UNIT I

DC CIRCUITS

Basic Electrical Engineering

UNIT-I

D.C Circuits

Concept of Charge

The charge is a particle, which experiences a force when it is placed in a electric (or) magnetic fields.
It is denoted as 'Q' (or) 'q'

The unit of charge is "Coloumb (C)".

1 coloumb = charge on 6.24×10^{18} electrons

i.e $1 e^- = -1.602 \times 10^{-19}$ coloumb.

Electric Current (I)

The electric current can be defined as "rate of flow of charge (i.e electrons) in an electric circuit" (or) "in any conductive (or) semiconductive mediums.

i.e $i = \frac{dq}{dt} \Rightarrow I = \frac{Q}{t}$

where I = Average current in circuit
Q = Total charge transferred in circuit
t = time taken for charge.

Units for current is Amperes (Amp) (or) (Coloumbs/sec)

1-Ampere :- "When 1-coloumb of charge is transferred in a circuit in 1-second, then 1-Ampere current is flowing in that circuit.

Electric Voltage (or) Electric Potential (V)

Potential difference (or) Voltage

The Voltage (V) is defined as " an electromotive force which causes the flow of charge (i.e electrons) in an electric circuit.

(or)

The ability of charge particle to do work in an electric circuit is called " Electric potential ".

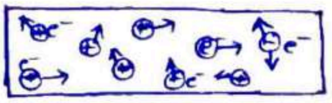
i.e $v = \frac{dW}{dq} \Rightarrow V = \frac{W}{Q}$

where V = Total voltage across two terminals
Q = Charge in electric circuit
W = Workdone in electric circuit

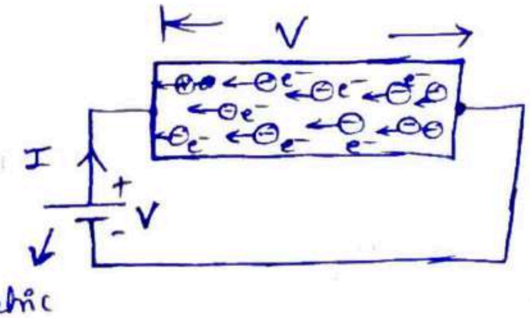
$\boxed{\text{Units for voltage is Volts (V)}}$ (or) (Jouls/Coloumb)

1 Volt : When 1-coloumb of charge is transferred between two points with 1-joule of work, then 1-volt potential is exist between the two points.

Ex:-



Inside piece of conductor



Electric cell

Electric Power or Power (P)

The electric Power can be defined as "the rate of electric workdone in an electric circuit is called as "Power"

(or) "the rate of flow of electrical energy in electric circuit.

i.e $P = \frac{dW}{dt} \Rightarrow P = \frac{dW}{dq} \times \frac{dq}{dt} \Rightarrow \boxed{P = VI}$

i.e Power is Product of Voltage & current

$\boxed{\text{Units for Power is Watts (W)}}$

Electrical Energy (E)

An Electrical energy is the total amount of electrical work done in an electric circuit

i.e $E = P \times \text{time} \Rightarrow \boxed{E = VIt}$

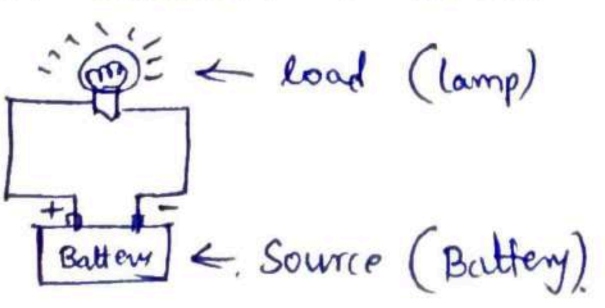
$\boxed{\text{Units for Electrical Energy is Watt-hr or kWh}}$

Electric Circuit

An electric circuit is a closed conducting path through which an electric current flows

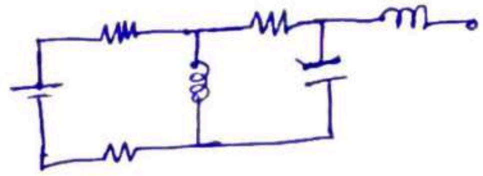
(or)

A closed path which consist of supply Source & load with conductors is called " Electric circuit



Electrical Network :- Network is a combination of circuit & which consist of more no. of sources & loads, and it may be closed or open circuit (i.e any arrangement)

Ex:-



Types of Circuit Elements :-

Active Elements :- An elements which are capable of supplying (or) delivering the power is called "Active elements"

Ex:- Voltage Source
Current Source

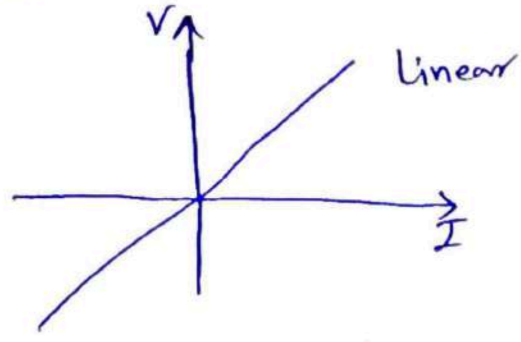
Passive Elements :- An elements which are capable of receiving (or) Utilizing the power is called "Passive elements".

Ex:- Resistor, Inductor, Capacitor. etc

Linear Elements :-

The V-I characterstics of an elements is at all times a straight line & passing through the origin, thus elements are called "Linear elements"

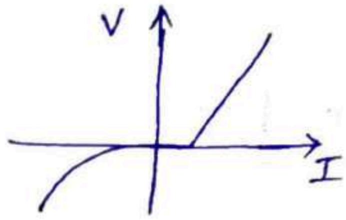
Example :- R, L, C



Non-Liniar Elements :-

The V-I characterstics of an elements is at all times not a straight line and not passing through a origin, thus elements are called "Non-linear elements

Ex :- Transistor, Diode



Bilateral Elements :-

Those elements characterstics & behaviour are independent of direction of current, thus elements are called "Bilateral Elements".

Ex :- Resistor, Inductor, capacitor, Transformer

Unilateral Elements :-

Those elements characterstics & behaviour are dependent on direction of current, thus elements are called unilateral Elements.

Ex :- Diode, Triode.

Lumped Elements :-

The elements which are possible to separate from the network physically, theas elements are called Lumped elements

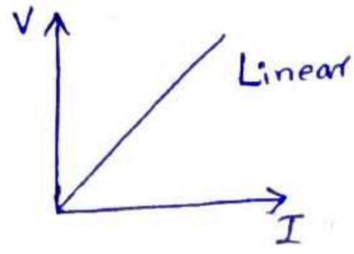
Ex :- R, L, C & transformer, diode,

Distributed Elements :- The elements which are not possible to separate from the network physically,

Ex :- Transmission line R-L-C paramenters.

Ohm's Law

Statement :- Ohm's Law states that " the current passing through a conductor is directly proportional to the applied voltage across the conductor, at constant temperature 'T'.



V-I - characteristics

i.e $\boxed{V \propto I}$ (or) $\boxed{I \propto V}$

$$V = IR$$

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

Where 'R' is resistance of conductor. (Units Ω).

Limitations of Ohm's Law:-

1. It is not applicable to temperature variying devices
2. It is not applicable to non-linear devices
3. It is not applicable to semiconductive materials.

Electrical Circuit Elements

In Electrical field we have 3-types of electrical circuit elements, as

1. Resistor (R)
2. Inductor (L)
3. Capacitor (C)

Resistance (R):- "The property of material which opposes (or) restrict the flow of electrons through material is called "Resistance". The element having this property is called "Resistor (R)"

→ It's symbol is 

→ Units are "Ohm" is "Ω"

→ Power absorbed by resistor $P = VI \Rightarrow$ $P = (IR)I = I^2R$, $= V\left(\frac{V}{R}\right) = \frac{V^2}{R}$

→ Energy lost in the resistor in a time 't'

$$W = \int_0^t P\,dt = P.t = I^2Rt \text{ (or) } \frac{V^2}{R}t.$$

→ Reciprocal of the resistance is called "Conductance" (G)"

i.e $G = \frac{1}{R}$ → unit "mho ($\mho$)

→ 1Ω is defined as "when 1V voltage is applied across a resistor, then 1A current flows, it having resistance is '1Ω',

Factors affecting resistance :-

1. Length of material (l)
2. Cross-sectional area (a)
3. Type of material (or) Nature of material (ρ)
4. Temperature (T).

i.e $R \propto \frac{l}{a} \Rightarrow \boxed{R = \frac{\rho l}{a}}$ Ω

where l = length of material

a = area of cross-sectional

ρ = Resistivity (or) Specific Resistance

Resistivity (or) Specific Resistance :- (ρ)

It is a fundamental property (or) natural property of material which opposes the flow of current is called resistivity (ρ)

i.e $\boxed{\rho = \frac{Ra}{l}}$ $\boxed{\text{units are "}\Omega\text{-m"}}$

Conductance (G) : The property of material which allows the flow of electrons in a conductor is called as "conductance"

i.e $G = \frac{1}{R} \Rightarrow \frac{a}{\rho l}$ — i.e reciprocal of 'R' is called "G".

$\boxed{\text{Units are "Siemens"}}$

→ The reciprocal of resistivity is called " Conductivity (σ)".

$\boxed{\sigma = \frac{1}{\rho}}$ units $(\Omega\text{-m})^{-1}$

Inductance (L) : Inductance is the property of a material ~~which~~ (or) element which stores the electrical energy in the form of magnetic field.

(or)

"the property of a material which opposes ~~the~~ any change of magnitude (or) direction of electric current passing through the material (or) element.

→ It's Symbol is

→ Units are "Henry (H)"

→ The voltage across the inductor is directly proportinal to the rate of change of current

$$v(t) \propto \frac{di(t)}{dt}$$

i.e $\boxed{V_L = L\frac{dI}{dt}}$ voltage across inductor

→ The current flowing through the inductor is

$$\boxed{i_L = \frac{1}{L}\int_0^t v\,dt + i_0}$$

→ Power absorbed by the inductor is

$$P = V \times i \Rightarrow Li \cdot \frac{di}{dt} \text{ watts.}$$

Energy stored in Inductor :-

The total energy in a inductor is

$$W_L = \int P_L(t)\, dt$$

$$= \int L . i . \frac{di}{\cancel{dt}} . \cancel{dt}$$

$$= \int L . \frac{i^2}{2} di \Rightarrow W_L = L . \frac{i^2}{2} \Rightarrow \boxed{W_L = \frac{1}{2} L i^2} \text{ Joule}$$

Capacitance (C)

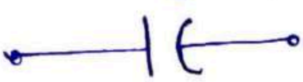
Capacitance is the property of a element (or) material which stores electrical energy in the form of electric field.

(or)

the property of element which opposes sudden changes in magnitude of applied voltage across the element.

→ It's Symbol is

C



→ Units are "Farads (F)"

→ The amount of charge(q) that can be stored in a capacitor of capacitance 'C' depends on applied voltage (V)

i.e $C = \frac{q}{V}$ $\qquad \because i = \frac{dq}{dt}$

i.e $\boxed{i_c = C \frac{dV}{dt}}$ Current flowing capacitor

→ Voltage across capacitor

$$\boxed{V_c = \frac{1}{C} \int i\, dt + V_0}$$

→ Power absorbed by capacitor

$$P = Vi = v\,c\,\frac{dv}{dt}$$

→ Energy stored in capacitor :-

The total energy in a capacitor is

$$W_C = \int P_C(t)\,dt$$

$$= \int v\,c\,\frac{dv}{\cancel{dt}} \cdot \cancel{dt}$$

$$= C \cdot \frac{v^2}{2} \Rightarrow \boxed{W_c = \frac{1}{2} C v^2} \text{ Joules.}$$

Problems :-

Q:- Find the energy dissipation and stored by the passive elements R & L, C..

(i) A resistance 5Ω carries ~~current of~~ 2A for 3 hours

(ii) A 10 H inductor carries a current 5 A

(iii) 30 F capacitor having applied voltage 20V

(Ans :- $E_R = 60$ Wh
$E_L = 125$ J
$E_C = 6000$ J)

Q Find the values of R, L & C

(a) A resistance carries 2A at 500V

(b). A inductor carries 2A and 20J of energy is stored

(c) A capacitor with 500V across it and 20J is stored energy

(Ans:- $R = 250\Omega$
$L = 10$ H
$C = 1600\mu F$)

Voltage and Current Sources

These are classified as two types

① Independent Sources

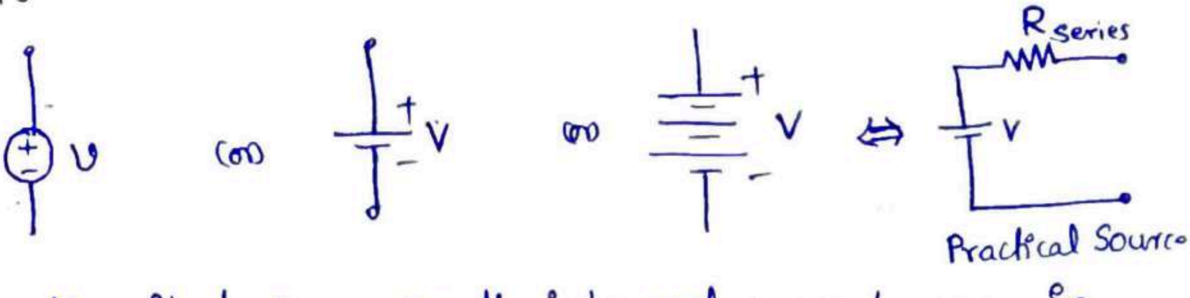
② Dependent Sources.

① **Independent Sources :** The values of energy sources does not depend on other voltages (or) currents in the network, thus sources are called "Independent Sources".

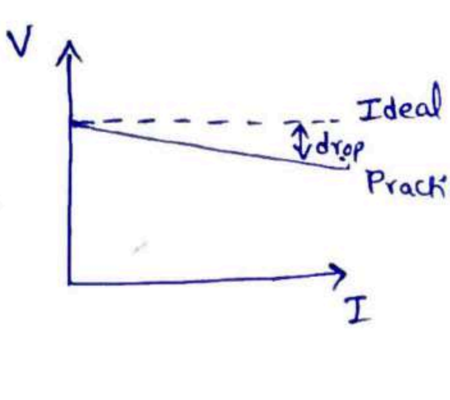
(i) Independent Voltage Source :-

The energy source which maintains constant voltage at its terminals irrespective of the current delivered to the external circuit, is called "Independent Ideal Voltage Source".

→ Symbol is



→ Practically it has a small internal resistance in series, due to this some amount of voltage drop is exist as shown below



* Internal resistance of an ideal voltage source is $R = 0$ i.e $V_{i/p} = V_{o/p}$

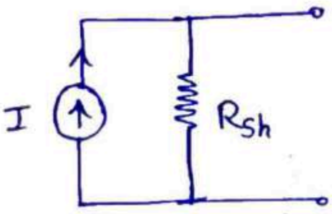
(ii) Independent current Source

The source which delivers a current of constant magnitude at its terminals irrespective of applied voltage across its terminals is called "Independent Ideal Current Source"

→ Symbol is

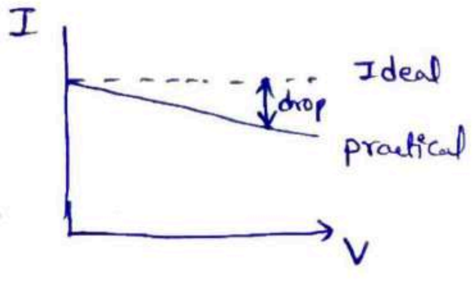
ideal Source

&



Practical Source

→ But practically it has high internal resistance connected parallel with it, due to this some amount of drop will exist. as shown below.



* Internal resistance of an ideal current source i.e $R = \infty$ i.e infinite

② Dependent Sources :-

The values of energy sources are depends on other voltages (or) currents in the network, thus sources are called "Dependent Sources".

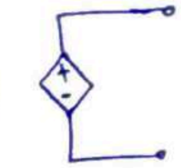
These are classified as 4-types

1. voltage ~~Dependent~~ dependent Voltage Source (VDVS)
2. Voltage Dependent Current source (VDCS)
3. Current Dependent voltage source (CDVS)
4. Current Dependent current Source (CDCS)

(i). Voltage Dependent voltage Source (VDVS)

The value of this voltage Source depends on function of voltages in elsewhere in the same circuit.

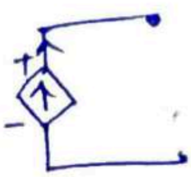
$V = KV_1$



(ii) Voltage Dependent Current source (VDCS)

The Value of this current source depend on function of voltages ~~currents~~ in elsewhere in the same circuit

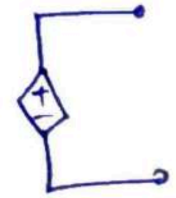
$I = KV_1$



(iii) Current Dependent voltage Source (CDVS)

The Value of this voltage source depend on function of currents in somewhere in the same Circuit

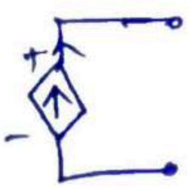
$V = KI_1$



(iv) Current dependent Current source (CDCS)

The Value of this current source depend on the function of current in somewhere in the same Circuit

$I = KI_1$

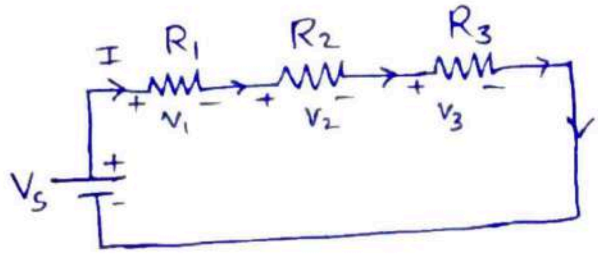


Series & Parallel connections of R, L & C electrical elements

① Resistors connected in Series

In a series circuit, all the components are connected such that there is only one closed path and same current flows through all the components. As shown in below figure

consider 3-Resistors R_1, R_2 & R_3 are connected in series with a voltage source V_s & causes the current I.



The total (or) Equalent resistance of circuit is

$$\boxed{R_{eq} = R_1 + R_2 + R_3}$$

Note :- ① In series circuit Current is Same $\boxed{I_s = I}$

② In series circuit Voltage is divided

i.e $\boxed{V_S = V_1 + V_2 + V_3}$

⇒ Application of series connection is to increase the resistance & to limit the current flow.

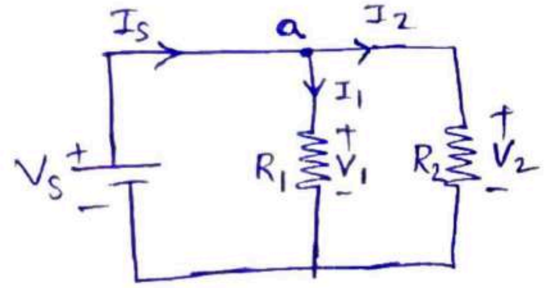
→ Resistances, Voltages & powers are additive in series connection.

⇒ Different current rating devices unable to connect in series.

(2) Parallel connection of Resistors

In parallel circuit "all the components in that circui are connected in a manner that there are more than one path (or) branches current can flows.

As shown below



consider a circuit having two resistors R_1 & R_2 in parallel across a source V_s & point 'a' current is

$$I = I_1 + I_2$$

The equalent Resistance is

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}} \quad (\text{or}) \quad \boxed{R_{eq} = \frac{R_1 R_2}{R_1 + R_2}}$$

Note :- (1) Parallel circuit Voltage is Same $\boxed{V_s = V_1 = V_2}$

(2) current is divided i.e $\boxed{I_s = I_1 + I_2}$

Advatages :-

(1) If there is a discontinuity (or) break in any one branch, the current will still flow in the other branc

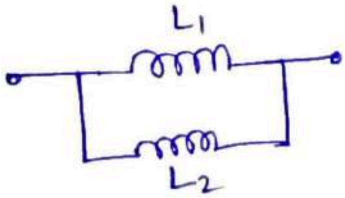
(2). The power & current rating can be distributed to the electrical appliances is Same

(3). These are used in all house hold & industrial wiring.

3 Inductors in Series

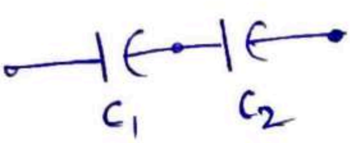
$$\Rightarrow \boxed{L_{eq} = L_1 + L_2}$$

4 Inductors in parallel



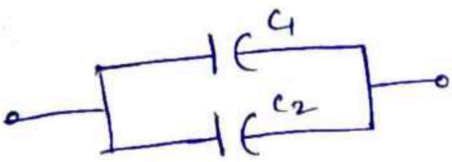
$$\Rightarrow \boxed{L_{eq} = \frac{L_1 L_2}{L_1 + L_2}}$$

5 Capacitors in series



$$\Rightarrow \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} \Rightarrow \boxed{C_{eq} = \frac{C_1 C_2}{C_1 + C_2}}$$

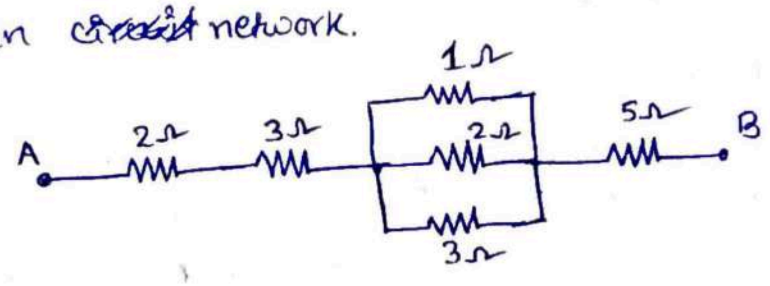
6 Capacitors in Parallel



$$\Rightarrow \boxed{C_{eq} = C_1 + C_2}$$

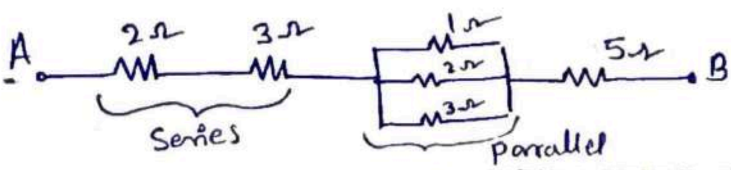
Problem :-

1. Find the total Resistance between the terminal A & B for given ~~circuit~~ network.

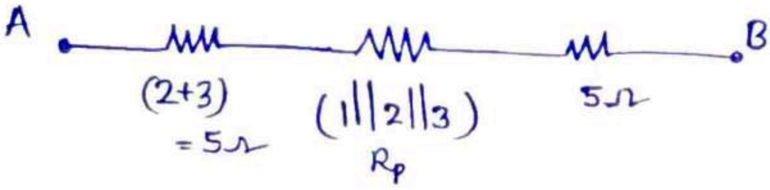


Solution:- In given circuit 2Ω & 3Ω resistors in series & $1\Omega, 2\Omega, 3\Omega$ are in parallel

i.e



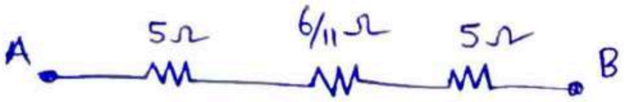
The circuit modified as



$$R_p = \frac{1 \times 2 \times 3}{2 + 6 + 3} \qquad \because R_{eq} = \frac{R_1 R_2 R_3}{R_1R_2 + R_2R_3 + R_3 1}$$

$$= \frac{6}{11}$$

then



Now

Total Resistance $R_{AB} = 5 + \frac{6}{11} + 5 = 5 + 0.545 + 5$

$= 10.545$

$$\boxed{R_{AB} = 10.545\,\Omega}$$

(2) Determine the voltage if the total power absorbed by the resistors is 100 Watts, thus resistor are 2Ω, 3Ω, 4Ω & 5Ω respectively are connected in parallel.

Solution :-

Given data : $R_1 = 2\Omega$, $R_2 = 3\Omega$, $R_3 = 4\Omega$ $R_4 = 5\Omega$ & $P = 100$ watt

Then in parallel R_T is

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \Rightarrow \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5}$$

$$= \frac{30+20+15*12}{60} = \frac{77}{60} \Rightarrow R_T$$

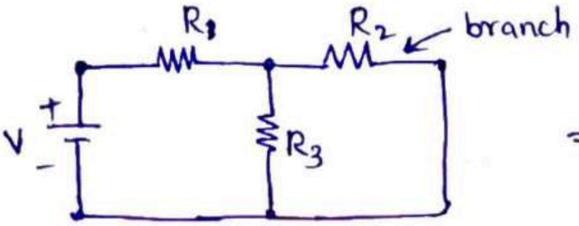
The total power absorbed $P = \frac{V^2}{R_T} = 100W$

$$V^2 = 100 \times R_T \Rightarrow 100 \times \frac{77}{60} = \boxed{V_s = 8.827 \text{ Volts}}$$

Basic Definations

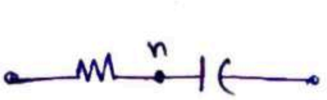
Branch :- "A part of a network which is connected between two nodes, usually called as "branch".

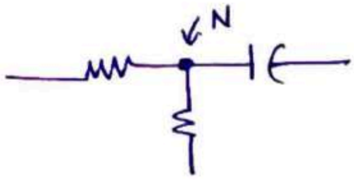
Ex :-



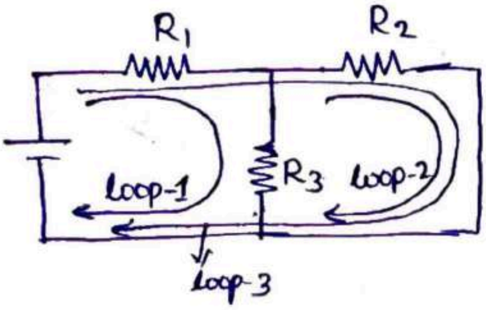
⇒ We have 4-branches

Node :- "A point at which two (or) more circuit elements are joined together is called 'node'

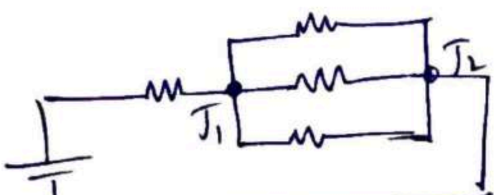




Mesh (or) Loop :- "A closed path which starts and ending at same node and which is not passing any node (or) branch twice is called mesh (or) loop.



