque equation of Three phase Induction motor.

In case of DC motor

$$T \propto \phi I_a$$

In case of Induction motor

$$T \propto \phi I_{2r} \cos\phi_{2r} \quad \text{—} ①$$

ϕ - Flux

I_{2r} - Rotor current under running Condition

$\cos\phi_{2r}$ - rotor power factor under running condition.

$$X_{2r} = S X_2$$

Also

$$E_2 \propto \phi$$

$$E_{2r} = SE_2$$

$$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

$$\cos\phi_{2r} = \frac{R_2}{Z_{2r}} = \frac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

In equation ①, ϕ can be replaced by E_2

$$T \propto E_2 \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}} \cdot \frac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

$$T \propto \frac{S E_2^2 R_2}{R_2^2 + (SX_2)^2}$$

$$\boxed{T = \frac{K S E_2^2 R_2}{R_2^2 + (SX_2)^2} \text{ N-m}} \quad \text{—} ②$$

K - Constant => $K = \frac{3}{2\pi n_s}$

At stand still, $S = 1$

$$\boxed{T_{st} = \frac{K E_2^2 R_2}{R_2^2 + X_2^2} \text{ N-m}}$$

Condition for maximum running torque

$$T = \frac{S K E_2^2 R_2}{R_2^2 + (SX_2)^2} \text{ N-m}$$

$$\frac{dT}{dS} = 0$$

(i.e) $R_2 = SX_2$

$S_m = \frac{R_2}{X_2}$ is the slip at which the torque is maximum.

Substitute $S = \frac{R_2}{X_2}$ in equ ②

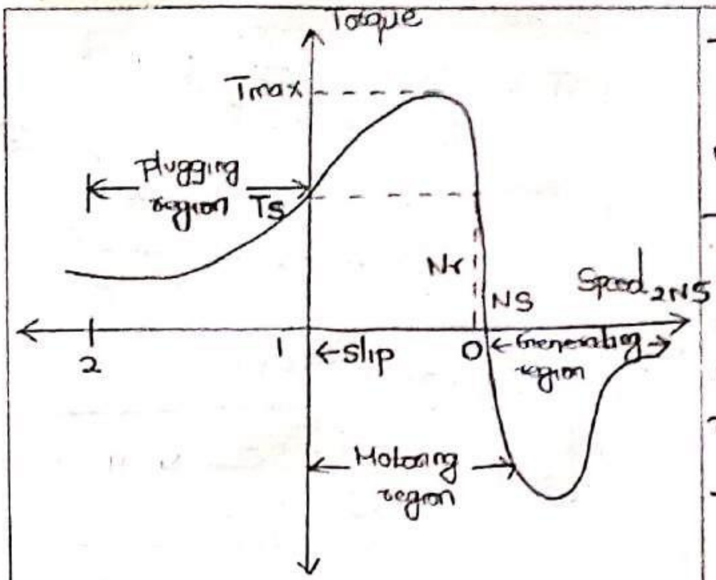
$$T_{max} = \frac{K S E_2^2 S X_2}{2 S^2 X_2^2}$$

$$\boxed{T_{max} = \frac{K E_2^2}{2 X_2}}$$

Torque - speed characteristics of Induction motor.

- The curve divided into 3 region according to the slip value.

(1) Motoring region $(0 \leq S \leq 1)$
(2) Generating region $(S < 0)$
(3) plugging region $(1.0 \leq S \leq 2.0)$



(i) Motoring region $(0 \leq s \leq 1)$

- In this region, the induction motor rotates in the same direction as that of field.
- Here the speed is decreases and torque increases till break down torque is reached.

(ii) Generating region $(s < 0)$

- In this region, machine operates as a generator. The rotor rotates at a speed greater than synchronous speed in the same direction as that of the rotating magnetic field.

(iii) plugging region $(1 \leq s \leq 2)$

- In this region, the slip becomes greater than unity. So that the motor rotates in the opposite direction of a rotating magnetic field.
- This region occurs only when the stator field is reversed by changing the phase sequence of the input supply of the motor.
- By changing the phase sequence the direction of the rotating magnetic field also changes (reverse)
- Under this condition the machine is quickly come to the stop, and if the supply is not disconnected, the motor starts to rotate in the reverse direction.
- Here the torque is positive, but the speed is negative

Torque-slip characteristics of Three phase Induction motor.

The torque equation of 3ϕ Induction motor

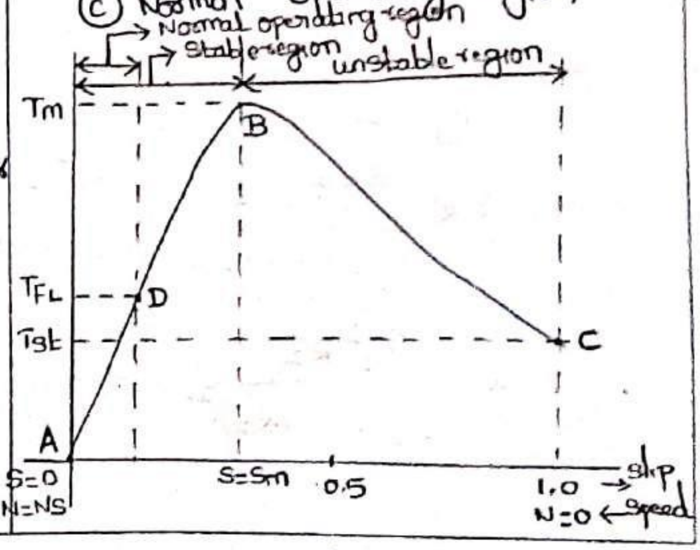
$$T \propto \frac{sE_2^2R_2}{R_2^2+(sX_2)^2} \quad — ①$$

Input Voltage is constant (i.e) E_2 is also constant

$$T \propto \frac{sR_2}{R_2^2+(sX_2)^2} \quad — ②$$

It consists of three region

ⓐ stable operating region
ⓑ unstable operating region
ⓒ Normal operating region



(a) Stable region:

- slip value 'S' is very small.

(i.e) the term $(SX_2)^2$ is very small as compared to R_2^2.

- Hence Neglect $S^2X_2^2$ in equation ②

$$T \propto \frac{SR_2}{R_2^2} \propto S$$

$\therefore T \propto S$ R_2 is Constant

- The slip value is directly proportional to the torque.
- In this region, Load increases, slip increases, speed decreases

$T\uparrow, S\uparrow$

- characteristics approximately a straightline. Indicated as curve AB.

(b) unstable region:

- when slip is further increased from Sm, the region is unstable region.
- Here, the slip value is high
- The term R_2^2 may be neglected as compared to $S^2X_2^2$

$$T \propto \frac{S}{(SX_2)^2} \propto \frac{1}{S}$$

X_2 is Constant

$$\therefore T \propto \frac{1}{S}$$

- Torque inversely proportional to slip

$S\uparrow, T\downarrow$

- By increasing the load, motor speed decreases, slip decreases.
- In unstable region, slipvalue is high
- slip increases and so torque must increase to satisfy the load demand.
- But again increasing the load, speed further decreases and slip increases.
- Due to this torque decreased, finally motor comes to standstill condition.

Normal operating region:

The region (AD) is also called low slip region and the operating region from this curve,

1. starting torque
2. Maximum torque (or) pull out torque
3. full load torque

Starting torque (Tst)

- In torque-slip characteristics, the slip 1 and speed is zero. At this condition motor produces a torque called starting torque (Tst)

Maximum torque (or) pull out torque (or) Break down torque

- The torque which the motor produces at slip S=Sm is called maximum torque
- S=Sm at which maximum torque occurs
- the maximum torque is also called pull out torque.

Full load torque

- In torque-slip characteristics, the point D corresponds to full load torque of the motor. It is also called the full load torque.
- Normally Full load torque is less than the maximum torque

Synchronous machines

The machine which produces 3 phase power from mechanical power is called an alternator (or) synchronous generator

It works on principle of Electromagnetic Induction

In Dc generator - 1. Armature winding placed in rotor
2. Field winding placed in Stator.

In Alternator - 1. Armature winding placed in stator
2. Field winding placed in Rotor.

- The frequency of output Ac voltage of a synchronous generator is directly proportional to the rotor speed
- To maintain frequency constant, the rotor must always move at synchronous speed

Advantages of stationary Armature

a Better Insulation
b Ease of current collection
c Increased armature tooth strength
d More rigid construction
e Reduced armature leakage reactance
f Lesser number of slip rings
g lesser rotor weight
h. Improved ventilation and heat dissipation

Construction of Alternator

An alternator has 3φ winding on the stator and dc field winding on the rotor

Stator:

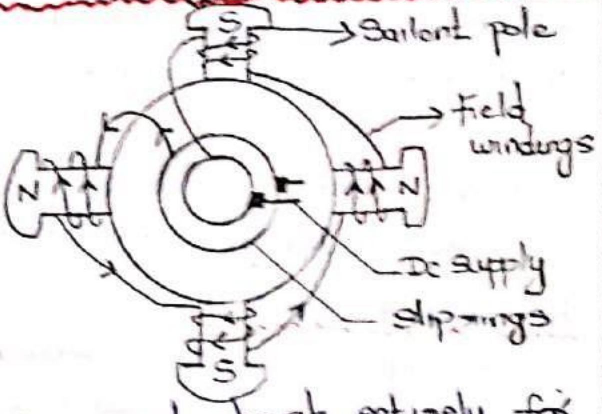
- It is the stationary part of the machine built up of sheet-steel laminations having slots
- A 3 phase winding is placed in these slots and serves as the armature winding
- winding always star connected, neutral is connected to ground

Rotor:

- Rotor carries a field winding which is supplied with direct current through two slip rings by a separate dc source

Rotor construction into two types

(i) Salient pole type [speed 120 to 400rpm]



- It is used almost entirely for slow and moderate speed
- Salient poles cannot be employed in high speed generators, difficulty to obtaining sufficient mechanical strength
- Salient poles made of thick steel laminations
- The pole faces are usually provided with slots for damper windings

Note:

1 Large diameter and short axial length
2 pole shoes cover about 2/3 of pole pitch

(ii) Non salient pole type (or) Cylindrical type
[Speed: 1000 to 3000 rpm]

- Used in very high speed Alternators.
- Diameter of the rotor is reduced and axial length is increased such rotors have two or four poles.
- the slots over certain portions of the core are ommitted to form pole faces.

Note:

1. Small diameter, very long axial length
2. Speed employed 1000 to 3000 rpm

Working of Alternator

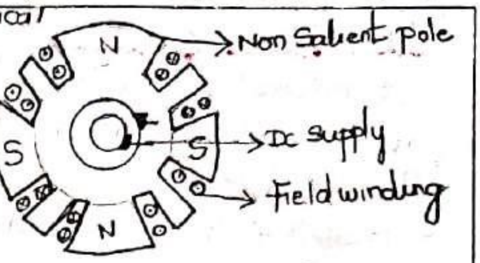
- The field magnets are magnetised by applying 125 volts or 250 volts through slip rings
- Field windings are connected such that alternate N and S poles are produced
- By the help of prime mover the rotor rotates, the armature conductors are cut by the magnetic flux. Here an emf is induced in the armature conductors
- As the magnetic poles are alternately N and S poles, this emf acts in one direction and then in other direction. Hence alternating emf is induced in stator conductors.
- The frequency of induced emf depends on the number of N and S poles moving past on armature conductors in one second
- Direction of emf Fleming right hand rule

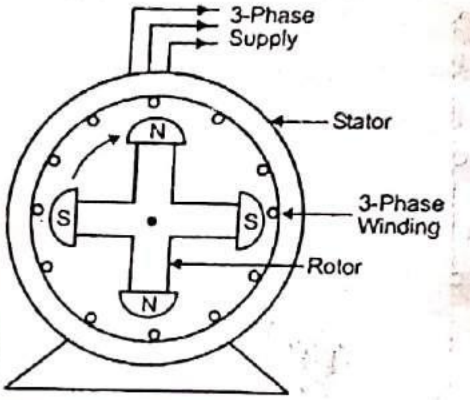
$$\boxed{F = \frac{PN}{120}}$$

N - speed of rotor in rpm

P - No of rotor poles

Smooth cylindrical Rotor :-





Frequency of Induced Emf:

- Consider a stator conductor that is successively swept by the N and S poles of the rotor.
- one complete cycle of emf is generated in the conductor as a pair of pole passes through it. (i.e) one N pole and the adjoining S-pole

No. of cycles/revolution = no. of pairs of poles = P/2

No. of revolution/second = N/60

No. of cycles/second = $\left[\frac{P}{2}\right] \times \left[\frac{N}{60}\right]$

But no. of cycles of emf per second is its frequency $\boxed{f = \frac{PN}{120}}$

- For Alternator the no of rotor poles is fixed.
- ∴ Alternator must run at synchronous speed to give an output of desired frequency.
- Alternator also called as synchronous generator.

Synchronous motor

- 3 phase Ac motors which operate at a constant speed from no load to full load.
- Construction is similar to Ac generator

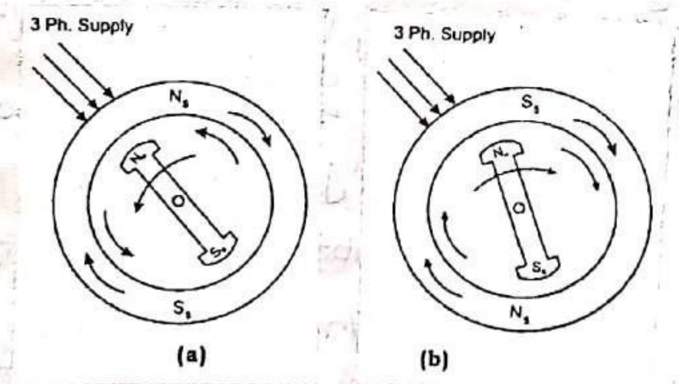
Principle of operation:

- 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.

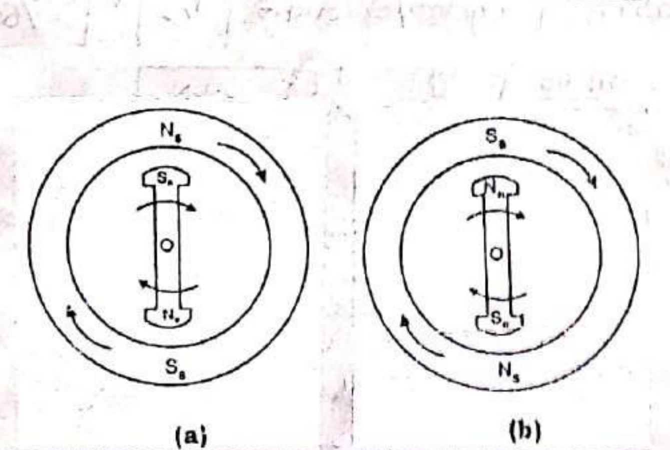
Field is rotating in space at a speed given by $NS = \frac{120f}{P}$ f - frequency, p - no. of poles

Note :- Stator - Armature winding
Rotor - field winding

3φ supply to the armature winding,
Dc supply to the field winding



(a) (b)



(a) (b)

- shows that stator poles marked Ns and Ss assumed to rotate clockwise at a synchronous speed NS.
- The rotor poles (Assumed to be only 2 in numbers) NR and SR are formed by the d c excitation.
- when Ns and NR are together and similarly Ss and SR like poles repel each other.
- Ns and Ss are moving in the clockwise direction.
- Half a cycle later the stator poles have moved, whereas the rotor poles moved.
- NS and SR, similarly Ss and NR get attracted and the rotor tries to rotate in the clockwise direction.
- This implies that the rotor experiences torque in different direction every half a cycle.
- As a result, rotor is at standstill.
- This why synchronous motor has no starting torque and cannot start by itself.
- So by using prime mover [Induction motor] relative speed between rotor and stator reduced to zero. then the rotor rotates at synchronous speed as the same as rotating magnetic field.
- Initially rotor is standstill, only, by using prime mover we making to rotate the rotor. once the rotor and stator relative speed zero means the rotor rotates in synchronous speed

Relative speed of stator and rotor zero } are magnetically locked

- So synchronous motor is not self starting, starts working as a motor if it is started up by some means.

Starting methods of synchronous motor

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.
- Speed of DC motor adjusted by speed regulator.
- At the moment of synchronising, the synchronous motor is switched on with AC mains, the DC motor is disconnected from the DC supply mains.
- The synchronous motor is operating as a motor, from AC supply mains and DC machine acts as load on it.

By means of AC motor

- A small direct coupled Induction motor, may be used for starting the synchronous motor.
- After normal operation is established, the pony motor is sometimes de-coupled from the synchronous motor.
- This method is not very satisfactory and not suited to industrial needs.
- Modern machines are usually of the self starting type and are arranged to start as Induction motor.

By means of Damper grids in the pole faces

- The synchronous motor is made self starting by providing a special winding on the rotor poles, known as damper winding.
- The damper winding consists of short circuited copper bars embedded in the face of the field poles.
- Ac supply given to stator produces a rotating magnetic field which causes the rotor to rotate, there-fore in the beginning synchronous motor provided with damper winding starts as a squirrel cage Induction motor
- The exciter moves along the rotor - when the motor attains synchronous speed, about 95% of synchronous speed, the rotor winding is connected to exciter and the rotor is magnetically locked by the rotating field of stator. The motor runs as a synchronous motor.

Advantages of synchronous motor

1. Speed constant, Independent of load.
2. High efficiency motor.
3. Construct with wider air gaps than Induction motor, make them better mechanically.

Disadvantages of synchronous motor.

1. Cannot be started under load
2. Requires dc excitation
3. Cannot be used for variable speed Jobs.

Applications of synchronous motor

Fans, Blowers, centrifugal pumps, paper mills.

Unit- III

ANALOG ELECTRONICS

INTRODUCTION:

Electronic Components:

* Electronic components are classified into active and passive components.

* Active components supply energy to the circuit. Eg: Battery, semiconductor devices etc

* Passive components consume energy from the source.
Eg: Resistors, Capacitors, Inductors etc.

RESISTORS (R)

*R is an electrical/electronic component used to limit the flow of current.

* Unit is ohm (Ω)

* Symbol:

* $\boxed{R = \frac{V}{I}}$ (By Ohm's law)

* $\boxed{R = \frac{\rho l}{A}}$

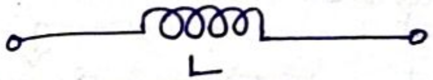
R → Resistance in ohm

ρ → Resistivity of the wire in ohm-cm

l → Length of the wire in cm.

INDUCTOR (L):

It is used to store the energy in the form of magnetic energy, when electricity is applied to it. The SI unit of inductor is Henry (H).



$\boxed{L = \frac{\varphi(i)}{i}}$;

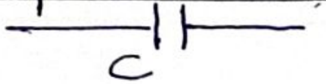
L → Inductance

$\varphi(i)$ → Magnetic flux of current i

i → Current.

CAPACITOR

Capacitor is used to store the energy in the form of electrical charge producing a potential difference across the plates. S.I unit of capacitor is Farad (F).



$\boxed{C = \frac{\varepsilon_0 \varepsilon_r A}{d}}$

C → Capacitance of a Capacitor

ε_0 → Permittivity of free space

ε_r → " " dielectric medium

d → Distance between plates.

A → Area of two conducting plates.

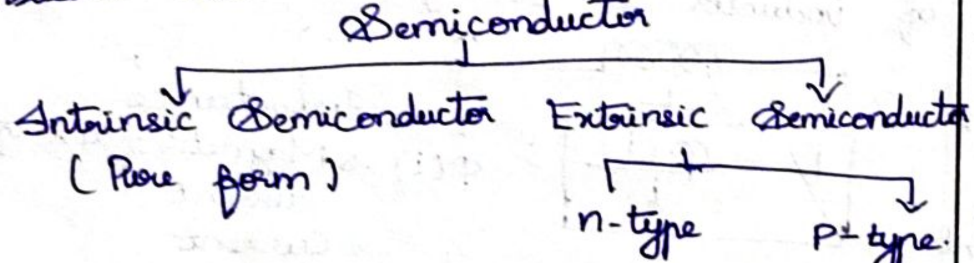
$$\boxed{C = \frac{Q}{V}}$$

Q → Charge

A → Area

SEMICONDUCTOR MATERIALS

Semiconductor is a material that has conductivity level between extremes of insulator and conductor.



The process of adding impurity to a pure semiconductor is called doping.

Types: n-type, P-type.

N-type Semiconductor:

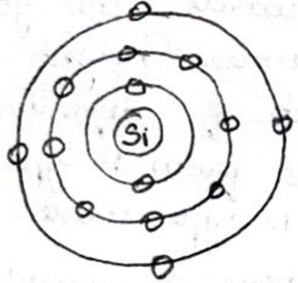
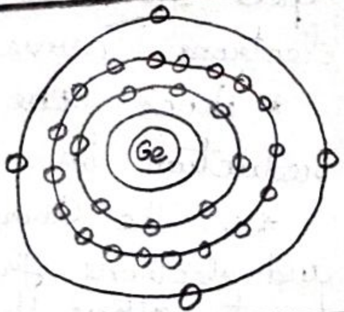
This is formed by doping pentavalent impurity atoms like arsenic, antimony or phosphorus. This process creates excess unbond electrons.

P-type Semiconductor:

This is formed by doping trivalent impurity like Aluminium or boron. This process creates excess holes.

Silicon and Germanium:

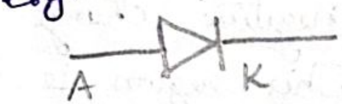
- Silicon and Germanium, are both in the same group (group 14) of the periodic table.
- Both have 4 valence electrons in the outer shell.
- Both have similar physical and chemical characteristics.
- Both are metalloids.

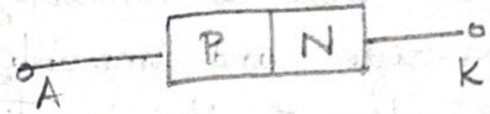
Parameter	Silicon	Germanium
Definition	Silicon is chemical element with atomic number 14 & symbol Si	Germanium is a chemical element with atomic number 32 & symbol is Ge.
Electron Configuration	1S2 2S2 2P6 3S2 3P2	1S2 2S2 2P6 3S2 3P6 4S2 3d10 4P2
D electrons	Has no d electrons	Has d electrons
Atomic Radius	Has a smaller atomic radius than Germanium	Has comparitively a larger atomic radius.
Conductivity	Comparatively low	Conductivity is comparatively higher.
Semiconductor	Widely used because they are used at higher temperatures.	Widely not used because of temperature limits
Atomic Structure	 	

PN Junction Diode:

A PN junction diode is formed when n-type and p-type semiconductors are joined together.

Symbol





In N-type material,
Majority Carriers - electrons
Minority Carriers - holes

In P-type material,
Majority carriers - holes
Minority carriers - electrons

* At the junction there is a tendency for free electrons to diffuse over the P-side and hole to N-side.
* This process is called diffusion.
* Electrons combine with holes in P-type material and creates a negatively charged immobilized acceptor ions.

* Similarly the holes move into N-material and combine with free electrons ~~of the donor atoms~~ and creates immobilized donor ions.

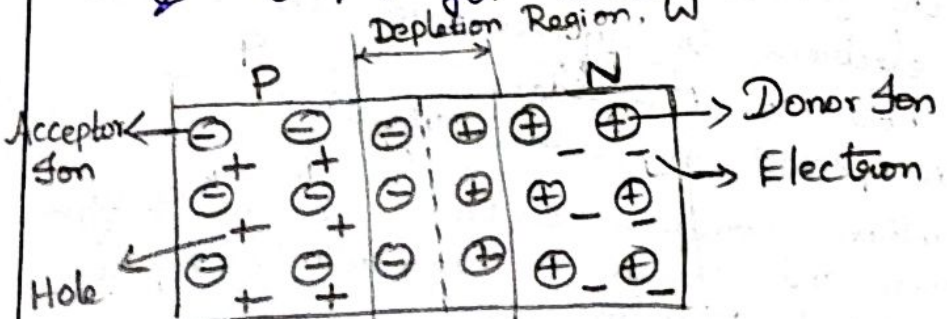
* Thus there is immobilized positive charge on N-side and immobilized negative charge on P-side of the junction. This region is known as Depletion region (or space charge region or transition region).

* It creates a built-in potential or barrier potential, V_b across the junction.

* The barrier potential V_b is

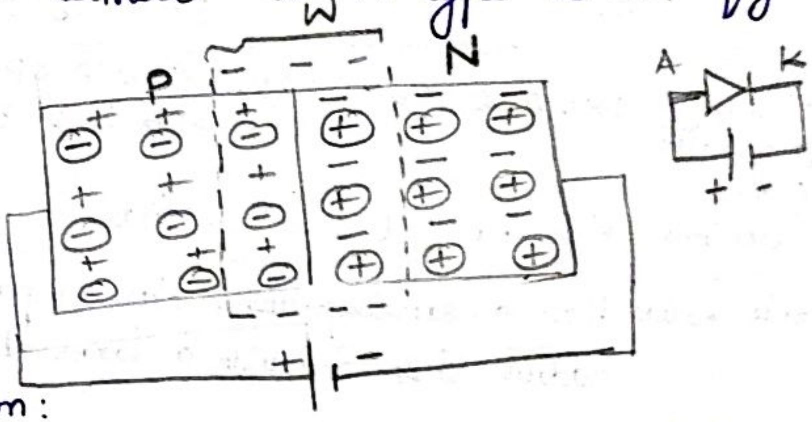
0.3 V for Germanium.

& 0.7 V for Silicon.



Diode under Forward Bias Condition:

This is done by connecting positive terminal of battery to P-type and its negative terminal to N-type as in figure.



Operation:

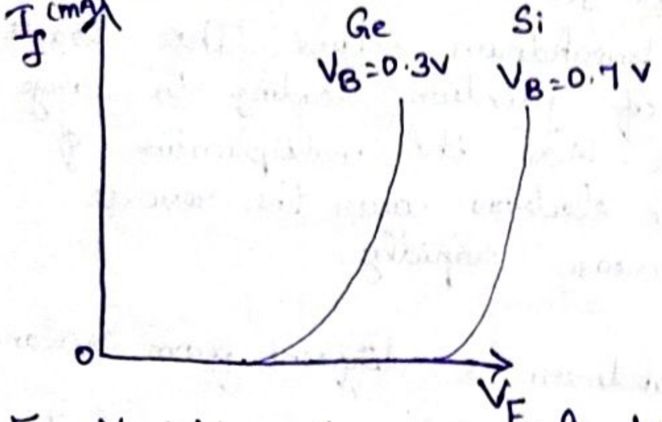
* Under Forward bias, the applied positive voltage repels the holes in P-type and holes move towards the junction.