Junction Point :- A point of a network at which three (or) more no. of circuit elements are joined together



Kirchhoff's Laws

Kirchhoff's Laws are classified into two types

1. Kirchhoff Current Law (KCL)
2. Kirchhoff Voltage Law (KVL)

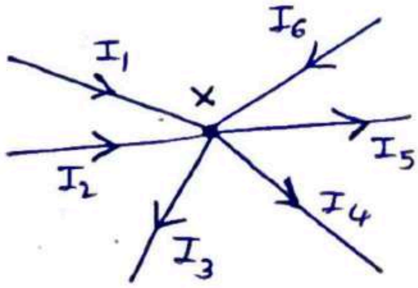
Kirchhoff Current Law (KCL)

Statement :- KCL states that algebraic sum of currents at any node is equal to "zero". i.e

the total current entering a node is equal to the total current leaving that node.

i.e $\boxed{\sum_{\text{at node}} I = 0}$ or $\boxed{\sum I_{ent} = \sum I_{leav}}$

Explanation :-



consider a node 'x' is connected by a 6-branches carriying a currents I_1, I_2, I_3, I_4, I_5 & I_6 as shown in fig.

Let the currents entering into the node are positive currents & leaving currents are negative currents as

I_1, I_2, I_6 are positive

& I_3, I_4, I_5 are negative

Then, according to KCL

$\sum I = 0$ i.e $I_1 + I_2 - I_3 - I_4 - I_5 + I_6 = 0$

(or) $I_1 + I_2 + I_6 = I_3 + I_4 + I_5$

i.e from KCL

Total current entering into node = Total current leaving from that node.

→ It is useful for Nodal analysis

Kirchhoff Voltage Law (KVL)

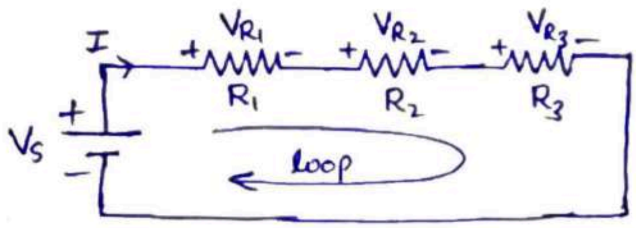
Statement :- KVL states that algebraic sum of the voltages around the closed loop (or) circuit is equal to "zero"

i.e $\boxed{\sum_{\text{In Loop}} V = 0}$

i.e the algebraic sum of the emf's (or) voltages of sources in loop is equal to sum of the voltage drop across the circuit elements of in that loop

i.e $\boxed{\sum_{\text{loop}} V_s = \sum_{\text{loop}} (IR)_{\text{drop}}}$

Explanation :- consider a circuit which is having resistors R_1, R_2 & R_3 & supply source V_s as shown below



According to KVL

$$V_s - V_{R_1} - V_{R_2} - V_{R_3} = 0$$

$$V_s = V_{R_1} + V_{R_2} + V_{R_3}$$

$$= IR_1 + IR_2 + IR_3$$

$$V_s = I(R_1 + R_2 + R_3) \Rightarrow I = \frac{V_s}{R_1 + R_2 + R_3}$$

→ Indicate the sign conventions for elements by the direction of currents

→ It is useful for mesh analysis.

Steps for applying Kirchhoff Laws :-

Step ① Draw the circuit diagram from given information

② Insert the all values of sources with appropriated polarities and all resistance values

③. By using KCL mark the all branch currents with some assumed directions at the nodes.

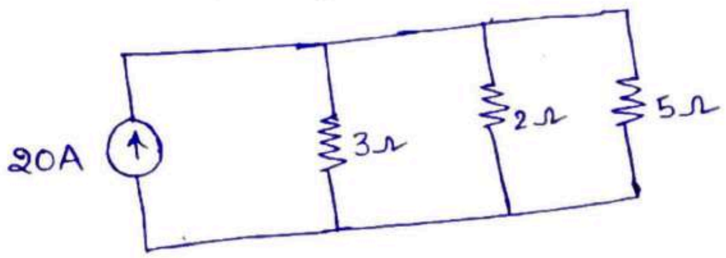
④ Mark the all the polarities of voltage drops of rises & drops

⑤ Apply KVL for different closed loops

⑥ Solve the equations by based on solution

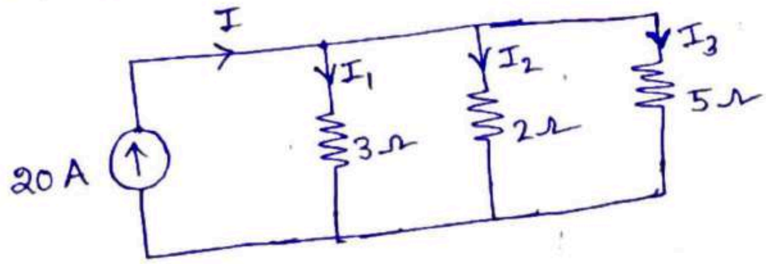
Problems :-

P1) Determine the current in all resistors in the by using KCL, for a given circuit below



Solution :-

Let the total current I, & respective branch currents I_1, I_2, I_3 as shown circuit & let the voltage 'V'



According to KCL

$$I = I_1 + I_2 + I_3$$

$$20 = \frac{V}{3} + \frac{V}{2} + \frac{V}{5}$$

$$20 = V\left[\frac{1}{3} + \frac{1}{2} + \frac{1}{5}\right]$$

$$20 = V\left[\frac{10+15+6}{30}\right] \Rightarrow V = \frac{20 \times 30}{31} \Rightarrow \boxed{V = 19.35}$$

∵ By the ohm's law $\because I = \frac{V}{R}$

$$\because I_1 = \frac{V}{3}$$

$$\because I_2 = \frac{V}{2}$$

$$\because I_3 = \frac{V}{5}$$

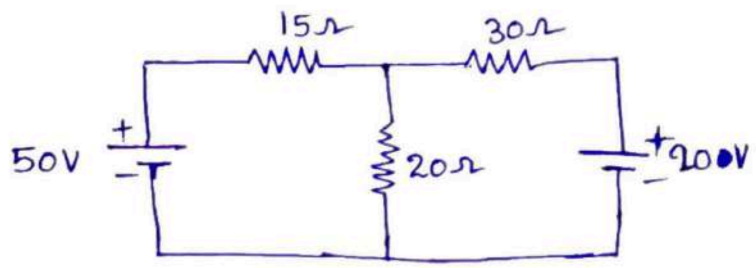
Now branch currents

Current in 3Ω Resistor $I_{3\Omega} = I_1 = \frac{V}{3} = \frac{19.35}{3} \Rightarrow \boxed{I_1 = 6.45}$

Current in 2Ω Resistor $I_{2\Omega} = I_2 = \frac{V}{2} = \frac{19.35}{2} = \boxed{I_2 = 9.67\ \text{Am}}$

Current in 5Ω Resistor $I_{5\Omega} = I_3 = \frac{V}{5} = \frac{19.35}{5} = \boxed{I_3 = 3.87\ \text{Amp}}$

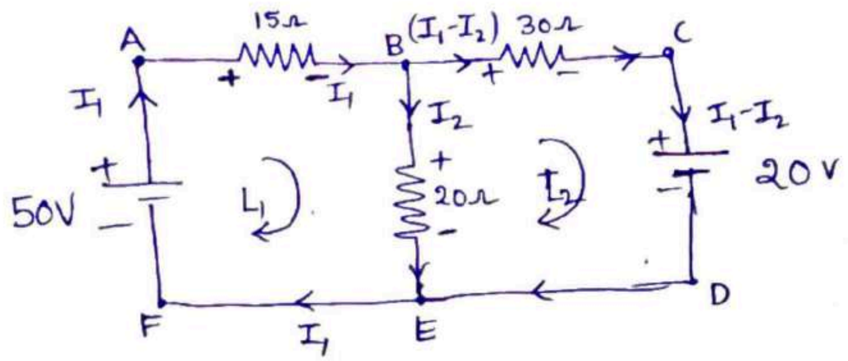
P(2) Apply Kirchhoff's laws to the given circuit



Determine the currents in all branches.

Solutions:-

Steps (1) & (2) Draw the circuit diagram with the values & polarities & branch currents by 50V source as reference, by KCL



→ Apply KVL for different loops L_1 & L_2

Loop 1 : ABEFA

$$50-(I_1 \times 15)-(I_2 \times 20)=0$$

$$15I_1+20I_2=50 \quad \text{—— (1)}$$

Loop 2 :- BCDEB

$$-30 \times (I_1-I_2)-20+(20 \times I_2)=0$$

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

$$-30I_1+50I_2=20 \quad \text{—— (2)}.$$

By solving the equations 1 & 2 (or) use the casio

Multiply eq 1 × 2

then
$$\cancel{30}I_1 + 40 I_2 = 100$$
$$-\cancel{30}I_1 + 50 I_2 = 20$$
$$90 I_2 = 120 \Rightarrow I_2 = \frac{120}{90} \Rightarrow \boxed{I_2 = 1.33 \text{ Amp}}$$

Substitute I_2 in eq 1 (or) 2.

$$15 I_1 + (20 \times 1.33) = 50$$
$$I_1 = \frac{(50-26.6)}{15} \Rightarrow \boxed{I_1 = 1.56 \text{ Amp}}$$

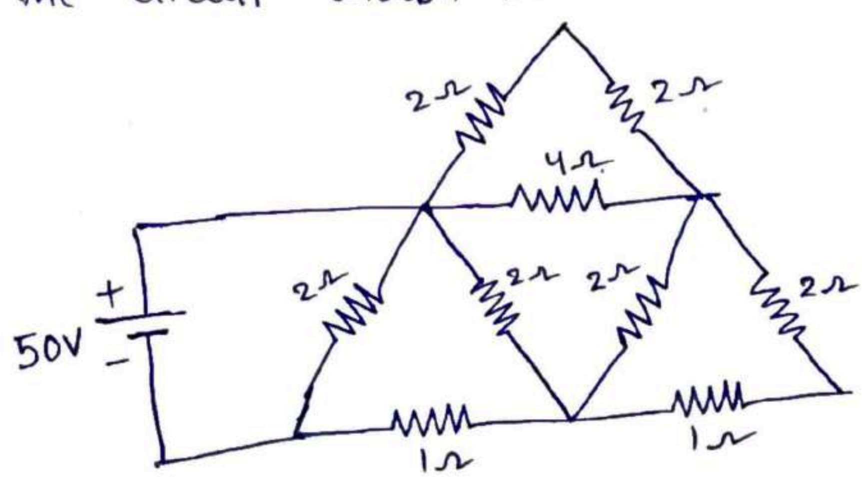
Now branch current

Current in 15Ω Resister $\boxed{I_{15\Omega} = I_1 = 1.56 \text{ Amp}}$

Current in 20Ω Resister $\boxed{I_{20\Omega} = I_2 = 1.33 \text{ Amp}}$

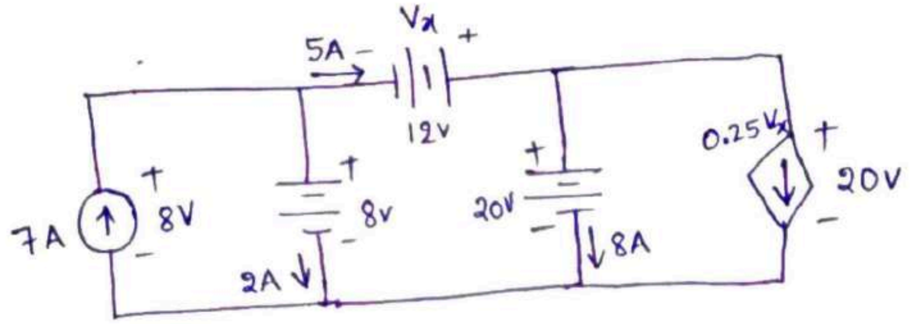
Current in 30Ω Resister $\boxed{I_{30\Omega} = (I_1 - I_2) = 0.23 \text{ Amp}}$

P3 :- Determine the current delivered by the source in the circuit shown in below.



Ans: I = 47.41

Q: Calculate the power absorbed by each component in the circuit shown in figure.



Solution :- In a given circuit we have 5-components as

3- voltage sources

1- current source & 1- voltage dependent current source.

Now Power absorbed by

7A current source is $P_{7A} = V \times I = 7 \times 8 \Rightarrow \boxed{P_{7A} = 56W}$

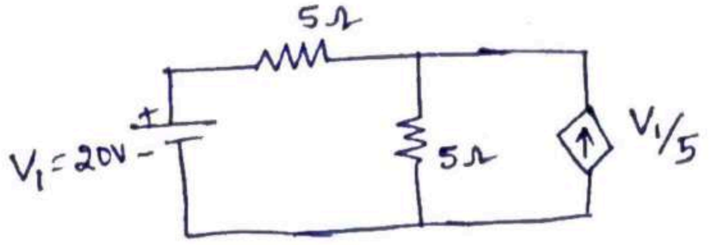
8V voltage source is $P_{8V} = 8 \times (-2) = 16 \Rightarrow \boxed{P_{8V} = -16W}$

12v voltage source is $P_{12V} = 5 \times 12 = 60 \Rightarrow \boxed{P_{12} = 60W}$

20V voltage source is $P_{20V} = 20 \times (-8) = -160 \rightarrow \boxed{P_{20} = -160W}$

0.25V_x VDCS is $P = (0.25 \times 12) \times (20) = 60 \rightarrow \boxed{P_{VDCS} = 60W}$

Q:- Find the power supplied by dependent source.



Ans: 80W

Analysis of Simple DC-Circuits

Analysis of DC-circuits can be done by Network Reduction techniques as

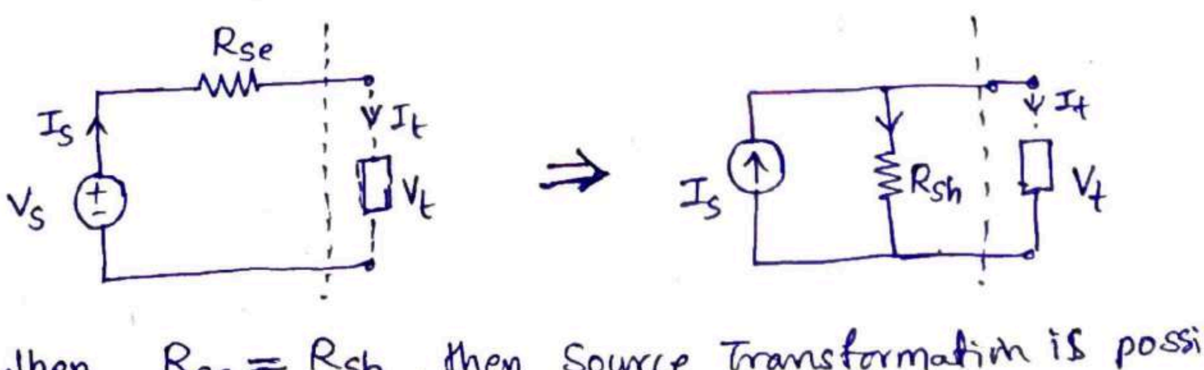
- → Source transformation
- → Current division rule
- → Voltage division rule
- → Nodal Analysis
- → Mesh Analysis
- → Star-Delta (or) Delt-Star transformation:-

Source Transformation:-

Source transformation is techniques for "reducing of complexity of network by replacing voltage source by current source (or) current source by voltage source.

Practically we know that voltage source has a series resistance and current source has a parallel ~~shunt res~~ (or) shunt resistance.

Let the Voltage & current souses as



When $R_{se} = R_{sh}$, then Source Transformation is possible

$$V_t = V_S - I_S R_{se} \quad (\because I_s = I_t)$$

$$I_t = \frac{V_S - V_t}{R_{se}}$$

$$I_t = \frac{V_S}{R_{se}} - \frac{V_t}{R_{se}} \Rightarrow I_t = I_S - \frac{V_t}{R_{se}} \quad \text{—(1)}$$

from abow

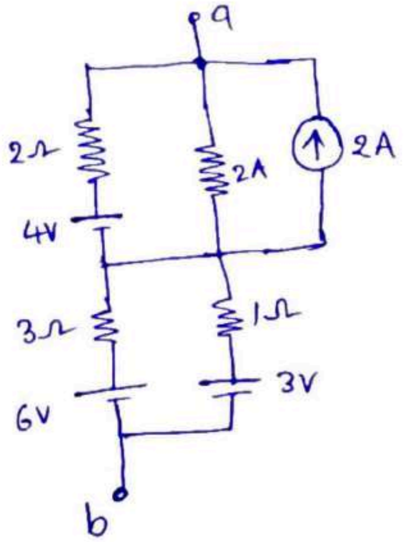
$$I_S = \frac{V_t}{R_{sh}} + I_t$$

$$I_t = I_S - \frac{V_t}{R_{sh}} \quad \text{—(2)}$$

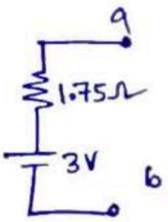
From above eq ① & eq ② when $R_{se} = R_{sh}$ then S.T is possible

As ... voltage source V_s and internal resistance R_{se} canbe replaced by equalent current source I_s in parallel with shunt resistance i.e $I_s = \frac{V_s}{R_s}$ & $R_{sh} = R_s$.

Prob:- convert given circuit into single voltage source.

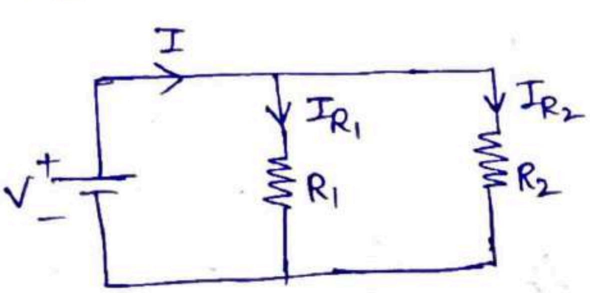


Ans:-



Current Division in parallel circuits

For a given circuit current division applied as



i.e current in branch Resistance = Total current X $\frac{\text{Opposite Resistance}}{\text{Total Resistance}}$

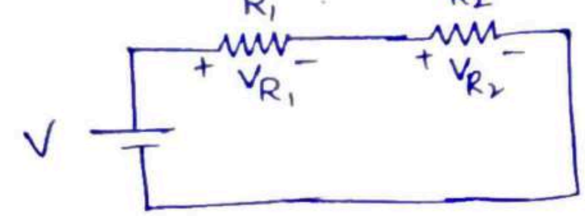
i.e current in $I_{R_1} = I \times \frac{R_2}{R_1+R_2}$

$I_{R_2} = I \times \frac{R_1}{R_1+R_2}$

i.e $I_{R_n} = I . \frac{R_1 . R_2 \ldots R_{n-1}}{\Sigma R_1 R_2 \cdots R_n}$

Voltage division in series circuits

VDR - is apply for a given circuit



i.e Voltage across any branch Resistance = Total voltage × $\frac{\text{Same Resistance}}{\text{Total Resistance}}$

(or)

i.e Voltage across R_1 is Total current × Same Resistance

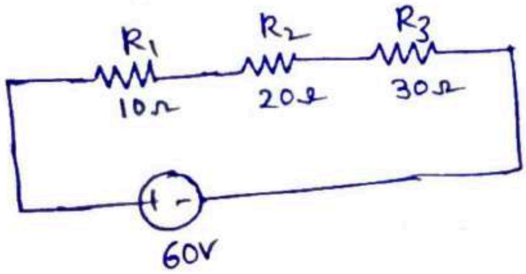
$$V_{R_1} = V \times \frac{R_1}{R_1+R_2} \text{ (or) } I_T R_1$$

i.e $V_{R_n} = V \cdot \frac{\Sigma R_1, R_2, \cdots R_n}{\Sigma R_n}$

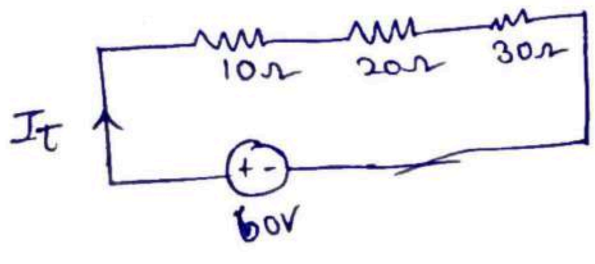
$$V_{R_2} = V \times \frac{R_2}{R_1+R_2} \text{ (or) } I_T R_2$$

Problems:-

①. Find the voltage across 3-resistors by using VDR.



Solution:- Let total current I_T & Total volty $V_t = 60V$



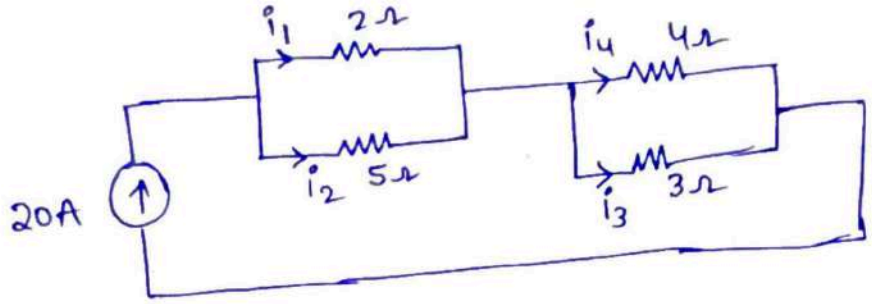
$$R_T = R_1 + R_2 + R_3$$
$$= 10 + 20 + 30 = 60\Omega$$

$$I_t = \frac{V_t}{R_t} = \frac{60}{60} = 1A$$

$$V_{10\Omega} = I_T R_{10} = 1 \times 10 = 10V$$

$$V_{20\Omega} = 20 \times 1 = 20V \quad \& \quad V_{30} = 30V$$

P② Find currents i_1, i_2, i_3 & i_4 in given circuit.



Solution

In a given circuit total current $I = 20A$, then

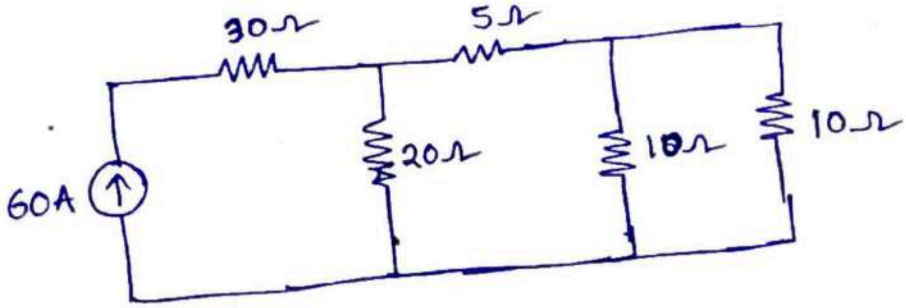
$$i_1 = I \times \frac{5}{2+5} = 20 \times \frac{5}{7} = \frac{100}{7} \Rightarrow \boxed{i_1 = 14.28 \text{ Amp}}$$

$$i_2 = 20 \times \frac{2}{2+5} = \frac{40}{7} \Rightarrow \boxed{i_2 = 5.71 \text{ Amp}}$$

$$i_3 = 20 \times \frac{4}{4+3} = \frac{80}{7} = \boxed{i_3 = 11.42 \text{ Amp}}$$

$$i_4 = 20 \times \frac{3}{4+3} = \frac{60}{7} \Rightarrow \boxed{i_4 = 8.57 \text{ Amp}}$$

Prob :- Find the current in all branches



Nodal analysis :-

→ This method is mainly based on "Kirchhoff Current Law

→ If a network has 'n' nodes (or) 'j' junction points, then we will get $(n-1)$ (or) $(j-1)$ of nodal equations.

Steps for Nodal Analysis :-

Step ① Choose the nodes & node voltages

Step ②. Assume the one of the node as "base node (or) refference node & Assume remaing all nodes are high potential nodes

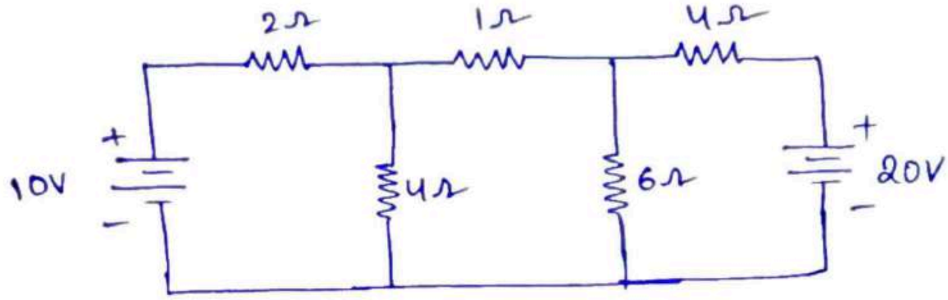
Step ③ Assume the branch currents leaving ~~leaving~~ from high potential node by using KCL at node

Step ④ obtain the current (or) nodal equations interms of node voltages

Step ⑤ Solving the nodal equations we get node voltages w.r.to them find branch currents.

Note :- If a network has a more no.of voltage sources then better to use mesh analysis otherwise nodal analysis if network has $m < n$ then nodal method is prefer problem :-

Find the current through each resistor of circuit shown in figure, by using nodal analysis

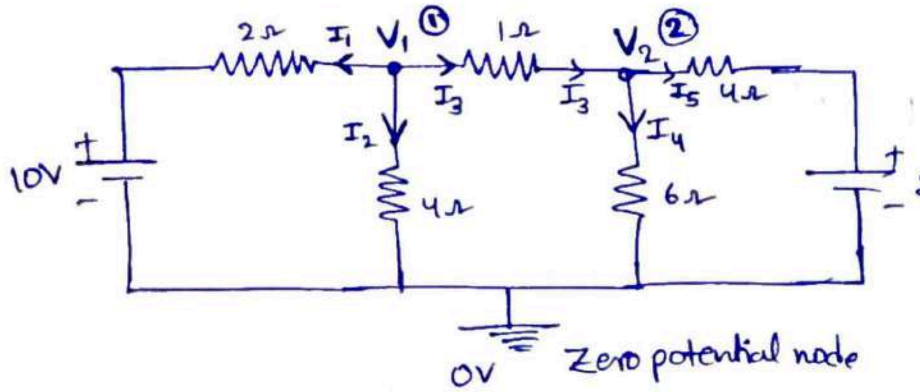


Solution :-

→ choose nodes & node voltages, Let a one node as refference

→ Assume branch currents as I_1 I_2 I_3 at node ①.

and I_4 & I_5 at n② as



→ At node 1, by applying KCL

We know $I_1 = \frac{V_1 - 10}{2}$

$$-I_1 - I_2 - I_3 = 0$$

$I_2 = \frac{V_1 - 0V}{4} = \frac{V_1}{4}$

Now

$$-\left[\frac{V_1 - 10}{2}\right] - \left[\frac{V_1}{4}\right] - \left[\frac{V_1 - V_2}{1}\right] = 0$$

$I_3 = \frac{V_1 - V_2}{1}$

$$-2(V_1 - 10) - V_1 - 4[V_1 - V_2] = 0$$

$$-2V_1 + 20 - V_1 - 4V_1 + 4V_2 = 0$$

$$-7V_1 + 4V_2 = -20 \quad \text{—— ①}$$

→ At node - 2 :

$$I_4 = \frac{V_2}{6}$$

$$I_5 = \frac{V_2 - 20}{4}$$

$$I_3 - I_4 - I_5 = 0$$

$$\frac{V_1 - V_2}{1} - \frac{V_2}{6} - \frac{V_2 - 20}{4} = 0$$

$$12(V_1 - V_2) - 2V_2 - 3(V_2 - 20) = 0$$

$$12V_1 - 17V_2 = -60 \quad \text{--- (2)}.$$

By solving eq (1) & eq (2).

$$V_1 = 8.169\,V \qquad \& \qquad V_2 = 9.295\,V$$

Now branch currents $I_1 = \frac{V_1 - 10}{2} = \frac{8.169 - 10}{2} = -0.9155$

i.e $\boxed{I_1 = 0.9155\,\text{Amp} \rightarrow}$ -Ve means opposite direction

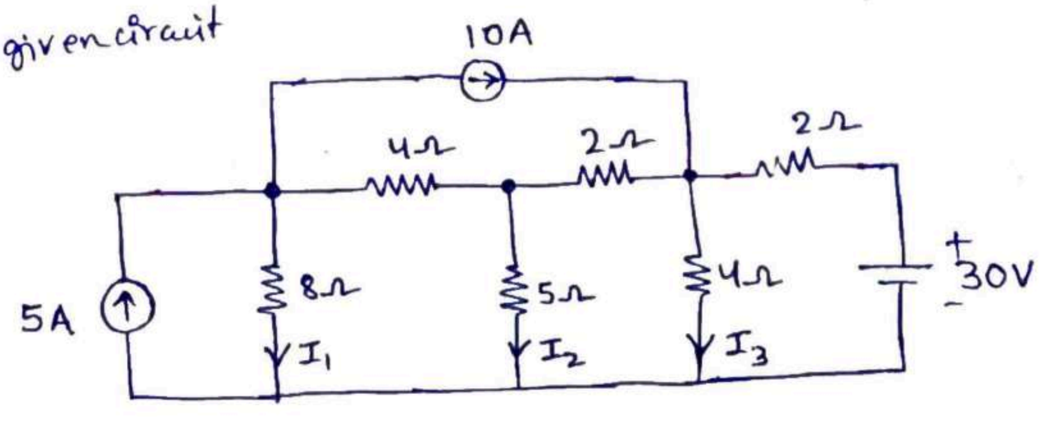
$$I_2 = \frac{V_1}{4} = \frac{8.169}{4} = 2.042 \Rightarrow \boxed{I_2 = 2.042\,A}$$

$$I_3 = \frac{V_1 - V_2}{1} = 1.126 \Rightarrow \boxed{I_3 = 1.126\,A}$$

$$I_4 = \frac{V_2}{6} = 1.361 \rightarrow \boxed{I_4 = 1.361\,A}$$

$$I_5 = \frac{V_2 - 20}{4} = -2.676 \quad \boxed{I_5 = 2.676\,A \leftrightarrow}$$

Problem:- Find the different node voltages & currents I_1, I_2, & I_3 for given circuit



Mesh analysis (or) Loop Analysis

→ This method is mainly based on KVL

→ If a network have 'b' of branches, 'J' of junctions, then we will get the independent mesh equations

i.e $m = b-(j-1)$ (or) $b-(n-1)$

Steps for mesh analysis :-

Step ①. Find the various loops in a network.

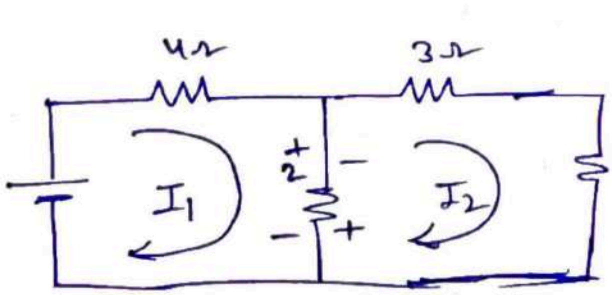
②. Indicate the assumed loop currents directions and w.r.to that mark the polarities

Note: Assumed loop current is higher value compare with other loop currents.

step ③ choose minium no. of loops and write the loop equations by applying KVL

step ④ By Solving the loop equtions we get loop currents.

Ex:-



At loop-1

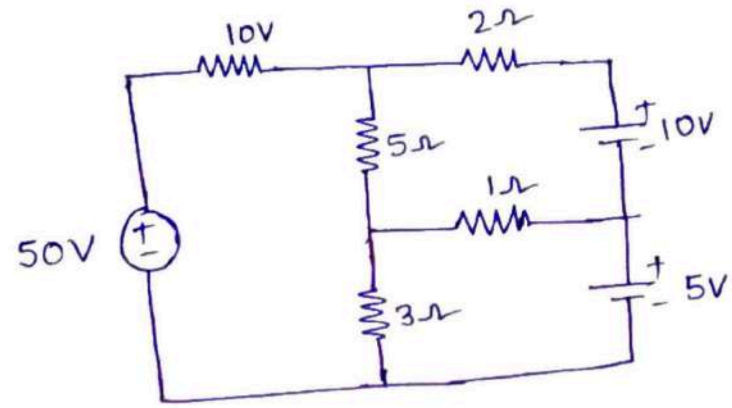
Voltage At 2Ω $V_{2\Omega} = 2(I_1 - I_2)$

At Loop-2

$V_{2\Omega} = 2(I_2 - I_1)$

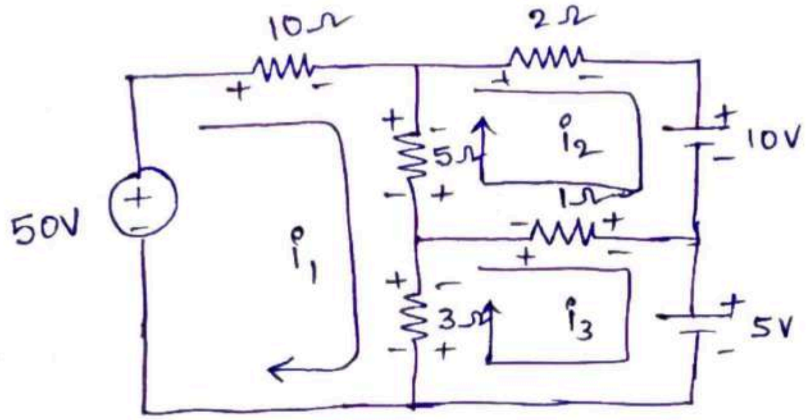
Problem:-

(1) Determine mesh current by using mesh analysis



Solution:-

step(1) Assumming loop currents i_1, i_2 & i_3



Step (2) At loop-1, Apply KVL.

$$50 - 10 i_1 - 5(i_1 - i_2) - 3(i_1 - i_3) = 0$$

$$-18 i_1 + 5 i_2 + 3 i_3 + 50 = 0$$

$$-18 i_1 + 5 i_2 + 3 i_3 = -50 \quad \text{--- (1)}$$

At loop-2,

$$-2 i_2 - 10 - 1(i_2 - i_3) - 5(i_2 - i_1) = 0$$

$$5 i_1 - 8 i_2 + i_3 = 10 \quad \text{--- (2)}$$

At loop ③

$$-(i_3-i_2) - 5 - 3(i_3-i_1) = 0$$

$$3i_1 + i_2 - 4i_3 = 5 \quad \text{—} \quad ③$$

by solving eq'n

$i_1 = 3.300$ Amp $\quad i_2 = 0.997$ A $\quad$ & $i_3 = 1.474$ A

Current in 10Ω $\quad I_{10\Omega} = 3.3$ A

$$I_{5\Omega} = \cancel{3.3 + I_3 + 0.997}\ (i_1 - i_2)$$

$$= 3.3 - 0.997 = 2.303 \text{ A}$$

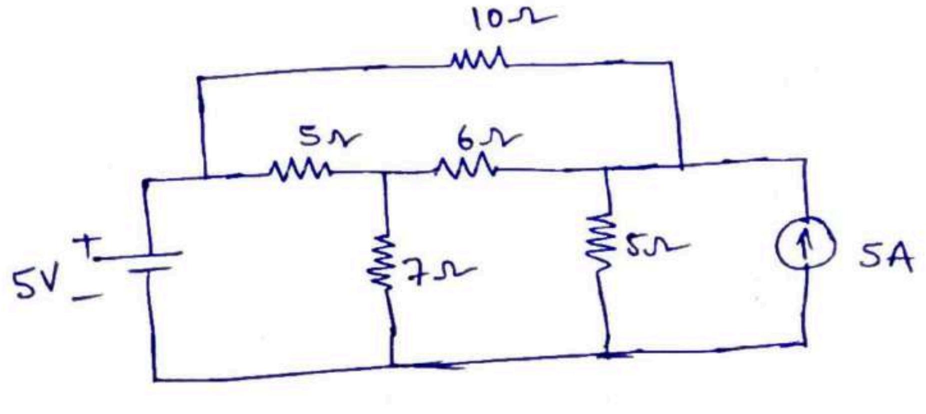
$$I_{2\Omega} = 0.997\text{A}$$

$$I_{1\Omega} = (i_2 - i_3) = 0.997 - 1.474 = -0.477 \text{ A}$$

$$I_{3\Omega} = (i_3 - i_1) = 1.474 - 3.3 = -1.825 \text{ A}$$

Prob ②

Find the voltage across 10Ω resistor in the network



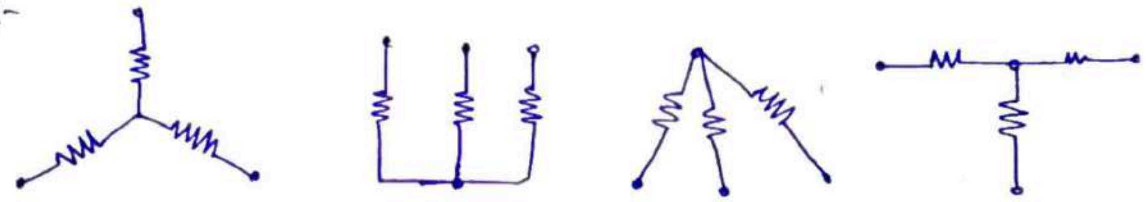
Ans: 9.138 V

Star to Delta (or) Delt to Star Transformation

Star connection (Y)

If 3-resistors are connected in such a manner that one end of each resistors are connected at a junction point (or) star point, then thus 3-resistors are said to be in "star connection"

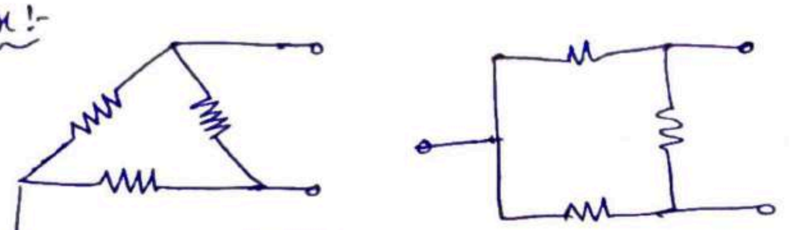
Ex:-



Delta Connection (Δ)

In 3-resistors, one end of the first resistor is connected to first end of second, the second end of second to first end of third and so on to complete a loop then thus resistors are said to be connected in "Delta"

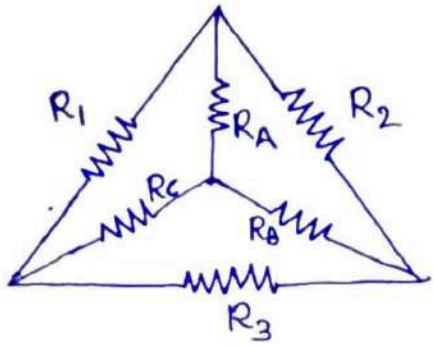
Ex:-



→ These Y & Δ connections are used in 3-phase systems (or) machines.

→ These connection can increases the voltages (or) current in 3-ϕ systems

Star-to-Delta ($Y \rightarrow \Delta$) Transformation



$\Delta \rightarrow Y$

Star Resistance values as

$$R_A = \frac{R_1 R_2}{R_1 + R_2 + R_3}$$

$$R_B = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

$$R_C = \frac{R_3 R_1}{R_1 + R_2 + R_3}$$

if $R_1 = R_2 = R_3 = R$ are same

then

$$R_Y = \frac{R_\Delta}{3}$$

$Y \rightarrow \Delta$

Delta Resistance values as

$$R_1 = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B}$$

$$R_2 = \frac{R_A R_B + R_B R_C + R_C R_A}{R_C}$$

$$R_3 = \frac{R_A R_B + R_B R_C + R_C R_A}{R_A}$$

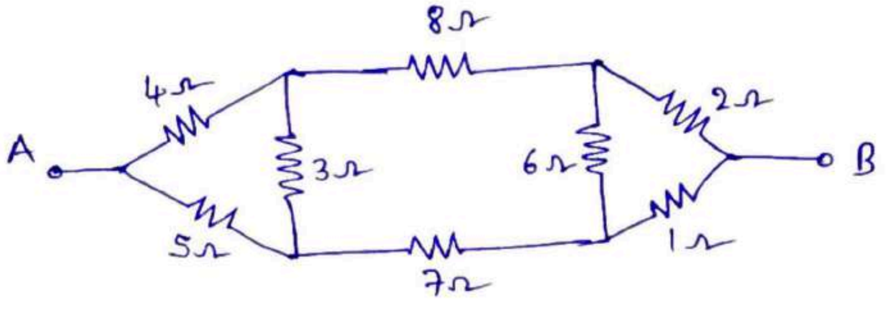
If $R_A = R_B = R_C = R$

then

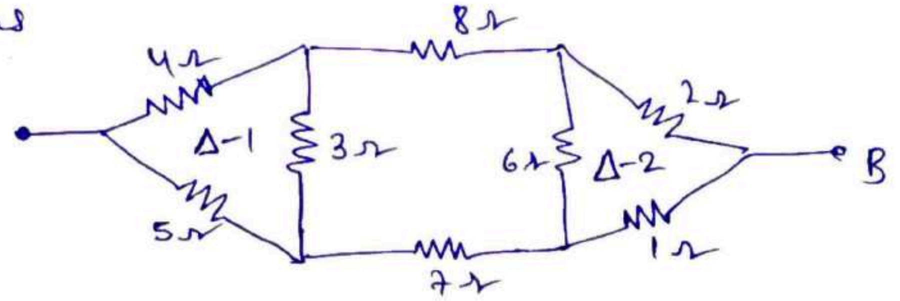
$$R_\Delta = 3 R_Y$$

Problem :-

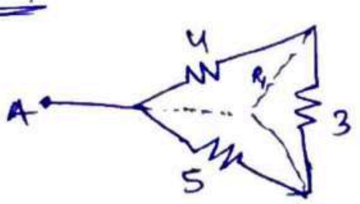
P(1). Find the voltage to be applied across A-B, if drive Current of 20A

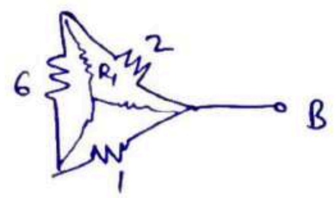


Solution :- In a given Circuit 2-Δ connections are present as



Δ-1





$R_1 = \frac{4 \times 3}{4+3+5} = \frac{12}{12} = 1\Omega$

$R_2 = \frac{3 \times 5}{3+5+4} = \frac{15}{12} = 1.25\Omega$

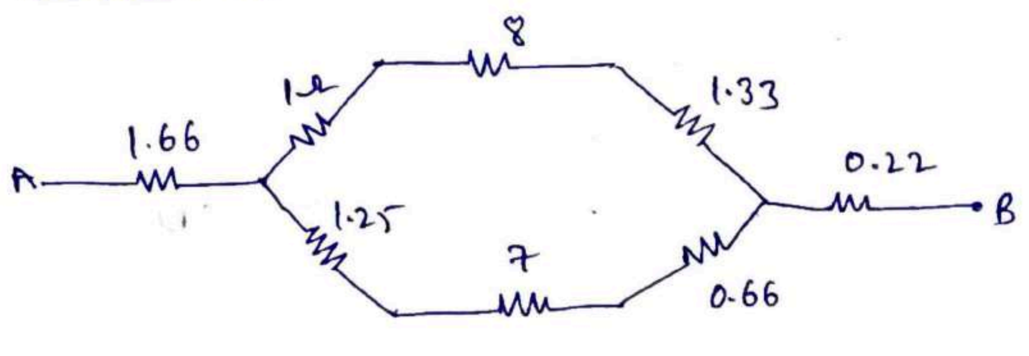
$R_3 = \frac{5 \times 4}{12} = 1.66\Omega$

$R_1 = \frac{6 \times 2}{6+2+1} = \frac{12}{9} = 1.33\Omega$

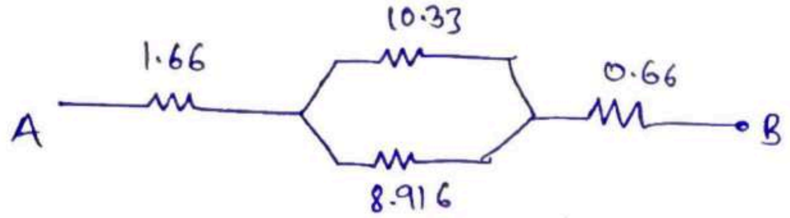
$R_2 = \frac{2}{9} = 0.22\Omega$

$R_3 = \frac{6}{9} = 0.66\Omega$

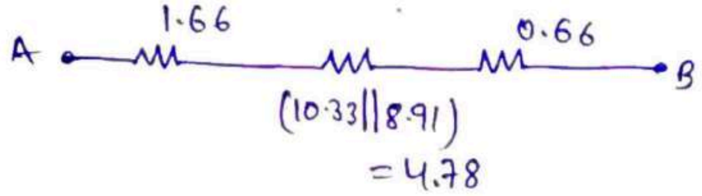
Circuit Redrawn as



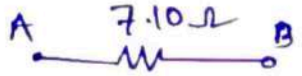
$\Rightarrow$



$\Rightarrow$



$\Rightarrow$

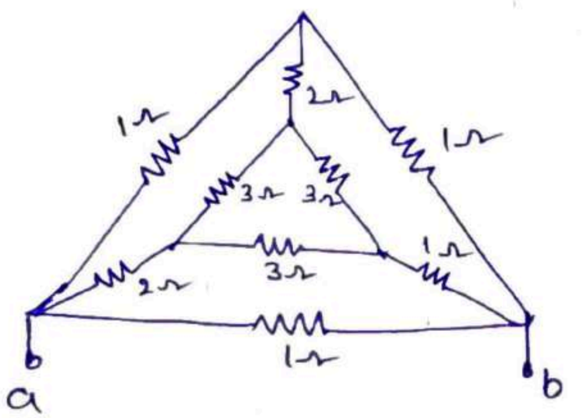


$\Longrightarrow$ we have $I = 20A$

$R_{AB} = 7.10$

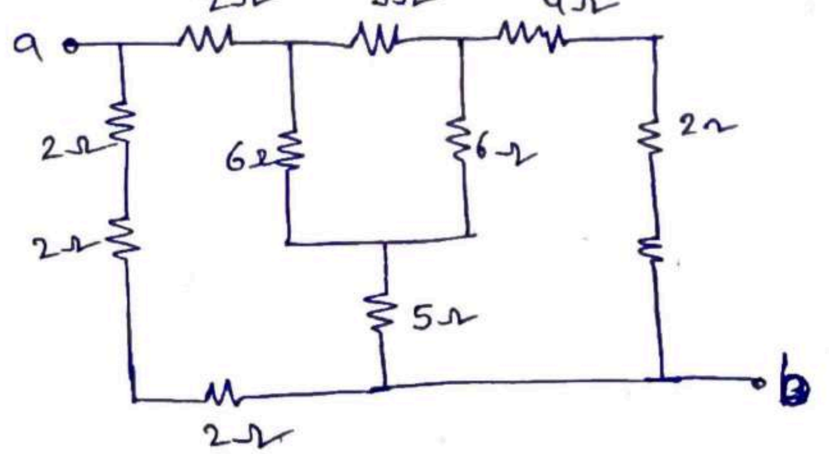
$$\boxed{V = I R = 142.07\ V}$$

P② Find Rab



Ans: $R_{ab} = 0.6\ \Omega$

P③ Find Rab



Network Theorems

The necessity of network theorems is to calculate single branch response in complecated network.

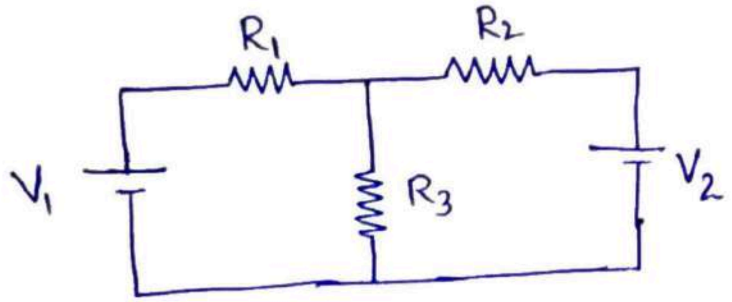
① Superposition theorem
② Thevenin's theorem
③ Norton's theorem
④ Maximum Power transfer theorem
⑤ Reciprocity theorem

1. Superposition Theorem

Statement : In any linear, bilateral network consist of two (or) more sources & Resistors, the response (i.e V (or) I) at any element in network is equal to the algebraic sum of the responses caused by indvidual sources acting separately, while other sources are replaced by their internal resistances at ideal conditions

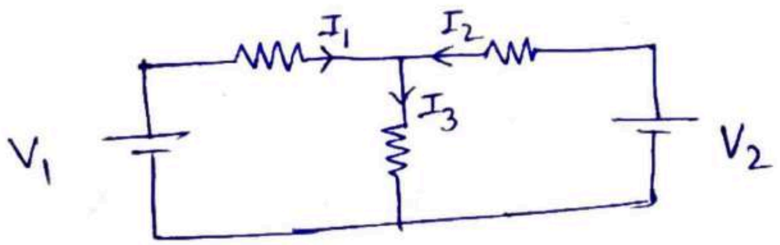
i.e Voltage Source as → short circuit
Current Source as → open Circuit

Explanation :- consider a dc-circuit which is having two voltage sources V_1 & V_2, and having 3-resisistors R_1, R_2 & R_3 as shown below circuit.



For above circuit verify superposition theorem, take response at "R_3" - element.

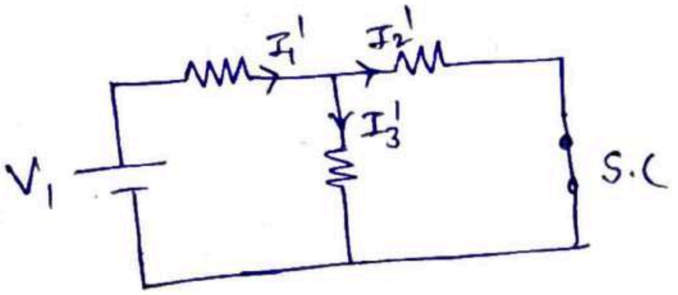
step ① Let all sources as two sources are in Active condition ~~as~~ i.e V_1 & V_2 are in ON, then let ~~re~~ respective currents as I_1, I_2 & I_3



$$I_3 = I_1 + I_2$$

where 'I_3' is response at 'R_3' Resistor

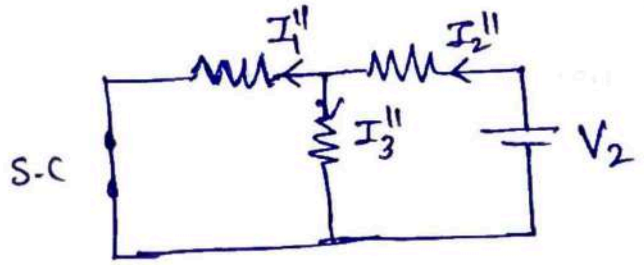
step ② ~~Let~~ Assume the $V_1 = ON$ & $V_2 = off$ state then



V_2 = is replaced by short circuit

$$I_3' = I_1' - I_2'$$

step ② Assumme the $V_1 = off$ & $V_2 = ON$ State



$$I_3'' = I_1'' + I_2''$$

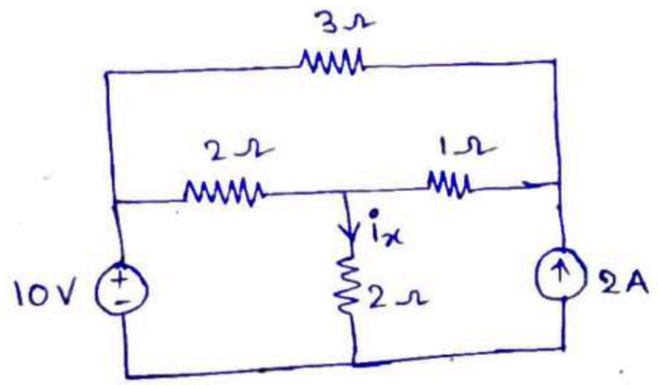
According to Superposition theorem

$$\boxed{I_3 = I_3' + I_3''}$$

Simillarly $\boxed{I_1 = I_1' + I_1''}$ & $\boxed{I_2 = I_2' + I_2''}$

Problem :-

Find 'i_x' for a given circuit using Superposition Theorem.