* Similarly, the applied negative voltage repels the electrons in N-type region and electrons move towards the junction.

* Hence the barrier height reduces with reduction in width of depletion region.

* ∴ The ~~Carr~~ holes from P-type move to N-type and electrons from N-type move towards P-type and due to ~~other~~ this there is current flow & it is called as forward current, I_f.

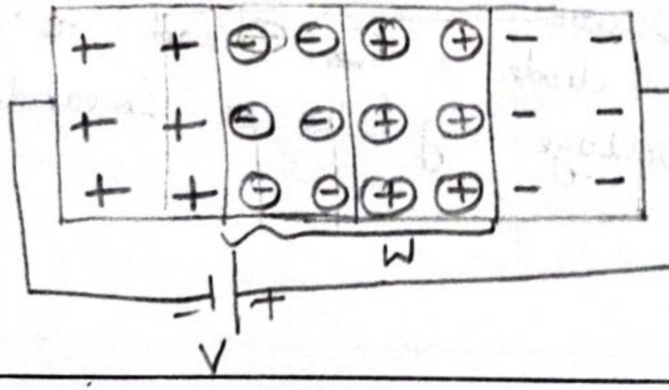
V-I Characteristics under Forward Bias :



For $V_F > V_B$, the potential barrier disappears at the junction and large current, I_f flows.

Diode under Reverse Bias Condition :

Reverse bias is obtained by connecting positive terminal of the battery to N-type and negative terminal to the P-type.



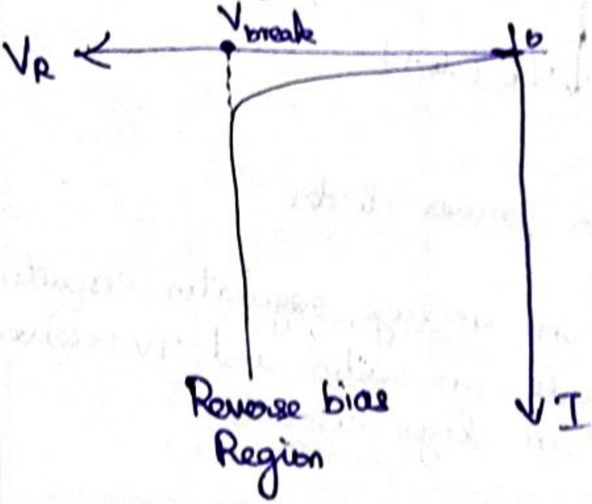
Operation :

* Under Reverse bias, the majority electrons are attracted by positive terminal and majority holes are attracted by negative terminal of battery.

* As a result, the depletion region is widened and the barrier potential rises.

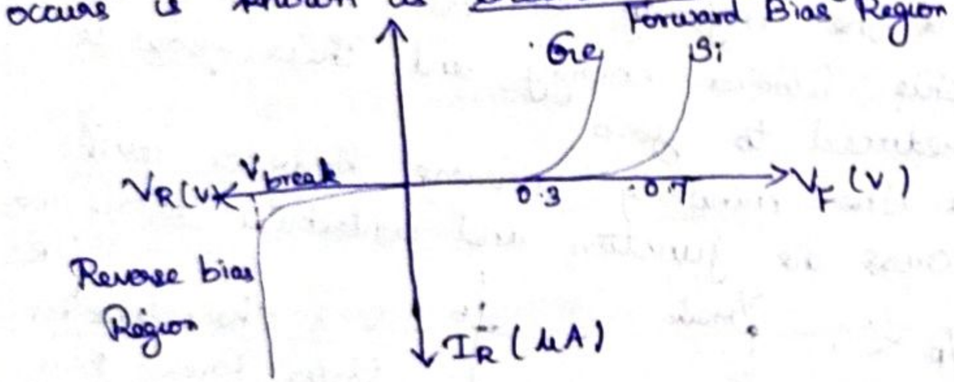
* The majority carriers cannot overcome this barrier energy and their flow is reduced to zero.

* The minority carriers however will cross the junction and contributes reverse current I_R.



V-I Characteristics Under Reverse Bias

For large applied reverse bias voltage, electrons move towards positive terminal of battery. Since a large number of electrons are formed, it is called avalanche of free electrons. This leads to breakdown of junction leading to large reverse current. The reverse voltage at which the junction breakdown occurs is known as breakdown voltage.



Diode Applications :

1) As rectifiers or power diodes
2) As signal diodes
3) As Zener diode in voltage regulator circuits.
4) As Varactor diode in radio and TV receiver
5) As a switch in logic circuits.

Avalanche Effect :

In PN-junction under reverse bias the avalanche breakdown occurs. This leads to breakdown of junction leading to large reverse current. Here the multiplication of number of free electrons cause the reverse current to increase rapidly.

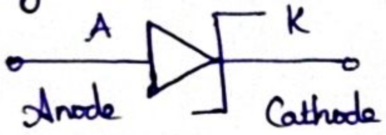
Zener Effect :

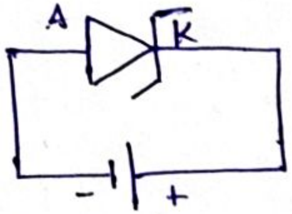
- Zener breakdown is different from avalanche breakdown.
- Zener breakdown occurs when the electric field in the depletion layer increases and it breaks covalent bond and generates electron-hole pair.
- In this a large number of carriers are generated.
- This process is quantum tunneling.

ZENER DIODE :

A Zener diode is also called as voltage reference, voltage regulator or breakdown diode.

Symbol



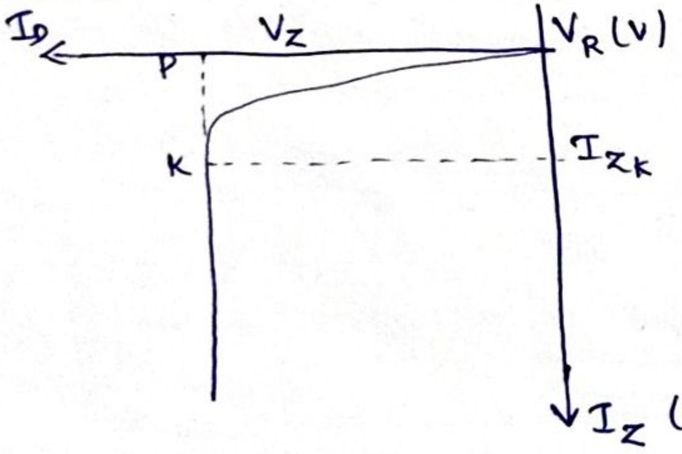


Circuit diagram

* Zener diode is operated in the reverse bias breakdown region.

* The breakdown voltage of a Zener diode is set by controlling the doping level during manufacture.

Reverse Characteristic of Zener Diode:



* Zener diode is operated in reverse bias only.

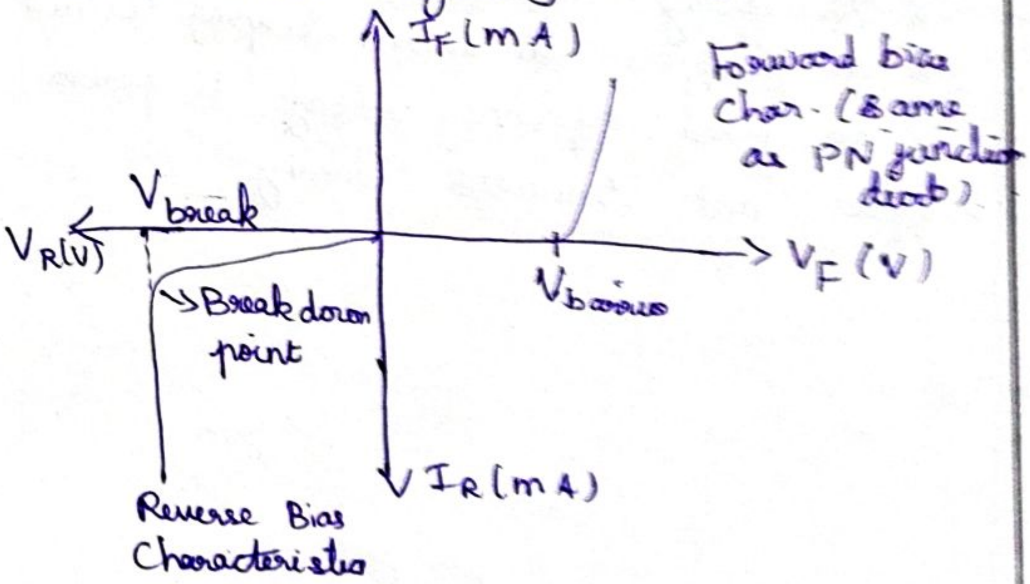
Fig: Reverse Characteristic of a Zener Diode.

* Zener diode is operated only in the reverse-bias region.

* From fig. the reverse voltage (V_R) is increased, the reverse current (I_z) remains negligibly small upto the 'knee' of the curve point 'p'.

* At this point, the effect of breakdown process begins.

* From the bottom of knee, the breakdown voltage, V_Z remains constant. This ability of a diode is called regulating ability.



* There is a minimum value of Zener current called breakover current ($I_{Z\,min}$) which must be maintained in order to keep the diode in breakdown or regulation region.

* When the current is reduced below knee, the voltage changes drastically and regulation is lost.

* Above the maximum value of Zener current $I_{Z(max)}$ the diode may be damaged.

Applications:

* As Voltage Regulators
* As Clippers in wave-shaping Circuits
* As fixed reference voltage is power supplies and transistor biasing.

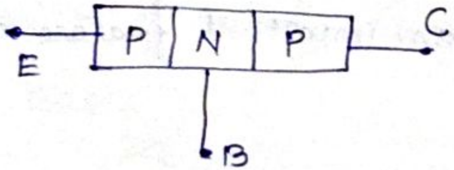
TRANSISTOR

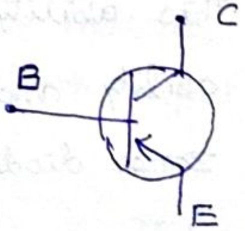
* A bipolar junction transistor is a three-layer two junction and three-terminal semiconductor device.

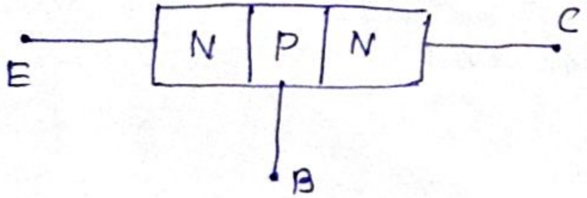
* It's operation depends on the interaction of magority and minority carriers. Therefore it is named as bipolar device.

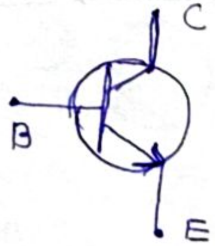
(TRANSfer + reSISTOR ⇒ Transistor)

* Transistor means, signals are transferred from low resistance circuit (input) into high resistance (output) circuit.









Emitter:-

It is more heavily doped than any of other regions because its main function is to supply majority charge carriers to the base.

* The current through the emitter is emitter current. It is denoted as I_E.

Base:-

* Base is the middle section of the transistor.
* It separates 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, and its denoted as "I_B".

Collector:-

* The main function of the collector is to collect the majority charge carriers coming from the Emitter and passing through the Base.

* It is a moderately doped. The current flows through Collector is Collector Current. It is denoted as I_C.

Types:-

PNP & NPN Transistors.

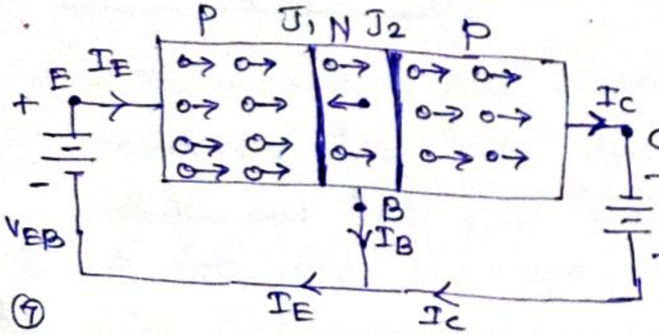
* Emitter section is always to provide charge Carriers, therefore, it is always forward biased.

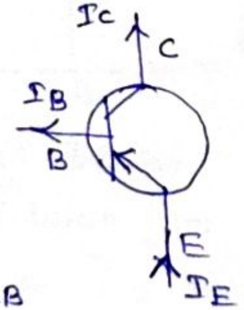
* First letter of transistor type indicates the polarity of the emitter voltage with respect to base.

* The main function of Collector is to collect (or) attract those Carriers through the base, hence it is always reverse biased.

* Second letter of transistor type indicates the polarity of Collector voltage with respect to the Base.

Working of PNP - Transistor





* The above diagram shows the Connection of PNP-Transistor.

* Here, the emitter-base junction is forward biased, and Collector-base junction is reverse biased.

* The holes in the emitter are repelled by the positive terminal of battery.

* Then the potential barrier at emitter-base junction is reduced as a result of this depletion region dis-appears, hence holes cross the junction and enter into N-region (base).

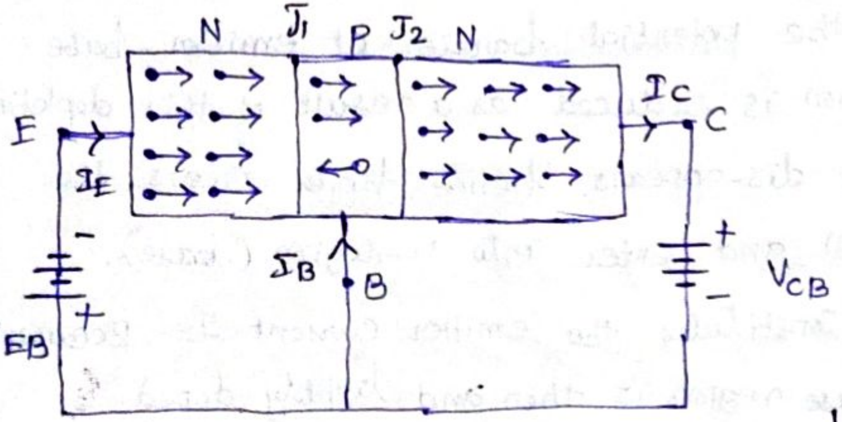
* This Constitutes the emitter current I_E. Because the base region is thin and lightly doped. majority of the holes (about 97.5%) are able to drift across the base without meeting electrons to combine with only 2.5% of the holes recombine with the free electrons (or) N-region.

* This Constitutes the base current I_B, which is very small.

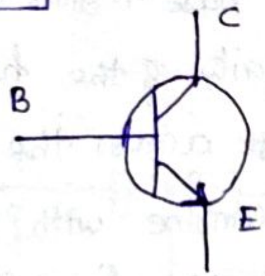
* The holes which after crossing the N-p Collector Junction enter the Collector region.

* They are swept out by the negative collector voltage V_{CB}. This constitutes the collector current I_C. $I_C = I_E - I_B$, $I_E = I_B + I_C$

Working of N-P-N Transistor



* In this circuit diagram, the Emitter-Base junction is forward biased. -ve negative polarity of the battery (V_{EB}) is connected to N-type Emitter terminal.



* Similarly, the Collector-Base junction (J_2) is reverse biased by connecting +ve terminal of battery with Negative (N-type) material.

* The electrons in the emitter region are repelled by the negative battery terminal towards the emitter junction.

* The electron crossover into the p-type base region because potential barrier is reduced due to forward bias, and base region is very thin and highly doped.

* Most of the electrons (about 97.5%) cross-over to the collector junction and enter the collector region, where they are readily swept up by the positive collector voltage V_{CB}. Only 2.5% of the emitter electrons combine with the holes in the base and are lost as charge carriers.

TRANSISTOR- CONFIGURATIONS

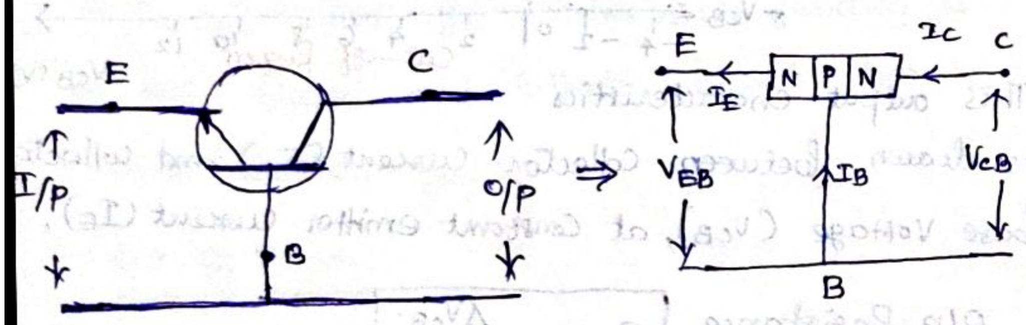
There are 3-Configurations.

1. Common-Base Configuration
2. Common-Emitter Configuration
3. Common-Collector Configuration.

COMMON-BASE CONFIGURATION

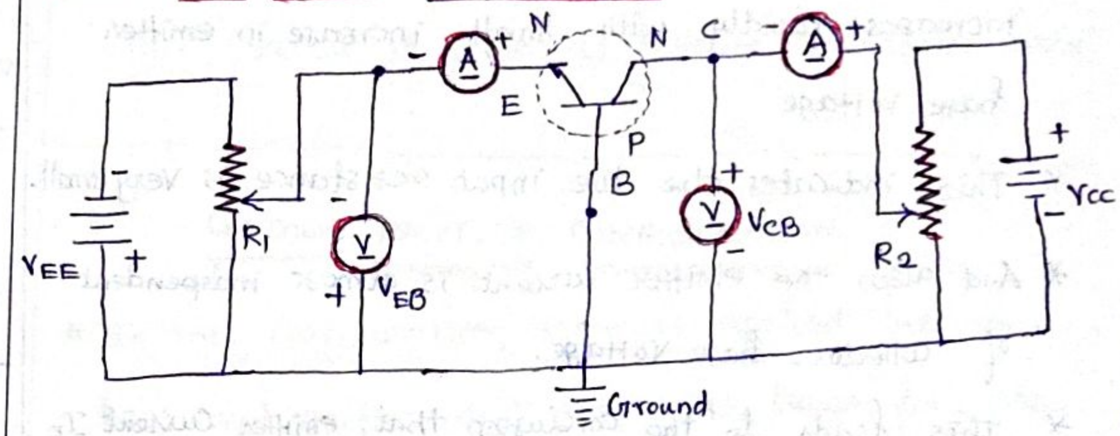
* In this Configuration, base terminal acts as a Common-terminal for input and output.

Diagram:-



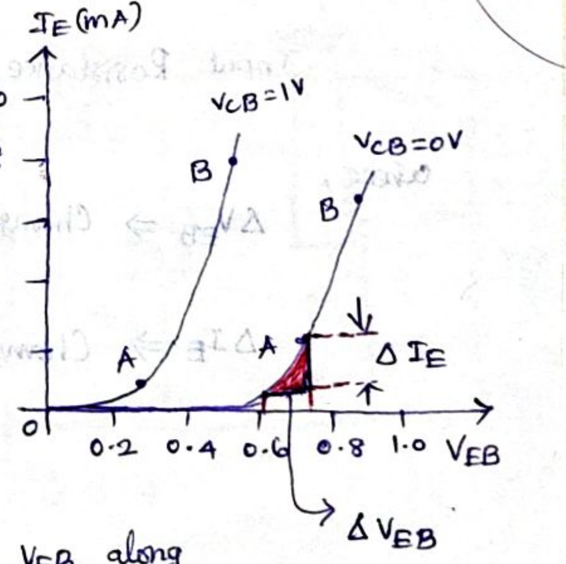
* In this Configuration, input is applied between emitter and base while output is taken from Collector and base. Here, Base acts as a Common to both input and output.

Input and output Characteristics:-



* This diagram, shows, how the input (I_E) emitter Current Varies with input voltage V_{EB}, when output voltage V_{CB} is held constant.

* To determine the input Characteristics initially, the output Voltage V_{CB} is set as zero, then the input Voltage V_{EB} is increased.



* The input charateristics drawn between emitter Current I_E and emitter-base Voltage V_{EB}.

* The emitter current (I_E) is taken along y-axis and V_{EB} along x-axis.

* From the above graph, the emitter current (I_E) increases rapidly with small increase in emitter base voltage.

* This indicates the the input resistance is very small.

* And also, the emitter current is almost independent of collector-base voltage.

* This leads to the conclusion that, emitter current I_E and hence collector current (I_c) is almost independent of collector-base voltage (V_{CB}).

* This input characteristics used to find the input resistance of the transistor.

Input Resistance $\boxed{(R_{in}) = \frac{\Delta V_{EB}}{\Delta I_E}}$ at constant V_{CB}

where,

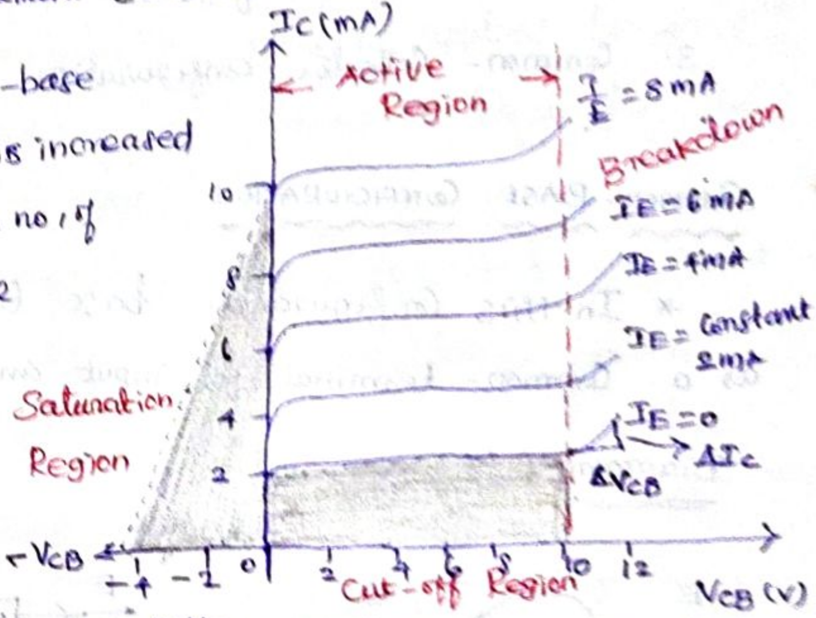
ΔV_{EB} ⇒ Change in Emitter-Base junction voltage

ΔI_E ⇒ Change in Emitter-Current.

Output Characteristics:-

To determine the output characteristics, the emitter current I_E is kept constant, at a suitable value by adjusting the emitter-base voltage V_{EB} and varying R_2 and output current (I_c) is measured.

* The collector-base voltage (V_{CB}) is increased from zero in a no. of steps, and the corresponding collector current (I_c) is noted.



* This output characteristics is drawn between collector current (I_c) and collector-base voltage (V_{CB}), at constant emitter current (I_E).

* O/P Resistance $\boxed{R_{out} = \frac{\Delta V_{CB}}{\Delta I_c}}$

* This characteristic is used to find amplification factor $\boxed{\alpha = \frac{\Delta I_C}{\Delta I_E}}$

Saturation Region:-

* It is the region left to the vertical line. In this region Collector-base voltage V_{CB} is negative. i.e the collector base junction is also forward biased and a small change in V_{CB} results in larger variation in Collector Current.

Active Region:-

* It is the region, between the vertical line to horizontal axis.

* In this region, the Collector Current is almost Constant and is equal to the emitter Current.

* In this region, the emitter base junction is forward biased and Collector-base junction is reverse biased.

Cut-off Region:-

* It is the region along the horizontal axis.

* In this region, both junctions are reverse biased.

* Due to this, there is no current flow in Collector terminal due to majority Carriers.

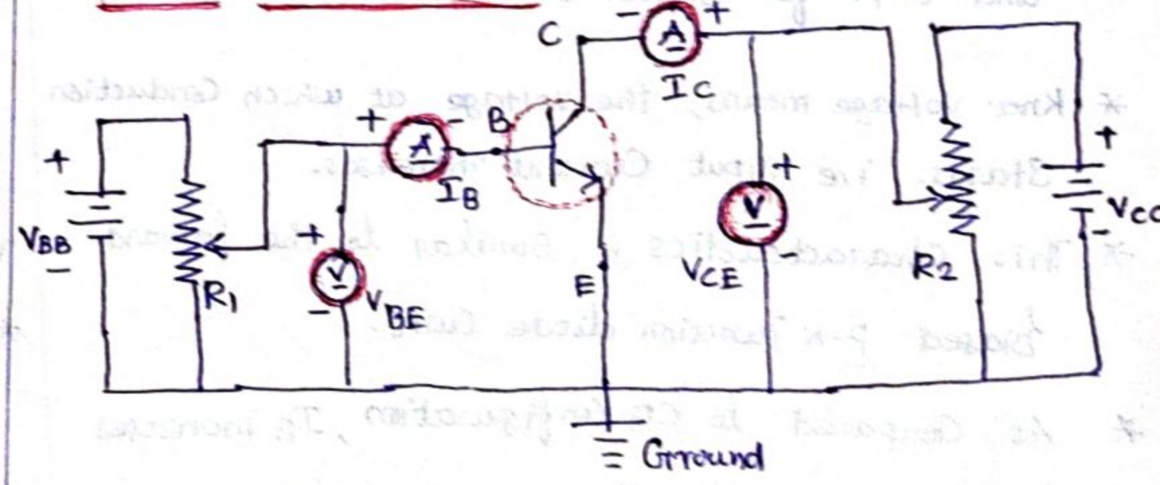
* But due to minority Carriers, current will flow. This Current is known as reverse Saturation Current.

COMMON EMITTER CONFIGURATION

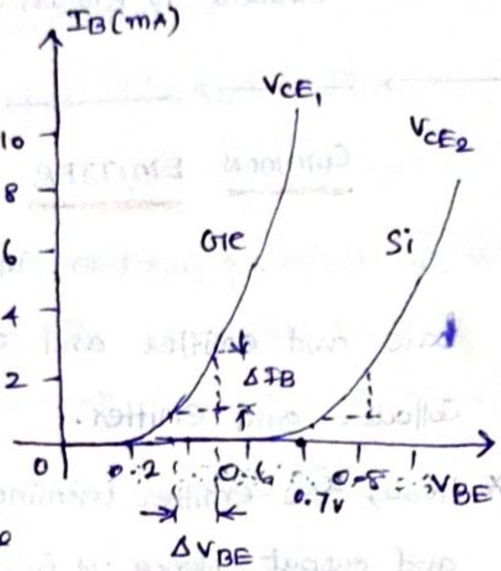
* In this Configuration, input is applied between base and emitter and output is taken from the Collector and emitter.

* Here, the emitter terminal is Common to both input and output. Hence it is Called Common-Emitter Configuration.

* **Input Characteristics:-**



* The above diagram shows the circuit diagram for Common-emitter configuration.



* At constant V_{CE}, the input current I_B varies with the variation of V_{BE}.

* If the input voltage (V_{BE}) is less than threshold (or) knee voltage below which the base current is very small.

* The value of knee voltage is 0.3V for germanium and 0.7V for silicon transistor.

* Knee voltage means, the voltage at which conduction starts. i.e input current increases.

* This characteristics is similar to the forward biased P-N junction diode curve.

* As compared to CB configuration, I_B increases less rapidly with V_{BE}.

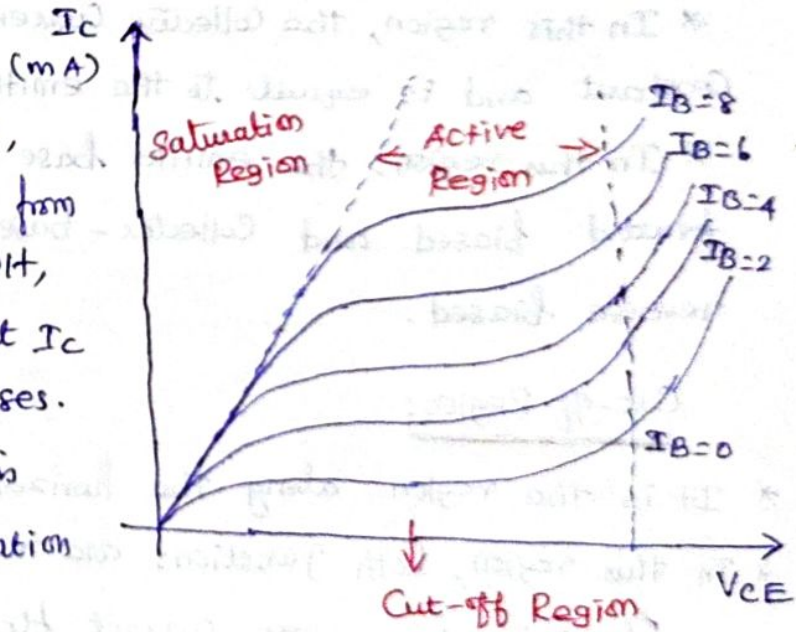
* Therefore, input resistance of a CE configuration is higher than that of CB configuration.

* Input resistance

$$\boxed{R_{in} = \frac{\Delta V_{BE}}{\Delta I_B}}$$ at constant V_{CE}

Output Characteristics :-

It is a curve between collector current and collector - emitter voltage at constant base current (I_B).



* From the graph, V_{CE} increases from zero to one volt, current I_c rapidly increases.

* This region is called Saturation region.

We know that $\frac{1}{1-\alpha} = \beta + 1 = \gamma$

Therefore $I_E = I_B(\beta+1) + I_{CBO}(\beta+1)$

3.15 COMPARISON OF CB, CE AND CC CONFIGURATION

No.	Property	CB	CE	CC
1.	Input resistance	Low $R_{in} = \frac{\Delta V_{EB}}{\Delta I_E}$ (about 100Ω)	Moderate $R_{in} = \frac{\Delta V_{BE}}{\Delta I_B}$ (about 750Ω)	High $R_{in} = \frac{\Delta V_{BC}}{\Delta I_B}$ (about 750)
2.	Output resistance	High $R_{out} = \frac{\Delta V_{CB}}{\Delta I_C}$ (about 450Ω)	Moderate $R_{out} = \frac{\Delta V_{CE}}{\Delta I_C}$ (about 45Ω)	Low $R_{out} = \frac{\Delta V_{CE}}{\Delta I_E}$ (about 25Ω)
3.	Current gain	1	High (100)	High (100)
4.	Voltage gain	About 150	About 150	Less than unity
5.	Phase shift between input and output voltage	0 (or) 360^0	180^0	0 or 360^0
6.	Leakage current	Very small	Very large	Very large
7.	Applications	Used in high frequency applications	Used in audio frequency applications	For impedance matching

Current Amplification Factor $\alpha = \frac{\Delta I_C}{\Delta I_E}$ $\beta = \frac{\Delta I_C}{\Delta I_B}$ $\gamma = \frac{\Delta I_E}{\Delta I_B}$

In a transistor amplifier with AC input signal, the ratio of change in output current to the change in input current is known as *current amplification factor.*

In CB configuration,

The current amplification factor $\alpha = \frac{\Delta I_C}{\Delta I_E}$ ... (1)

In CE configuration,

The current amplification factor $\beta = \frac{\Delta I_C}{\Delta I_B}$ ... (2)

* After this, Collector Current I_C becomes almost Constant, and independent with V_{CE}.

* This value of V_{CE} upto which Collector Current I_C Changes is Called the "knee Voltage".

* when $I_B = 0$, a small amount of Collector Current flows. It is called reverse saturation Current (I_{CEO}). Since the main Collector Current is zero, the transistor is said to be Cut-off region.

* It may be noted that, if V_{CE} is increased Continuously, then depletion region in CB junction increased, it increases I_C and operates the transistor in active region.

* Further increase in V_{CE} causes avalanche breakdown in CB junction as a result of this, enormous I_C will flow and the transistor enters into breakdown region.

* This Characteristics can be used to find Current gain β. It is defined as the ratio of change in output current (ΔI_C) to the change in input Current (ΔI_B).

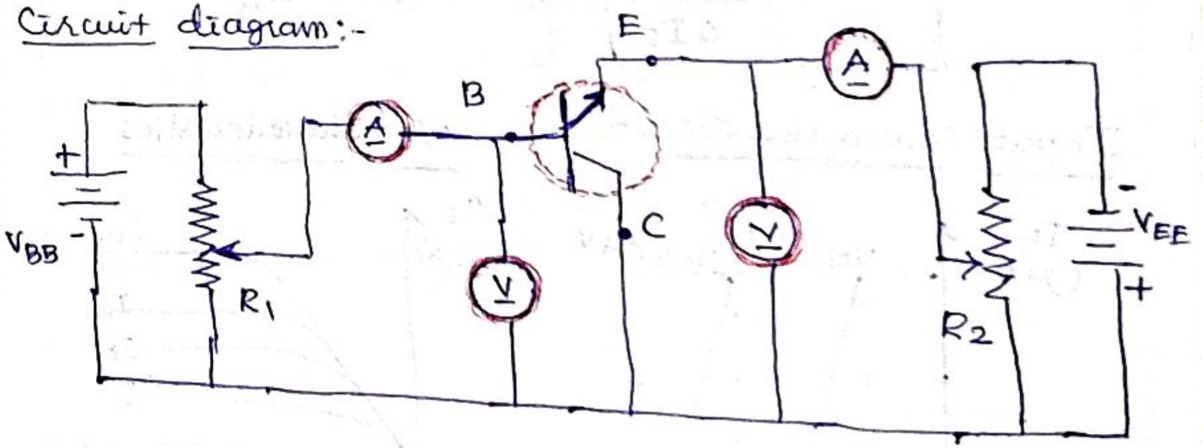
$$\boxed{\beta = \frac{\Delta I_C}{\Delta I_B}}$$

* output resistance $\boxed{R_{out} = \frac{\Delta V_{CE}}{\Delta I_C}}$ at Constant I_B.

COMMON COLLECTOR CONFIGURATION

In this Configuration, Collector terminal is Common to input and output.

Circuit diagram :-



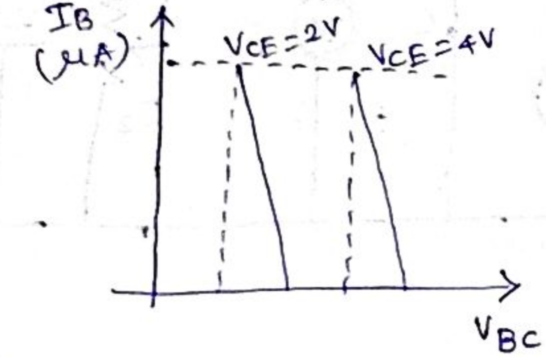
* The above diagram shows the circuit diagram of Common Collector Configuration.

* To determine the output characteristics, the base current I_B is kept constant. At a suitable value by adjusting the base-collector voltage and varying R_2 and the output current (Emitter current I_E) is measured.

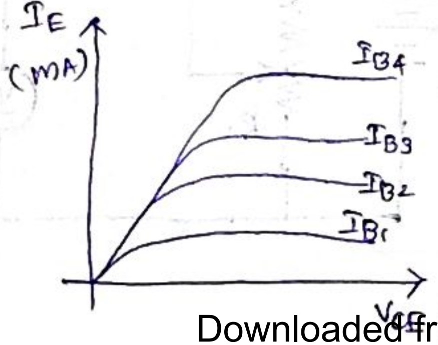
* Since I_C is approximately equal to I_E, thus Common Collector characteristics is identical to CE-configuration.

$$\boxed{R_{out} = \frac{\Delta V_{CE}}{\Delta I_E}} \text{ at constant } I_B.$$

Input characteristics:-



o/p Characteristics



* This characteristics may be used to find current amplification factor(γ).

$$\boxed{\gamma = \frac{\Delta I_E}{\Delta I_B}} \text{ at constant } V_{CE}$$

—x—x—x—x—

~~RECTIFIER~~

FIELD EFFECT TRANSISTOR:

* FET is a device in which the flow of current through the conducting region is controlled by electric field.

* Hence the name is called as Field Effect Transistor (FET).

* Current conduction is only by majority carriers. ∴ FET is said to be unipolar device.

* Based on construction, FET is classified into two types.

i) Junction Field Effect Transistor (JFET)

ii) Metal Oxide Semiconductor Field Effect Transistor (MOSFET).

i) JFET

Depending on the majority carriers, JFET is classified into two types.

i) N-Channel JFET

ii) P-Channel JFET

N-Channel JFET

- majority carriers are electrons.

P-Channel JFET

- majority carriers are holes.

N-Channel JFET:

It consists of N-type silicon base. The small piece of P-type materials is are attached to its sides forming P-N junction.

Source (S): Through which the majority carriers enters into N-Channel bar.

Drain (D): Through which the majority carriers leaving from N-channel bar.

Gate (G): Heavily doped P-type silicon is diffused on both sides of N-type bar. Both junctions are connected to form gate.

Channel: The region between two depletion region is said to be n-channel.

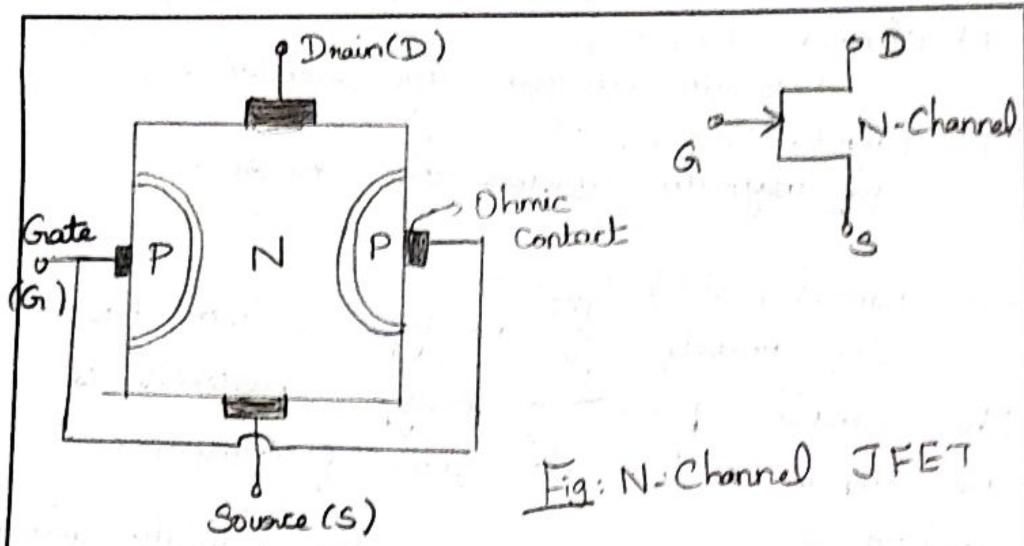


Fig: N-Channel JFET

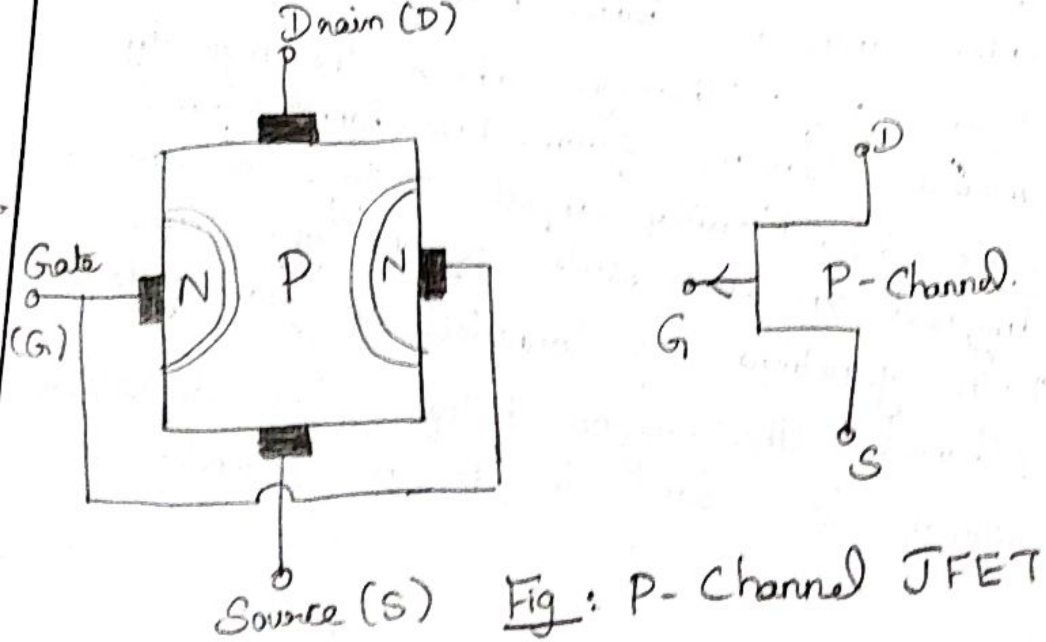


Fig: P-Channel JFET

It consists of N-type N-type silicon bar. The small pieces of P-type material are attached to its sides forming PN-junction.

Source (S): Through which the majority carriers enters into N-Channel bar.

Drain (D): Through which the majority carriers leaving from the N-channel bar.

Gate (G): Heavily doped P-type silicon is diffused on both side of N-type bar. Both junctions are connected to form gate.

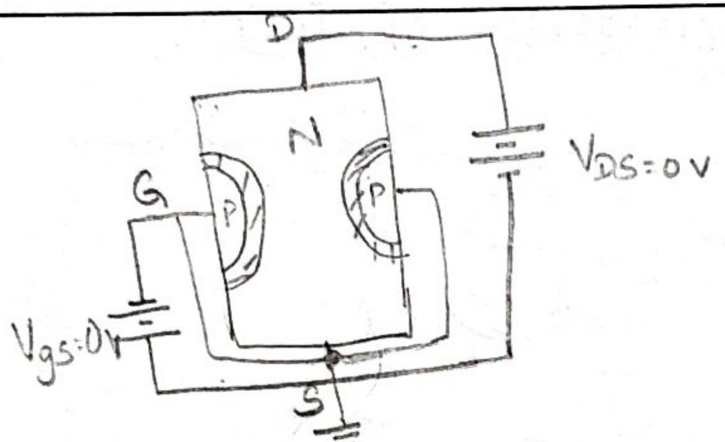
Channel:

The region between two depletion region is said to be N-channel.

Operation:

(i) When $V_{gs} = 0$ & $V_{DS} = 0$

When no voltage is applied between drain and source, and gate to source the thickness of depletion region is uniform, as shown in diagram.

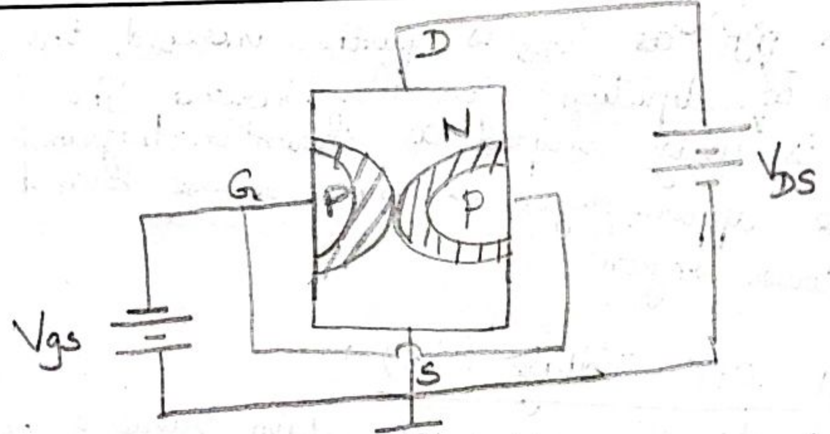


ii) When V_{DS} = 0V & V_{GS} is decreased from Zero:

In this case, PN junctions are reverse biased. Hence thickness of the depletion region is increased. As V_{gs} is further decreased from Zero, the reverse biased voltage of increases. Hence thickness of the depletion regions are also increased until the 2 depletion regions contact with each other. This condition in said to be cut-off.

Cut-off Voltage [$V_{gs(OFF)}$]:

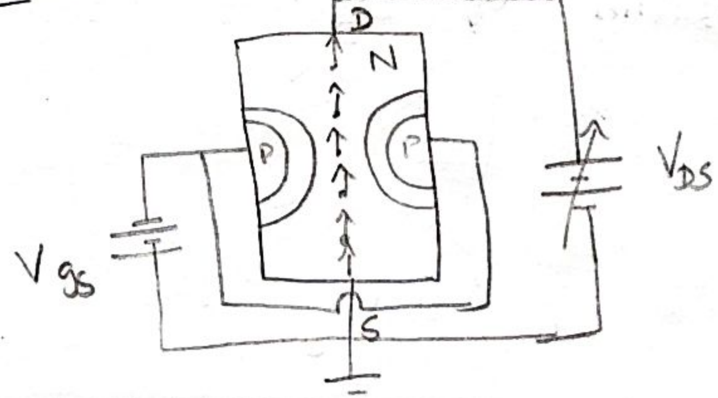
The V_{gs} value at which the I_D current ~~cutt~~ cut-off in JFET is called cut-off voltage (or) $V_{gs(OFF)}$



(iii) When V_{GS} = 0 and V_{DS} is increased from 0

As shown in diagram drain is positive with respect to source with V_{gs} = 0V.

Now the majority carriers (electrons) flow through the N-channel from source to drain. I_D (Drain current) flow from drain to source.



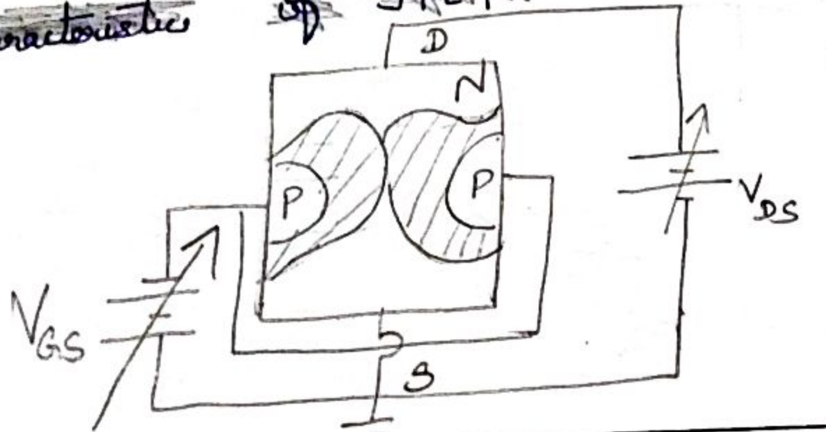
From fig. as V_{DS} is further increased, the thickness of depletion region also increases. The Channel is wedge shaped as shown in diagram. Hence, upper region is more reverse biased than lower region.

PINCH- OFF Voltage (V_P):

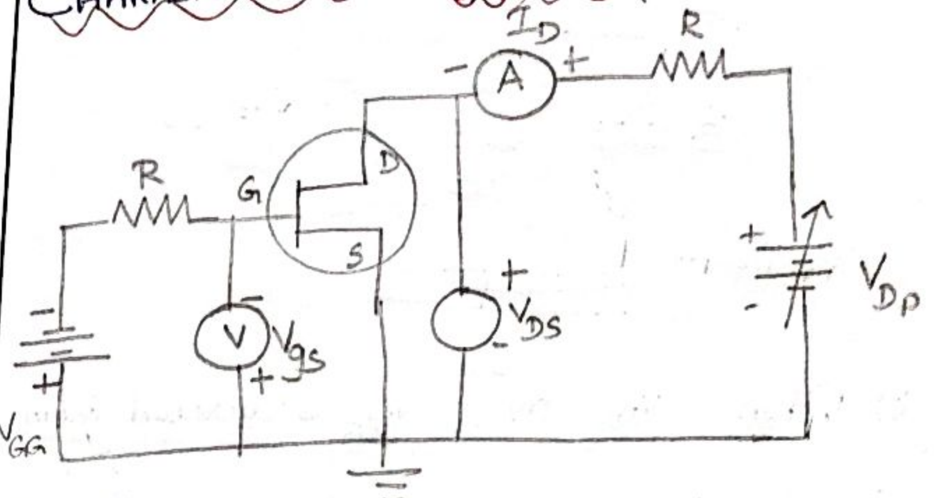
At the ~~constant~~ certain value of V_{DS}, the cross ~~val~~ sectional area (channel path) of JFET becomes minimum.

At this voltage the channel is said to be pinch off and the voltage (V_P) is ~~so~~ called pinch off voltage.

~~Characteristic of JFET~~:



CHARACTERISTICS OF JFET:

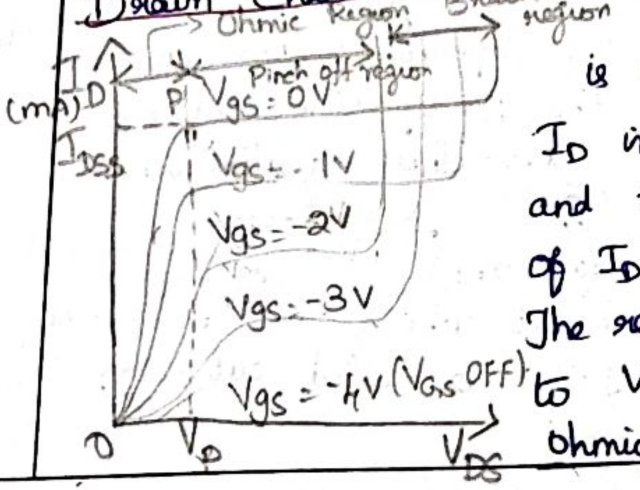


Two Types

(i) Drain Characteristics

(ii) Transfer Characteristics

Drain Characteristics:



As in graph, V_{DS} is increased from zero, I_D increases along V_P, and the rate of increase of I_D with V_{DS} decreases. The region from $V_{DS} = 0V$ to $V_{DS} = V_P$ is called ohmic region.

In Ohmic region, the drain to source resistance $\frac{\Delta V_{DS}}{\Delta I_D}$ is related to gate voltage V_{gs}

When $V_{DS} = V_P$, I_D becomes maximum. When V_{DS} is increased beyond V_P, the length of the pinch-off (or) saturation region increases

Hence, there is no further increase of I_D.

At a certain voltage corresponding to the point 'B', I_D suddenly increases.

This effect is due to the Avalanche multiplication of electrons caused by breaking of covalent bonds.

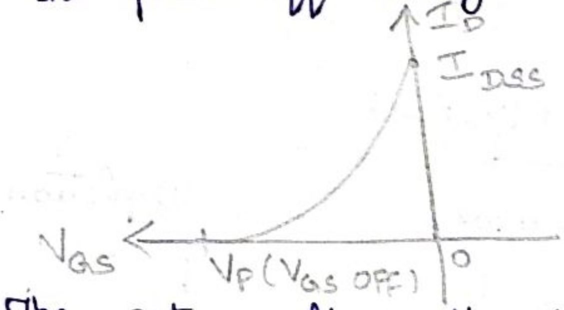
The drain voltage (V_{DS}) at which the breakdown occurs is denoted by BV_{DGO}

When $V_{gs} = 0V$, variation of I_D with V_{DS} is shown as curve OABC.

When V_{gs} is negative & V_{DS} is increased when gate is maintained at negative voltage ($V_{gs} = -1V$, $V_{gs} = -2V$, ...) The reverse voltage across the junction is further increased. Hence, I_D current decreases ~~then~~ above the pinch off voltage

Transfer Characteristics

For the transfer characteristics V_{DS} is kept constant at a suitable value greater than the pinch off voltage (V_P).



The gate voltage V_{GS} is decreased from zero till I_D is reduced to zero. The transfer characteristics I_D Vs V_{GS} is shown in graph.

Applications of JFET:

1) Used as an electronic switch.
2) Used as an amplifier
3) Used as chopper.
4) Used as buffer
5) Used in digital circuits.

METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR (MOSFET)

* MOSFETs are electronic devices used to switch or amplify voltage in circuits.

* It is a current controlled device.

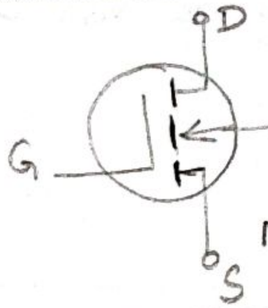
* It has 4 terminals

1) Soure 2) Gate 3) Drain 4. Body.