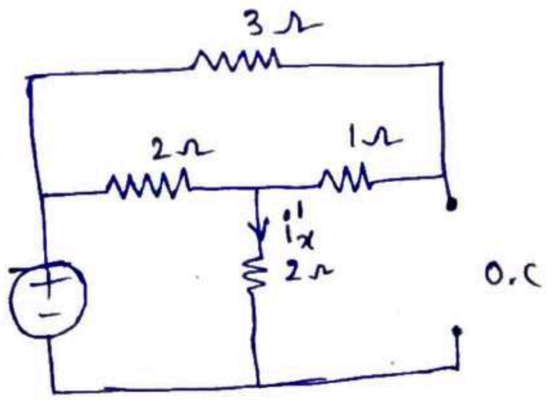
Solution:- In a given circuit we have 2- sources

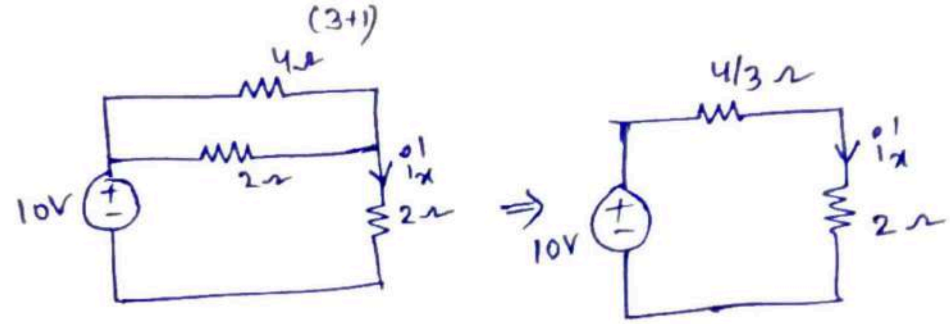
as 10V → voltage source

& 2A → current source

Let individual sources acting separately, then

Step① 10V → ON & 2A → off , circuit drawn as

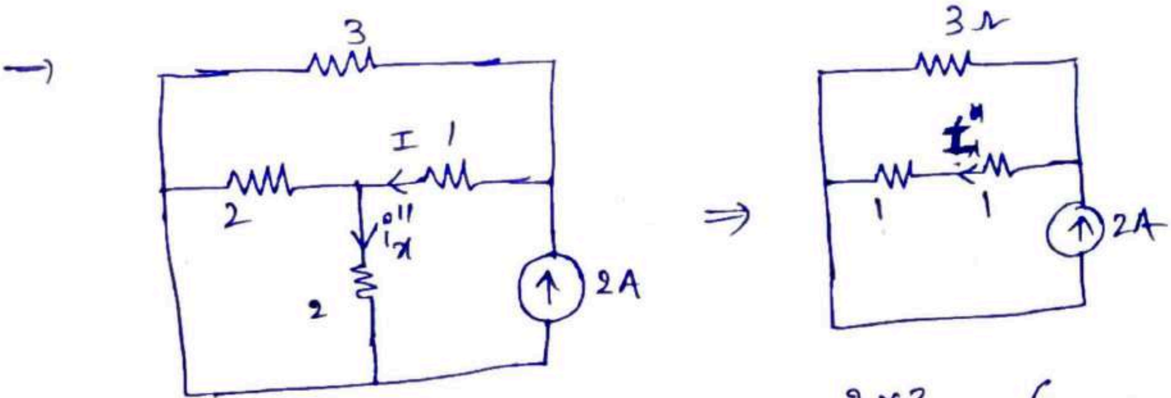




$\frac{4\times 2}{4+2} = \frac{\cancel{8}}{\cancel{6}}\frac{4}{3}$

Now $i_x' = \frac{10}{\frac{4}{3}+2} = \frac{10}{10/3} = \frac{30}{10} \Rightarrow \boxed{i_x' = 3A}$

Step ② Let 10V → OFF & 2A → ON, then



$\frac{2\times 2}{2+2} = \frac{4}{4} 1$

$I = \frac{2\times 3}{2+3} = \frac{6}{5} = 1.2A$

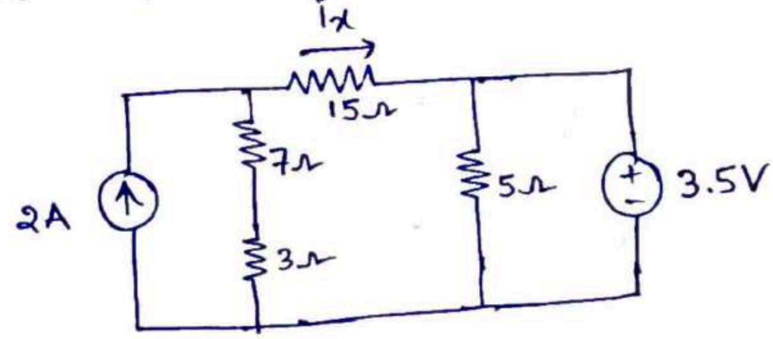
$i_x'' = I \times \frac{2}{2+2} = 1.2 \times \frac{2}{2+2} = 0.6A$

According to superposition theorem

$i_x = i_x' + i_x'' \Longrightarrow i_x = 3 + 0.6 \Rightarrow \boxed{i_x = 3.6\ A}$

Problem:-

Using the superposition ~~to~~ theorem compute the current "i_x"

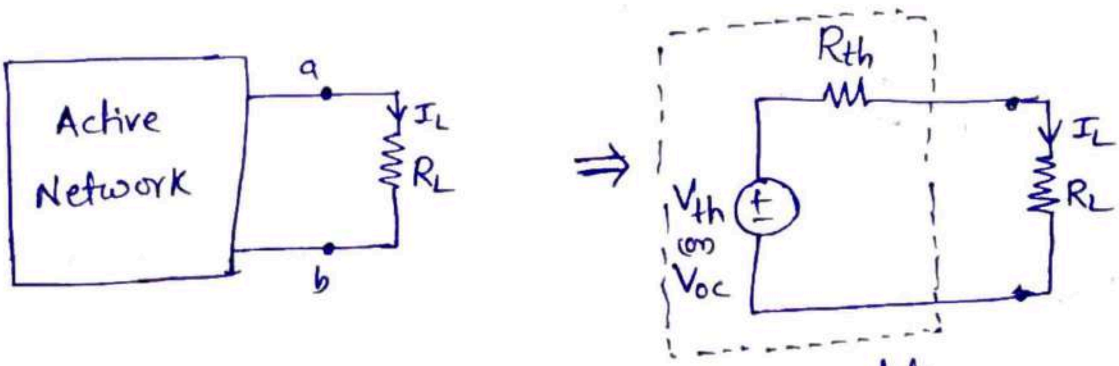


Ans: 660 mA.

Thevenin's Theorem :

In any linear, bilateral network consist of more no. of sources and resistors can be replaced by an equalent circuit of single voltage source in series with resistor, while all other sources are replaced by their internal resistances at ideal conditions as

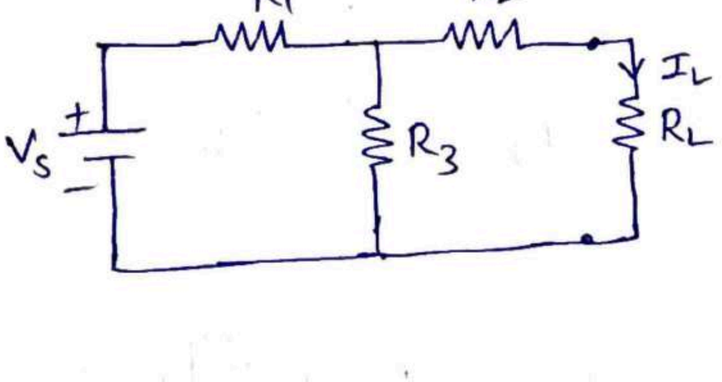
voltage source as short circuit (S.C)
current source as open circuit



Thevenin's equalent ckt

$$\therefore I_L = \frac{V_{th}}{R_{th}+R_L}$$

Explanation:- consider a dc-circuit which is having voltage source (V_s), & resistors R_1 R_2 & R_3 are connected with a load Resistor 'R_L' as shown below

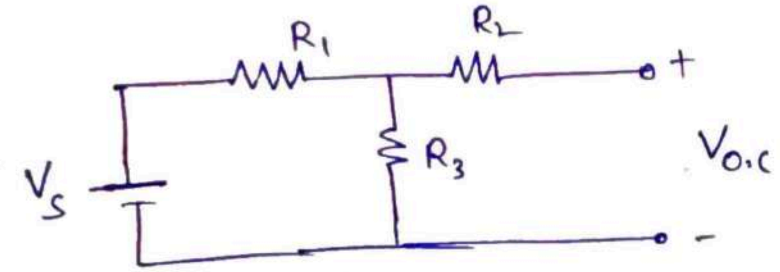


~~Step~~ Find current in load 'R_L' using thevenins theorem

~~Step~~ To find 'I_L' value, we have to find thevenin's equalent circuit. To find equalent circuit we have to find "V_{th} & R_{th}"

Step① To find 'V_{th}', remove the load resistor 'R_L' from the circuit, across open terminal find the voltage ($V_{o.c}$)

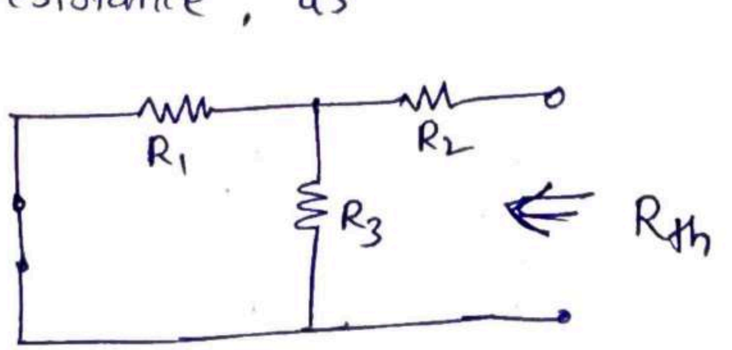
Then circuit modified as



Let $I \rightarrow$ current flows in circuit, $R_2 = 0$ because no current flows, then $V_{o.c}$ = voltage across R_3 resistor

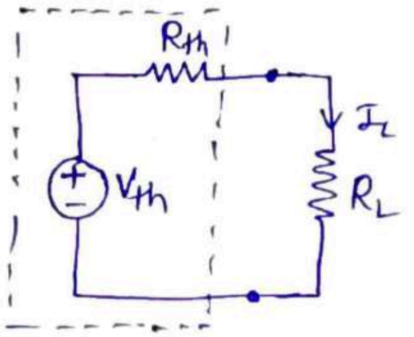
$$V_{oc} = I R_3$$

step② To find 'R_{th}', Voltage source is replaced by its internal resistance, as



then $R_{th} = R_2 + (R_1 \| R_3)$

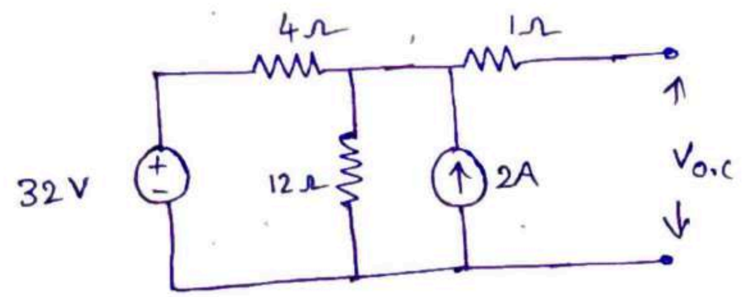
Step 3 The thevenins equalent circuit drawn as



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

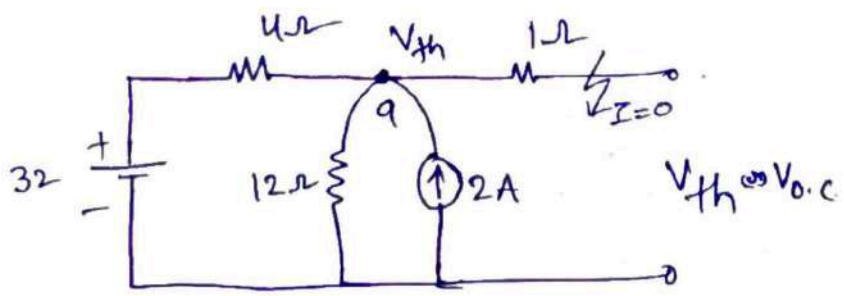
$$P_L = I_L^2 R_L$$

Problem:- (1) Find current flowing in load resistor '$R_L = 10\Omega$' using thevenin's theorem for a given circuit



Solution :-

Step 1: To find "$V_{oc} = V_{th}$", circuit redrawn as



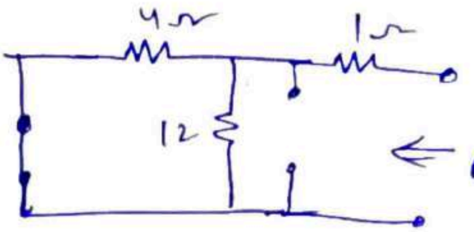
→ In 1Ω resister $I_b = 0$, at Node 'a' V_{th} will appears, the by using nodal analysis

$$\frac{V_{th} - 32}{4} + \frac{V_{th}}{12} - 2 = 0$$

$$\Rightarrow 3V_{th} - 96 + V_{th} - 24 = 0$$

$$V_{th} = \frac{120}{4} = \boxed{V_{th} = 30V}$$

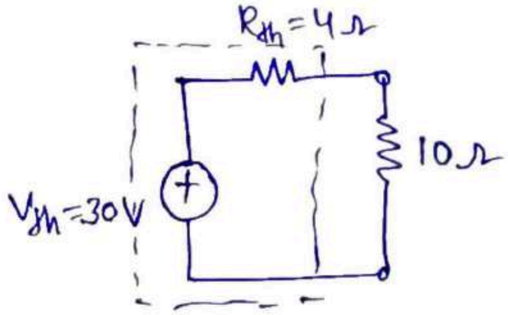
Step ②:- To find 'R_{th}' all sources are replaced by their resistance



$$R_{th} = 1 + \frac{4 \times 12}{4+12}$$

$$= 1+3 = 4\Omega$$

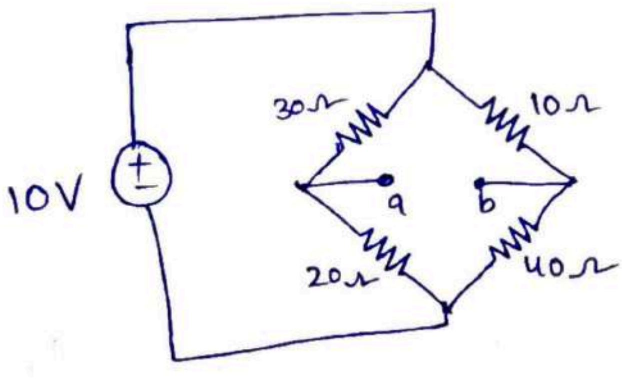
current flowing through load resistor can be found by thevenin's equal circuit as



$$I_L = \frac{V_{th}}{R_{th}+R_L} = \frac{30}{4+10} = \frac{30}{14} = 2.142 \text{ Amp}$$

$$\boxed{I_L = 2.142 \text{ Amp}}$$

Pro ②:- Find thevenin's equalent circuit for a given circuit



Ans:- $V_{th} = -4V$

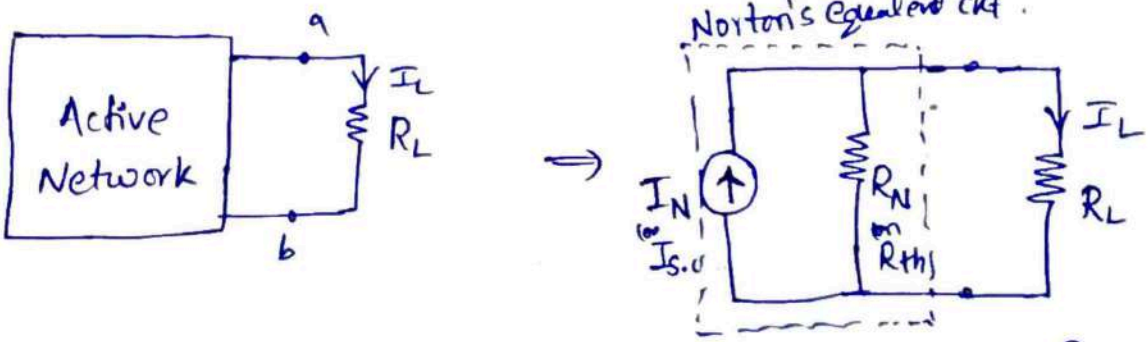
$R_{th} = 20\Omega$.

Norton's Theorem

In any linear, bilateral network consist of more no. of sources and resistors can be replaced by an equalent circuit of single current source in parallel with resistor, while all other sources are replaced by their internal resistances at ideal conditions as

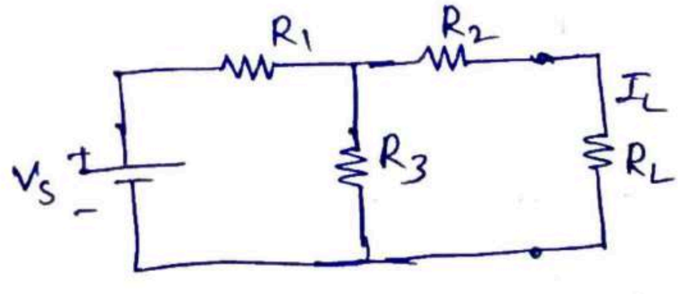
Voltage source as short circuit (S.C)

Voltage source as open circuit (O.C).



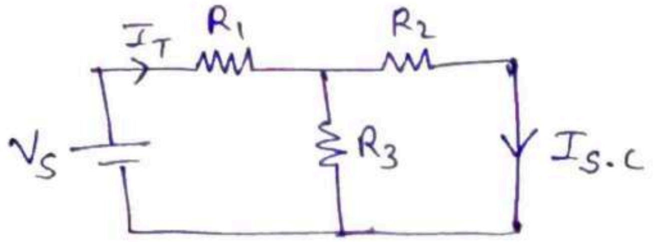
$$I_L = I_N \times \frac{R_N}{R_N + R_L}$$

Explanation :- Consider a dc-circuit which is having voltage source (V_s), resistors R_1, R_2 & R_3 are connected with load resistor 'R_L' as shown below



To find Norton's equalent circuit, we have to find I_N & R_N

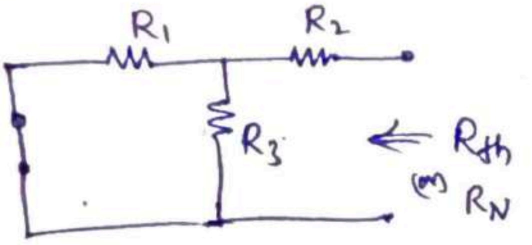
Step ① To find "I_N" remove the 'R_L' and short circuit the terminals, as norton's current I_N (or) $I_{s.c}$, then



Here $I_{s.c}$ is current flowing R_2 i.e $I_{s.c} = I_T \times \frac{R_3}{R_2+R_3}$

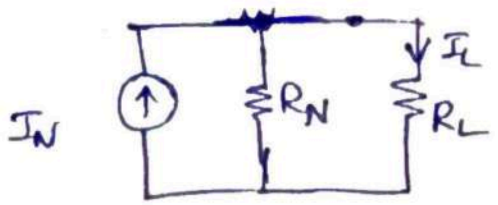
I_T = Total current.

Step ② To find R_N (or) R_{th}, voltage source is replaced by it's internal resistance as



$\Rightarrow R_N = R_2 + (R_1 \parallel R_3)$

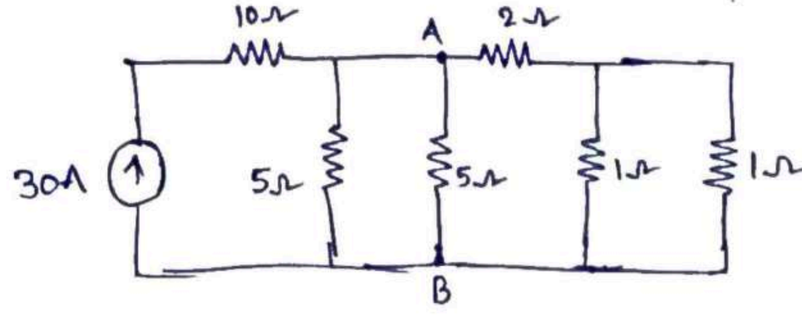
Step ③ The Norton's equalent circuit as



$$I_L = I_N \times \frac{R_N}{R_N + R_L}$$

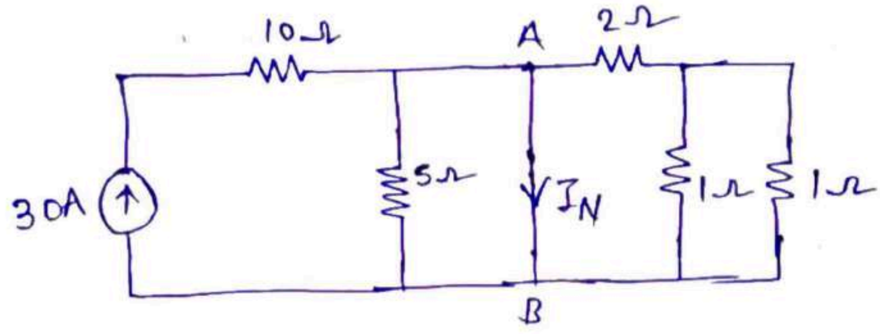
$$P_L = I_L^2 R_L.$$

Prob:-
① Determine the current through AB in the network.



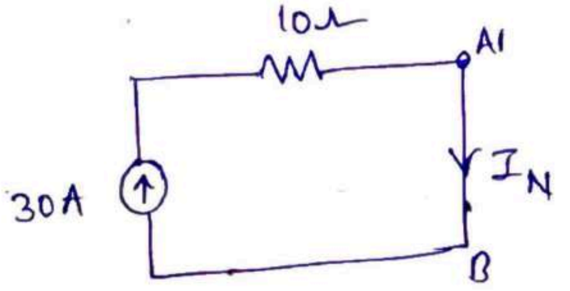
Solution :- In given circuit AB is 5Ω resistor is load Resistor $R_L = 5\Omega$

step ① To find I_N :; the AB is short circuited, then circuit redrawn as



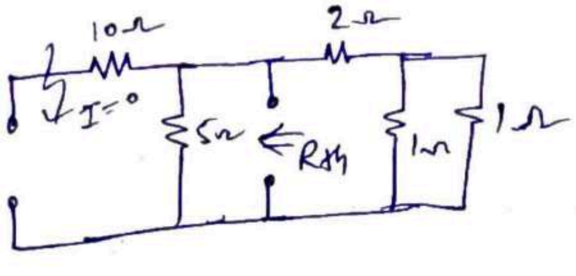
When AB-branch circuited, then all currents passes through AB branch, then no-current in 2Ω, 1Ω's & 5Ω resistors

As



since $I_N = 30A$

step ② To find R_N, AB branch is removed then

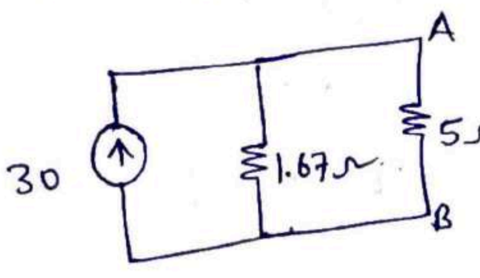


So

$$I_N = \{(1||1) + 2\} || 5$$

$$= \frac{2.5 \times 5}{2.5 + 5} = 1.67\Omega$$

step ③ Norton equalent circuit



$$\Rightarrow I_L = 30 \times \frac{1.67}{1.67 + 5}.$$

$$\boxed{I_L = 7.5A}$$

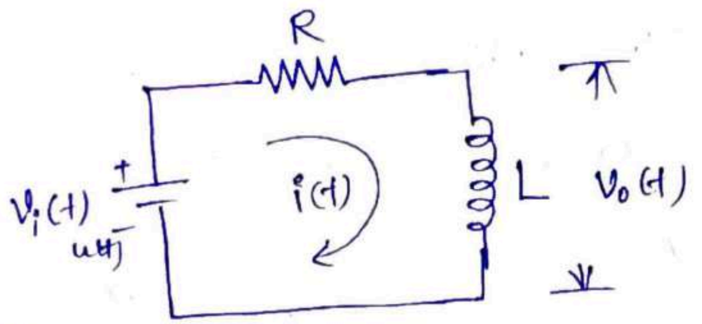
Time - domain analysis of frist order RL & RC circuits

Time domain analysis (or) Time response analysis is ~~are~~ nothing that the responses of circuits analysed in time domain.