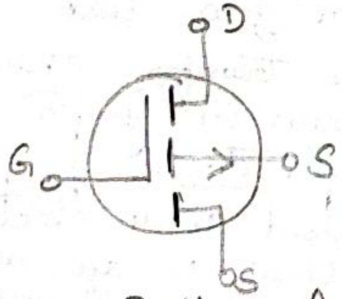
Types

- MOSFET
  - Enhancement mode
    - P-channel
    - N-channel
  - Depletion mode
    - P-channel
    - N-channel

Enhancement MOSFET :

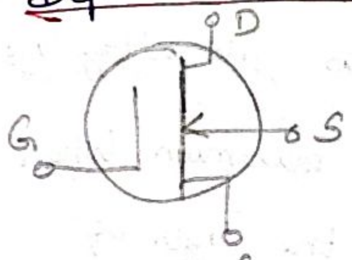


N-Channel

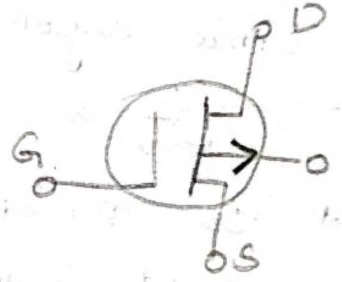


P-Channel

Depletion MOSFET



N-Channel

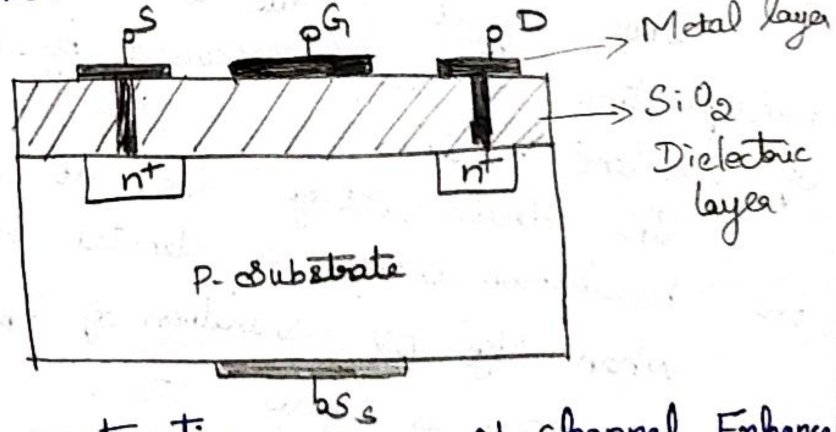


P-Channel

Enhancement MOSFET :

Construction :

The construction of an N-channel Enhancement MOSFET is shown in fig.



The construction of a N-channel Enhance MOSFET is shown in fig.

As there is no channel in E-MOSFET, the symbol is represented by the break line in the symbols.

Two heavily doped N$^+$ regions are diffused in lightly doped substrate of P-type Silicon substrate
D N$^+$ region is called the source (S) and the other is called Drain (D).

A thin insulating layer of SiO_2 is grown over the surface of the structure and holes are cut into the oxide layer, allowing contact with source and drain

Then a thin layer of metal aluminium is formed over the layer of SiO_2. This metal layer covers the entire channel region and it forms the gate (G).

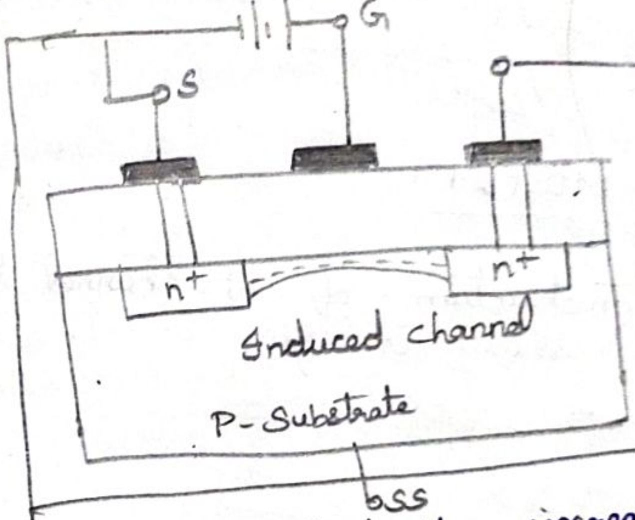
Operation :

The substrate and source are grounded and positive voltage is applied at the gate.

The positive charge on gate induces an equal negative charge on the substrate side between source and drain region.

The path is created between source and drain regions. The negative charge of electrons which are minority carriers in the P-type substrate forms an inversion layer.

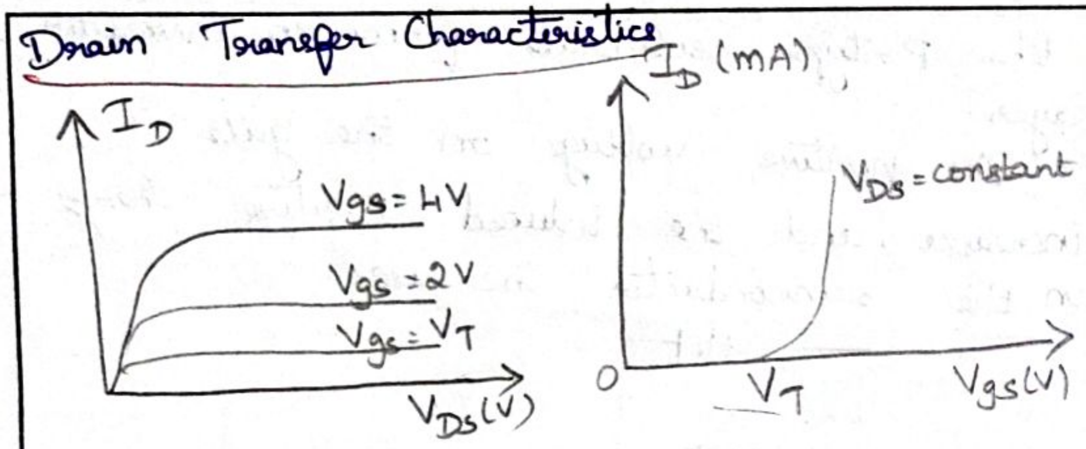
The positive voltage on the gate increases, and the induced negative charge on the semiconductor increases.



Hence, the conductivity increases and current flows from source to drain through the induced channel.

The drain current is enhanced by the positive gate voltage as in graph.

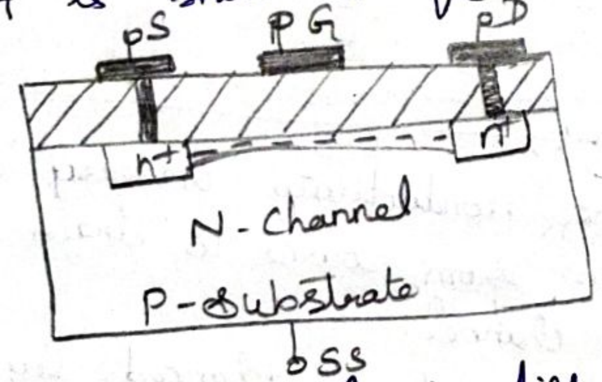
Drain Transfer Characteristics



DEPLETION MOSFET :

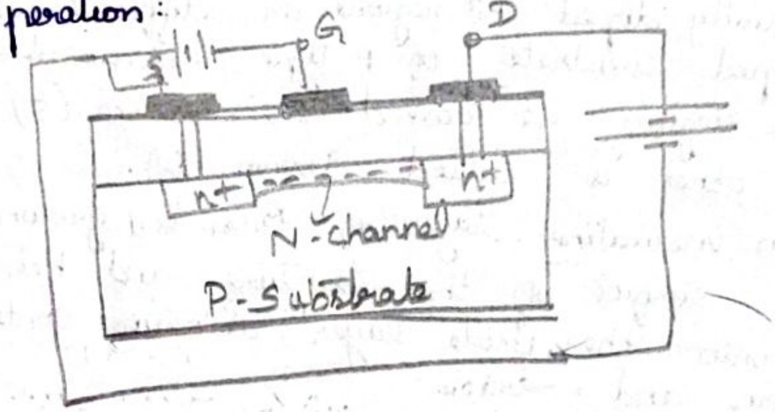
Construction:

The construction of N-channel depletion MOSFET is shown in fig.



When N-channel is diffused between the source and drain to the basic structure of Depletion MOSFET.

Operation:



When $V_{GS} = 0$;

The drain is positive w.r.t source the current flow (I_D) from source to drain through N-channel.

When $V_{GS} = -1V, -2V, \cdots$

The drain to source current flow is reduced, since the N-channel width is reduced.

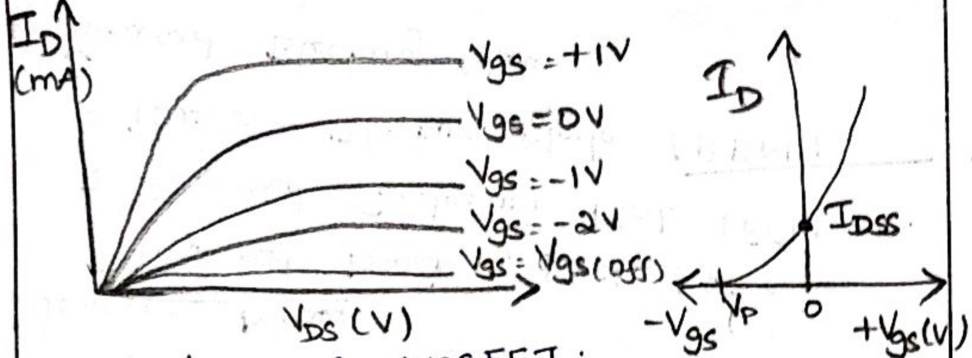
When $V_{GS} = V_{GS}$ (OFF) :

Between Source to drain the N-channel width becomes zero. So no I_D flows.

When $V_{gs} = +V, +2V, \cdots$

~~Based~~ When V_{gs} is positive voltage, this induces the increase the N-channel width between source to drain. So current flows through N-channel is also more. This is called Enhancement mode.

Drain Transfer Characteristics :



Applications of MOSFET :

1) Used as amplifier in radio frequency (RF) applications.

2) Used as passive element like resistor (R), Capacitor (C) & Inductor (L)

3) Used as Power Regulators

4) Used as High speed switch

5) Used as Electronic DC relay

SILICON CONTROLLED RECTIFIER (SCR)

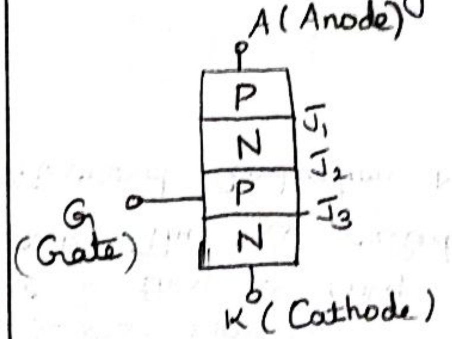
* A Silicon Controlled Rectifier is a four layer solid state current controlling device.

* It is also called as Semiconductor Controlled Rectifier.

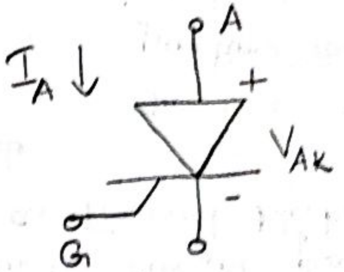
* SCRs are available from few voltages to several KV and few amperes to several KA.

* It is a unidirectional device.

* It is a bipolar device (both electrons & holes are charge carriers).



a) Structure of SCR



b) Symbol of SCR

* It is a 4 layer PNPN switching device with alternate layers of P & N semiconductor materials.

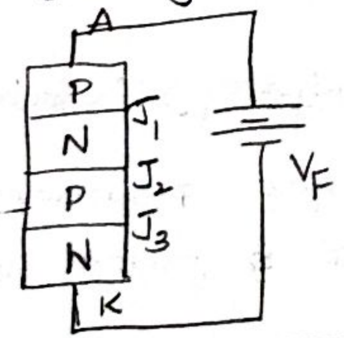
* It converts the AC signal to DC signal in controlled manner.

* For current conduction, J_1, J_2, J_3 must be forward biased.

Working Modes :

1. Forward Blocking Mode (FBM)
2. Forward Conduction Mode (FCM)
3. Reverse Blocking Mode (RBM)

1) Forward Blocking Mode :



$J_1 \rightarrow$ F·B

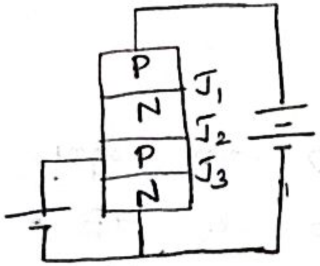
$J_2 \rightarrow$ R·B

$J_3 \rightarrow$ F·B

* J_1 & J_3 are forward biased, whereas J_2 is reverse biased.

* So there is only small current flowing through SCR. This is called as Forward blocking mode.

2) Forward Conduction Mode :



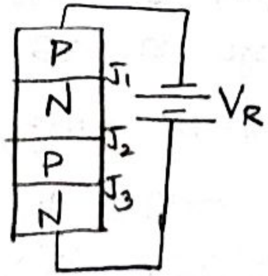
$J_1 \rightarrow$ F·B

$J_2 \rightarrow$ F·B

$J_3 \rightarrow$ F·B

In this, the three junctions are forward biased. Hence the forward voltage drops and current starts to increase linearly.

3) Reverse Blocking Mode:

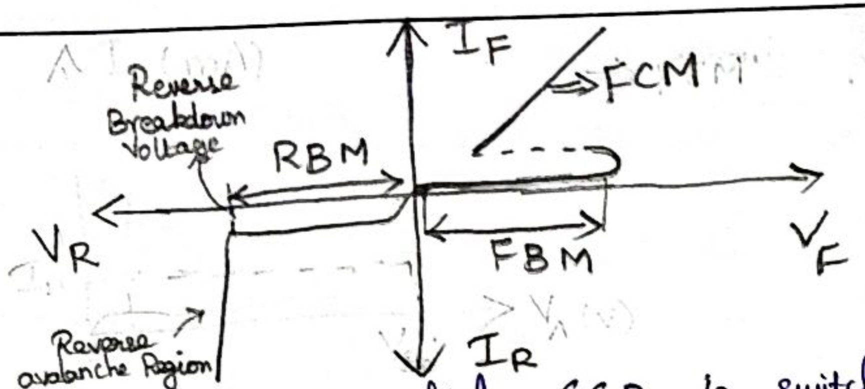


$J_1 \rightarrow$ R·B

$J_2 \rightarrow$ F·B

$J_3 \rightarrow$ R·B

In this, J_1 & J_3 are reverse biased. When V_R voltage is increased there is small amount of current flow. At one level, there is junctional breakdown and the current starts to increase suddenly rapidly.



The voltage at which SCR is switched ON can be controlled by verifying the gate current.

Applications of SCR

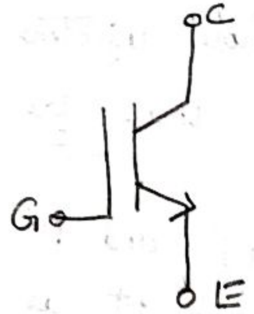
1.) Used in AC voltage stablizers.
2) Used as switch.
3) Used as choppers.
4) Used in inveater circuit.
5) Used in battery charger.
6) Used for speed controlled DC motor

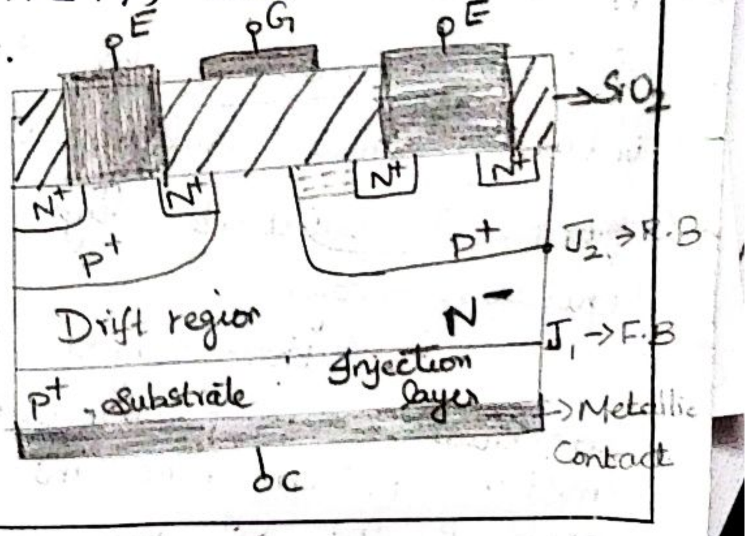
INSULATED GATE BIPOLAR TRANSISTOR (IGBT):

* IGBT is a multi-layer semiconductor structure with alternate p-type and n-type doping.

* IGBT is combination of both power MOSFET and power BJT. (MOSFET → at i/p side BJT → at o/p side)

* IGBT is also known as Metal Oxide Insulated Gate Transistor (MOSIGT), Conductively-Modulated Field Effect Transistor (COMFET), Gain Modulated FET (GMFET).





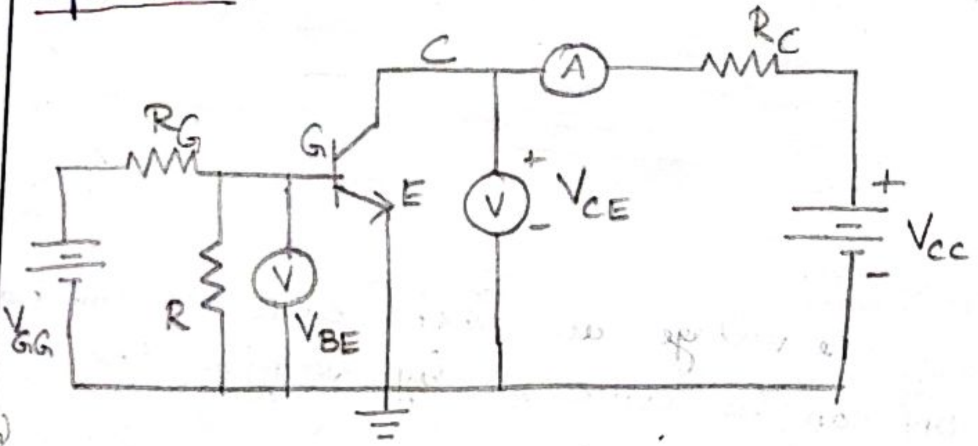
The N^+ layer substrate in drain is substituted in the IGBT by a P^+ layer substrate called collector.

When gate is positive with respect to emitter and emitter voltage greater than the threshold voltage of IGBT, a N-Channel is formed in the P-region as in power MOSFET. ($V_{GE} > V_T$, N-channel formed in P region)

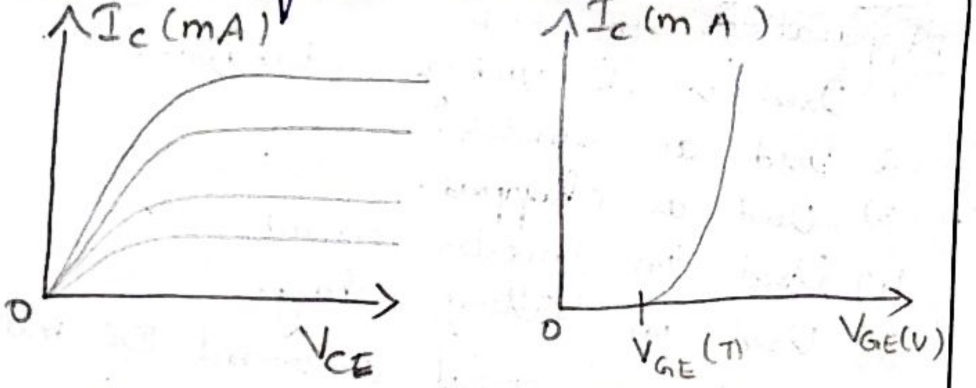
Thus N-channel short circuits the N^- region with N^+ emitter region. As electron movement in the N-channel in turn, causes substantial hole injection from P^+ substrate layer into that are epitaxial layer.

The three layers P^+, N^- and P^+ constitute a PNP transistor with P^+ as emitter, N^- as base and P as collector. Also P and N^+ layers constitute to NPN ansistor.

Operation :



VI & Transfer Characteristics :



Static V-I characteristics of IGBT is shown in figure. The plot of collector current, (I_C) Vs collector emitter voltage, V_{CE} for various values of gate emitter voltage, V_{GE}.

The shape of the output characteristics is similar to that of BJT. But here the controlling parameter is gate emitter voltage (V_{GE}). Hence IGBT is voltage-controlled device.

The transfer characteristics of an IGBT is a plot of collector current (I_C) Vs Gate-emitter voltage (V_{GE}) as in figure. This characteristics is similar to power MOSFET.

When $V_{GE} < V_T$, IGBT is in the off state. When the device is off, junction J_2 blocks forward voltage and in case reverse voltage appears across collector and emitter junction, J_1 blocks it.

Applications of IGBT:

1) Used in SMPS
2) Used in UPS
3) Used for speed control of AC and DC motors.

* Used in inverters.
* Used in e-automobile system

INVERTER:

The inverter is an electronic circuit that converts fixed DC supply to variable AC supply.

The inverter is used to run the AC loads through a battery.

Types:

1. Single Phase Inverter
2. Three Phase Inverter

Single Phase Inverter:

The single phase inverter is also called as half bridge rectifier. It converts DC supply to single phase AC supply. For this purpose two switching devices (SCR, MOSFET, IGBT) are used to convert DC to AC. Diodes and

Capacitors helps the circuit to operate smoothly.

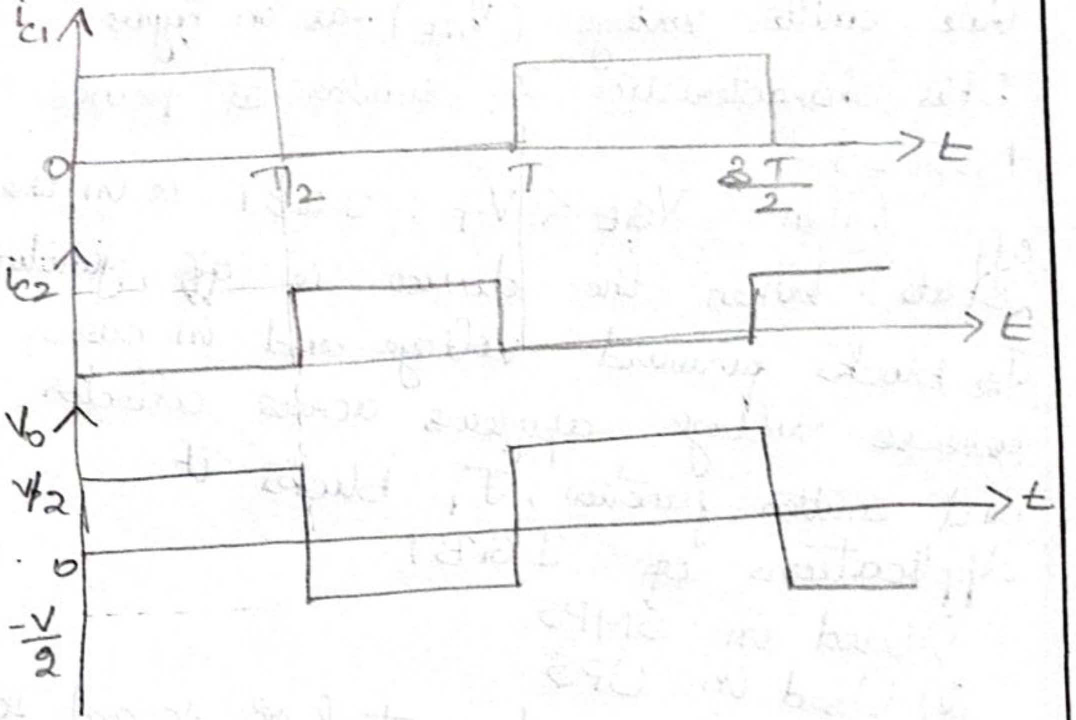
Working:

In the half bridge inverter, the output varies from $\frac{+V_s}{2}$ to $-\frac{V_s}{2}$. As shown in the circuit, two switching devices are connected in one common branch. The switching device may be SCR, MOSFET or IGBT.

Generally in inverter, MOSFET is commonly used as switching device. Two switches S_1 & S_2 are used. To obtain one cycle of alternating voltage each device is triggered at one time. The other being off at the same time. For example to obtain the positive cycle, of alternating supply, devices S_1 is turned ON, while S_2 is kept OFF.

Similarly to obtain negative cycle of alternating supply, device S_2 is turned ON while S_1 is kept off. The output wave is shown in figure.

Output Waveform:



As shown in the output waves, when S_1 is conducting from 0 to $\frac{T}{2}$, the output $+\frac{V_s}{2}$ is obtained. Similarly, the ~~output $\frac{V_s}{2}$~~ ~~is~~ when S_2 is conducting from $\frac{T}{2}$ to T, the output $\frac{V_s}{2}$ is obtained. Hence the output alternate between $+\frac{V_s}{2}$ to $-\frac{V_s}{2}$, which is regarded as alternating voltage. T is the total time period of the conduction of two devices.

It can be noted that the output voltage waveform is a stepped square waveform.

In inverters the stepped square waveform alternates between two values, which is considered as alternating voltage.

Applications :

1) Used in UPS
2) Used as speed control in DC motor.
3) Used in High Voltage DC systems. (HVDC).
4) Used in refrigeration compressors.
5) Used in solar power generation system.

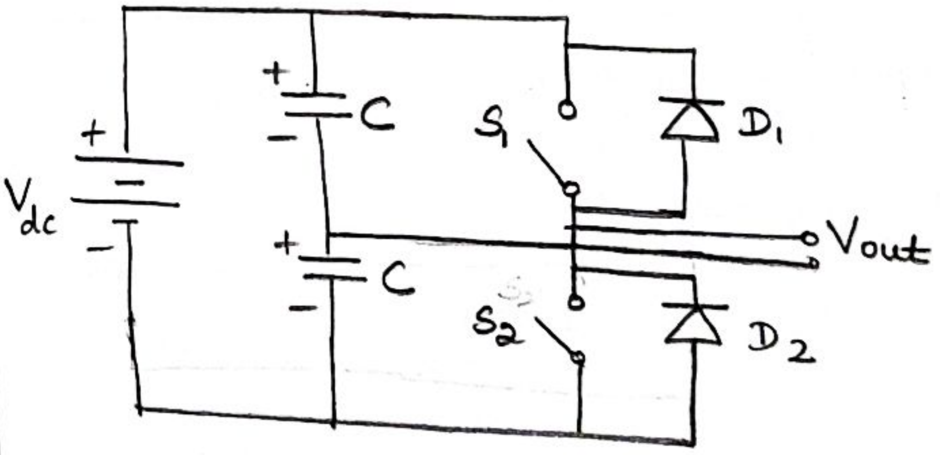


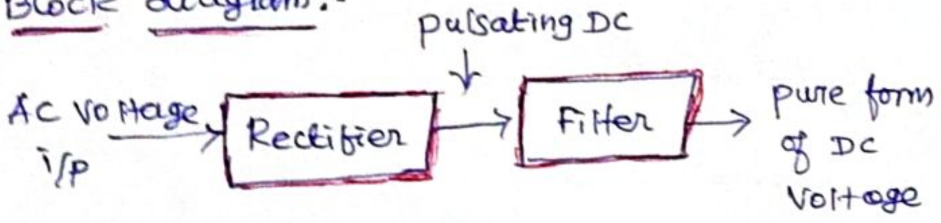
Fig: Single Phase Inverter

ansistor.

Rectifiers

* The Circuits which are used to Convert a-c voltage to d-c voltage are called 'Rectifiers'.

* **Block diagram:-**

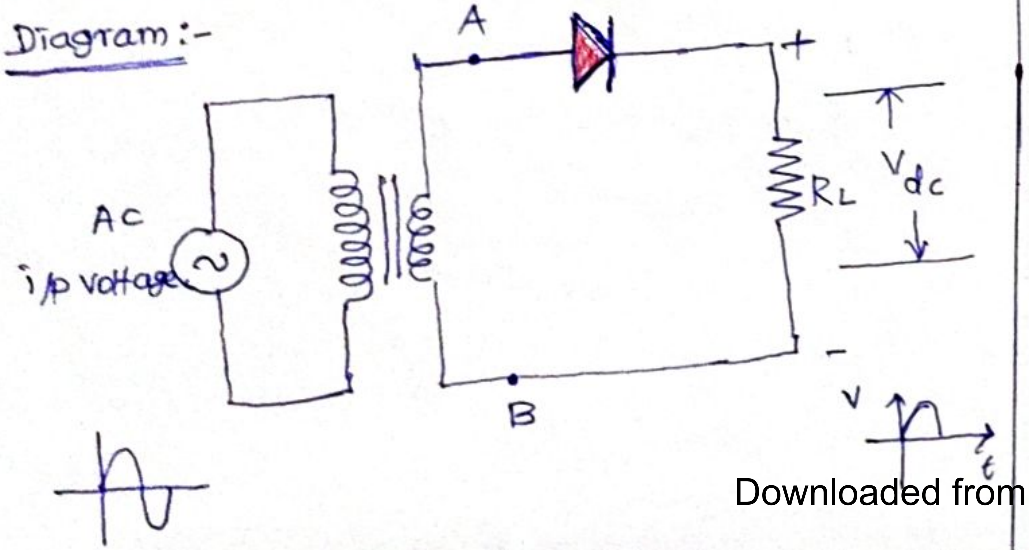


* **Types:-**

1. Half-wave Rectifier
2. Centre tapped full-wave rectifier
3. Full-wave bridge rectifier

Half-wave Rectifier:-

Diagram:-



* It consists of transformer, diode and load resistance.

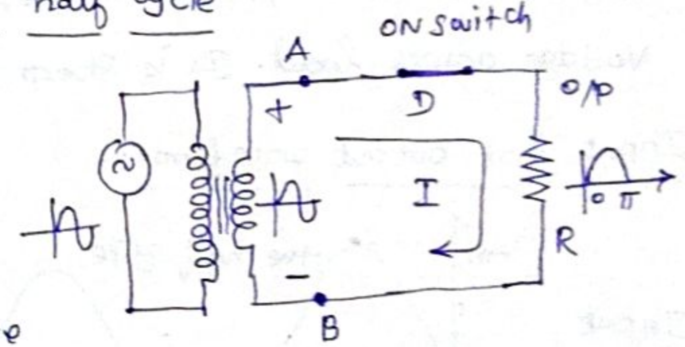
* Here, diode acts as a switch. i/e under forward biasing condition, it is a closed switch, and reverse biasing Condition, it is a open switch.

* The transformer used to step-down the a-c voltage (I/p Voltage).

* **Operation:-**

During +ve half cycle

* During +ve half-cycle of the input voltage (0 to π), the point 'A' is +ve with respect to point 'B'.

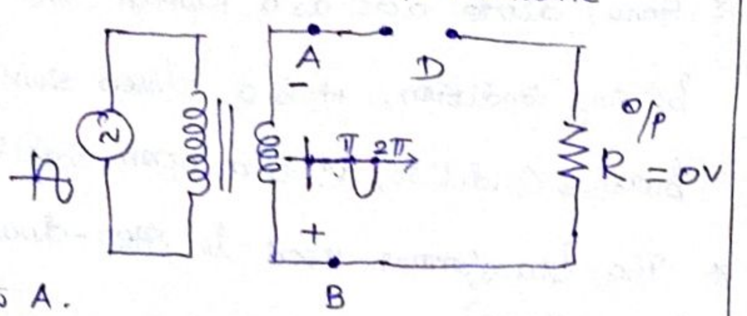


* During this period, the diode becomes forward biased and it acts as a (ON) closed switch.

* The entire positive input voltage is applied across the load. The current path is A-D-R-B. It is shown in figure above.

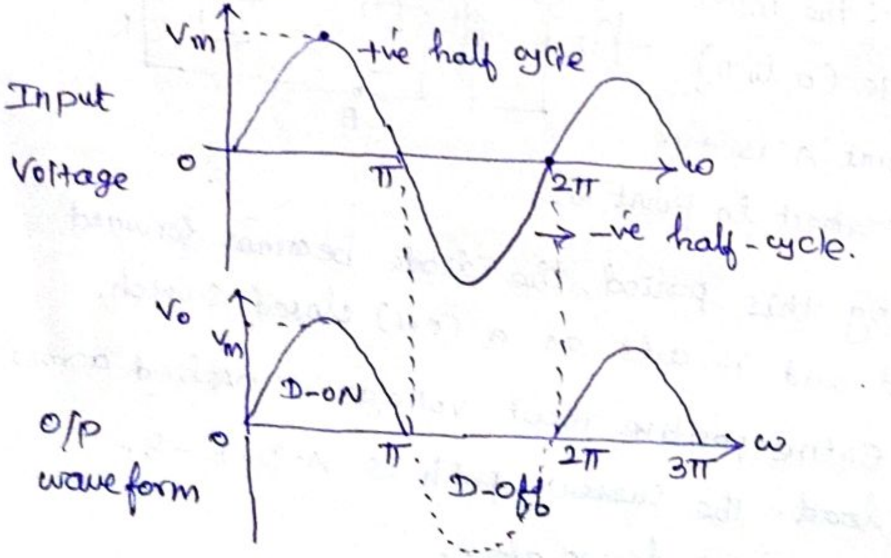
-* During negative half cycle:

* During this period (π-2π), the point 'B' is positive with respect to A.



* In this period, Diode 'D' becomes reverse biased. Then it acts as a open switch. So, there is no O/P Voltage across load. It is shown in above figure.

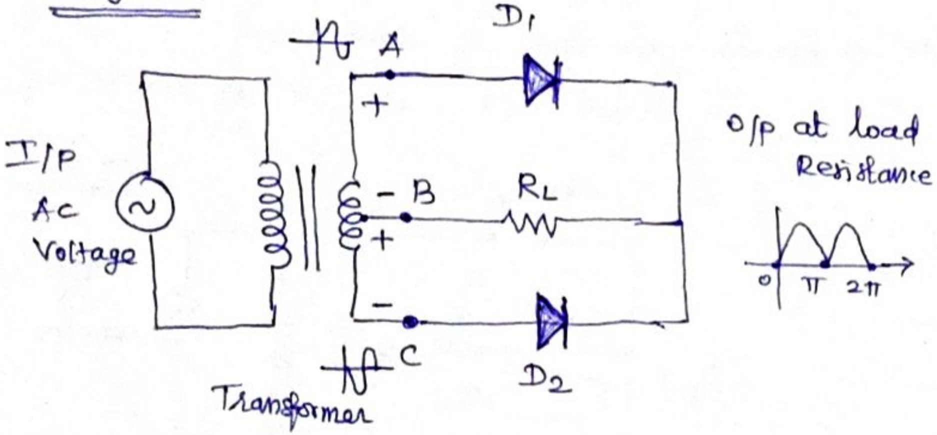
Input and output waveforms:-



During negative half cycle of the input voltage

II: Centre tapped Full-wave Rectifier

Diagram:-



* The fig, shows the centre tapped fullwave rectifier circuit.

* It consists of two diodes, one centre tapped trasformer and load resistance.

* By centre tapping, the secondary winding is divided into two equal parts.

* Thus, the voltage available between A to B is 180° out of phase with the voltage available between B to C.

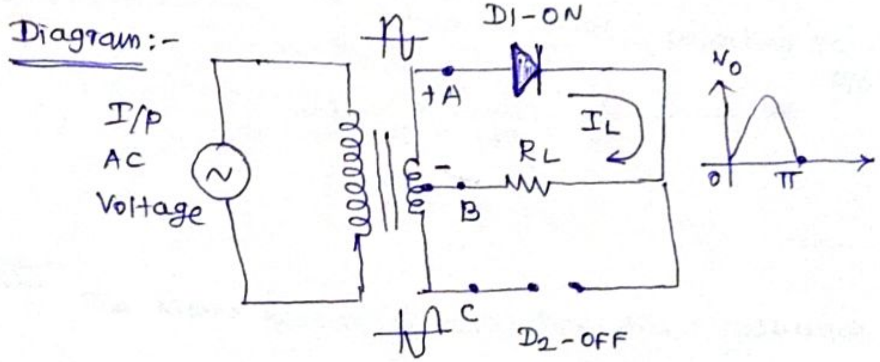
I/P at D2' Vin ↑

Operation:-

When an A.C voltage is applied to primary winding of transformer, as per the principle of transformer, it transfers the primary voltage into secondary voltage without changing its frequency.

* During positive half cycle:-

Diagram:-



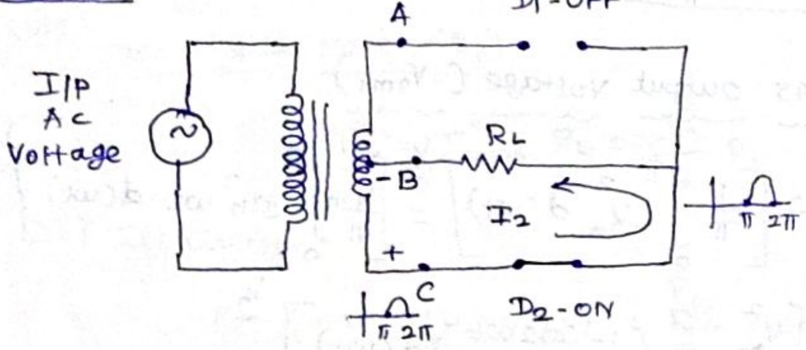
* During positive half cycle of the input voltage, the terminal 'A' is more positive than terminal 'C'. Thus diode 'D1' becomes more forward biase.. than diode D2.

* Thus, D1 → acts as a closed switch, D2 → acts as a open switch. The current path is A - D1 - RL - B.

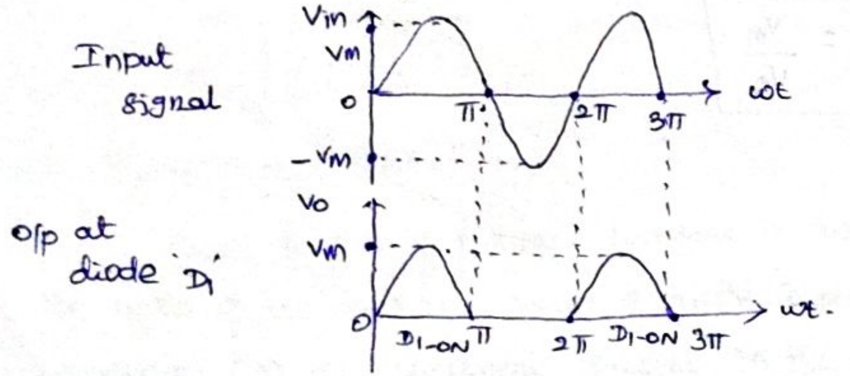
* Therefore, we can get positive output voltage across load. It is shown in below fig.

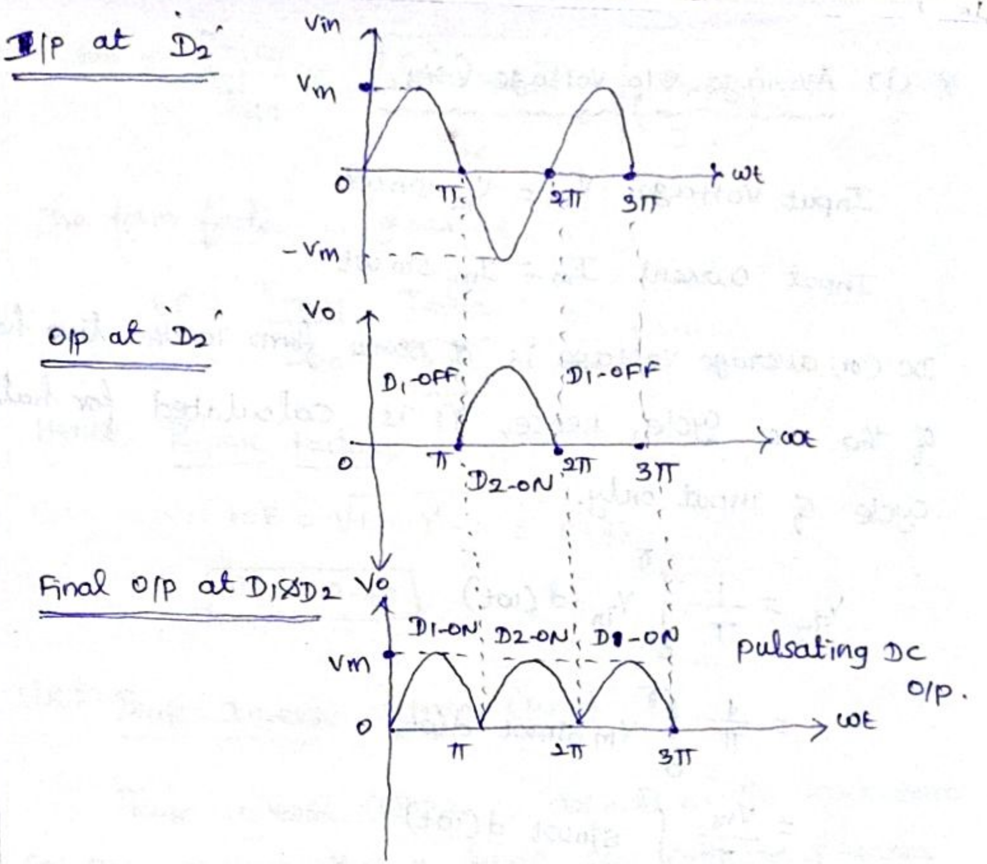
During negative half cycle of the input voltage the terminal 'C' is more positive than terminal 'A' thus, diode 'D_2' becomes more forward biased than diode D_1. Thus, diode D_2 acts as a closed switch and diode D_1 acts as a open switch.

Diagram:-



* Then the current path is C - D_2 - R_L - B. Here, we can get positive output voltage across load. It is shown in below fig. I/p & o/p wave forms.





Note:-

The Ripple frequency on a single phase full-wave rectifier is twice the supply frequency. i/e 2f.

* If the supply frequency is 50 Hz, the ripple frequency of this rectifier is 2×50 = 100 Hz.

* (i) Average o/p voltage (V_{dc})

Input voltage $V_{in} = V_m \sin\omega t$

Input current $I_{in} = I_m \sin\omega t$

DC (or) average voltage is of same form in the two hal of the ac cycle. Hence, it is calculated for half cycle of input only.

$$V_{dc} = \frac{1}{T}\int_0^{\pi} V_{in}\, d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t\, d(\omega t)$$

$$= \frac{V_m}{\pi}\int_0^{\pi} \sin\omega t\, d(\omega t)$$

$$= \frac{V_m}{\pi}\left(-\cos\omega t\right)_0^{\pi} = \frac{V_m}{\pi}\left[-\cos \; -(-\cos 0)\right]$$

$$V_{dc} = \frac{V_m}{\pi}\left[1+1\right] = \frac{2V_m}{\pi}$$

$$\boxed{V_{dc} = \frac{2V_m}{\pi}}$$

(ii) Average input current (I_{dc})

$$I_{dc} = \frac{1}{T}\int_0^{T} I_{in}\, d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t\,(d(\omega t))$$

$$\boxed{I_{dc} = \frac{2I_m}{\pi}}$$

(iii) RMS output voltage (V_{rms})

$$V_{rms} = \left[\frac{1}{\pi}\int_0^{\pi} V_{in}^2\, d(\omega t)\right]^{1/2} = \left[\frac{V_{in}^2}{\pi}\int_0^{\pi} \sin^2\omega t\, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{V_m^2}{\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)\right]^{1/2}$$

$$= \left[\frac{V_m^2}{\pi}\left(\omega t - \frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]^{1/2}$$

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

(iv) RMS output current :- (I_{orms})

$$I_{orms} = \frac{V_{orms}}{R_L} = \frac{V_m}{\sqrt{2} \cdot R_L} = \frac{I_m}{\sqrt{2}} \quad \left(\because I_m = \frac{V_m}{R_L}\right)$$

(v) Dc output power :- (P_{dc})

$$P_{dc} = I_{dc}^2 R_L = \frac{4 I_m^2}{\pi^2} \cdot R_L$$

(vi) Ac Input power (P_{in})

$$P_{in} = I_{orms}^2 \cdot R_L = \frac{I_m^2}{2} \cdot R_L$$

(vii) Efficiency.

$$\text{Rectifier efficiency} (\eta) = \frac{P_{dc}}{P_{ac}} \times 100$$

$$= \frac{\frac{4 I_m^2}{\pi^2} \cdot R_L}{\frac{I_m^2}{2} \cdot R_L} = \frac{8}{\pi^2} \times 100$$

$$\boxed{\eta = 81\%.}$$

(viii) Ripple factor (RF)

Ripple factor of fullwave rectifier is defined as the ratio of ac (or) rms value of ripple component to average (or) dc component present in the output.

$$RF = \frac{I_{orms}}{I_{dc}} = \frac{\sqrt{I_{orms}^2 - I_{dc}^2}}{I_{dc}} = \sqrt{\left(\frac{I_{orms}}{I_{dc}}\right)^2 - 1}$$

The form factor is given by,

$$FF = \frac{I_{orms}}{I_{dc}} = \frac{I_m/\sqrt{2}}{\frac{2 I_m}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Hence, Ripple Factor,

$$RF = \sqrt{(1.11)^2 - 1} = 0.48$$

$$\boxed{RF = 0.48}$$

(ix) Peak-Inverse Voltage (PIV)

Peak inverse voltage is defined as the maximum (or) peak voltage that a diode can withstand under reverse biased condition.

PIV- calculated as follows:-

Assume, positive half cycle of input, D_1 is Conduction and D_2 is off. The maximum voltage is Vm droped at R_L. similarly for negative half cycle, D_1 is OFF, D_2 is ON. So o/p is again Vm.

So $\boxed{PIV = V_m + V_m = 2V_m}$

(x) Transformer utilisation Factor (TUF):

In this case, TUF is found by considering primary and secondary VA rating separately and take the average of two halves.

TUF for secondary (or) secondary utilisation factor SUF can be calculated as,

$$SUF = (TUF)_s = \frac{P_{dc}}{P_{ac}\ \text{rated}}$$

$$= \frac{I_{dc}^2 \cdot R_L}{V_{orms} \cdot I_{orms}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\frac{I_m \cdot I_m \cdot R_L}{2}}$$

$$= \frac{4I_m^2/\pi^2}{I_m^2/2} = \frac{8}{\pi^2} \times 100 = 81.1\%$$

$$\boxed{SUF = (TUF)_s = 81.1\%}$$

Transformer primary supplies input for both half cycle of input, thus,

$$TUF \text{ for primary} = (TUF)_p$$

$$= 2 \times 28.8\% = 57.2\%$$

$$\% \ TUF = \frac{(TUF)_p + (TUF)_s}{2} = 69.15\%$$

$$\boxed{TUF = 69.15\%}$$

Advantages:-

1. The output voltage and transformer efficiency are high.
2. Low ripple factor
3. High transformer utilisation factor.

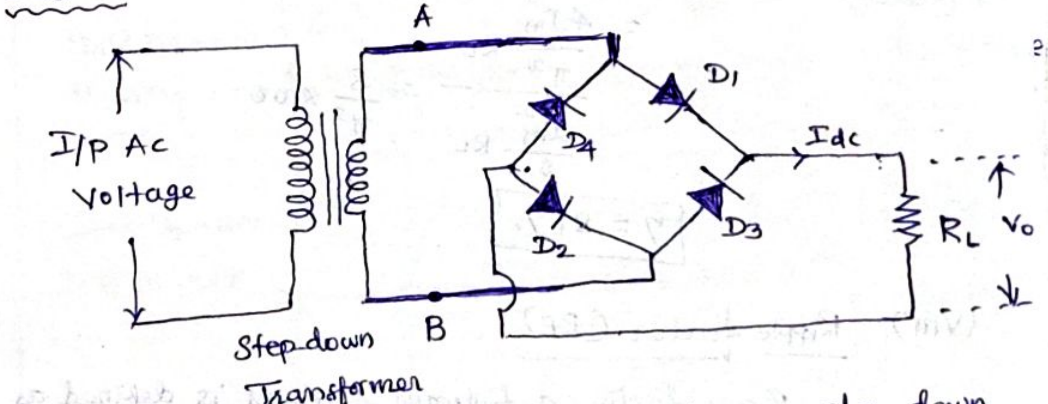
Dis-advantages:-

1. Usage of additional diode and bulky transformer is needed, and hence increase in cost
2. The peak inverse voltage of diode is high (2Vm).

* * *

FULL WAVE BRIDGE RECTIFIER

Diagram:-

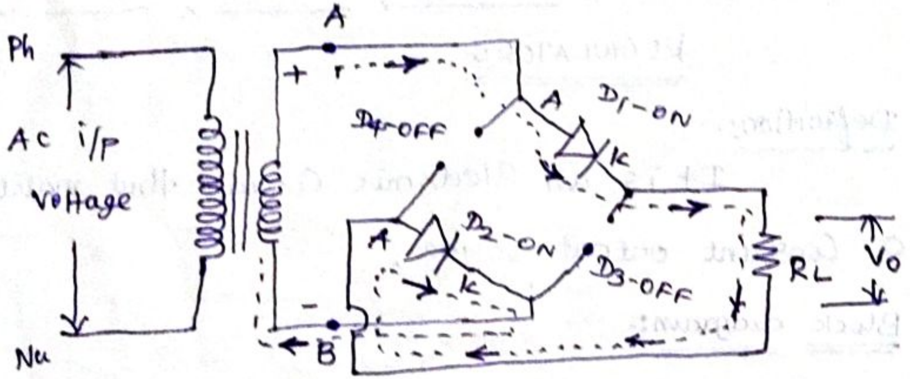


* Bridge rectifier diagram consists of one-step down transformer, 4-pn-Junction diode, and one load resistor (RL).

Operation:-

* During the positive half cycle of the input voltage, the terminal 'A' is positive with respect to 'B'. Thus, diodes D_1 & D_2 are in forward biasing and D_3 & D_4 are in reverse biasing.

* Then the current flow is shown in below fig.

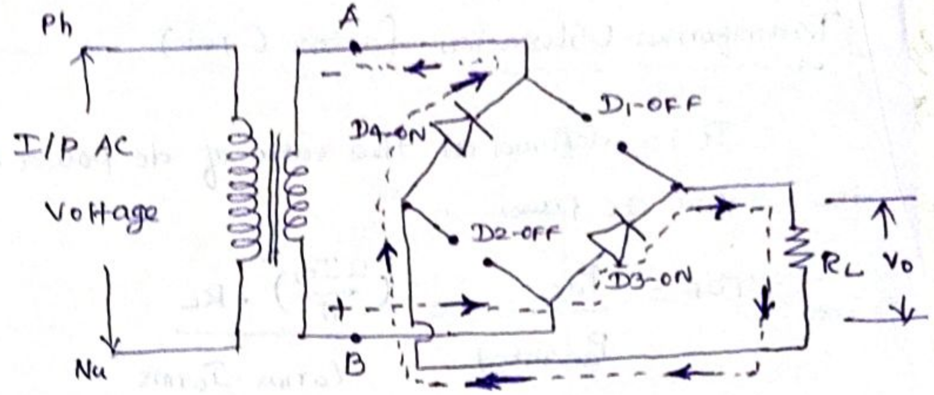


* During negative half cycle of the input voltage, the terminal 'B' is positive with respect to 'A'.

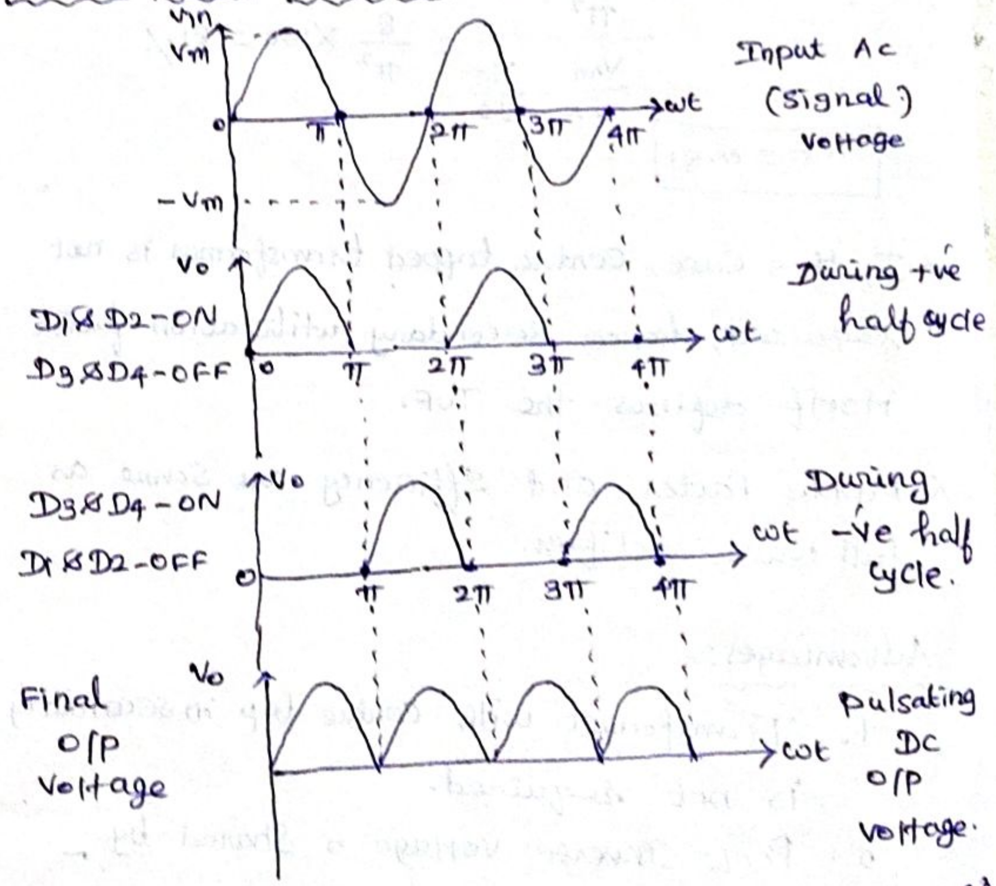
* Thus, diodes D_3 and D_4 are forward biased and diodes D_1 and D_2 are reverse biased.