Time Response Analysis of Frist order RL - circuit

Consider a series RL circuit as shoun in figure below, which is excited by a DC - Source $V_i(t)u(t)$

Applying KVL to the for given circuit



$$L\frac{di(t)}{dt} + Ri(t) = V_i(t)u(t)$$

Taking laplace transform on both sides of the equation

$$L\{sI(s) - i(0)\} + RI(s) = \frac{V_i}{s}$$

Initial $i(0) = 0$, then

$$LsI(s) + RI(s) = \frac{V_i}{sL}$$

$$I(s) = \frac{V_i}{sL[s+R)}$$

$$\Rightarrow I(s)[Ls+R] = \frac{V_i}{s}$$

$$I(s) = \frac{V_i}{s[Ls+R]}$$

$$I(s) = \frac{V_i}{sL\left[s+\frac{R}{L}\right]}$$

using partial fraction for above equation

$$I(s) = \frac{A_1}{s} + \frac{A_2}{s+\frac{R}{L}}$$

where $A_1 = s\,I(s)\Big|_{s=0} = \frac{V_i}{L} \times \frac{1}{s+\frac{R}{L}}\Big|_{s=0} \Rightarrow A_1 = \frac{V_i}{R}$

$$A_2 = \left(s+\frac{R}{L}\right) I(s)\Big|_{s=\frac{-R}{L}} = \frac{V_i}{L} \times \frac{1}{s}\Big|_{s=\frac{-R}{L}} = A_2 = \frac{-V_i}{R}$$

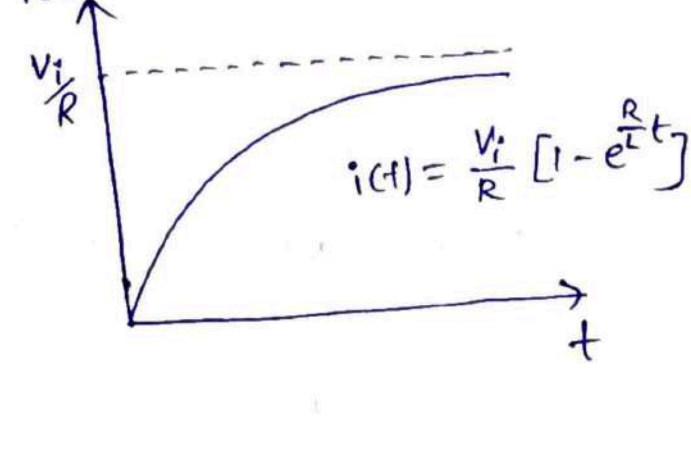
Thereforce $I(s) = \frac{V_i/R}{s} + \frac{\frac{-V_i}{R}}{s+\frac{R}{L}}$

$$I(s) = \frac{V_i}{R}\left[\frac{1}{s} - \frac{1}{s+\frac{R}{L}}\right]$$

Taking inverse laplace transform, we get

$$\boxed{i(t) = \frac{V_i}{R}\left[1-e^{\frac{R}{L}t}\right]}$$

By this equation time ~~equation~~ response of system is



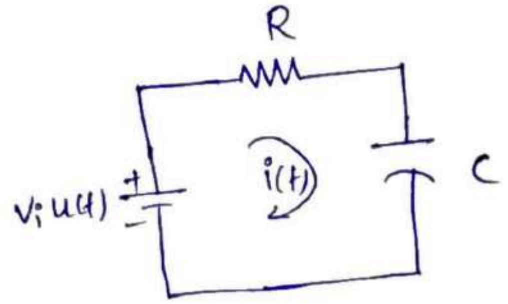
for RL-circuit

Time constant value is

$$\boxed{\tau = \frac{R}{L}} \text{ secans}$$

Time Response Analysis of First Order RC-Circuit

consider a series RC-circuit as shown figure, excited by DC-source $V_i u(t)$.



using KVL to the circuit

$$\frac{1}{C}\int_{-\infty}^{t} i(t)\,dt + R\,i(t) = V_i u(t)$$

i.e $$R\,i(t) + \frac{1}{C}\int_{-\infty}^{0} i(t)\,dt + \frac{1}{C}\int_{0}^{t} i(t)\,dt = V_i u(t)$$

Taking Laplace transform on both sides.

$$R\,I(s) + \frac{1}{C}\left[\frac{I(s)}{s} + \frac{q(0^+)}{s}\right] = \frac{V_i}{s}$$

$\because q(0^+) = 0$
C is uncharge

There force $$R\,I(s) + \frac{1}{Cs} I(s) = \frac{V_i}{s}$$

$$I(s) \cdot \left[R + \frac{1}{Cs}\right] = \frac{V_i}{s}$$

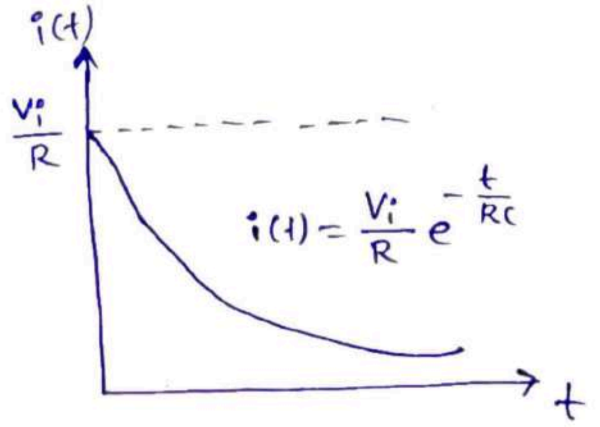
$$I(s) = \frac{\frac{V_i}{s}}{R + \frac{1}{Cs}} \Rightarrow I(s) = \frac{V_i/\cancel{s}}{R/\cancel{s}\left[s + \frac{1}{RC}\right]}$$

$$I(s) = \frac{V_i}{R\left[s + \frac{1}{RC}\right]}$$

Taking inverse Laplace Transform

$$\boxed{i(t) = \frac{V_i}{R} e^{-\frac{t}{RC}}}$$

The time response of the first order series RC circuit is

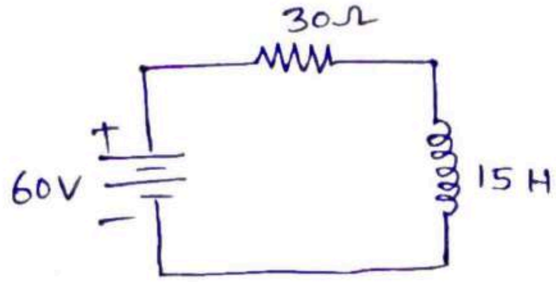


Time constant

$$\boxed{\tau = \frac{1}{RC}}$$ sec.

problem:-

Derive the expression for the current in the circuit as shown in figure



Solution:-

Applying KVL to the given

$$15 \frac{di(t)}{dt} + 30 i(t) = 60$$

$$\frac{d i(t)}{dt} + 2 i(t) = 4$$

Taking laplace transform on both sides, we get

$$\{s I(s) - i(0^-)\} + 2 I(s) = \frac{4}{s}$$

since $i(0^-) = 0$, we get

$$I(s) = \frac{4}{s(s+2)}$$

using partial fraction

$$I(s) = \frac{4}{s(s+2)} = \frac{A_1}{s} + \frac{A_2}{s+2}$$

where $A_1 = s\, I(s)\Big|_{s=0} = \dfrac{4}{s+2}\Big|_{s=0} = 2$

$$A_2 = (s+2)\, I(s)\Big|_{s=-2} = \frac{4}{s}\Big|_{s=-2} = -2$$

Therefore $I(s) = \dfrac{2}{s} - \dfrac{2}{s+2}$

Taking Inverse laplacetransform, we get

$$\boxed{i(t) = 2\left(1 - e^{-2t}\right)}\,A$$

$= x =$

<u>UNIT II</u>

AC CIRCUITS

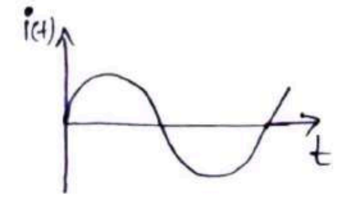
UNIT - II

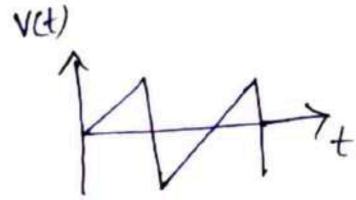
A.C Circuits

Alternating Quantity : "A quantity which changes periodically its magnitude and direction with respect to time" is Known as "Alternating quantity".

Alternating Current : (A.C) : "The current which changes periodically its magnitude and direction with respect to time, is called as "Alternating Current".

Ex :-

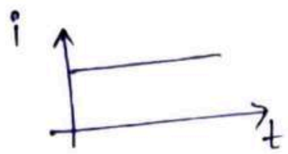


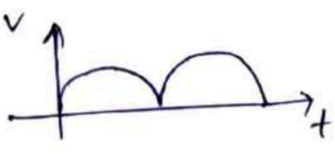


- → it has magnitude & phase angle
- → it has finite frequency
- → it is dependent of the time
- → it changes direction in +Ve & -Ve field.

Direct Current (D.C) : The current which maintains constant magnitude & only one direction

Ex :-





- → It is independent of the time
- → frequency is "zero (0)
- → Magnitude is constant.

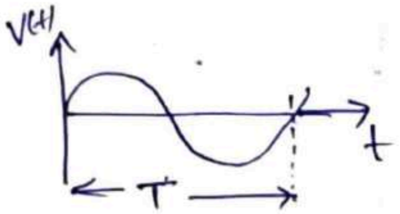
Cycle : A set of positive & negative instantaneous value of the alternating quantity.

1 Cycle = 2π radians (or), 360°.

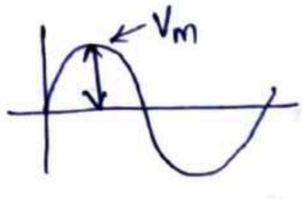
Frequency : (f) : Frequency is 'no. of cycle per a second" for an alternating quantity.

$\boxed{f = \frac{1}{T}}$ units "Hz" (Hertz)

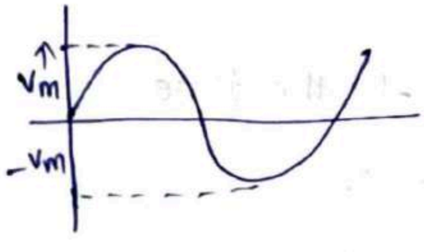
Time period (T) : It the time required by the alternating quantity to complete one cycle "



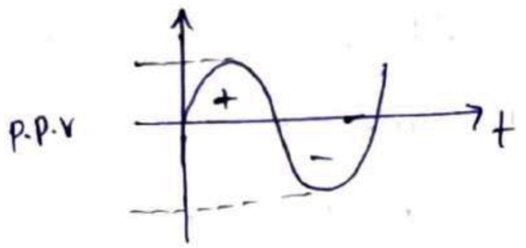
Maximum Value :- The maximum Value is the "Value reached by alternating quantity in total time 't'



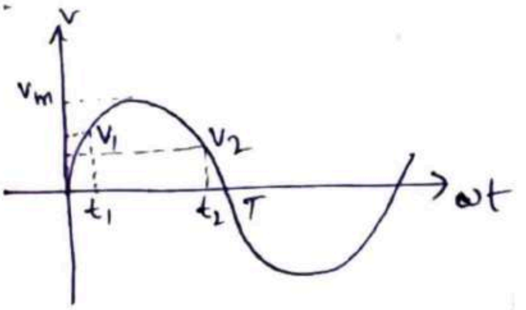
Peak Value :- It is the maximum Value of the wave during either positive (or) negative half cycle



Peak to Peak Value :- It is maximum difference between peak to peak values of +ve and -ve cycles.



Instantaneous Value :- The value of alternating quantity at a particular instant time is known as instanteneous value.



where
V_1 is I.V of wave at t_1
V_2 is I.V of wave at t_2.

Angular frequency (ω) :-

It is the frequency expressed in electrical radians per second.

It is expressed as $\Rightarrow 2\pi \times$ Cycle/sec

i.e $\boxed{\omega = 2\pi f}$ rad/sec (or) $\boxed{\omega = \frac{2\pi}{T}}$ rad/sec

& $\boxed{\theta = \omega t}$ rad (or) $\boxed{\theta = 2\pi f t}$ rad.

Equation of Alternating quantity :-

For AC - Current $i(t) = I_m \sin \omega t$ (or) $i(t) = I_m \sin \theta$.

where $I_m \rightarrow$ maximum current
$\omega \rightarrow$ angular frequency.

R.M.S Value (Root Mean Square Value)

(or) Effective Value

The RMS value of an alternating current is equalent to steady current (D.C-current), which produces the same amount of heat as that produced by an alternating current when it passing through a same circuit for a same time (or) specified time.

(or)

The RMS-Value of an alternating quantity means that square root of average of the squares of it's instanteneous values over a one-complete cycle.

→ For any alternating quantity $f(t)$, the time period 'T' then rms value is

$$f_{rms} = \sqrt{\frac{1}{T}\int_0^T f^2(t)\,dt} \Rightarrow \sqrt{\frac{\text{Area covered by wave}}{\text{Length of base over a cycle}}}$$

→ If $f(t) = (a_0 + a_1\cos\omega t + a_2\cos 2\omega t + \ldots)$
$+ (b_1\sin\omega t + b_2\sin 2\omega t) + \ldots)$

then

$$f_{rms} = \sqrt{a_0^2 + \frac{a_1^2 + a_2^2}{2} + \ldots \frac{b_1^2 + b^2}{2} \ldots}$$

i.e $$f_{rms} = \sqrt{\frac{f_1^2 + f_2^2 + f_3^2 \ldots f_n^2}{n}}$$

Note:- For Alternating Current RMS value can be calculated for complete one cycle.

Average Value :-

The Average Value can be defined as the direct steady current (D.C) which transfer charge across any circuit, the same amount of charge transfered by that alternating current during the same time for the same time

(or)

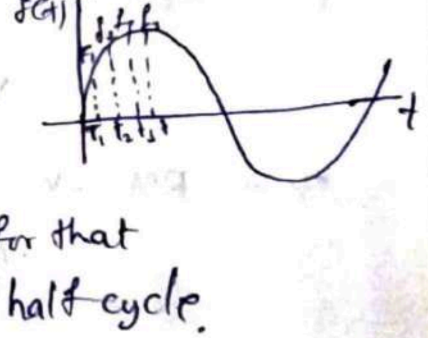
The Average Value of an alternating quantity is defined as that value which is obtained averaging all the instanteneous values over a period of half cycle.

i.e $$f_{avg} = \frac{1}{T}\int_0^T f(t)\,dt$$

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

(or) $$f_{avg} = \frac{\text{Area under curve for half cycle}}{\text{Length of base over half cycle}}$$

(or) $$f_{avg} = \frac{f_1 + f_2 + f_3 + \dots f_n}{n}$$ $\Rightarrow$



Note :- Average value for AC-Signal is zero, for that we have to calculate averge value for half cycle.

Form Factor :- Form factor is the ratio of RMS & Average values

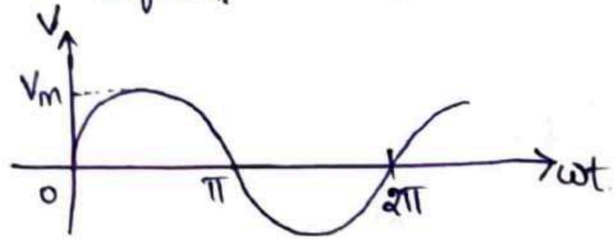
i.e Form factor (F.F) $= K_f = \dfrac{\text{RMS Value}}{\text{Averge value.}}$

Peak factor (or) Crest factor

Peak factor it is the ratio of Peak value (or) maximum value to the RMS value

i.e $P.F = \dfrac{\text{Maximum (or) Peak Value}}{\text{RMS Value.}}$

Problem:- Determine RMS value for given signal
(or)
Derive the relation between RMS value & maximum value. for given signal.



Solution:- For given signal is Sinusoidal Alternating voltage, its mathematical equation is

$$V = V_m \sin\omega t \quad \text{with timeperiod } T = 2\pi$$

Then RMS-value is

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V^2\, d(\omega t)}$$

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

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{2\pi}\left[\frac{1-\cos 2\omega t}{2}\right] d(\omega t)}$$

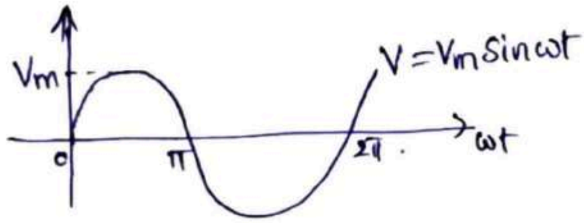
$$= \sqrt{\frac{V_m^2}{2\pi}\cdot\frac{1}{2}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{2\pi}}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{2\cancel{\pi}} \cdot \frac{1}{\cancel{2}}\left[\cancel{2\pi} - 0\right]}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}} \Rightarrow \boxed{V_{rms} = 0.707\ V_m}$$

Problem:- Determine Average Value for given wave form

(or) Derive the relation between Average Value & maximum Value



Solution:- For given Alternating voltage wave form Average Value is zero for "total timeperiod i.e 2π

So, let half time period as "T = π" . then

$$V_{avg} = \frac{1}{T}\int_0^T V\ d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} V_m \sin(\omega t)\ d(\omega t)$$

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

$$= \frac{V_m}{\pi} \cdot \left[-\left[\cos\pi - \cos 0\right]\right]$$

$$= \frac{V_m}{\pi} \cdot \left[-\left[-1 - 1\right]\right]$$

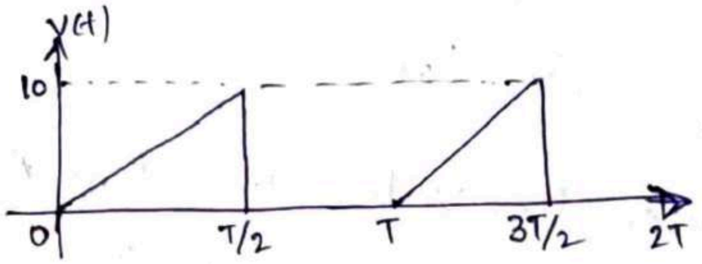
$$V_{avg} = \frac{2V_m}{\pi} \longrightarrow V_{avg} = \frac{2V_m}{\pi} \Rightarrow \boxed{V_{avg} = 0.637\ V_m}$$

For Sinusoidal Signal Form factor & peak factor are

$$\text{Form factor} = \frac{\text{RMS Value}}{\text{Avg Value}} = \frac{0.707\,V_m}{0.637\,V_m} = 1.11$$

$$\text{Peak factor} = \frac{\text{Maximum value}}{\text{rms Value}} = \frac{V_m}{0.707\,V_m} = 1.414$$

Problem:- Determine RMS & Avg Values, form factor & peak factor of periodic function



Solution:- From Given data, we have to calculate function equation with in the limits of $0 < t < T$

i.e $0 < t < T/2$ & $T/2 < t < T$

so

v(t) points are $(0,0), (T/2, 10)$ $(T/2, 0)\ (T, 0)$

x, y
$(v(t), t)$ $\Rightarrow v(t) - 0 = \frac{10}{T/2}(t-0)$ $v(t) - 0 = \frac{0-0}{T-T/2}(t - T/2)$

$v(t) = \frac{20}{T} t$ $v(t) = 0.$

Now RMS Value is

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\,dt}$$

$$= \sqrt{\frac{1}{T}\int_0^{T/2} \left(\frac{20}{T}t\right)^2 dt} \quad \because \int_{T/2}^{T} v(t)\,dt = 0.$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^{T/2} \frac{400}{T^2} t^2\, dt}$$

$$= \sqrt{\frac{400}{T^3} \cdot \left(\frac{t^3}{3}\right)_0^{T/2}}$$

$$= \sqrt{\frac{400}{3.\cancel{T^3}} \left(\frac{\cancel{T^3}}{8} - 0\right)} = \sqrt{\frac{400}{24}} \Rightarrow \boxed{V_{rms} = 4.08}$$

Average Value:

$$V_{Avg} = \frac{1}{T}\int_0^T v(t)\, dt$$

$$= \frac{1}{T}\int_0^{T/2} \frac{20}{T} t\, dt + \underbrace{\int_{T/2}^{T} \frac{-20}{T} t\, dt}_{= 0 \text{ (zero)}}$$

$$= \frac{20}{T^2}\int_0^{T/2} t\, dt$$

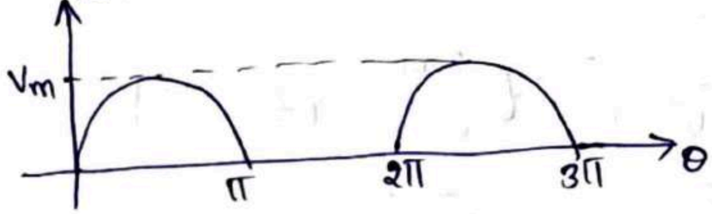
$$= \frac{20}{T^2}\left[\frac{t^2}{2}\right]_0^{T/2} = \frac{20}{2\cancel{T^2}} \cdot \frac{\cancel{T^2}}{4} \Rightarrow \frac{20}{8} \Rightarrow V_{avg} = 2.5$$

Then

$$\text{Form factor } F.F = \frac{\text{rms Value}}{\text{Avg Value}} = \frac{4.08}{2.5} = 1.632$$

$$\text{Peak Value } P.F = \frac{\text{Maximum Value}}{\text{Rms Value}} = \frac{10}{4.08} = 2.45$$

HW Determine the rms & Averge Values of a half wave rectified sinusoidal voltage of a peak value V_m



Ans:-
$V_{rms} = V_m/2$

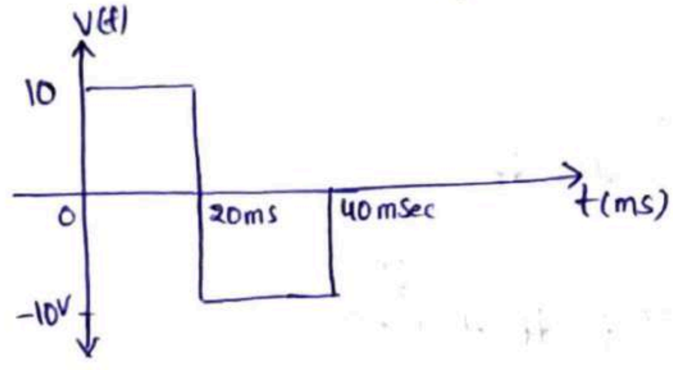
$V_{avg} = V_m/\pi$.

problem:-

Obtain RMS - Value, Average Value, Form factor & peak Value for a voltage of Symmetrical Square shape whose amplitude is 10 V and time period is 40 msec

Solution:-

From the given data voltage wave form can be drawn as



For total time period of wave is 40 msec, then voltage equation for different intervals

for $0 < t < 20ms \rightarrow V(t) = 10V$

$20ms < t < 40ms \rightarrow V(t) = -10V$

For RMS Value :-

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T (V(t))^2 dt}$$

then

$$V_{rms} = \sqrt{\frac{1}{40ms}\left[\int_0^{20ms} (V(t))^2 dt + \int_{20ms}^{40ms} (V(t))^2 dt\right]}$$

$$= \sqrt{\frac{1}{40ms}\left[\int_0^{20ms} (10)^2 dt + \int_{20ms}^{40ms} (-10)^2 dt\right]}$$

$$= \sqrt{\frac{100}{40\times10^{-3}}\left[(t)_0^{20ms} + (t)_{20m}^{40ms}\right]}$$

$$= \sqrt{\frac{100}{40\cancel{ms}}\left[20\cancel{ms} - 0 + 40\cancel{ms} - 20\cancel{ms}\right]}$$

$$V_{rms} = \sqrt{100} = \underline{10V}$$

For Average Value

$$V_{avg} = \frac{1}{T/2} \int_0^{T/2} v(t)\, dt$$

$$= \frac{1}{20ms} \int_0^{20ms} 10\, dt$$

$$= \frac{10}{20ms} (t)_0^{20m} \Rightarrow \frac{10}{20ms}(20ms - 0) \Rightarrow \boxed{V_{avg} = 10}$$

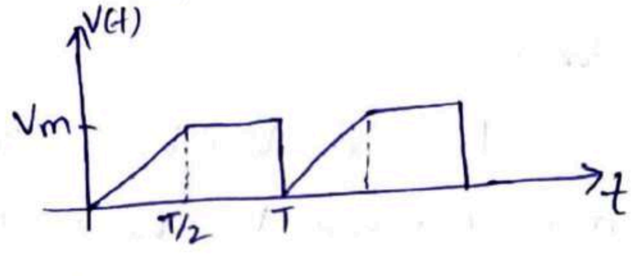
$$\text{Form Factor} = \frac{V_{rms}}{V_{avg}} = \frac{10}{10} = 1$$

$$\text{Peak factor} = \frac{V_p}{V_{rms}} = \frac{10}{10} = 1$$

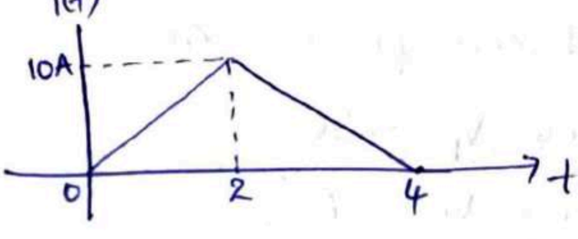
Q:- Find Average, RMS, Form factor & peak factor for given voltage wave form which is having 20V maximum value at $0 < t < 0.1$ sec, $0.3 < t < 0.4$ intervals and at the "0V" the interval of $0.1 < t < 0.3$ sec.

Q:- Determine Avg, RMS, F.F & P.F for given signals

(i)



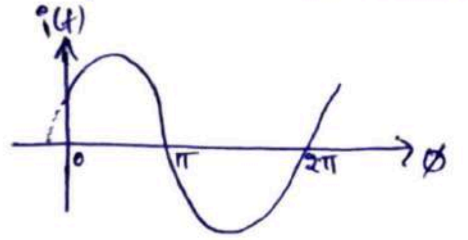
(ii)

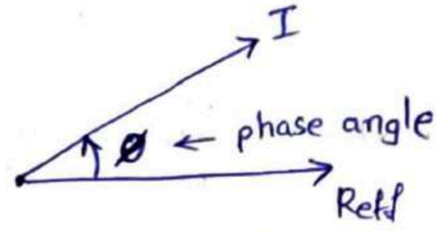


Phase :- Phase is the relative position of the waveform with respect to zero position.

(or)

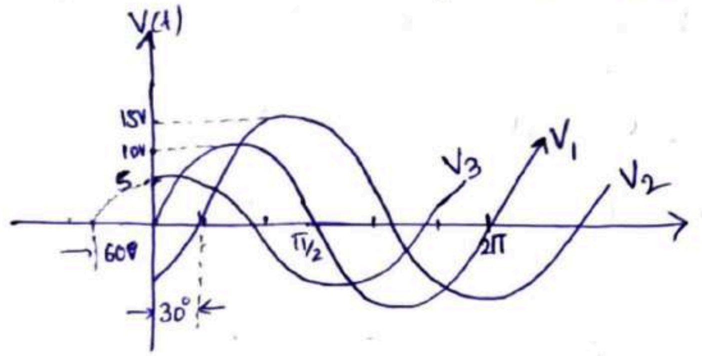
Phase is the relative position of the phase or phasor with respect to reference phase



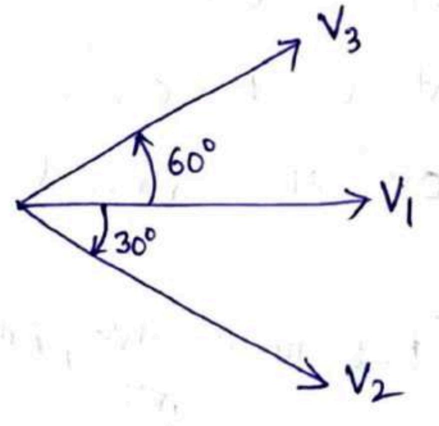


Vector diagram.

Phase difference :- It is the phase angle difference between two phasors or vectors



⇒



From the above vector diagram

We have phase difference between V_1 & V_2 is 30°

we have phase difference between V_1 & V_3 is 60°

And

if we take `V_1' is reference phasor then

V_2 is lags by $V_1 \rightarrow 30^\circ$

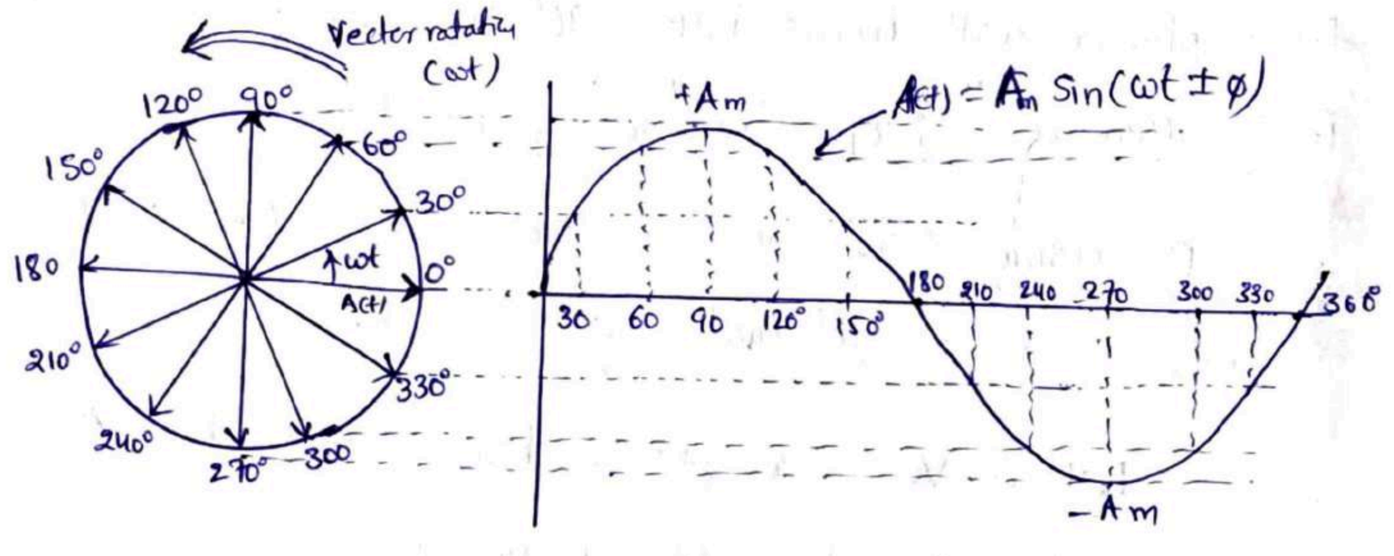
V_3 is lead by $V_1 \rightarrow 60^\circ$.

Phasor representation of an Alternating Quantity :-

The graphical reprecention of sinusoidally varying alternating quantity by a straight line with an arrow, such line is called as "phasor" or "Vector"

The diagram which represents the different alternating quantities by individual phasors, which gives the exact phasor interrelationships is known as, **phasor diagram.**

Let phasors are assumed to be rotated in anticlockwise direction with constant speed, as shown below



→ consider a phasor rotating in anticlockwise direction from the phasor angle 0° to 30°, then alternating quantity increases from 0 to upto 30° on y-axis

→ And from 30° to 60° phasor rotates then again alternating quantity function will changes. as

i.e $A(t) = A_m \sin\theta$

as like that

at 90° it is $A(t) = A_m$

& 180° it is $A(t) = 0$

& 210 or 240 it is $A(t) = -A_m$ ... and so on,

the alternating quantity can be changed.

Like ~~thing~~ this type of rotating vector is called phasor, and this diagram is called as "phasor diagram".

J-operator or j-notation :-

It is a quantity when it acts on any phasor then phasor will turns into 90° in anticlockwise direction it is called as "j-operator" or 'j-notation'.

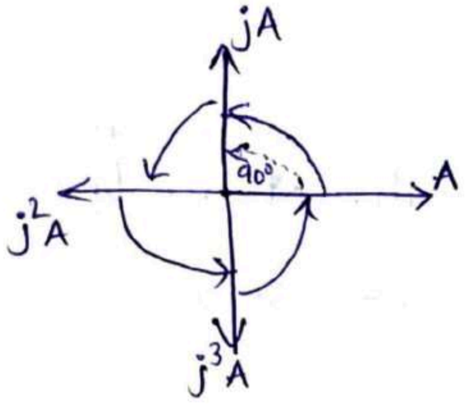
By using this we can solve the complex phasor calculations of alternating quantities.

Let a vector or phasor having magnitude A & phase angle 0°, then it shown as

$A\angle 0^\circ$

if we apply j-operator then it rotates to 90° anticlockwise direction

i.e $A\angle 90^\circ$



$A\angle 0$
to ↓
$A\angle 90$
to ↓
$A\angle 180°$
↓
$\angle 270°$

as
$j = \sqrt{-1} = 1\angle 90°$
$j^2 = -1 = 1\angle 180°$
$j^3 = -j = 1\angle 270$
$j^4 = 1 = 1\angle 360°$

Repreentation of Altenating Quantities:- It is by two forms,

① Reetangular form

It is the form is
Sum of real & imajinary parts

i.e $Z = a + jb$

→ It is usefull for
adding & Substraction of A.Q's

Add → $(R_1+R_2) + j(x_1+x_2)$
Sub → $(R_1-R_2) + j(x_1-x_2)$

⇒ Reetangular to polar conversion is

$z = a+jb \Rightarrow r\angle\theta$

ther
$r = \sqrt{a^2+b^2}$
$\theta = \tan^{-1}(b/a)$

② Polar form

it is reprecents
as magnitude & phase angle

$p = r\angle\theta°$

→ It usefull for
Multiplaying & dividing

Multply → $r_1 r_2 \angle\theta_1+\theta_2$

devidin → $\frac{r_1}{r_2}\angle\theta_1-\theta_2$

⇒ polar to Rectangular form

$r\angle\theta \Rightarrow z = a+jb$

$a = r\cos\theta$
$b = r\sin\theta$

Basic definitions !-

Impedance (Z) : It is the total opposition offered by an AC-circuit for the flow of current through it is called "Impedance"

(or)

The ratio of phasor voltage (V) to the phasor current (I) is called "Impedance"

i.e $Z = R \pm jX$ (or) $Z = \frac{V\angle\theta_1}{I\angle\theta_2}$

→ It magnitude value is $Z = \sqrt{R^2+X^2}$

→ Units are "Ω"

Reactance (X) : The opposition offered by reactive components i.e inductor (or) capacitor in an A.C circuit for the flow of current through it is called "Reactance (X)"

i.e imajinary part of impedance

$$Z = R \pm jX$$

for inductor it is "X_L" & ~~for~~ capacitor it is "X_C"

X_L = inductive reactance

$$\boxed{X_L = 2\pi f L}$$

X_C = Capacitive reactance

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

→ Units are "Ω"!

Admittance :- (Y) : The reciprocal of impedance is called as Admittance (Y).

→ Units are ℧ (mho)

i.e $Y = \frac{1}{Z} = \frac{1}{R \pm jX}$

by Rationalizing the denominator we get

$$Y = \frac{R}{R^2+X^2} \mp \frac{jX}{R^2+X^2}$$

$$\boxed{Y = G \mp jB}$$

Where $G \rightarrow$ conductance $= \frac{R}{R^2+X^2}$

$B \rightarrow$ Susceptance $= \mp \frac{jX}{R^2+X^2}$

Susceptance (B) : The imajinary part of admittance is called as susceptance (B)

→ Units are "Mho(℧) (or) Siemens

$B = \mp \frac{jX}{R^2+X^2}$ where $\frac{-X}{R^2+X^2}$ → inductive Susceptance

$\frac{+X}{R^2+X^2}$ → Capacitive Susceptance

Conductance (G) :- It is the real part of admittance

$G = \frac{R}{R^2+X^2}$ units are "℧".

Real Power (or) Active Power (or) True Power (or) Average Power (or) Watt Power (P)

The product of r.m.s values of voltage and current with the cosine of angle between them is called "Active Power".

i.e $\boxed{P = VI \cos \phi}$

→ Units are Watts.

(or)

The power in a.c circuit can be defined as the product of the r.m.s values of voltage and ~~current with the sine of angle between them is called~~ active component of the current is called "Active power".

Reactive Power (or) Wattless Power (or) Quadrature Power (Q)

The product of r.m.s values of voltage & current with the sine of angle between them is called "Reactive power"

i.e $\boxed{Q = VI \sin \phi}$

→ Units are VAR - Volts Amperes per ~~[illegible]~~ Reactance

(or)

The power in a.c circuit can be defined as the product of r.m.s value of voltage and reactive component of the current is called "Reactive Power Q".

Apparent Power (S)

The product of r.m.s values of voltage & current is called "Apparent Power" in a.c circuit

i.e $S = V_{rms} \times I_{rms}$

(or) $S = \sqrt{P^2 + Q^2}$ (or) $S = P \pm jQ$

Power factor :-

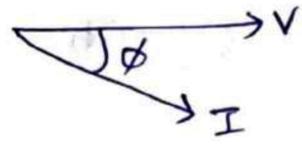
Power factor is the "cosine of the angle between voltage phasor to current phasor in a.c circuit.

The term "$\cos\phi$" is called power factor.

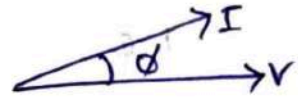
Example :-

for Resistive load → $\cos\phi = 1$ (Inphase)

Inductive load → Current lags



Capacitive load → Current leads



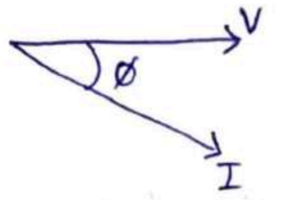
Power Triangle :- Power triangle is the geomentrical reprecentation of the apparent power, active power & reactive power.

We have power Triangle for → Inductive load
→ Capacitive load.

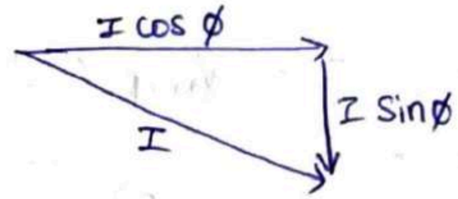
Power Triangle for Inductive load:-

For inductive load current laggs by voltage

i.e

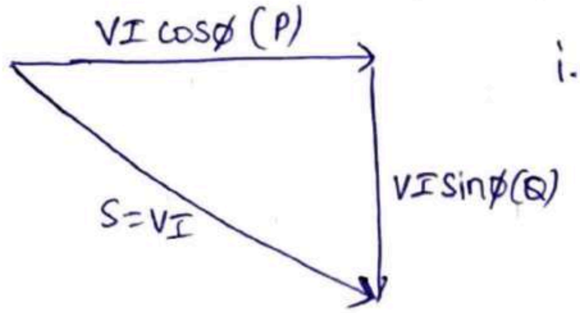


So



$I\cos\phi$ = active component
$I\sin\phi$ = reactive component

the power triangle is



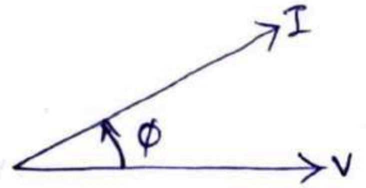
i.e $S = \sqrt{P^2+Q^2}$

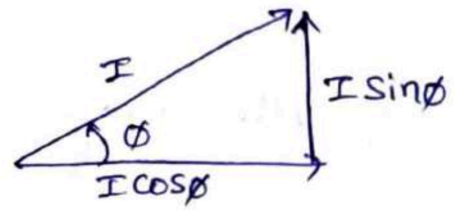
$S = \sqrt{(VI\cos\phi)^2 + (VI\sin\phi)^2}$

$\underline{S = VI}$

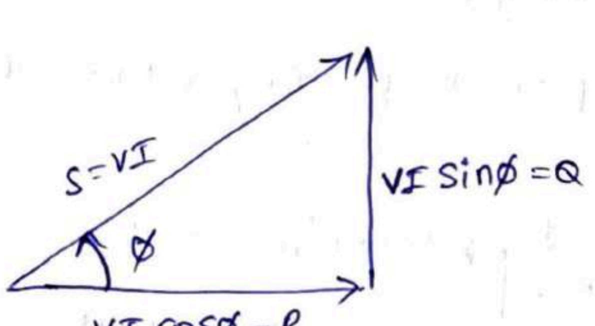
Power Triangle for Capacitive load:-

For capacitive load current leads by voltage





Power Triangle is



$S = \sqrt{P^2+Q^2}$

$S = VI$.

Complex power :-

Complex power is the product of voltage to the conjugate current component (or) product of conjugate voltage component to current

$$C.P = VI^* \text{ (or) } V^*I$$

Let

$$VI^* = Ve^{j\theta} . Ie^{-j(\theta+\phi)}$$

$$= VI e^{-j\phi}$$

$$VI^* = VI\cos\phi - j\, VI\sin\phi$$

$$S = \boxed{VI^* = P - jQ}$$ — is for Capacitive Circuit

Simillardy for inductive

$$\boxed{S = V^*I = P + jQ}$$ — is for inductive Circuit.

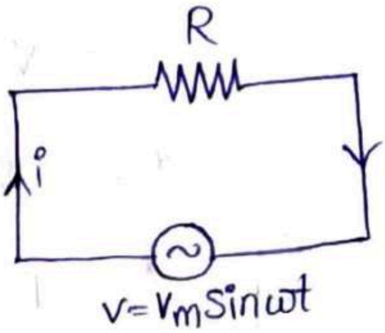
Analysis of Single-phase ac-circuits

AC through Pure Resistance:-

(or)

~~Resistance~~ Sinusoidal response of Pure Resistive Circuit

consider a simple circuit consisting of a pure resistance 'R' connected with sinusoidal voltage $V = V_m \sin\omega t$, as shown below



→ According to ohm's ~~law~~ the current in circuit is

$$i = \frac{V}{R} = \frac{V_m \sin\omega t}{R}$$

i.e $i = \left(\frac{V_m}{R}\right) \sin\omega t$ —— (1)

→ compare eq (1) with standard current equation

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

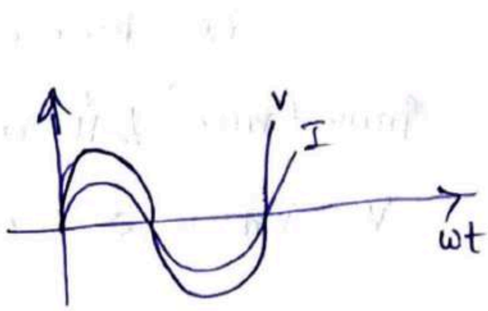
then $I_m = \frac{V_m}{R}$ & $\phi = 0°$

→ The maximum current value is $I_m = \frac{V_m}{R}$

→ $\phi = 0$ reprecent Voltage & currents are inphase so

$i = I_m \sin \omega t$ at $\phi = 0$

→ The instantaneous power is ~~product of~~ instantaneous values of voltage and current



In phase

$$P_i = v \times i$$
$$= V_m \sin\omega t \times I_m \sin\omega t$$
$$= \frac{V_m I_m}{2} \sin^2\omega t$$
$$= \frac{V_m I_m}{2} (1 - \cos 2\omega t)$$
$$P_{inst} = \frac{V_m I_m}{2} - \frac{V_m I_m}{2} \cos(2\omega t) \quad \text{—} (2)$$

In eq (2) the term $\frac{V_m I_m}{2} \cos(2\omega t)$ is having double frequency

So this value becomes zero,

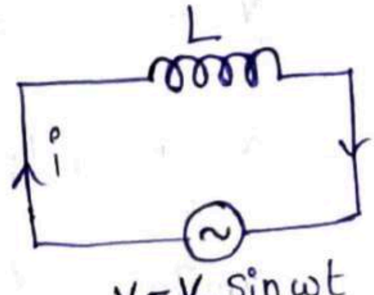
→ The average power value is equal to instantaneous power of constant power component $\frac{V_m I_m}{2}$

$$P_{avg} = \frac{V_m I_m}{2}$$
$$P_{avg} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$
$$\boxed{P_{avg} = V_{rms} \cdot I_{rms}}$$

For pure resistive circuit power is $\boxed{P = VI}$ Watts.

AC - through Pure Inductance

consider a Simple circuit consisting of a pure inductance 'L' Hem connected with Sinusoidal voltage $v = V_m \sin\omega t$ as shown below.



$V = V_m \sin\omega t$

For pure inductive Circuit current laggs by voltage $90°$, it can be proved as

Voltage across inductor is $V = L\frac{di}{dt}$

So $$V_m \sin\omega t = L\frac{di}{dt}$$

$$di = \frac{V_m}{L}\sin\omega t$$

$$i = \int di = \int \frac{V_m}{L}\sin\omega t$$

$$= \frac{V_m}{L} \cdot \frac{-\cos\omega t}{\omega}$$

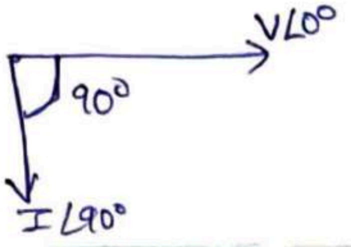
$$i = \frac{V_m}{\omega L}\sin(\omega t - \tfrac{\pi}{2})$$

& we have standard eqn
$i = I_m \sin(\omega t \pm \phi)$

$i = I_m \sin(\omega t - \frac{\pi}{2})$ where $I_m = \frac{V_m}{X_L}$ & $\phi = -\frac{\pi}{2}$

Above equation gives that Current lags by voltage $90°$

vector diagram is



→ The instantaneous power

$$P_{inst} = v \times i = V_m \sin\omega t \times I_m \sin(\omega t - \tfrac{\pi}{2})$$

$$= -V_m I_m \sin\omega t \cos\omega t \qquad \because \sin 2A = 2 \sin A \cos A$$

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

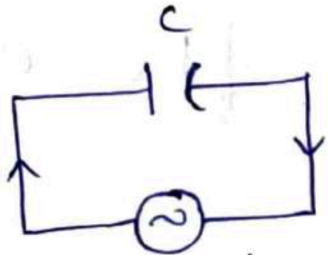
→ The Average power Value for pure inductive is zero, why because we have double frequency term ($\sin 2\omega t$)

so $\boxed{P_{avg} = 0}$

Pure inductance never consumes power

AC - through Pure Capacitance

consider a simple circuit consisting of a pure capacitan C Farady connected with sinusoidal voltage $V = V_m \sin\omega t$.



$V = V_m \sin\omega t$

For pure capacitive circuit current leads by Voltage $90 = \pi/2$, it can be proved as

→ The instantaneous charge in capacitor is

$$q = C.V = C.V_m \sin\omega t.$$

→ Current is is rate of charge so $i = \frac{dq}{dt}$

$$i = \frac{d}{dt}(C\, V_m \sin\omega t)$$

by standard current Equation: $i = I_m \sin(\omega t \pm \phi)$

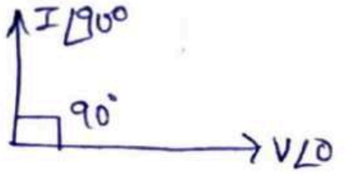
$$= C \cdot V_m \cdot (\omega \cos\omega t)$$

th.

$$i = \left(\frac{V_m}{1/\omega C}\right) \sin\left(\omega t + \frac{\pi}{2}\right) \rightarrow I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

The equation give that current leads by voltage $90^\circ = \pi/2$

i.e



$\phi = \frac{+\pi}{2}$.

→ The instantaneous power

$$P_{inst} = V \times i = V_m \sin\omega t \times I_m \sin(\omega t + \pi/2)$$

$$P_{in} = \frac{V_m I_m}{2} \sin(2\omega t).$$

→ The average power value is zero for pure capacitive circuit, because it has double frequency term ($\sin 2\omega t$)

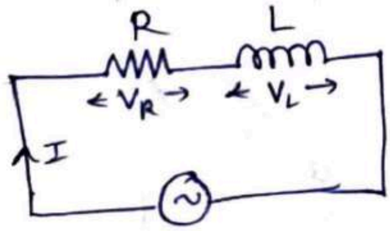
$$\boxed{P_{avg} = 0}$$

Pure capacitor never consumes the power.

Note:- For pure inductive & capacitive circuits never consumes the power, because these are energy stored compoment circuits.