* The current path is B - D_3 - R_L - D_4 - A.

* It is shown in below fig.



Input & output waveforms:-



Transformer Utilisation factor (TUF)

It is defined as the ratio of dc power to the rated ac power.

$$\text{i.e } TUF = \frac{P_{dc}}{P_{ac\ rated}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{V_{rms} \cdot I_{rms}}$$

$$= \frac{\frac{4I_m^2}{\pi^2} \cdot R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}} = \frac{8}{\pi^2} \times 100 = 81\%$$

$$\boxed{TUF = 0.81}$$

* In this case, centre tapped transformer is not required, hence secondary utilization factor itself defines the TUF.

* Ripple Factor and Efficiency are same as full wave rectifier.

Advantages:-

1. Transformer with centre tap in secondary is not required.
2. Peak Inverse voltage is shared by D1, D2 and D3, D4 combinations equivally.
3. Better transformer utilization factor.

Dis-advantages:-

1. Additional 2-diodes are required.
2. Efficiency is slightly reduced than the FWR.

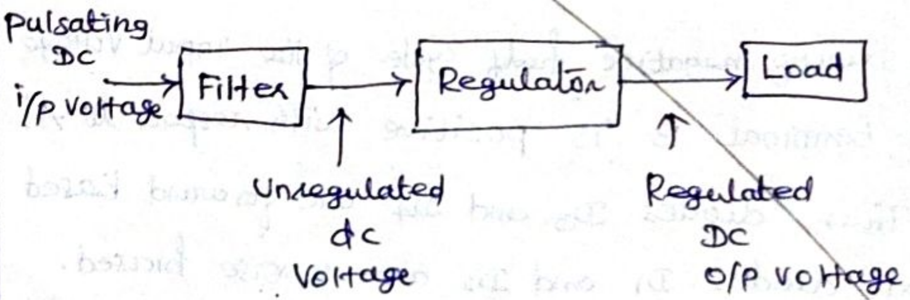
—— x —— x —— x —— x —— x ——

REGULATORS

Definition:

It is an Electronic Circuit that maintains a constant output voltage.

Block diagram:-



The reverse voltage appearing across the reverse biased diodes is $2V_m$ but two diodes are sharing it.

Hence PIV rating of the diode is V_m and not $2V_m$ as in case of full wave rectifier.

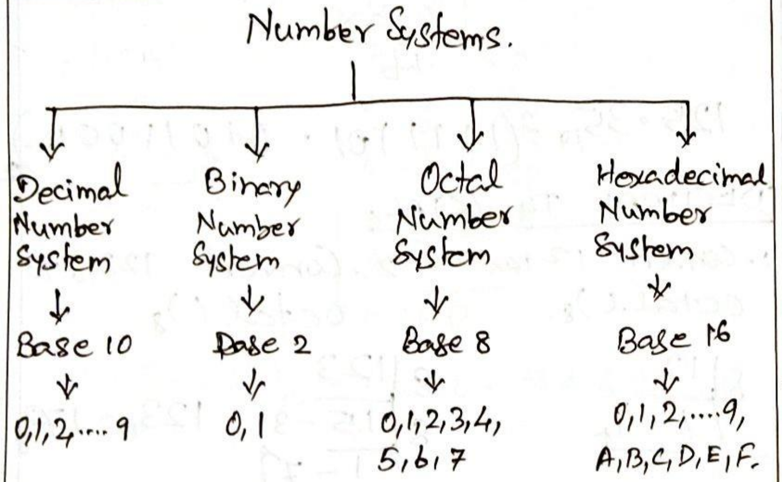
3.26. COMPARISON OF HWR, FWR & BRIDGE RECTIFIER

Parameter	**Half wave Rectifier**	**Full wave Rectifier**	**Bridge Rectifier**
No. of diodes	One	Two	Four
Ripple Frequency	f_s	$2\ f_s$	$2f_s$
PIV	V_m	$2\ V_m$	V_m
I_m	$\frac{V_m}{R_f+R_L}$	$\frac{V_m}{R_f+R_L}$	$\frac{V_m}{2R_f+R_L}$
Average current (I_{dc})	I_m/π	$2I_m/\pi$	$2I_m/\pi$
RMS value	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
DC value (V_{DC})	$\frac{V_m}{\pi}-I_{dc}R_f$	$\frac{2V_m}{\pi}-I_{dc}R_f$	$\frac{2V_m}{\pi}-2I_{dc}R_f$
Ripple factor	1.21	0.482	0.482
P_{DC}	$I_{dc}^2R_L$	$I_{dc}^2R_L$	$I_{dc}^2R_L$
P_{AC}	$I_{RMS}^2(R_f+R_L)$	$I_{RMS}^2(R_f+R_L)$	$I_{RMS}^2(2R_f+R_L)$
Efficiency (η)	40.5%	81.0%	81.0%
TUF	0.286	0.692	0.812

UNIT-IV DIGITAL ELECTRONICS.

Review of number systems, binary codes, error detection and correction codes, combinational logic - representation of logic functions - SOP and POS forms, K-map representations - minimization using K-maps (Simple problems only).

REVIEW OF NUMBER SYSTEMS.



Decimal	Binary	Octal	Hexadecimal
0	0	0	0
1	1	1	1
2	10	2	2
3	11	3	3
4	100	4	4
5	101	5	5
6	110	6	6
7	111	7	7
8	1000	10	8
9	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F

NUMBER CONVERSIONS.

DECIMAL TO BINARY.

1. Convert 43_{10} to Binary.

$$\begin{array}{r|l} 2 & 43 \\ 2 & 21 - 1 \\ 2 & 10 - 1 \\ 2 & 5 - 0 \\ 2 & 2 - 1 \\ & 1 - 0 \end{array}$$

$43_{10} = 101011_2$

2. Convert 13_{10} to Binary

$$\begin{array}{r|l} 2 & 13 \\ 2 & 6 - 1 \\ 2 & 3 - 0 \\ & 1 - 1 \end{array}$$

$13_{10} = 1101_2$

3. Gnvert 12.25_{10} to Binary.

$$\begin{array}{r|l} 2 & 12 \\ 2 & 6 - 0 \\ 2 & 3 - 0 \\ & 1 - 1 \end{array}$$

0.25×2

0.50×2

1.00

$12.25_{10} = 1100.01_2$

4. Convert 125.35_{10} to Binary.

$$\begin{array}{r|l} 2 & 125 \\ 2 & 62 - 1 \\ 2 & 31 - 0 \\ 2 & 15 - 1 \\ 2 & 7 - 1 \\ 2 & 3 - 1 \\ & 1 - 1 \end{array}$$

0.35×2

0.70×2

1.40×2

0.80×2

1.60×2

1.20×2

0.40×2

0.8×2

1.6

$125.35_{10} = (1111101.01011001\ldots)_2$

DECIMAL TO OCTAL.

1. Convert 12_{10} to octal $(\ )_8$.

$$\begin{array}{r|l} 8 & 12 \\ & 1 - 4 \end{array}$$

$12_{10} = 14_8$

2. Convert 123_{10} to octal $(\ )_8$.

$$\begin{array}{r|l} 8 & 123 \\ 8 & 15 - 3 \\ & 1 - 7 \end{array}$$

$123_{10} = 173_8$

3 . Convert 45.96_{10} to Octal $(\ )_8$.

$$8 \,|\, 45 \qquad 5 - 5$$

$$0.96 \times 8$$

$$\leftarrow 7.68 \times 8$$

$$\leftarrow 3.84 \times 8$$

$$\leftarrow 7.62$$

$$(45.96)_{10} = (55.737\ldots)_8.$$

4. Convert $(158.45)_{10}$ to octal $(\ )_8$.

$$8 \,|\, 158$$

$$8 \,|\, 19 - 6$$

$$2 - 3$$

$$0.45 \times 8$$

$$3.60 \times 8$$

$$4.80 \times 8$$

$$6.40 \times 8$$

$$3.20 \times 8$$

$$1.60$$

$$(158.45)_{10} = (236.34631\ldots)_8$$

DECIMAL TO HEXADECIMAL.

1. Convert 125_{10} to Hexadecimal $(\ )_{16}$.

$$16 \,|\, 125$$

$$7 - ⑬ - D$$

$$125_{10} = 7D_{16}$$

2. Convert 450_{10} to Hexadecimal $(\ )_{16}$.

$$16 \,|\, 450$$

$$16 \,|\, 28 - 2$$

$$1 - ⑫ - C$$

$$450_{10} = 1C2_{16}$$

3. Convert 157.25_{10} to Hexadecimal $(\ )_{16}$.

$$16 \,|\, 157$$

$$9 - ⑬\ D$$

$$0.25 \times 16$$

$$\leftarrow 4.00$$

$$157.25_{10} = 9D.4_{16}$$

4. Convert 255.132_{10} to Hexadecimal $(\ )_{16}$.

$$16 \,|\, 255$$

$$⑮ - ⑮ - F$$

$$F$$

$$0.132 \times 16$$

$$\leftarrow 2.112 \times 16$$

$$\leftarrow 1.792 \times 16$$

$$\leftarrow C \leftarrow ⑫.672$$

$$(255.132)_{10} = (FF.21C\ldots)_{16}$$

2

BINARY TO DECIMAL

1. Convert 1011_2 to Decimal $(\ )_{10}$.

1011

$\rightarrow 1\times2^0 = 1$

$\rightarrow 1\times2^1 = 2$

$\rightarrow 0\times2^2 = 0$

$\rightarrow 1\times2^3 = 8$

11_{10}

$1011_2 = 11_{10}$

2. Convert 10110_2 to Decimal $(\ )_{10}$.

10110

$\rightarrow 0\times2^0 = 0$

$\rightarrow 1\times2^1 = 2$

$\rightarrow 1\times2^2 = 4$

$\rightarrow 0\times2^3 = 0$

$\rightarrow 1\times2^4 = 16$

22

$10110_2 = 22_{10}.$

3. Convert $111\cdot01_2$ to Decimal $(\ )_{10}$.

111

$\rightarrow 1\times2^0 = 1$

$\rightarrow 1\times2^1 = 2$

$\rightarrow 1\times2^2 = 4$

7

0·01

$\rightarrow 1\times2^{-2} = 0\cdot25$

$\rightarrow 0\times2^{-1} = 0$

0·25

$111\cdot01_2 = 7\cdot25_{10}$

4. Convert $1010\cdot101_2$ to Decimal $(\ )_{10}$.

1010

$\rightarrow 0\times2^0 = 0$

$\rightarrow 1\times2^1 = 2$

$\rightarrow 0\times2^2 = 0$

$\rightarrow 1\times2^3 = 8$

10

0·101

$\rightarrow 1\times2^{-3} = 0\cdot125$

$\rightarrow 0\times2^{-2} = 0\cdot00$

$\rightarrow 1\times2^{-1} = 0\cdot5$

0·625

$(1010\cdot101)_2 = (10\cdot625)_{10}$

OCTAL TO DECIMAL

1. convert 123_8 to Decimal $(\ )_{10}$.

123

$\rightarrow 3\times8^0 = 3$

$\rightarrow 2\times8^1 = 16$

$\rightarrow 1\times8^2 = 64$

83

$123_8 = 83_{10}$

2. Convert 765_8 to Decimal $(\ )_{10}$.

765

$\rightarrow 5\times8^0 = 5$

$\rightarrow 6\times8^1 = 48$

$\rightarrow 7\times8^2 = 448$

501

$765_8 = 501_{10}$

3. Convert $123 \cdot 45_8$ in to Decimal $(\,)_{10}$

123
↳ $3 \times 8^0 = 3$
↳ $2 \times 8^1 = 16$
↳ $1 \times 8^2 = 64$
83

$0 \cdot 45$ ~~×8~~
↳ $5 \times 8^{-2} = 0 \cdot 078$
↳ $4 \times 8^{-1} = 0 \cdot 5$
$0 \cdot 578$

$123 \cdot 45_8 = 83 \cdot 0 \cdot 578125_{10}$

4. Convert 77.22_8 into Decimal $(\,)_{10}$.

77
↳ $7 \times 8^0 = 7$
↳ $7 \times 8^1 = 56$
63

$0 \cdot 22$
↳ $2 \times 8^{-2} = 0 \cdot 03125$
↳ $2 \times 8^{-1} = 0 \cdot 25$
$0 \cdot 28125$

~~$77 \cdot 22_8 = 6368 \cdot 28125_{10}$~~ .

$77 \cdot 22_8 = 63 \cdot 28125_{10}.$

HEXADECIMAL TO DECIMAL

1. Convert $A2_{16}$ in Decimal $(\,)_{10}$.

A 2
↳ $2 \times 16^0 = 2$
↳ $A(10) \times 16^1 = 160$
162

$A2_{16} = 162_{10}$

2. Convert $C5_{16}$ into Decimal $(\,)_{10}$

C 5
↳ $5 \times 16^0 = 5$
↳ $C(12) \times 16^1 = 192$
197

$C5_{16} = 197_{10}$

3. Convert $1B \cdot 12_{16}$ into $(\,)_{10}$

1 B
↳ $B(11) \times 16^0 = 11$
↳ $1 \times 16^1 = 16$
27

$0 \cdot 12$
↳ $2 \times 16^{-2} = 0 \cdot 0078125$
↳ $1 \times 16^{-1} = 0 \cdot 0625$
$0 \cdot 0703125$

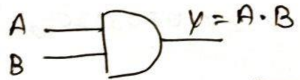
$1B \cdot 12_{16} = 27 \cdot 0703125_{10}$

BINARY CODES.

Decimal	BCD 8421	2421	Excess-3
0	0000	0000	0011
1	0001	0001	0100
2	0010	0010	0101
3	0011	0011	0110
4	0100	0100	0111
5	0101	1011	1000
6	0110	1100	1001
7	0111	1101	1010
8	1000	1110	1011
9	1001	1111	1100

LOGIC GATES.

AND GATE

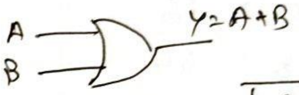


A	B	Y=A·B
0	0	0
0	1	0
1	0	0
1	1	1

* If both the inputs are logic one(High), then output is logic one(High).

* If any one of the input is logic zero (low), then, Output is logic zero (low).

OR GATE.

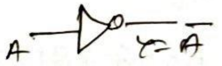


A	B	Y=A+B
0	0	0
0	1	1
1	0	1
1	1	1

* If any one of the inputs ~~are~~ is logic one (High), then, Output is logic one (High).

* If both the inputs are logic zero (low), then, output is logic zero(low).

NOT GATE.

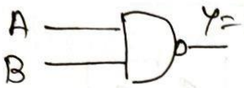


A	$Y=\bar{A}$
0	1
1	0

* If input is logic zero, then, output is logic one.

* If input is logic one (High), then, output is logic zero (low).

NAND GATE.



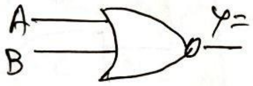
$Y = \overline{A \cdot B}$

A	B	$Y = \overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

* If any one of the input is logic zero(low), then, output is logic one (High).

* If both the inputs are logic one(High), then, output is logic zero (low).

NOR GATE.



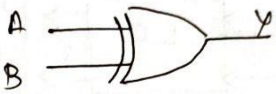
$Y = \overline{A + B}$

A	B	$Y = \overline{A + B}$
0	0	1
0	1	0
1	0	0
1	1	0

* If both the inputs are logic zero (low), then, output is logic one(High).

* If any one of the inputs ~~are~~ is logic one(High), then, Output is logic zero(low).

EX-OR (EXCLUSIVE OR) GATE:



$Y = A \oplus B = \bar{A}B + A\bar{B}$

A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

* If both the inputs are different, then, output is logic one(High).

* If both the inputs are same, then, output is logic zero(low).

EX-NOR GATE.

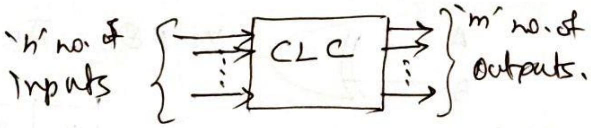
$Y = A \odot B = \bar{A}\bar{B} + AB$

A	B	$Y = A \odot B$
0	0	1
0	1	0
1	0	0
1	1	1

* If the both the inputs are ~~logic~~ same, then the output is logic one (High).

* If bothe inputs are different, then, output is logic zero (low).

COMBINATIONAL LOGIC CIRCUITS.



The logic circuits, whose outputs at any instant of time are entirely depedent upon the input signals present at that time are known as combinational logic circuits.

Eg. Adder, Subtractor, Decoder, Encoder, Multiplexer, Demultiplexer.

ADDERS.

HALF ADDER: A combinational circuit that performs the addition of two bits is called half adder.

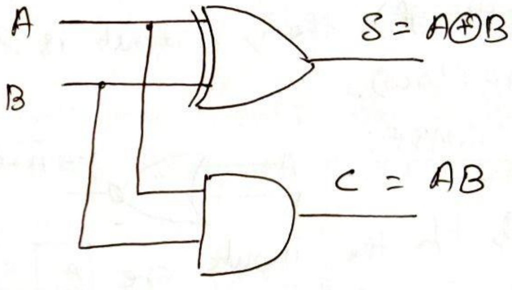
FULL ADDER. A circuit that performs addition of three bits is called full adder.

HALF ADDER.

A	B	C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

$S = \bar{A}B + A\bar{B} = A \oplus B$

$C = AB$



* A combinational logic circuit which is used to adde two binary bits is called Half adder.

- * The two inputs are named A & B. ~~If~~
- * The two outputs are named Sum & Carry. (S & C)
- * If both the inputs are Logic zero (low), then, output is logic zero for. ~~Sum~~ both outputs (Sum & Carry)
- * If the both the inputs are ~~diffent~~ different logic one or zero, then the sum output is logic one (High), carry output is zero (low).
- * If both the inputs are logic one (High), then, the output sum is zero, and carry logic one (high).

FULL ADDER.

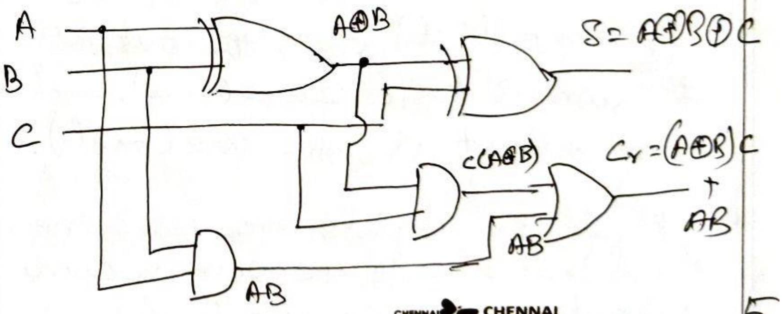
A	B	C	S	C_r
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

$$S = \bar{A}\bar{B}C + \bar{A}B\bar{C} + A\bar{B}\bar{C} + ABC$$

$$\boxed{S = A \oplus B \oplus C}$$

$$C_r = \bar{A}BC + A\bar{B}C + AB\bar{C} + ABC$$

$$\boxed{C_r = AB + (A \oplus B)C}$$



- * full adder means adding of three binary bits and outputs are sum and carry.

- * If all the three inputs are logic zero (low), then, both the outputs of Sum & carry ~~to~~ are logic zero (low).

- * If any one of the input is logic one (high) only one input. then, the output of sum is logic one (high) and carry output is logic zero (low).

- * If any of the two inputs are logic one (high), then, the output of sum is logic zero (low), and carry output is logic one (high).

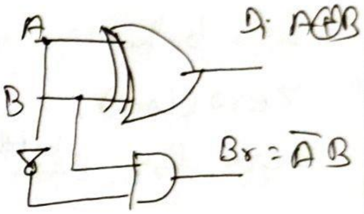
- * If all the inputs are logic one (high), then, Both the sum & carry outputs are logic one (high).

SUBTRACTOR.

They are ~~type~~ two types of Subtractor circuits (i) Half subtractor, (ii) Full Subtractor.

HALF SUBTRACTOR.

A	B	B_r	D_i
0	0	0	0
0	1	1	1
1	0	0	1
1	1	0	0



- * If both the inputs are logic zero (low), then, output of both Borrow and Difference logic zero (low).

- * If inputs A logic zero (low), and ~~B~~ Input B logic one (high), then ~~logic~~ outputs Diffence and Borrow logic one (high).

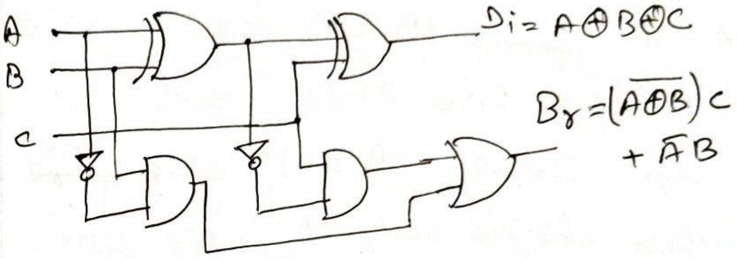
* If input A, logic one(high) and input B, logic zero(low) then, output Borrow logic zero (low) and Difference logic one(high).

* If inputs are logic one(high), then. Outputs are both borrow & Difference logic zero.

~~FULL ADDE~~

FULL SUBTRACTOR.

A	B	C	Br	Di
0	0	0	0	0
0	0	1	1	1
0	1	0	1	1
0	1	1	1	0
1	0	0	0	1
1	0	1	0	0
1	1	0	0	0
1	1	1	1	1



* If all the inputs are ABC are logic zero(low), and inputs A&B, A&C are logic one(high), then outs are Borrow & Difference logic zero.

* If inputs (A&B), (A&C), ~~(A,B,C)~~ logic zero(low), the inputs A,B,C logic one(high) then, outputs are both borrow & Difference logic one(high).

- If inputs (B & C) logic zero & A logic one and, input A logic zero, (B &C) logic ~~zero~~ one then, ~~logic~~ output logic one

- If inputs B &C are logic one and input A ~~logic~~ zero, then output Difference logic zero, & Borrow logic one.

- If inputs B &C logic zero & 'A' logic one then, output Borrow logic zero & Difference logic one.

SUM OF PRODUCT FORM.

1. $AB\bar{C} + A\bar{B}\bar{C}$
2. $XY + X\bar{Y}Z + YZ$
3. $\bar{P}Q + PQR + Q\bar{R}S$

PRODUCT OF SUM FORM.

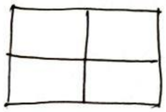
1. $(A+B+C)(A+\bar{B}+C)$
2. $(X+\bar{Y})(X+\bar{Y}+Z)(Y+\bar{Z})$
3. $(P+\bar{Q})(P+Q+R)(Q+\bar{R}+S)$

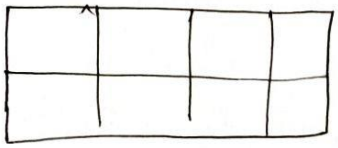
MINTERMS & MAXTERMS

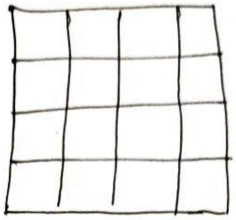
A	B	C	Minterms (m_i)	Maxterms (M_i)
0	0	0	$\bar{A}\bar{B}\bar{C} = m_0$	$A+B+C=M_0$
0	0	1	$\bar{A}\bar{B}C = m_1$	$A+B+\bar{C}=M_1$
0	1	0	$\bar{A}B\bar{C} = m_2$	$A+\bar{B}+C=M_2$

A	B	C	Minterms (m_i)	Maxterms (M_i)
0	1	1	$\bar{A}BC = m_3$	$A+\bar{B}+\bar{C} = M_3$
1	0	0	$A\bar{B}\bar{C} = m_4$	$\bar{A}+B+C = M_4$
1	0	1	$A\bar{B}C = m_5$	$\bar{A}+B+\bar{C} = M_5$
1	1	0	$AB\bar{C} = m_6$	$\bar{A}+\bar{B}+C = M_6$
1	1	1	$ABC = m_7$	$\bar{A}+\bar{B}+\bar{C} = M_7$

KARNAUGH MAP (K-MAP)


2-Variable Map (4-Cells)


3-Variable Map (8-Cells)


4-Variable Map (16-Cells)

	$\bar{B}$	B
$\bar{A}$	m_0	m_1
A	m_2	m_3

2-Variable Map.

	$\bar{B}\bar{C}$	$\bar{B}C$	BC	$B\bar{C}$
$\bar{A}$	m_0	m_1	m_3	m_2
A	m_4	m_5	m_7	m_6

3-Variable Map

	$\bar{C}\bar{D}$	$\bar{C}D$	CD	$C\bar{D}$
$\bar{A}\bar{B}$	m_0	m_1	m_3	m_2
$\bar{A}B$	m_4	m_5	m_7	m_6
AB	m_{12}	m_{13}	m_{15}	m_{14}
$A\bar{B}$	m_8	m_9	m_{11}	m_{10}

4-Variable Map.

A \ B	0	1
0	m_0	m_1
1	m_2	m_3

A \ BC	00	01	11	10
0	m_0	m_1	m_3	m_2
1	m_4	m_5	m_7	m_6

AB \ CD	00	01	11	10
00	m_0	m_1	m_3	m_2
01	m_4	m_5	m_7	m_6
11	m_{12}	m_{13}	m_{15}	m_{14}
10	m_8	m_9	m_{11}	m_{10}

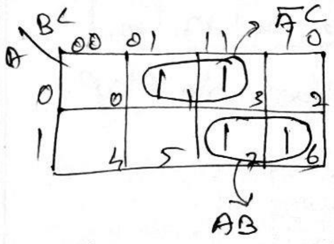
GROPING CELLS FOR SIMPLIFICATON.

PAIR - Grouping two adjacent ones.