Analysis of Series RL-Circuit :-

Consider a series RL-Circuit connected with alternating voltage $v = V_m \sin \omega t$ as shown below



In a given circuit, the current 'I' draws by RL-, then it causes two voltage drops as

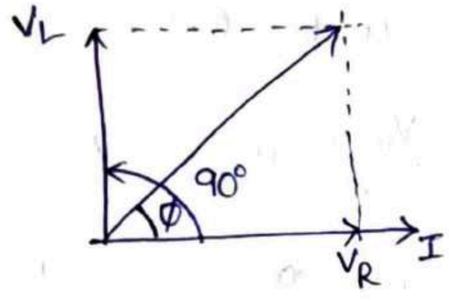
→ Voltage drop across pure resistance $V_R = IR$

→ voltage drop across pure inductance $V_L = IX_L$

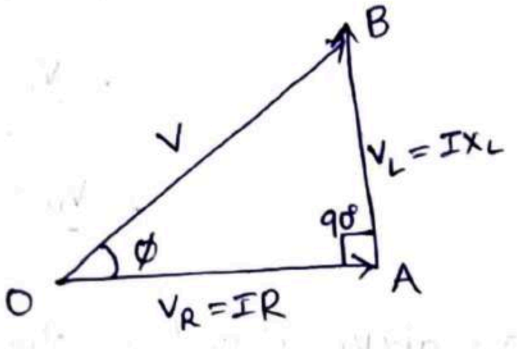
If we will take voltages should be a phasors, then according to KVL, the addition of phasor is

$$\bar{V} = \bar{V}_R + \bar{V}_L = \bar{I}R + \bar{I}X_L$$

by above equation their phasor diagram & voltage triangle is



phasor diagram



voltage Triangle

From phasor diagram

V_R → is inphase with I

I → is lags V_L by 90°

From $\angle OAB$

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

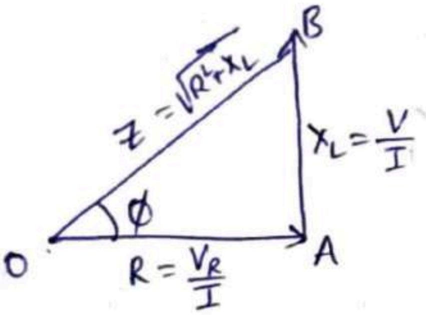
$$V = \sqrt{(IR)^2 + (IX_L)^2}$$

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

Impedance & Impedance Triangle :-

The impedance for RL-Circuit is $Z = R + jX_L$ (Rectangular form)

where $X_L = 2\pi f L$ $\qquad Z = |Z| \angle \phi$ (Polar form)



from $\angle OAB$

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

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

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

→ It can be seen that current lags by voltage by 'ϕ'

so $\qquad v(t) = V_m \sin\omega t$

$\qquad\qquad i(t) = I_m \sin(\omega t - \phi)$

→ The instanteneous Power $P_{inst} = v \times i$

$$= V_m \sin\omega t \times I_m \sin(\omega t - \phi)$$

$$= V_m I_m \sin\omega t \cdot \sin\omega t - \phi$$

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

$$= \frac{V_m I_m}{2}\cos\phi - \frac{V_m I_m}{2}\cos(2\omega t - \phi)$$

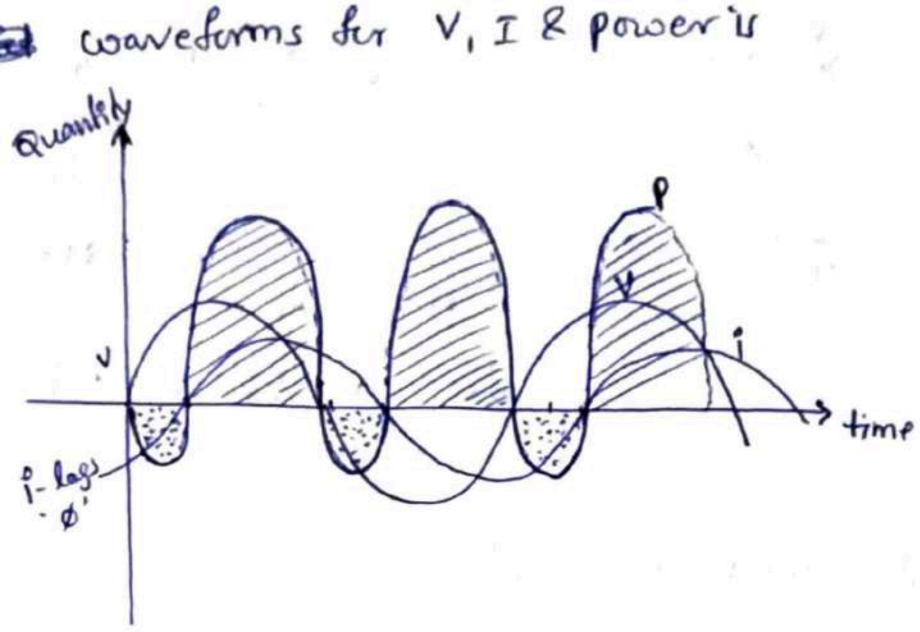
→ In above equation the second term $\cos(2\omega t - \phi)$ has double frequency & average value for cycle is zero

$$P_{avg} = \frac{V_m I_m}{2}\cos\phi$$

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

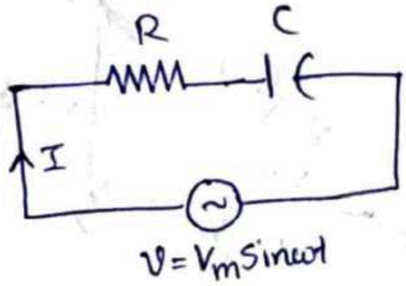
$$\boxed{P = VI \cos\phi} \text{ watts}$$

→ The ~~output~~ waveforms for V, I & power is



Analysis of series RC-Circuit :

Consider a series RC-circuit connected with a source $v = V_m \sin\omega t$, as shown below



The give circuit draws the current 'I', causes the two voltage drops

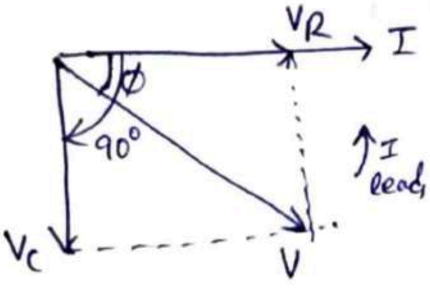
→ Voltage drop across pure resistance $V_R = IR$

→ voltage drop across pure capacitance $V_C = IX_C$

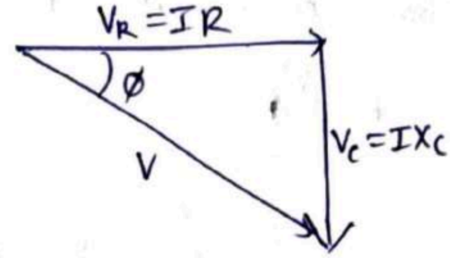
For a given circuit, apply KVL then by addition of two phasors

$$\bar{V} = \bar{V_R} + \bar{V_C} = \overline{IR} + \overline{IX_C}$$

From the above equation their phasor diagram & voltage triangle is



Phasor diagram



From $\angle OAB$

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

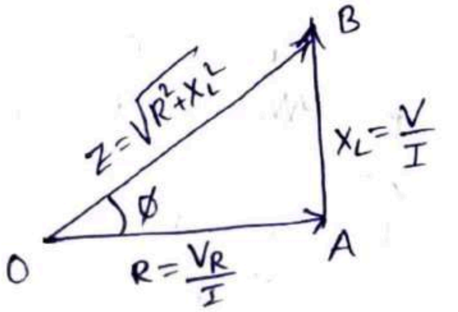
$\boxed{V = IZ}$

Impedance & Impedance Triangle :-

The impedance for RC-Circuit is $Z = R - jX_L$ (Rectangul form)

$Z = |Z| \angle -\phi$ (Polar form)

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



from $\angle OAB$

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

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

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

→ It can be seen that current ~~lags~~ leads by voltage 'ϕ'

So $v(t) = V_m \sin\omega t$

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

→ The instanteneous Power $P_{inst} = v \times i$

$= V_m \sin\omega t \times I_m \sin(\omega t + \phi)$

$= V_m I_m (\sin\omega t \cdot \sin \omega t + \phi)$

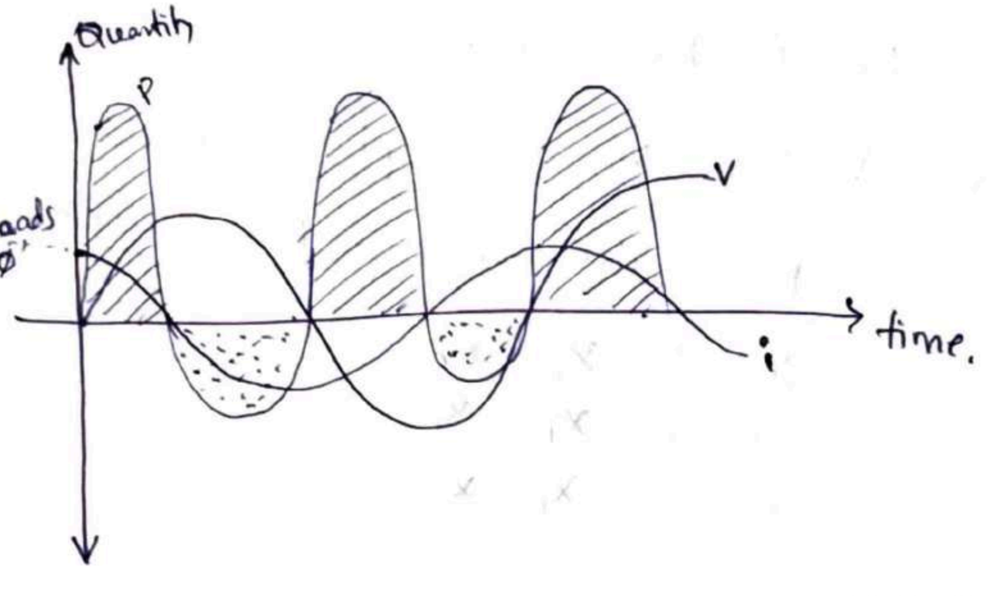
$$P_{inst} = \frac{V_m I_m}{2}\cos\phi - \frac{V_m I_m}{2}\cos(2\omega t+\phi)$$

In above equation the cosine term "$\cos 2\omega t$" has double frequency, hence its averge power value is zero, So

$$P_{avg} = \frac{V_m I_m}{2}\cos\phi = \frac{V_m}{\sqrt{2}}\cdot\frac{I_m}{\sqrt{2}}\cos\phi$$

$$\boxed{P_{avg} = VI\cos\phi} \text{ watts}$$

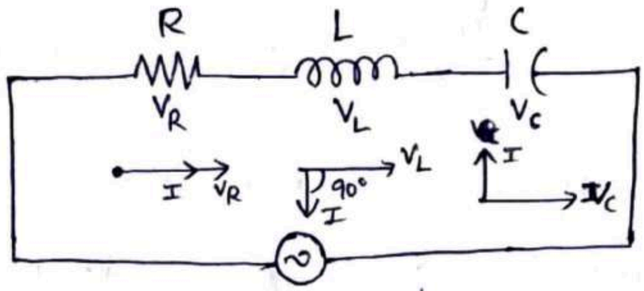
→ Waveforms for V, I & Power is



Analysis of Series RLC Circuit :-

Consider a circuit consisting of resistance R ohms pure inductance L Henries and Capacitance C farads connected in series with supply $v = V_m \sin\omega t$, as shown below.

When supply is connected, then current 'I' draws and it causes 3-voltage drops



$V = V_m \sin\omega t$

→ Due to current 'I', there are different voltage drops across R, L & C with are given by

→ Drop across resistance R is $V_R = IR$

→ Drop across inductance L is $V_L = IX_L$

→ Drop across Capacitance C is $V_C = IX_C$

By According KVL for RLC-circuit

$$\bar{V} = \bar{V_R} + \bar{V_L} + \bar{V_C}$$ — is phasor addition.

For drawing phasor diagram, we have to consider 3-cases as

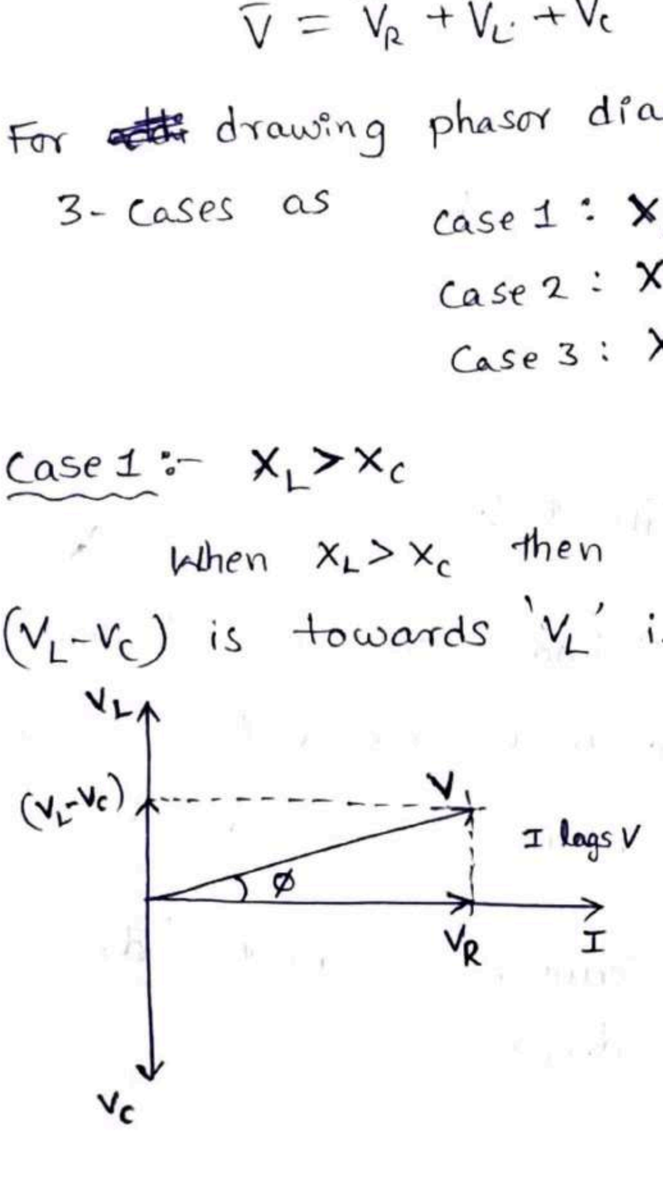
case 1 : $X_L > X_C$

Case 2 : $X_L < X_C$

Case 3 : $X_L = X_C$

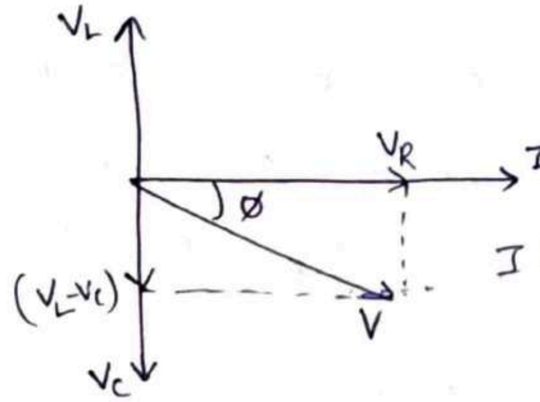
Case 1 :- $X_L > X_C$

When $X_L > X_C$ then $V_L > V_C$, so resultant of $(V_L - V_C)$ is towards 'V_L' i.e leading I,



→ the circuit behaves as inductive nature case 2 :- $X_L < X_C$

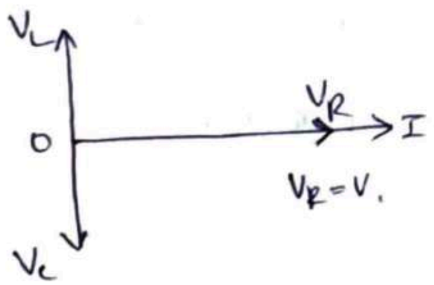
When $X_L < X_C$ then $V_L < V_C$, so resultant of $(V_L - V_C)$ is "$-$ve" is towards 'V_C' i.e lagging 'I'



i.e the circuit behaves as capacitive nature.

case 3 :- $X_L = X_C$

when $X_L = X_C$ then $V_L = V_C$, so resultant of this is zero, means cancel eaach other, $\phi = 0$



i.e the circuit behaves pure resistive nature.

→ This condition $X_L - X_C = 0$ (or) $X_L = X_C$ is called "Resonance condition.

Problems :-

1. A coil has resistance of 4Ω and an inductance of $9.55\,mH$. Calculate (i) the reactance (ii) the impedance (iii) the current taken from a 240V, 50Hz Supply.

2. Draw the phasor diagram for a coil of 80mH & 60Ω resistor connected to 200V, 100 Hz Supply. Calculate the circuit impedance & the current taken from the supply

3. A Coils takes a current of 2.5A at 0.8 lagging power factor from a 220V, 60HZ, single phase source. If the coil is modeld by a series RL- circuit find

   (i) the complex power in the coil
   (ii) the values of R & L.

4. Devlop the phasor diagram for a series RC- Circuit with $R = 10\Omega$ & $C = 10\,\mu F$ & excited with $1-\phi$, 230V Supply.

5. A coil of resistance 5Ω and inductance 120mH in series with a $100\,\mu F$ capacitor, is connected to 300V, 50Hz supply. Find

   (a) The current flowing
   (b) The phase difference between supply voltage & current
   (c) The voltage across the coil
   (d) The voltage across the capacitor
   (e) Draw the phasor diagram.

Resonance in Series RLC-circuit

In a series RLC-circuit, when $X_L = X_C$ or $(X_L - X_C) = 0$ i.e when reactance of circuit becomes to zero, then it is called as "the circuit is at "series resonance".

→ At this time circuit behaves a "purely resistive

→ And the power factor $\cos\phi = 1$

→ At this time it draws maximum current.

Applications:-

1. It is used in Tuning circuits
2. In inverters
3. Wave traping circuits.

Resonance frequency (f_r) for Series RLC-circuit:-

In a RLC-circuit at which frequency the resonance occures, that frequency called as "Resonance frequency (f_r).

i.e $\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$ Hz.

Let 'f_r' be the frequency at which resonance occurs in series RLC-circuit

→ At resonant frequency 'f_r' the reactance is zero

i.e $X_L = X_C$ or $X_L - X_C = 0$.

$$2\pi f_r L = \frac{1}{2\pi f_r C}$$

$$f_r^2 = \frac{1}{4\pi^2 LC}$$

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}\ \text{Hz} \quad \text{or} \quad \boxed{\omega_r = \frac{1}{\sqrt{LC}}}\ \text{rad.}$$

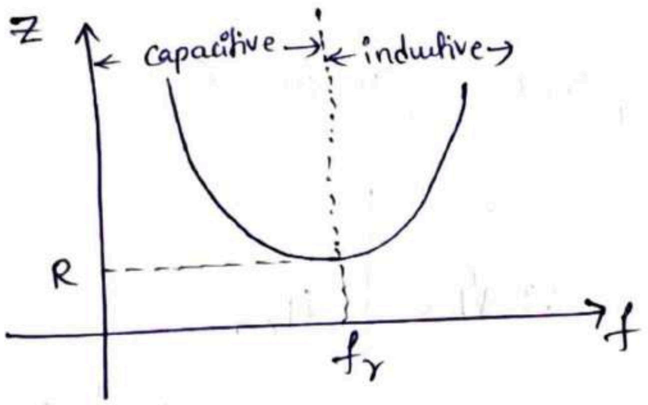
Angular resonance frequency

→ If $f_r > f$ then circuit is Capacitive nature

$f_r < f$ then circuit is inductive nature

$f_r = f$ is pure resistive nature

→ It canbe shown as



→ At resonance current is maximum $I_m = \frac{V}{R}$

→ The power at resonance $P_m = I_m^2 R$.

Band width and Quality factor (Q) for Resonance Circuit

In a series RLC-circuit, at resonance condition we have the two half power frequencies which ~~da~~ are due to reactive components, as

$$\left(\omega L - \frac{1}{\omega C}\right) = \pm R$$

Consider two half power frequencies as

$$\left(\omega_1 L - \frac{1}{\omega_1 C}\right) = +R \quad \text{—} (1)$$

$$\left(\omega_2 L - \frac{1}{\omega_2 C}\right) = -R \quad \text{—} (2)$$

→ Add eq (1) + eq (2), then

$$(\omega_1 + \omega_2) L - \left(\frac{1}{\omega_1} + \frac{1}{\omega_2}\right)\frac{1}{C} = 0$$

$$(\omega_1 + \omega_2) L = \left(\frac{\omega_1 + \omega_2}{\omega_1 \omega_2}\right)\frac{1}{C}$$

$$\omega_1 \omega_2 = \frac{1}{LC} \quad \text{—} (3) \qquad \text{but } \omega_r = \frac{1}{LC}$$

So $\boxed{\omega_1 \omega_2 = \omega_r^2}$ ~~or~~ $\boxed{f_1 f_2 = f_r^2}$

→ Substract eq (1) − eq (2), then

$$(\omega_2 - \omega_1) + \frac{(\omega_2 - \omega_1)}{\omega_1 \omega_2} \cdot \frac{1}{LC} = \frac{2R}{L}$$ multplay '$\frac{1}{L}$' on both side

$$(\omega_2 - \omega_1) + (\omega_2 - \omega_1) = \frac{2R}{L} \qquad \because \omega_1 \omega_2 = \frac{1}{LC}$$

$$(\omega_2-\omega_1) = \frac{R}{L}$$

$$\boxed{f_2 - f_1 = \frac{R}{2\pi L}}$$

$$\boxed{\text{Band width} = B.W = f_2 - f_1 = \frac{R}{2\pi L}} \quad \& \quad \boxed{\Delta f = \frac{R}{4\pi L}}$$

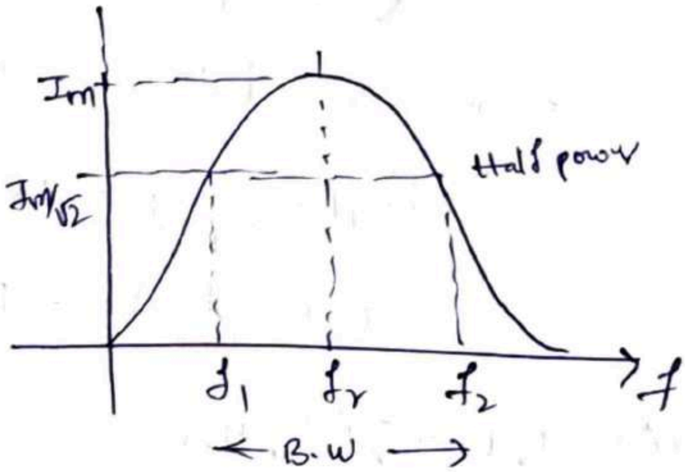
→ And we have

Upper cut-off frequency

$$f_2 = f_r + \Delta f$$

Lower cut-off freq

$$f_1 = f_r - \Delta f$$



Quality factor :-

It ratio of voltage across L (or) C with supply voltage.

i.e voltage magnification is circuit.

$$Q = \frac{V_L}{V} \text{ (or) } \frac{V_C}{V} \quad \text{(or)} \quad \frac{X_L}{R} \text{ (or) } \frac{X_C}{R}$$

for RL → ~~Q = V~~

$$Q = \frac{\omega_r L}{R} \Rightarrow \boxed{Q = \frac{1}{R}\sqrt{\frac{L}{C}}}$$

for RC → $\boxed{Q = \frac{1}{R}\sqrt{\frac{L}{C}}}$ i.e Same.

Parallel RLC Circuits

Pro:- In series-parall circuit A & B are in parallel and in series with 'C'. The impedances are

$Z_A = 4+j3\ \Omega$, $Z_B = 4-j5\ \Omega$ & $Z_C = 2+j8\ \Omega$.

If the current $I_C = (25+j0)$, calculate

(i) Branch ~~Curr~~voltage (ii) Branch current (iii) Total power

(iv) Phasor diagram.

Resonance in Parallel Circuit :-

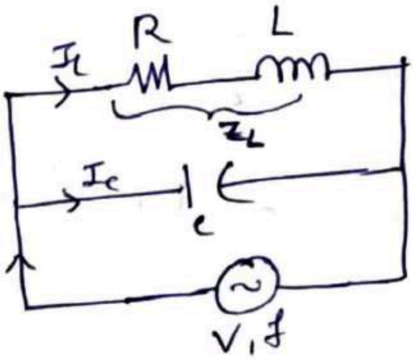
In a parallel circuit when susceptance is becomes to zero, then circuit is said to be in resonance. i.e $(B_L - B_C) = 0$.

→ Power factor is unity. & current is minimum.

→ It is used in Oscillators

→ complex communication circuits & filters.

Consider a parallel circuit which is having series of R&L in parallel with 'C' as shown below



This circuit is called Tuned circuit. If impedance of circuit is Z_L and reactances are X_L & X_C the at resonance we have relation

$$Z_L^2 = X_L X_C$$

$$R^2 + (2\pi f_r L)^2 = (2\pi f_r L) \times \frac{1}{2\pi f_r C}$$

$$R^2 + (2\pi f_r L)^2 = \frac{L}{C}$$

$$(2\pi f_r L)^2 = \frac{L}{C} - R^2$$

$$2\pi f_r = \frac{1}{L}\sqrt{\frac{L}{C} - R^2}$$

$$\boxed{f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}}$$

i.f $\frac{R^2}{L^2} << \frac{1}{LC}$ then

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$$

it is same as ~~res~~ series resonanc

→ Quality factor is current magnification

i.e $\dfrac{\frac{V}{Z_L}}{\frac{V}{Z_D}} = \dfrac{\frac{L}{RC}}{\sqrt{L/C}}$

then Quality factor $\boxed{Q = \frac{1}{R}\sqrt{\frac{L}{C}}}$

Three-phase balanced Circuits :-

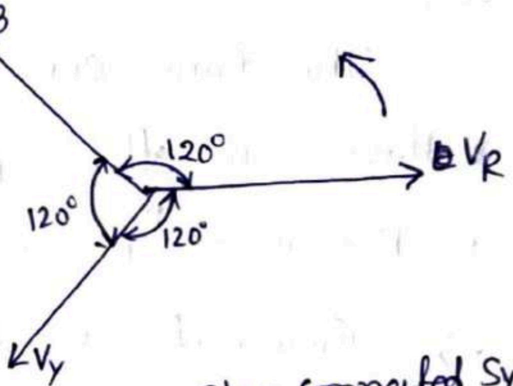
Three-phase Circuit ~~or~~ System :- The system which is having three voltages with same magnitude & same frequency ~~[illegible]~~ and having each one with a phase difference 120°. As fallows

$$V_R = V_m \sin\omega t$$

$$V_Y = V_m \sin(\omega t - 120°)$$

$$V_B = V_m \sin(\omega t - 240)$$

$$\text{or } V_m \sin(\omega t + 120°)$$



→ we have 2-types of 3-φ Systems
- → Star connected System
- → Delta connected System.

Advatages of 3-φ System :-

→ By using 3-φ System output power increases, it is 1.5 times of 1-φ System power.

→ In 3-φ system ~~copper~~ the designing of transmission and distribution it require less copper as compared with 1-φ System.

→ By using 3-φ system we can produce rotating magnetic field.

→ In 3-φ System instanteneous power is constant

→ Three phase system give steady output.

→ The 3-ϕ system having better regulation, with 1-ϕ System

→ 3-ϕ can be used to supply the 1-ϕ load system

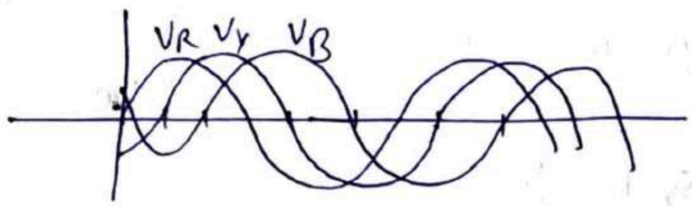
→ 3-ϕ can be rectified into DC-Supply with low ripple factor

→ Parallel operation is easy in 3-ϕ system.

Phase sequence:-

The time order on the sequence in which the voltages in three-phases reach their maximum values is known as "phase sequence".