QUAD: Grouping four adjacent ones.

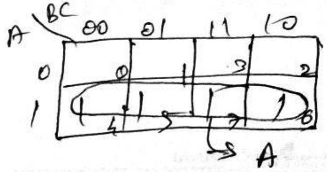
OCTET: Grouping eight adjacent ones.

1. $f(A,B,C) = \Sigma m(1,3,6,7)$



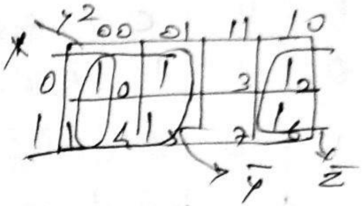
$f = \bar{A}C + AB.$

2. $f(A,B,C) = \Sigma m(4,5,6,7)$



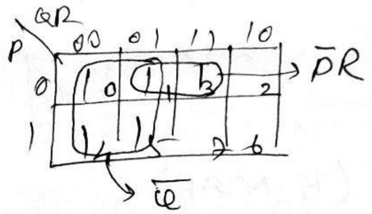
$f = A$

3. $f(X,Y,Z) = \Sigma m(0,1,2,4,5,6)$



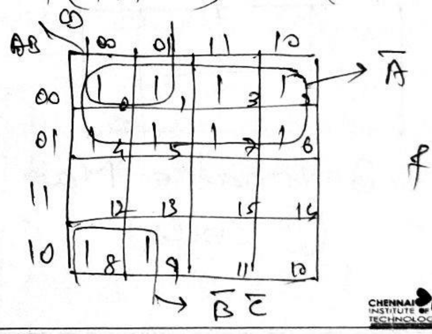
$f = \bar{Y} + \bar{Z}$

4. $f(P,Q,R) = \Sigma m(0,1,3,4,5)$



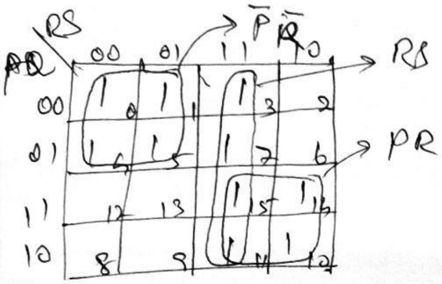
$f = \bar{Q} + \bar{P}R$

1. $f(A,B,C,D) = \Sigma m(0,1,2,3,4,5,6,7,8,9)$



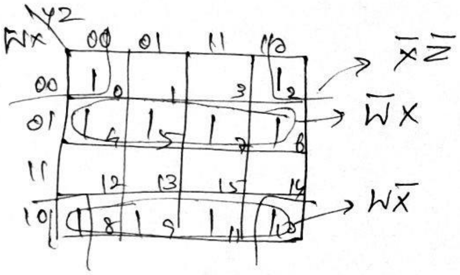
$f = \bar{A} + \bar{B}\bar{C}$

2. $f(P,Q,R,S) = \Sigma m(0,1,3,4,5,7,10,11,14,15)$



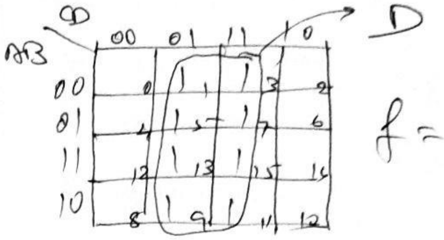
$f = \bar{P}\bar{Q} + RS + PR$

3. $f(W,X,Y,Z) = \Sigma m(0,2,4,5,6,7,8,9,10,11)$



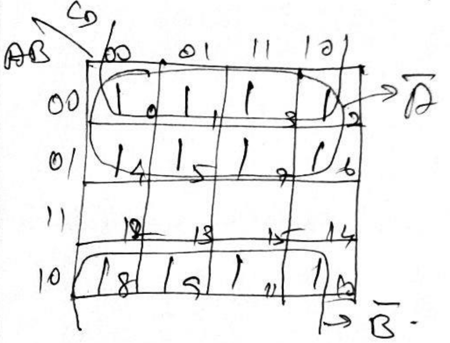
$f = \bar{W}X + W\bar{X} + \bar{X}\bar{Z}$

4. $f(A,B,C,D) = \Sigma m(1,3,5,7,13,15,9,11)$



$f = D$

5. $f(A,B,C,D) = \Sigma m(0,1,2,4,5,6,8,9,10,3,7,11)$

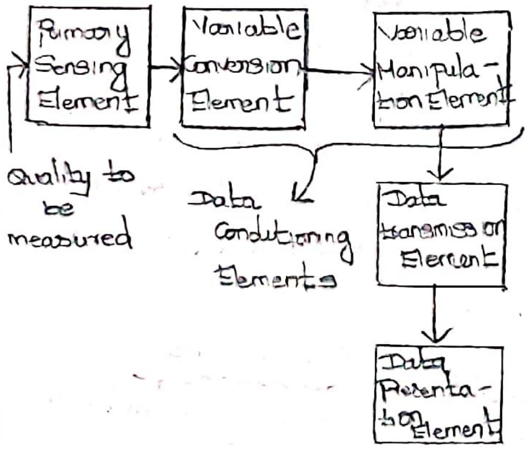


$f = \bar{A} + \bar{B}$

Introduction :

Measurement is an act or the result of quantitative comparison between an unknown magnitude and the predefined standard.

Functional Elements of an Instrument :



Three main functional elements

1. primary sensing element
2. Variable conversion element
3. Data Presentation element

1. Primary sensing element

The quantity under measurement is made to be in contact with primary sensing element. The primary sensing element is transducer. The transducer converts measurand into an analogous electrical signal

2. Variable conversion element

- The output of the primary sensing element is the electrical signal
- It may be a voltage, a frequency or some other electrical parameter
- Instrument to perform the desired function, it is necessary to convert this output to some other suitable form.

Ex : If the output is an analog signal form but the next stage of the system accepts input signal only in digital form.
∴ we have to use analog to digital converter in this system.

Variable manipulation element :

- The main function is to manipulate the signal presented to it but, preserving the original nature of the signal.

Ex : An electronic amplifier circuit accepts a small voltage signal as input and produces as output signal which is also voltage but of greater amplitude voltage amplifier acts as a variable manipulation element.

3. Data presentation element

- The information about the quantity under measurement has to be conveyed to the person handling the instrument (or) system for control (or) analysis purposes.

- The information conveyed must be in the form of intelligible form to the person.
- The output or data of the system can be monitored by using visual display devices.
- These devices may be analog or digital like ammeter, digital meter etc.
- In case the data to be recorded, we can use analog or digital recording equipment.
- In Industries for control and analysis purpose we can use computers.

Standards of measurement:

- Standard is a physical representation of a unit of measurement.
- A known accurate measure of physical quantity is termed as standard. These standards are used to determine the values of other physical quantities by the comparison method.

standards are classified into four categories as

1. International standards
2. Primary standards
3. Secondary standards
4. Working standards.

1. International standards

- They are periodically evaluated and checked by absolute measurements in terms of fundamental units of physics.
- These international standards are not available to ordinary users for measurements and calibrations.

2. Primary standards

- Function of primary standards is the calibration and verification of secondary standards.
- They are not available for outside usage other than the National laboratory.
- High accuracy that can be used as ultimate reference standards.

3. Secondary standards

- Secondary standards are maintained by the particular Industry to which they belong
- Each Industry has its own secondary standard

- Each laboratory periodically sends its secondary standard to the National standard Laboratory for calibration and comparison against primary standard.

4 Working standards

- These standards are used to check and calibrate laboratory instruments for accuracy and performance.

Ex: Manufacturers of electronic components such as capacitors, resistors etc, use a standard called working standard for checking the component values being manufactured.

(i.e) standard resistor for checking of resistance value manufactured.

Calibration

Calibration is the result of quantitative comparison between a known standard and the output of the measuring system measuring the same quantity.

Types of Calibration

1. Primary Calibration
2. Secondary Calibration
3. Direct Calibration
4. Indirect calibration
5. Routine calibration

1. Primary calibration

- When a device/meter is calibrated again primary standards, the procedure is termed primary calibration.
- After primary calibration, the device is employed as a secondary calibration device.

2. Secondary Calibration

- When a secondary calibration device is used for further calibrating another device of lesser accuracy, then the procedure is termed as secondary calibration.

3. Direct calibration

- Direct calibration with a known input source is of the same order of accuracy as primary calibration
- ∴ devices calibrated directly are also used as secondary calibration devices.

4. Indirect calibration

- Indirect calibration is based on the equivalence of two different devices that can be employed for measuring a certain physical quantity.

- To predit the performance of one meter on the basis of an experimental study of another.

Routine Calibration:

Routine calibration is the procedure of periodically checking the accuracy and proper functioning of an Instrument with standards.

classification of Analog Instruments

1. Indicating Instruments.
2. Recording Instruments
3. Integrating Instruments.

1. Indicating Instruments:

Instrument which indicate the magnitude of a quantity being measured by using a dial and pointer arrangement. Eg: voltmeter Ammeter

2. Recording Instruments:

Instrument which give a continuous record of the quantity being measured over a specific period.

Eg:- Drawing a graph using a pen and a sheet of paper.

3. Integrating Instruments:

Instrument which totalize the events over a specified period of time.

Eg: house hold Energy meter. $(E = p \times t)$

Torque in Indicating Instruments

1. Deflecting force
2. Controlling force
3. Damping force

1. Deflecting force

The deflecting force is the operating force required for moving the pointer from its zero position.

2. Controlling force:

Controlling force is the opposing force required by an indicating instrument in order that the current to be measured produces deflection of the pointer proportional to its magnitude.

3. Damping force:

Damping force is provided in order to bring the pointer to rest within short time.

The quickness with which the moving system settles to the final steady position without overshooting depends on relative damping.

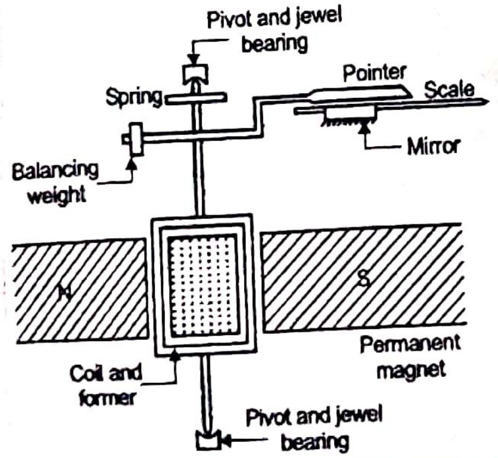
Permanent Magnet Moving Coil (PMMC) Instruments

PMMC Instruments are used to give accurate reading in DC measurements.

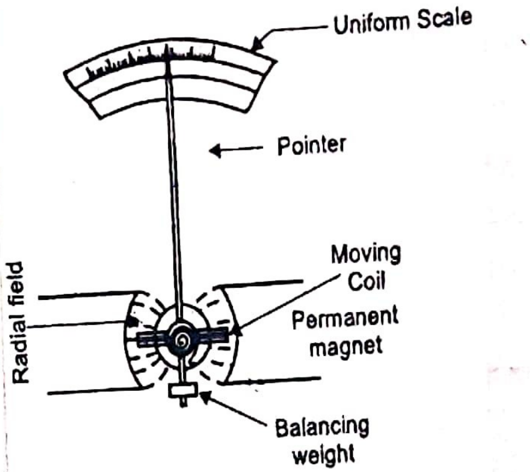
Basic principle:

- It works on motoring principle
- when a current carrying conductor is placed in a magnetic field produced by a permanent magnet, the coil experiences a force and hence moves.
- Coil is moving and magnet is permanent this Instrument called permanent magnet moving coil.
- Force experienced by the coil proportional to the current passing through the coil.

Construction:



- Consist of a moving coil which is either rectangular or circular in shape, which has number of turns of fine wire



- Coil suspended so that it is free to turn about its vertical axis.
- Coil is placed in uniform magnetic field of a permanent magnet.
- Iron core is spherical if the coil is circular.
- Iron core is cylindrical if the coil is rectangular.
- Due to Iron core deflection torque increases.
- Controlling torque is provided by spring control.
- Damping torque provided by movement of aluminium former in the magnetic field.
- Pointer is connected to the spindle moves over a uniformly scale
- Pointer is light weight one
- Total weight of Instrument counter balanced by balancing weight.

- Mirror is placed below the pointer to get an accurate reading without parallax error.
- In PMMC deflection of the pointer is directly proportional to the current passing through the coil.

Torque Equation:

Deflecting torque is derived from basic equation of electromagnetic torque

$T_d = NBAI$ —— ①

where

T_d – Deflecting torque in N-m

N – Number of turns of the coil

A – Effective coil area in m^2

I – Current passing through moving coil in amperes

B – Flux density in air gap in wb/m^2

G – NBA – Constant.

$T_d = GI$ —— ②

Controlling torque is provided by the spring and is proportional to the angular deflection of the pointer

$T_c \propto \theta$

$T_c = K_s\theta$ —— ③

where

T_c = Controlling torque (N-m)

K_s – Spring constant

θ – Angular deflection in degree

At final steady deflection

$T_c = T_d$

$K_s\theta = GI$

$\theta = \left(\frac{G}{K_s}\right) I$

$\boxed{\theta \propto I}$

Deflection of pointer is directly proportional to the current to be measured.

Errors in PMMC:

- Weakening of permanent magnet, springs due to ageing.

Advantages:

- Uniform scale
- High sensitivity
- Low power consumption

Disadvantages:

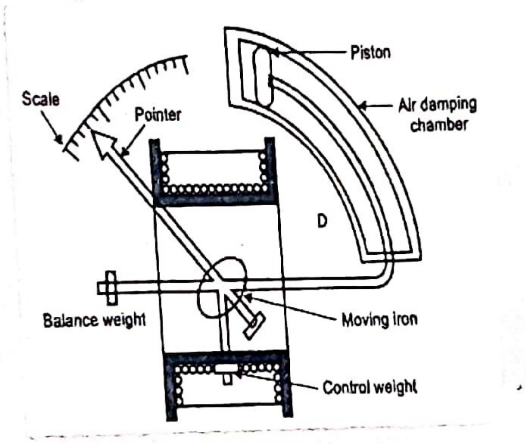
- Used only for DC measurement
- PMMC cost is higher than moving Iron Instrument.

Moving Iron (MI) Instruments

Moving Iron most commonly used laboratory Instruments.

classified into
1. Moving Iron Attraction type
2. Moving Iron Repulsion type

1. Moving Iron Attraction type Instrument:



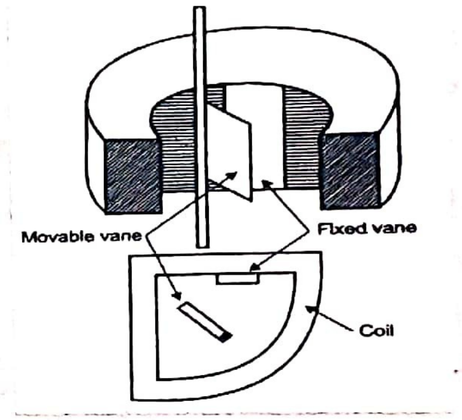
- Moving Iron is a flat disc
- when the current to be measured flows through the coil, magnetic field is produced which attracts the moving Iron towards it, this makes the pointer to move.
- controlling torque is provided by springs.
- Air friction damping is provided with the help of light

2. Moving Iron repulsion type Instrument

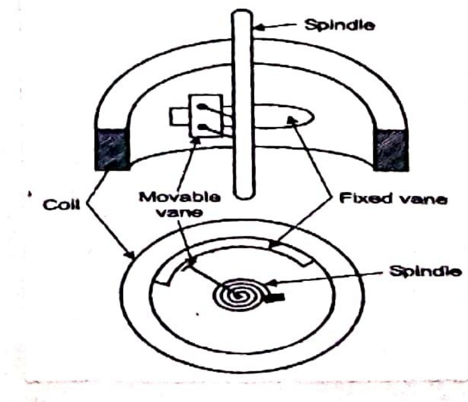
- It consist of two vanes inside the coil. One vane is fixed other is movable.
- When the current to be measured flows through the coil, both the vanes get magnetised, a force of repulsion exists between the two vanes which results in movement of the moving vane and thus the pointer moves.

Two types of Repulsion types

(1) Radial vane type:



- Fixed vane is attached to the coil and the movable vane is attached to the spindle of the instrument which in turn is attached to the pointer.



- Fixed and moving vanes are sections of Coaxial cylinder.
- Controlling torque provided by springs.
- Damping torque is provided by air friction damping.
- MI type used for both Ac and DC measurements.
- Because, whatever may be direction of the current through the coil, the Iron vanes get magnetised and there will be a force a attraction in attraction type and there will be a force of repulsion in the repulsion type Instrument.

Torque Equation

Small increment in the current dI supplied to the coil, there will be small deflection dθ and some mechanical work will be done

If Td is deflection torque then

Mechanical workdone = Td. dθ

let

I - Initial current in A
L - Instrument Inductance in H
θ - Deflection in radians
dI - Increase in current in A
dθ - change in deflection in radians
dL = change in Inductance in H.

If current increases by dI, deflection changes by dθ, which changes Inductance dL.

$$e = \frac{d}{dt}(LI)$$

where 'e' is applied voltage

$$e = I\frac{dL}{dt} + L\frac{dI}{dt}$$

Electrical energy supplied given by

$$eI\,dt = \left[I\frac{dL}{dt} + L\frac{dI}{dt}\right]I\,dt$$

$$eIdt = I^2 dL + LIdI$$

From principle of Conservation of energy

Electrical energy supplied = change in stored energy + Mechanical work done

$$I^2 dL + ILdI = ILdI + \frac{1}{2}I^2 dL + Td\,d\theta$$

$$Td\,d\theta = \frac{1}{2}I^2 dL$$

$$\boxed{Td = \frac{1}{2}I^2\frac{dL}{d\theta}} \quad —①$$

Controlling torque.

$$\boxed{Tc = Ks\theta} \quad —②$$

At final steady state

$$T_c = T_d$$

$$K_S \theta = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

$$\theta = \frac{1}{2} \frac{I^2}{K_S} \frac{dL}{d\theta}$$

$$\boxed{\theta \propto I^2}$$

Deflection of pointer ∝ square of the current to be measured

- Deflection torque unidirectional what ever may be the polarity of the current.
- MI used for both AC and DC

Advantages:

- used for both AC and DC measurement.
- Highly accurate.
- Simple in construction

Disadvantages:

- scale is not uniform

Induction type Energy meter

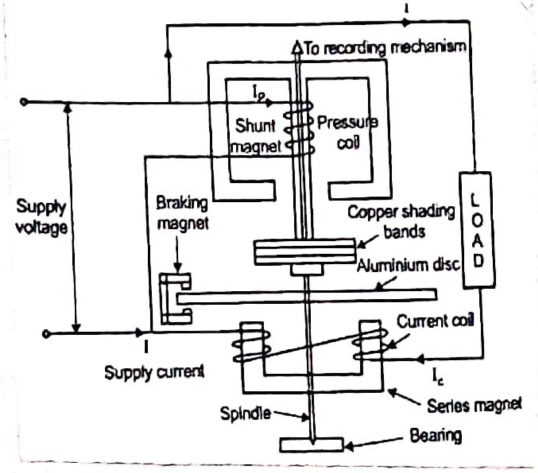
Used to measure energy which is the total power consumed over a specific interval of time. unit kwh (or) unit

Energy = power x time

Basic principle

- operation based on passage of alternating current through two coils current coil and pressure coil)
- coil produces rotating magnetic field which interacts with a disc and makes the disc rotates
- current coil carries line current which is inphase with supply voltage.
- pressure coil are highly inductive hence current passes it lags the supply voltage by 90°
- Therefore phase difference 90° exist between the fluxes developed by two coils.
- Due to this rotating field develops which interacts with disc to rotate.

Construction Details



(I) Driving system

- It consist of two electromagnets, whose core is made up of silicon steel.
- current coil which is excited by load current.
- pressure coil which is connected across the supply
- shading band on central limb to bring the flux produced by the shunt magnet is exactly quadrature with applied voltage

(II) Moving system

- consist of aluminium disc mounted on shaft.
- Disc is placed between series and shunt magnet.
- Moving system connected to bearing.

(III) Braking system

- consist of permanent magnet, near the edge of aluminium disc
- Aluminium disc moves in the field of the magnet
- By adjusting the position of permanent magnet, braking torque adjusted

(IV) Registering/Counting mechanism

- It is function is to record no. of revolutions made by the moving system.
- pointer rotates on round dial which are marked with ten equal divisions.

Operation:

- Current coil carries the load current. Its magnetic field is inphase with line current.
- Pressure coil carries current proportional to the supply voltage. Magnetic field by pressure coil lags 90° behind the supply voltage
- phase difference exist b/w two flux by two coils.

- Due to this rotating magnetic field develops which interacts with the disc to rotate.
- Braking magnet produces braking torque on the disc.
- The spindle is geared to the recording mechanism so that electrical energy consumed in the circuit directly given in kwh (kilowatt hour)

Advantages:

- simple operation
- cheap in cost.

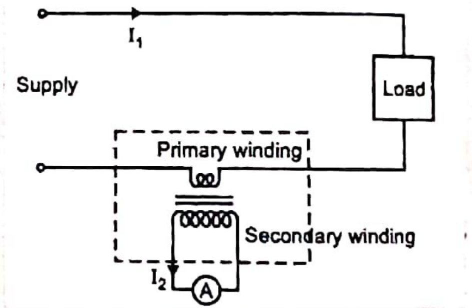
Instrument transformers:

- Instrument transformers are used in Ac system for measurement of electrical quantities (i.e) voltage, current.
- Basic function of Instrument transformers is to step down the Ac system voltage and current
- The voltage and current level of power system is very high. It is very difficult and costly to design the measuring Instruments for measurement of such high level voltage and current.
- Generally measuring Instruments are designed for 5A and 110V.
- Measurement of such large electrical quantities can be made possible by using Instrument transformer with these small rating measuring Instruments.

Types of Instrument transformers

(1) current transformer (C.T)
(2) potential transformer (P.T)

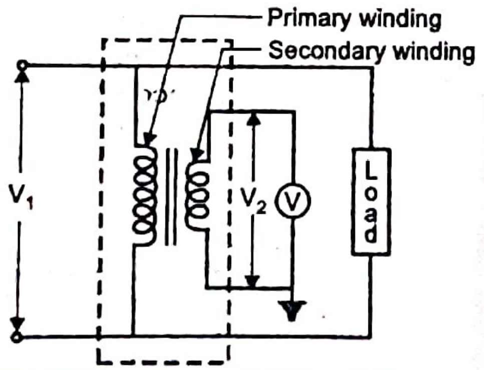
(1) current transformer (C.T)



- It is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e 5A Ammeter)
- Primary of C.T having very few turns.
- Primary connected to power circuit.

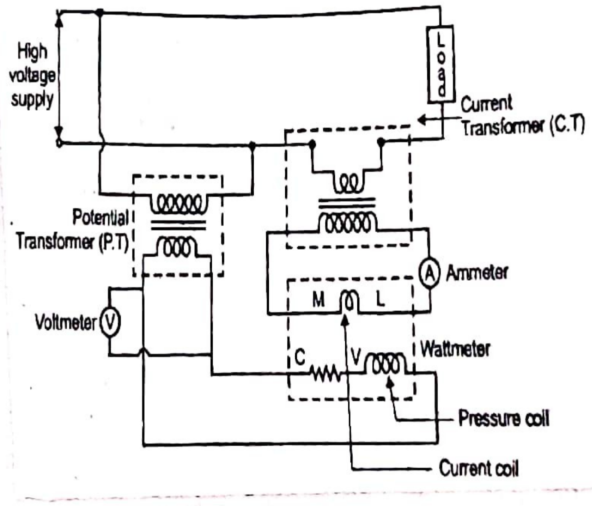
- It is also called Series transformer.
- Secondary having large no. of turns.
- Secondary is connected to Ammeter.
- As Ammeter having very small resistance.
- Secondary of C.T operates almost short circuit condition
- one terminal secondary is earthed.
- Before disconnecting Ammeter secondary is short circuit through switch 'S'.

(2) potential transformer: (P.T)



- Primary (P.T) having large no. of turns.
- It is also called parallel transformer.
- Secondary of P.T having few turns and connected directly to a Voltmeter.
- As Voltmeter having large resistance
- Hence Secondary of P.T operates almost in open circuit condition
- one terminal of secondary of P.T is earthed, which assures the safety.

Measurement of Power using C.T and P.T



- The primary winding of C.T is connected in series with the load secondary is connected in series with an ammeter and the current coil of a wattmeter.

- The primary winding of P.T is connected across the supply voltage and the secondary is connected across voltmeter and the pressure coil of the wattmeter

- The circuit connections of single phase energy meter is exactly similar to the connections of wattmeter along with C.T and P.T for power measurement.

- The only difference in that, the pressure coil of wattmeter is replaced by pressure coil of energy meter and the current coil of wattmeter is replaced by current coil of Energy meter.

Advantages:

- High voltage and high current can be measured using low range voltmeter and ammeter along with the Instrument transformer.
- The rating of low range meter can be fixed irrespective of the value of high voltage or current to be measured.
- It isolate the high voltage and high current from measuring Instruments.

Disadvantages:

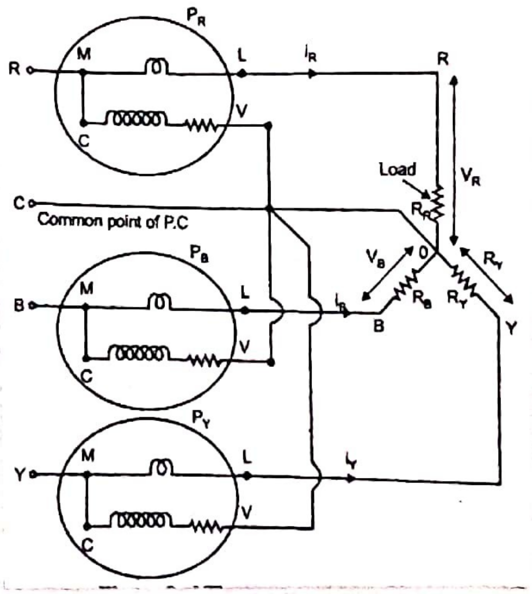
- It can be used only for Ac circuits and not for DC circuits.

Measurement of three phase power

1. Three wattmeter method (using 3 - single phase wattmeter)
2. Two wattmeter method (using 2 - single phase wattmeter)
3. By using three phase wattmeter

1. Three wattmeter method

- Measurement of power in 3 phase 4-wire system.
- This method consists of 3 wattmeter and hence the name 3 wattmeter method, and combination of a pressure coil and current coil is called element



- 3 phase 4 wire system, the common point 'c' of pressure coils and neutral point 'o' of the load coincides

- Voltage across pressure Coil of wattmeter is equal to phase Voltage across the load

i.e)

Voltage across pressure Coil wattmeter 1 = VR

Voltage across pressure Coil wattmeter 2 = Vy

Voltage across pressure Coil wattmeter 3 = VB

where

VR - Voltage across R-phase of the Load

Vy - voltage across y-phase of the Load

VB - Voltage across Z-phase of the load

iR - Current flowing through R-phase of load

iy - Current flowing through Y phase of Load

iB - Current flowing through B phase of Load

Instantaneous Power Consumed by Load

$= V_R i_R + V_y i_y + V_B i_B$

As voltage across the pressure Coil of each wattmeter = voltage per phase of the load

Current flowing through Current Coil of each wattmeter = Current flowing through each phase of Load.

i.e) $P = P_R + P_y + P_B$

$$\boxed{P = V_R i_R + V_y i_y + V_B i_B}$$

2. Two wattmeter method

- Measurement of Power for 3 phase three wire system.

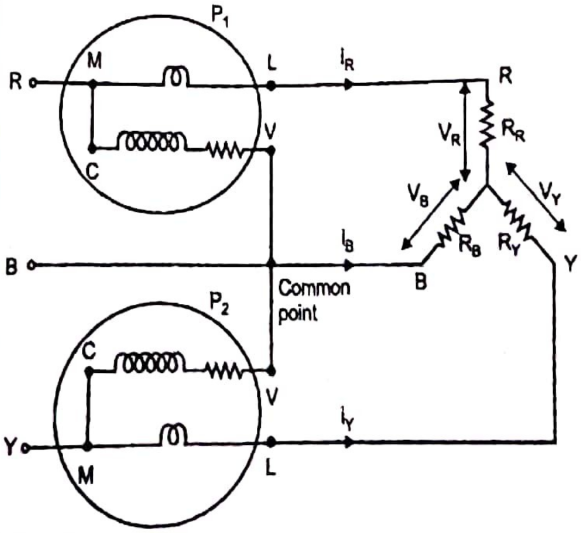
- 3φ 3 wire system requires three wattmeter. we Coincide the Common point pressure Coil of two wattmeters with the third phase

- this method also called 2 element method

Two cases

1. Star Connected load
2. Delta Connected load

Case (1) Star Connection



i_R - Current flowing through R-phase load

i_y - Current flowing through Y-phase load

i_B - Current flowing through B-phase load

V_R - Voltage across R-phase

V_y - voltage across Y-phase

V_B - Voltage across B-phase

Reading of wattmeter 1

$$P_1 = i_R(V_R - V_B) \quad \text{— ①}$$

Reading of wattmeter 2

$$P_2 = i_y(V_y - V_B) \quad \text{— ②}$$

Sum of Reading of two wattmeters

$$= P_1 + P_2$$

$$= i_R(V_R - V_B) + i_y(V_y - V_B)$$

$$= i_R V_R - i_R V_B + i_y V_y - i_y V_B$$

$$P_1 + P_2 = V_R i_R + V_y i_y - V_B(i_R + i_y) \quad \text{— ③}$$

Load is connected using KCL

$$i_R + i_y + i_B = 0$$

$$i_R + i_y = -i_B \quad \text{— ④}$$

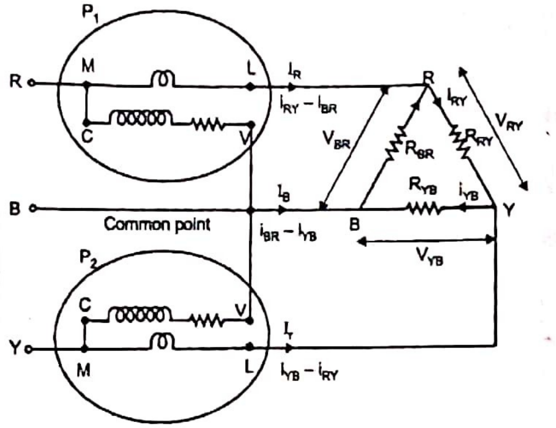
Sub ④ in ③ we get

$$P_1 + P_2 = V_R i_R + V_y i_y - V_B(-i_B)$$

$$\boxed{P_1 + P_2 = V_R i_R + V_y i_y + V_B i_B}$$

Sum of two readings of two wattmeters = total power consumed by the load

Case 2 Delta Connection



Reading of wattmeter 1

$$P_1 = -V_{BR}(i_{Ry} - i_{BR}) \quad \text{— ①}$$

Reading of wattmeter 2

$$P_2 = V_{YB}(i_{YB} - i_{RY}) \quad \text{— ②}$$

Sum of two wattmeter given by

$$P_1 + P_2 = -V_{BR}(i_{Ry} - i_{BR}) + V_{YB}(i_{yB} - i_{Ry})$$

$$P_1 + P_2 = -V_{BR} i_{Ry} + V_{BR} i_{BR} + V_{yB} i_{yB} - V_{yB} i_{Ry}$$

$$P_1 + P_2 = V_{BR} i_{BR} + V_{yB} i_{yB} - i_{Ry}(V_{yB} + V_{BR}) \quad \text{— ③}$$

Apply KVL $V_{Ry} + V_{yB} + V_{BR} = 0$

$$V_{yB} + V_{BR} = -V_{Ry} \quad \text{— ④}$$

Sub ④ in ③

$$P_1 + P_2 = V_{BR} i_{BR} + V_{yB} i_{yB} - i_{Ry}(-V_{Ry})$$

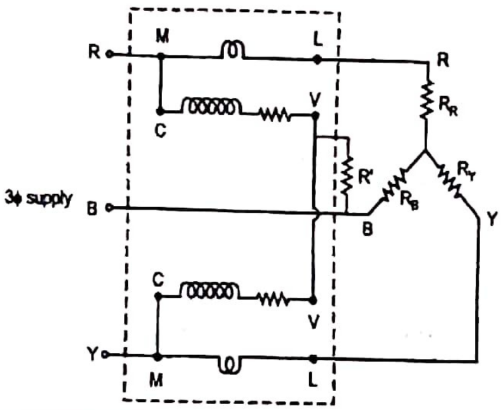
$$P_1 + P_2 = V_{BR} i_{BR} + V_{yB} i_{yB} + V_{Ry} i_{Ry}$$

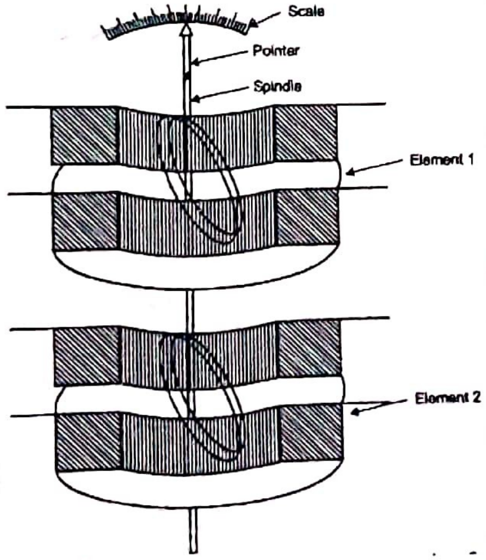
Rearrange

$$P_1+P_2 = V_{RY}\,i_{RY} + V_{YB}\,i_{YB} + V_{BR}\,i_{BR}$$

Sum of two wattmeter is equal to the total power consumed by the load

(3) Three phase wattmeter





- It consists of two separate wattmeters mounted together in one case with the two moving coils mounted on the same spindle.
- A current coil together with its pressure coil is known as element
- The connection of two element of a 3φ wattmeter is same as that of the two wattmeter method using two single phase wattmeters.

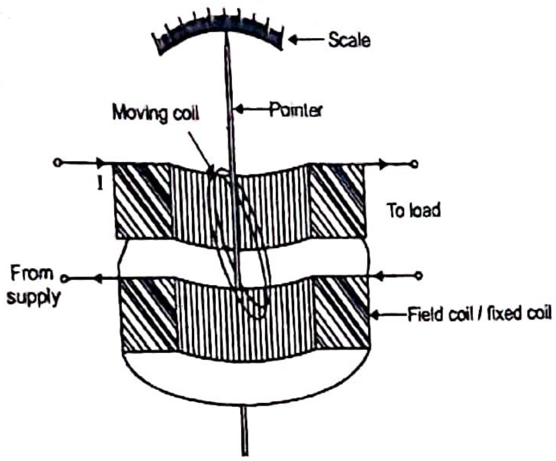
Electrodynamometer wattmeter (1φ power measurement)

The construction of electrodynamometer wattmeter is similar to that of Ammeter and voltmeter.

- It consist of fixed coil which is connected in series with the load and it carries the current through the load
- Hence the fixed coil is also called field coil (or) current coil.
- The moving coil is connected across the load and it carries the current proportional to the voltage across the load
- Hence moving coil is also called potential coil (or) pressure coil (or) voltage coil

Construction and operation

- Used for 1ϕ power measurement



Fixed coil:

- The fixed coils are wound with heavy wire with less number of turns in order to have low resistance and hence low voltage drop across the meter.
- The maximum current range of wattmeter is 20A

Moving coil:

- The moving coil also called pressure coil is made of thin wire but has more number of turns in order to have high resistance
- The voltage rating of the wattmeter is limited to 600V

Control torque:

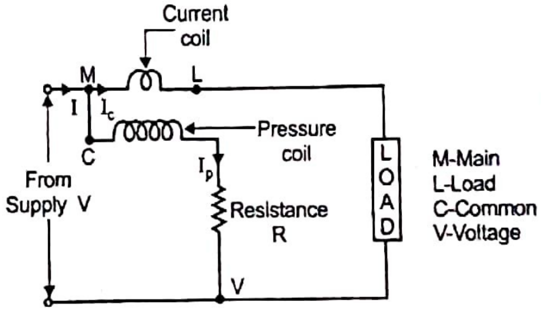
Control torque is provided by springs, as it is a electrodynamometer type instrument.

Damping

Air friction damping is used.

Pointer and scale

This type of instrument has mirror type scales and knife edge pointers to avoid parallax error while reading.



Errors in Electrodynamometer type wattmeter

1. Error due to pressure coil inductance and it can be avoided by compensation
2. Error due to pressure coil capacitance.
3. Error due to wrong connection of current coil and pressure coil.
4. Error caused by vibration of moving system.
5. Temperature error

Digital Storage Oscilloscope

Digital storage oscilloscope stores a signal by converting successive samples to binary numbers, which are stored in a digital memory and used to recreate a composite waveform in much the same manner as the sampling oscilloscope display is created.

Below figure shows the Block diagram of a digital storage oscilloscope.

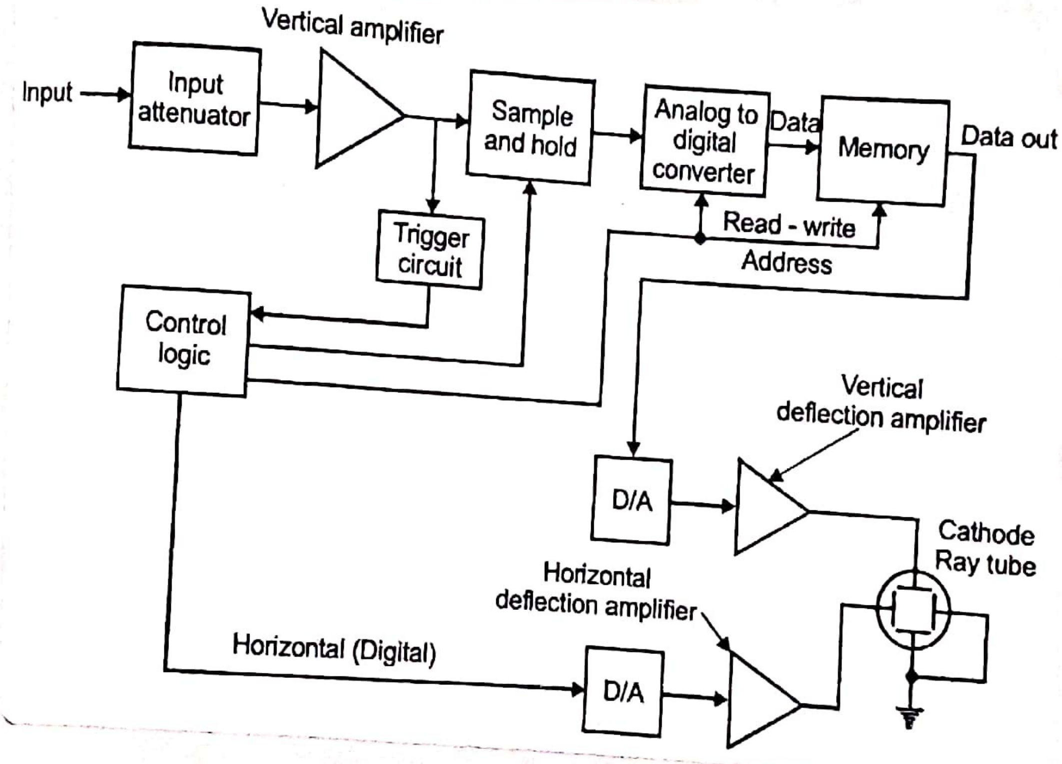
- The input is amplified and attenuated with input amplifier as in any oscilloscope.
- Then, the samples are taken by a sample-and-hold circuit that is connected to the input signal for a very short period of time compared to the length of one cycle.
- The sample and hold circuit effectively snaps a picture of the voltage level.
- the output of the sample and hold circuit is connected to an analog to digital converter, where the analog voltage level is converted to a digital number and stored in memory.
- When enough samples have been taken, the stored digital numbers are successively converted into analog values by a digital to analog converter, and are then sent to the vertical deflection circuit as the trace is swept horizontally in synchronism.
- This digital to analog conversion process is repeated continuously maintaining the trace on the screen as long as desired, through the vertical deflection amplifier.

Advantages:

- Infinite storage time
- Easy to operate
- signal processing is possible
- It is capable of displaying X-Y plots, P-V diagrams and B-H curve
- A number of traces depending on the memory size can be stored and recalled.

Application:

- It can be used to measure AC as well as DC voltages and currents, frequency, timeperiod.
- It can also used to analyze TV waveforms.
- It can also used to check faulty components in various circuits.


Vertical amplifier
Input
Input attenuator
Sample and hold
Analog to digital converter
Data
Memory
Data out
Trigger circuit
Read - write
Address
Control logic
Vertical deflection amplifier
D/A
Cathode Ray tube
Horizontal deflection amplifier
Horizontal (Digital)
D/A

Data Acquisition system

It Consist of individual sensors with the necessary signal conditioning, data Conversion, data processing, multiplexing, data handling and associated transmission, storage and display system.

- Analog data is generally acquired and Converted into digital form for the purpose of Processing, transmission display and storage.
- To increase the speed with which information is accurately converted, sample and hold (S/H) circuits are used

Data Acquisition with example

⊗ The process of digitizing data from the world around us, so it can be displayed, analyzed, and stored in a computer. A simple example is the process of measuring the temperature in a room as a digital value, using a sensor such as a thermocouple.

objectives of Data Acquisition system

- It must acquire the necessary data, at correct speed and at the correct time.
- Use of all data efficiently to inform the operator about the state of the plant.
- It must be able to collect, summarise and store data for diagnosis of operation and record purpose
- It must be reliable and not have a down time greater than 0.1%.

Classification of Data Acquisition system:

1. Analog data acquisition system
2. Digital data acquisition system

1. Analog data acquisition system:

Basic Components of Analog data acquisition system are

Transducer:

The transducer is used to convert the physical quantity into an electrical signal.

Signal Conditioner:

Signal conditioner are used for amplifying, modifying (or) selecting certain portions of such signals.

Multiplexing:

- Multiplexing is the process of sharing a single channel with more than one input.
- It accepts multiple analog inputs with the help of multiplexer; we can transmit more than one quantity using same channel.

Calibrating Equipment:

- Before each test, there is a pre-calibration and often after each test, there is a post-calibration.

Integrating Equipment:

- This block is used for integration of summation of a quantity. The digital techniques are normally used for integration purposes.

Visual Display devices:

- These are necessary to monitor the Input signal Continuously.
- These devices include panel mounted meters, numerical displays, single (or) multichannel CRO's and Storage type CRO's.

Analog Recorders:

- These are required to record type output signal. Analog Recorders include strip chart recorders, magnetic tape recorders.

Analog computers:

- The function of DAS is not only to record data acquired by the transducers and the sensors, but also to reduce this data to desired form.
- The output voltage of an analog computer can either be recorded in analog form or be converted to a digital form for further computations.

High speed cameras and T.V equipment:

- In any industrial process such as engine testing and aerodynamic testing it is not possible for the test operator to have a view of the equipment being tested.
- ∴ closed circuit TV is used to enable the operator to make visual observation of the test.
- Also high speed cameras are employed to obtain a complete visual record of the process for further analysis.

2. Digital Data Acquisition System:

Various component of digital Data Acquisition system are

Transducers:

- It converts physical parameters into electrical quantities

Signal conditioners:

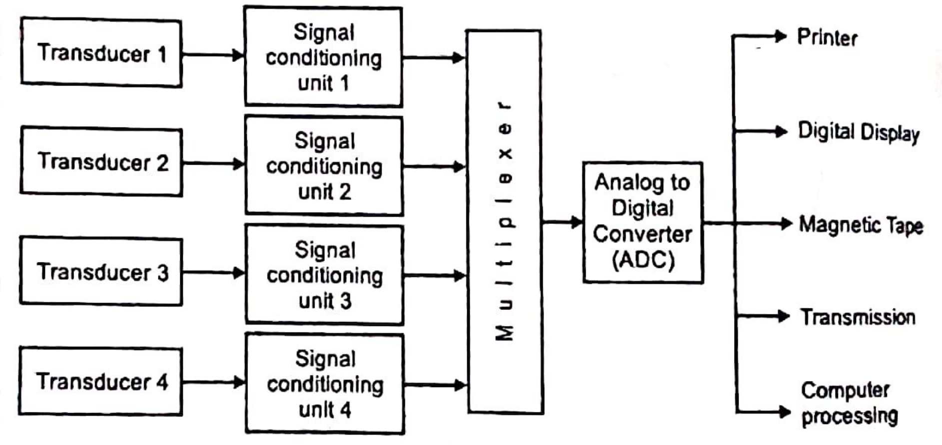
- Signal conditioners usually includes the supporting circuitry for the transducer.

Multiplexers:

It accepts multiple analog inputs and connects them sequentially to one measuring instrument.

Signal converter:

Signal converter translates the analog signal, to a form acceptable by the analog to digital converter (ADC). An example of a signal converter is an amplifier used for amplifying low level voltage produced by strain gauges or thermocouples



Analog to Digital Converter:

- Analog to digital converter converts the analog voltage to its equivalent digital form.
- The output of ADC may be displayed visually (or) recording on a digital recorder.

Digital Recorder

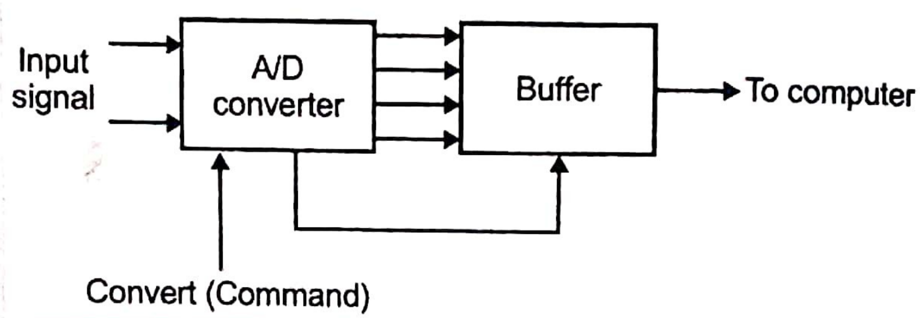
- It records digital information on punched cards, paper tape, magnetic tape, type written pages.

Configuration of data acquisition system:

The factors that decide the configuration and the sub systems of the data acquisition system are as follows

(I) Resolution and Accuracy
(II) Numbers of channels to be monitored
(III) Sampling rate per channel
(IV) Signal Conditioning requirement of each channel
(V) Cost

(1) Single channel data acquisition system



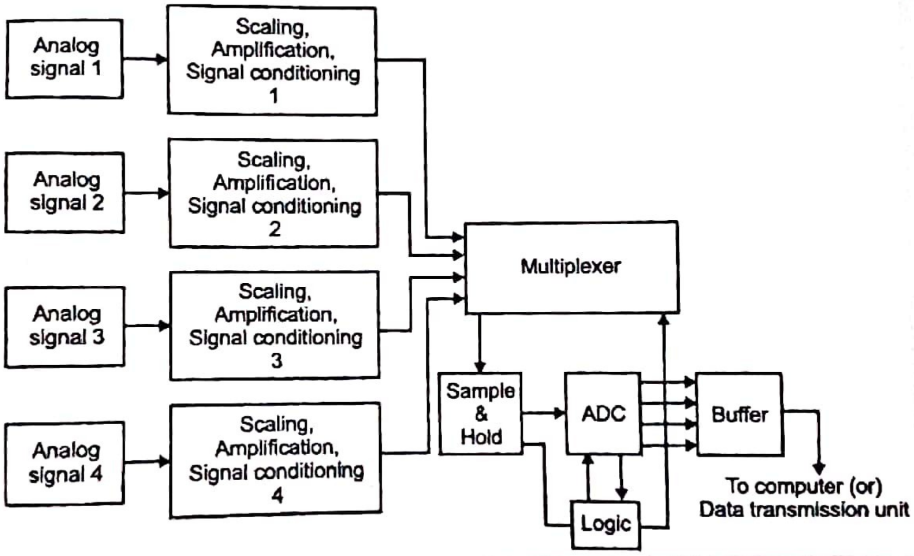
- It consist of a signal conditioner followed by an analog to digital converter (ADC).
- The outputs are in digital code words, including over-range indication, polarity information and a status output to indicate whether the output digits are valid.
- The digital output is further supplied to a storage (or) Printout device (or) to a digital computer for analysis
- The Digital panel meter (DPM) is a well known example of such a system
- Two major drawbacks are

1. It is slow and the Binary Coded Decimal (BCD) digital coding has to be changed into binary coding, if the output is to be processed by digital equipment.

2. While free running, the data from ADC is transfered to the interface register at a rate determined by DPM itself, rather than by a command originating from the external interface.

2. Multichannel data acquisition system

ⓐ Multichannel analog multiplexed system:

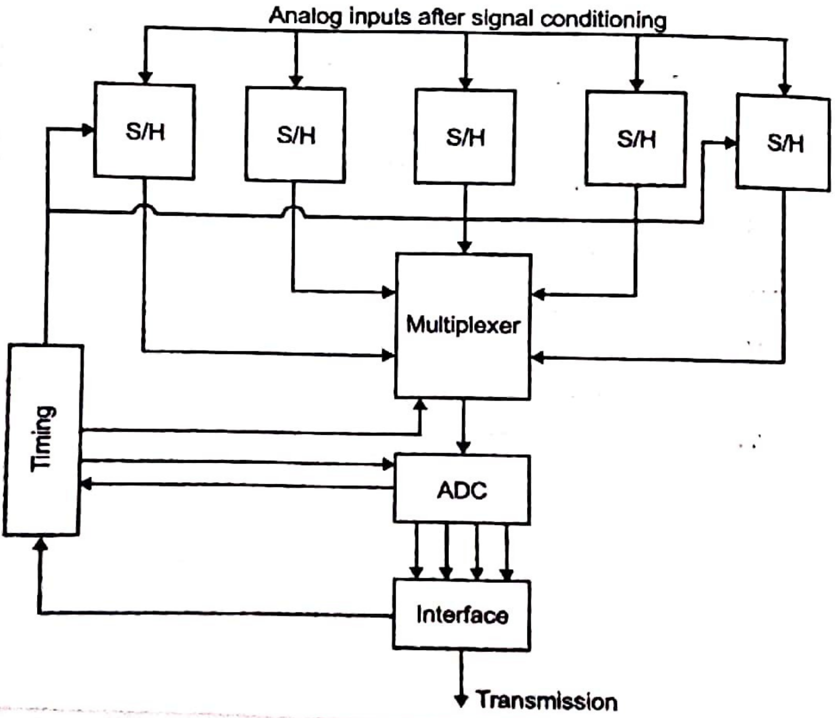


- The individual analog signals are applied to scaling, Amplification, signal conditioning, whenever necessary to the multiplexer.

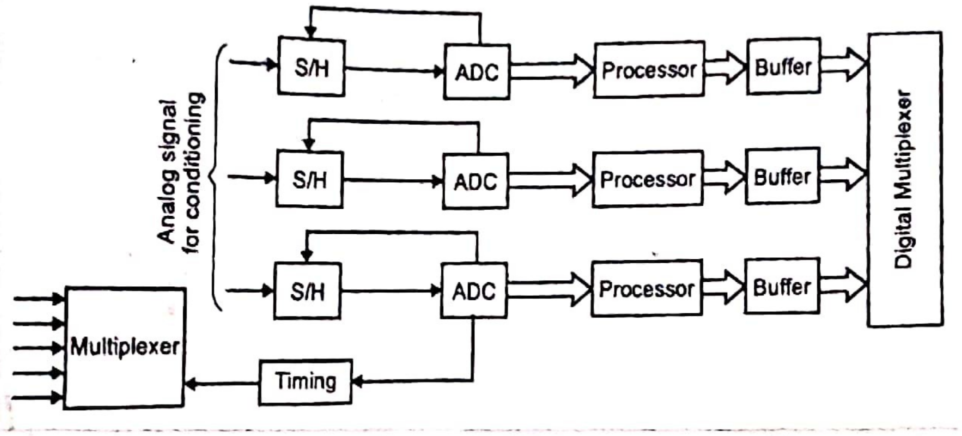
- These are further converted to digital signals by using ADCs sequentially. The multiplexer is made to seek the next channel to be converted while the previous data stored in the S/H is converted into digital form.

- When the conversion is complete, the status line from the converter causes the S/H to return to the sample mode and acquires the signal of the next channel.
- On completion of acquisition, immediately or by command, the S/H is switched to the hold mode, a conversion begins again the multiplexer selects the next channel.
- This method is relatively slower than systems where the S/H outputs or even ADC outputs are multiplexed.

ⓑ Multiplexing the outputs of sample-hold (S/H) circuit.



(c) Multiplexing after analog to digital conversion :



(d) Multiplexing low level data :