→ Generally we have R-Y-B is phase sequence



Phase voltage:- (V_{ph}) The voltage which is measured between a line and neutral called as phase voltage

Ex:- $\bar{V}_{RN}$, $\bar{V}_{YN}$ or $\bar{V}_{BN}$

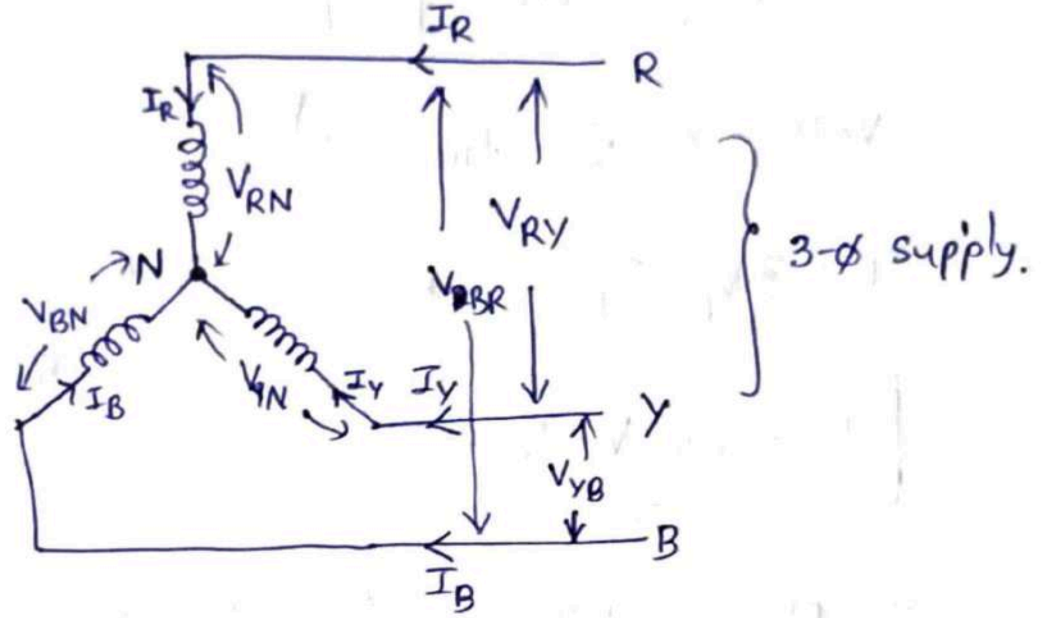
Line voltage:- (V_L): The voltage measured between any two lines in a 3-phase system

Ex: $\bar{V}_{RY}$, $\bar{V}_{YB}$, $\bar{V}_{BR}$

$$\bar{V}_{RY} = \bar{V}_R - \bar{V}_Y$$
$$\bar{V}_{YB} = \bar{V}_Y - \bar{V}_B$$

Voltage & Current relations in 3-ϕ Star connected system

The circuit diagram for a 3-ϕ balanced star connected circuit with phase sequence RYB as shown below



For a given 3-ϕ star connected System has

→ Phase voltages $V_{ph} = V_{RN} = V_{YN} = V_{BN}$

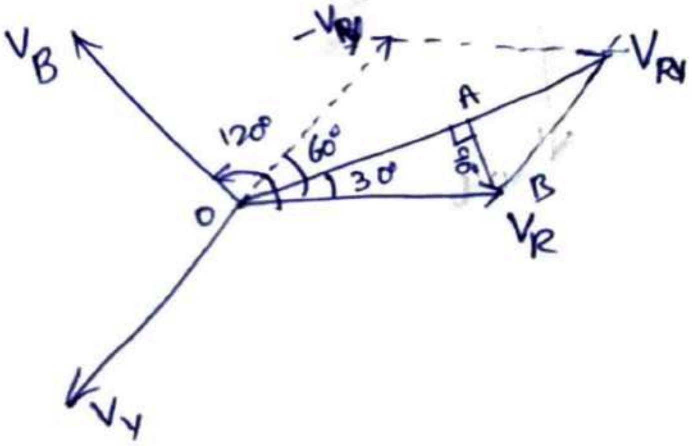
& phase currents $I_{ph} = I_R = I_Y = I_B$

→ Line voltages $V_L = V_{RY} = V_{YB} = V_{BR}$

& line current $I_L = I_R = I_Y = I_B$.

$V_{RY} = V_R - V_Y$
$V_{YB} = V_Y - V_B$
$V_{BR} = V_B - V_R$

→ The phasor diagram for line & phase voltages is



From ΔOAB $\cos 30 = \frac{OC}{OA} \Rightarrow \frac{V_L/2}{V_{ph}} = \frac{\sqrt{3}}{2}$ $\qquad \frac{\left(\frac{V_{RY}}{2}\right)}{V_R} = \frac{OC}{OA}$

So, In star connected system

$$\boxed{V_L = \sqrt{3}\ V_{ph}} \quad \text{and} \quad \boxed{I_L = I_{ph}}$$

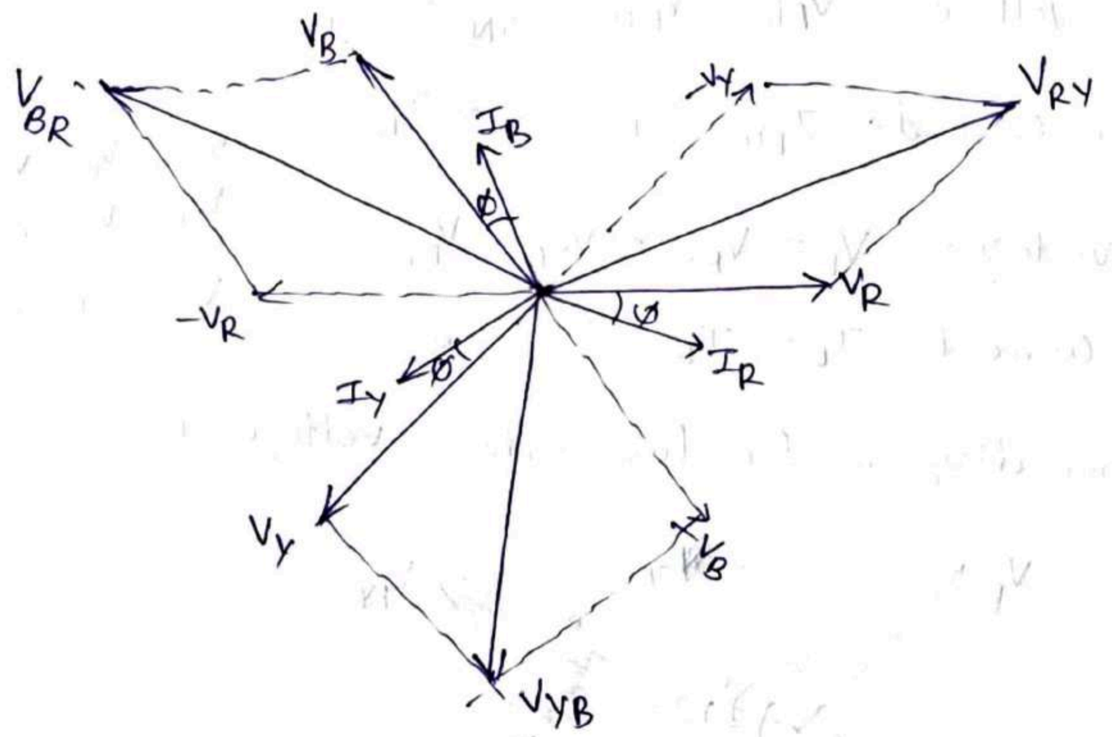
Thuse line voltage is $\sqrt{3}$ times of phase voltage star connection

→ Power $P = 3 V_{ph} I_{ph} \cos\phi$ for 3-ϕ system

$\because V_{ph} = \frac{V_L}{\sqrt{3}}$

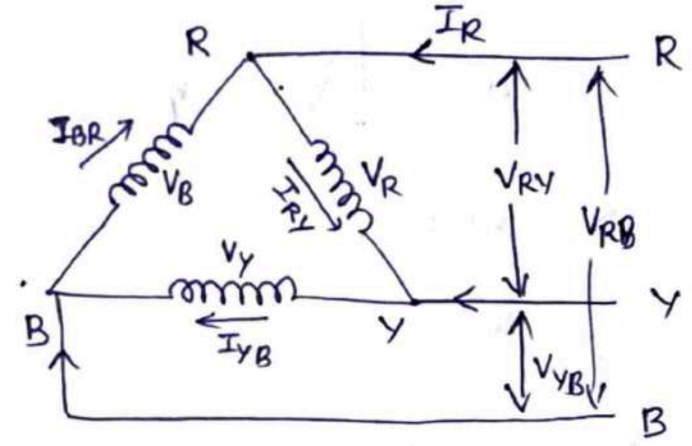
So $$\boxed{P = \sqrt{3}\ V_L I_L \cos\phi}$$

→ The 3-ϕ phasor diagram for star connected inductive load is



Voltage & current relations in 3-ϕ Delta connected System :-

The circuit diagram for a 3-ϕ Delta connected System with phase sequence R-Y-B as shown below.



For a given 3-ϕ delta connected system has

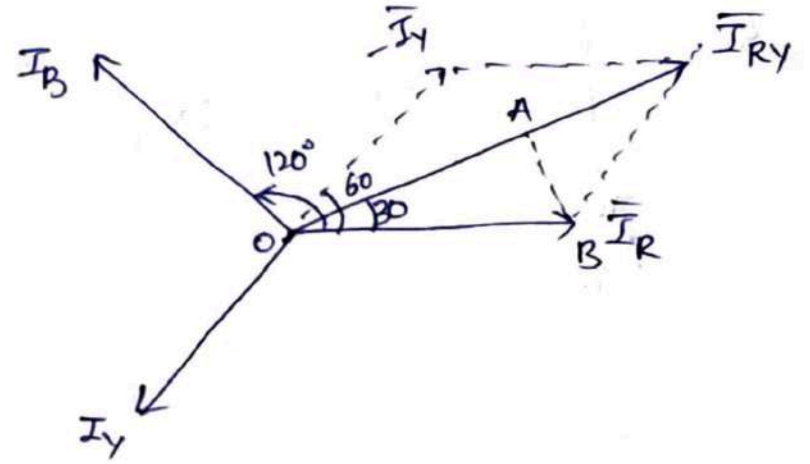
→ phase voltages $V_R = V_y = V_B = V_{ph}$

& phase currents $I_{ph} = I_{RY} = I_{YB} = I_{BR}$

→ line voltages $V_L = V_{RY} = V_{YB} = V_{BR}$

& line currents $I_L = I_R = I_y = I_B$

→ The phasor diagram for line current & phase current is



From Triangle OAB $\cos\overset{30}{\phi} = \frac{OC}{OA} = \frac{I_R/2}{I_{RY}}$

$$\frac{\sqrt{3}}{2} = \frac{I_L/2}{I_{ph}}$$

So In delta connected System

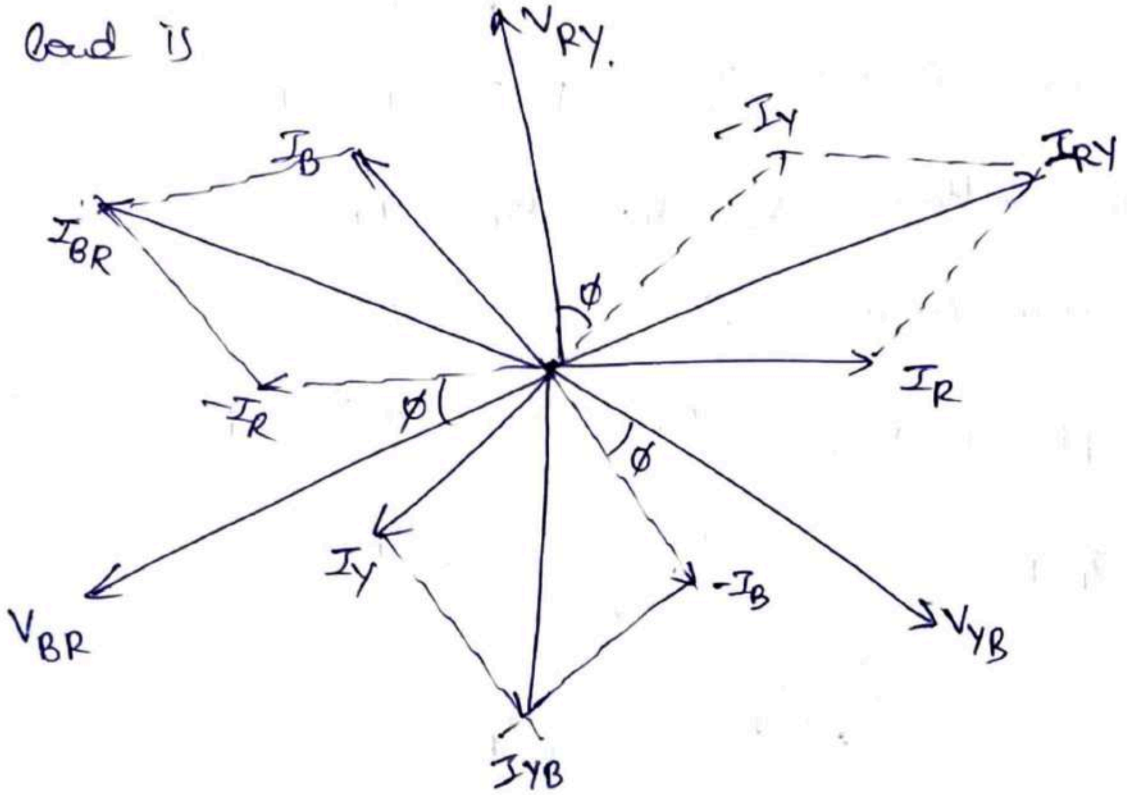
$$\boxed{I_L = \sqrt{3}\ I_{ph}} \quad \text{and} \quad \boxed{V_{ph} = V_{PL}}$$

→ The Power in 3-ϕ System is

$$P_{ph} = 3V_{ph} I_{ph} \cos\phi$$

$$\boxed{P = \sqrt{3}\ V_L I_L \cos\phi}\ \text{watts}$$

→ The 3-ϕ phasor diagram for delta connected inductive load is



UNIT III

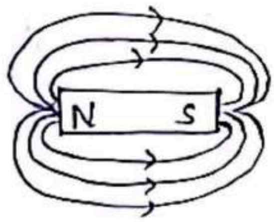
TRANSFORMERS

UNIT-3

TRANSFORMERS

Basic Definations :-

Magnetic field :- The area which attracts magnetic materials and iron pieces, that region is called "magnetic field".



Magnetic flux (Ø) :- It is the total number of lines of force existing in a magnetic field is called as "magnetic flux (Ø). Units are "webers".

Magnetic flux density : (B)

The flux per unit area in a magnetic field is called "magnetic flux density (B).

i.e $\boxed{B = \frac{\phi}{A}}$ → Units are "web/m^2"

Magnetic field Strength :(or) Magnetic field intesity (H)

It is the force experienced by unit North pole at particular point in a magnetic field is called "MFI".

Units are AT/web (or). Aamper-Turns/web

Magneto motive force (mmf) :- The force which drives the flux through a magnetic material is called "mmf". units are "AT".

Permeability (μ) :- It is the ability of the medium which allows the magnetic fluxes through it self, is called permeability :

(or)

It is the ratio of flux density (B) to the magnetic field strength

$$\mu = B/H \quad \text{(or)} \quad \boxed{\mu = \mu_0 \mu_r}$$

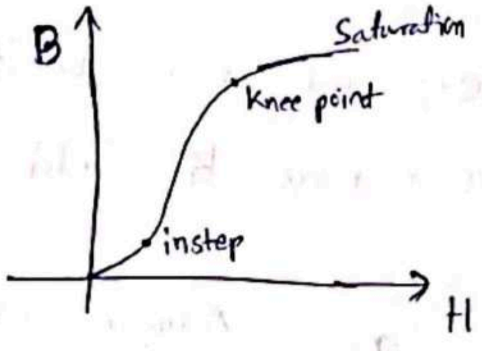
→ No units

μ_0 = Absolute permeability
= 1 for air

μ_r = relative permeability

· B-H Curve of Magnetic material :-

→ The graph between flux density (B) and field intensity (H) is called B-H Curve.



Transformer :-

The transformer is a static device which transfers electrical power one circuit to another circuit, at constant frequency.

→ The transformer is power constant device

→ The transformer is constant frequency device

→ It can be used for different voltage & current changing values of A.C supply

→ It is used in different stages of electrical systems as generation, transmission, distribution and utilization.

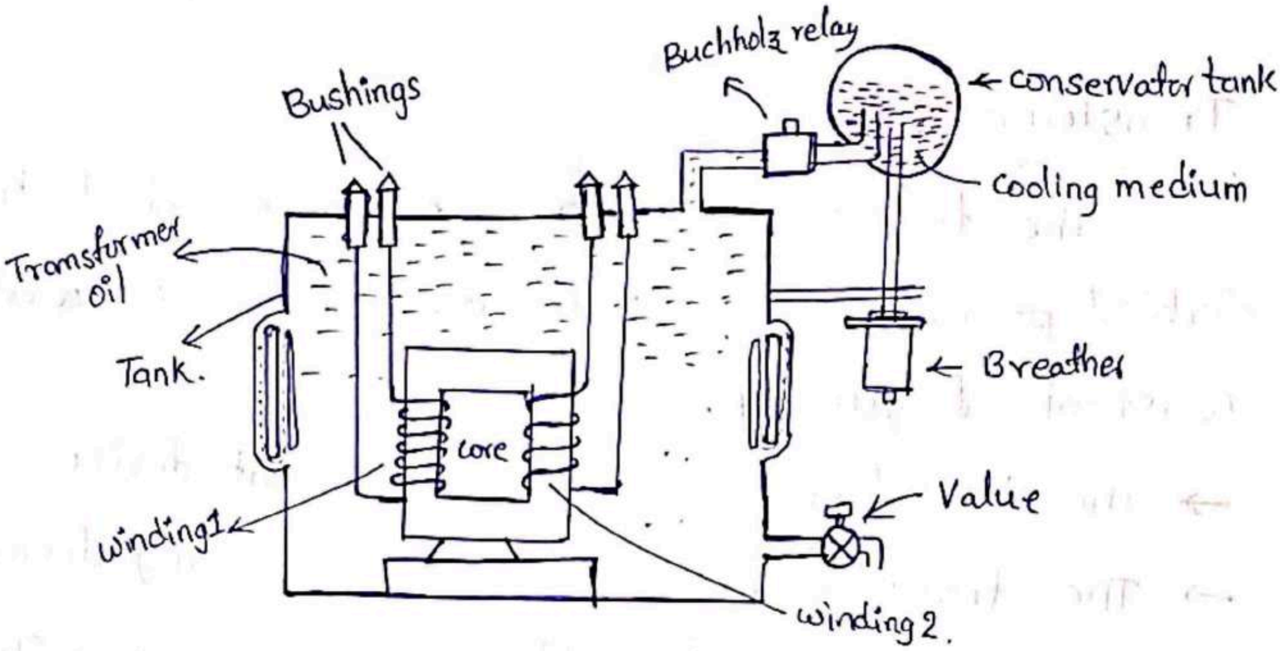
Construction of Transformer

The essential components of the transformer are

1. Magnetic core
2. Two windings, namely primary and Secondary windings
3. A time varying magnetic flux.

The constructional diagram of Single-phase transformer as shown in below, it having different components as

1. Core
2. Limb
3. Yoke ~~or~~ Tank
4. Windings
5. Conservator Tank.
6. Cooling medium
7. Breather
8. Explosion vent
9. Buchholz relay
10. Bushings.
11. Transformer Oil.

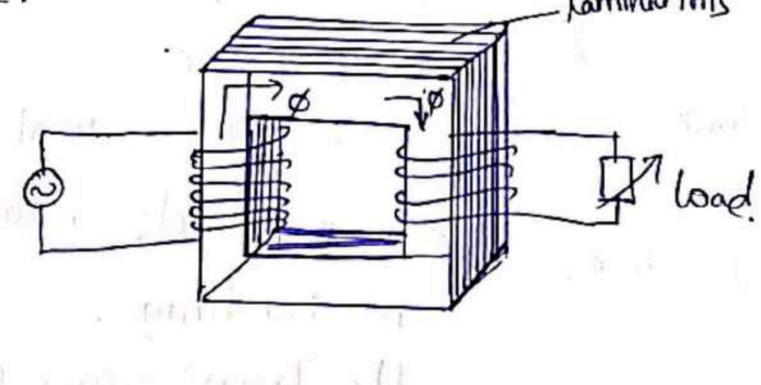


constructional diagram of Single-phase Transformer

① Transformer core :- The main function of transformer core which gives accomidation for windings transformer. It may be reactangular or square, having limbs. It is made up of cast iron. It is two types

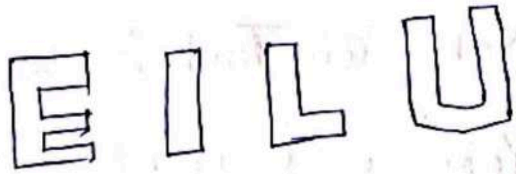
ⓐ core type
ⓑ Shell type

ⓐ core type transformer :- In this transformer rectangular frame laminations are formed to build the core.
→ It has single magnetic circuit
→ In this transformers windings are surrounded by limbs of core.



→ The laminations are pressed or punched out from the steel sheets, we can ~~desi~~ manufacture the core of Transforma

→ These laminations sheets are assemble as letter

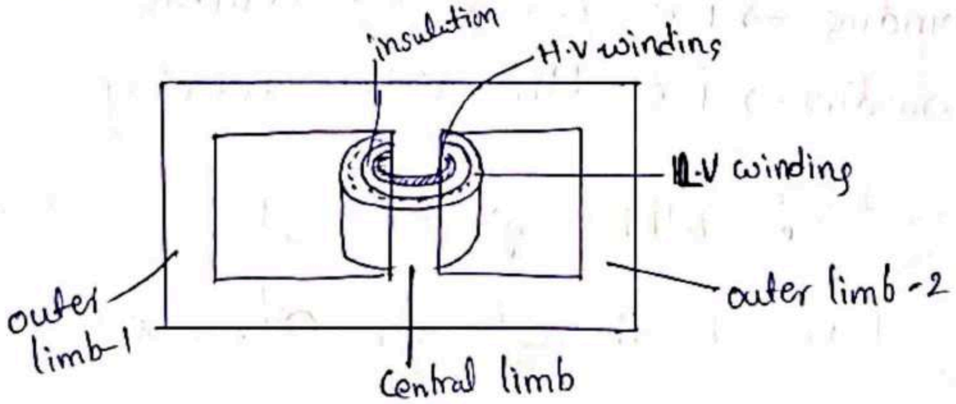
E, I, L, U as 

→ In this type of core, interleaving windings is used which reduces leakage fluxes.

(b) **Shell type transformer** :- In this shell type windings are surrounded by core of transformer.

→ It has double magnetic circuit.

→ It has a central limb and two outer limbs, as



→ For construction of this type core, we use E & I shape lamination sheets.

→ It require less insulation for designing it

→ Cooling mechanism is easy.

2. Limb :- Limb is a part of core, which gives accomidation for winding and protect the winding for physical stress.

3. Yoke (or) Tank :- ~~It is a total cover~~

Yoke is part of transformer which protects transformer winding from physical stress and gives accomidation for transformer oil.

4. Windings :- We have two windings in transformer

→ Primary winding → which is connected with supply
&
→ Secondary winding → which is connected with load.

(or)

L.V winding → i.e Low voltage winding
H.V winding → i.e High voltage winding.

5. conservator :- Which gives a place for increasing decreasing levels of transformer oil i.e cooling medium

6. Breather :- Which is protects the transformer oil from all weather condition problems.

7. Buchholz relay :- The relay which rings the alaram when fault is occured in transformer.

8. Bushings :- Which provides insulation between winding terminals to the transformer tank.

9. Transformer oil :- The main function of T/F oil is to provide cooling of windings and insulation between windings

10. Explosion Vent :- It is a Valve for ~~when~~ realising oil from the tank when sudden explosion is occures.

Faradays Law:-

Faraday Frist law :- " whenever a conductor cuts the flux then an "emf" induces in that conductor.

Faraday's Second Law :- The induced emf in a conductor is directly proportional to the rate of change of flux linkages

i.e $\boxed{e = -N\dfrac{d\phi}{dt}}$ i.e $e \propto \dfrac{d\phi}{dt}$

Self induced emf :- It is induced emf in a coil when it's own flux links with it self.

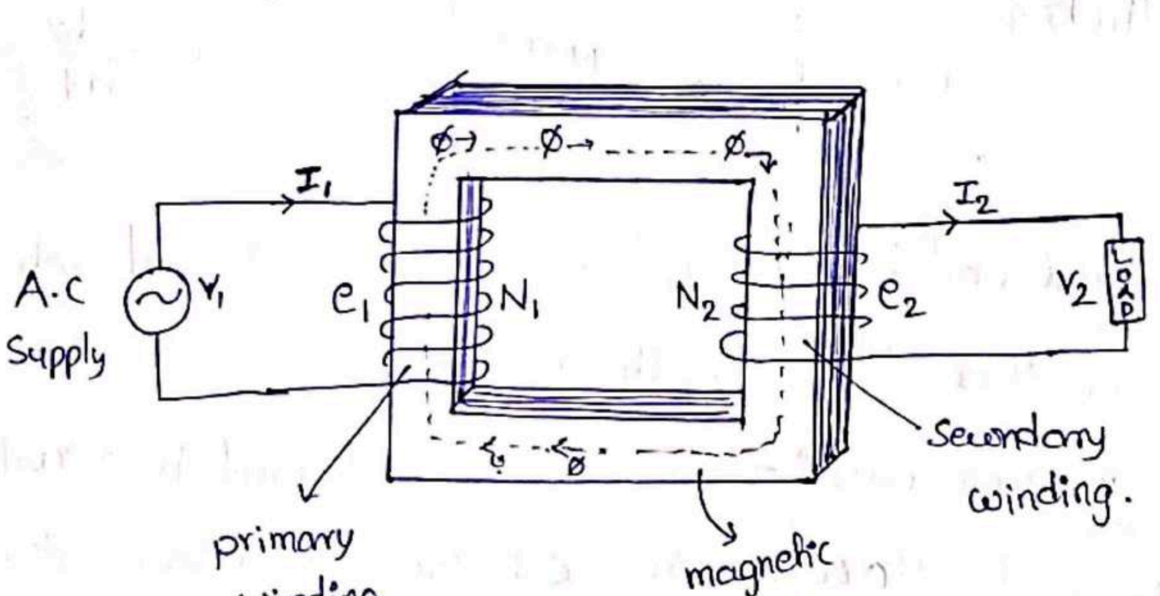
Mutual induced emf :- It is induced emf in a coil due current flowing in ~~a~~ beside coil & it's flux linkages.

Working Principle of Transformer

The transformer works on the principle of Fraday's Laws of ~~mutual~~ electromagnetic mutual induction principle, which states that when two coils are magnetically coupled, then current in one coil changes uniformely and induces ~~or~~ developes the emf in other coil.

In a transformer the coil which is connected with supply is called primary winding and the coil which is connected with load is called secondary winding.

Consider a basic transformer, ~~pri~~ which is having N_1 no. of turns in primary and N_2 no. of turns in secondary as shown in below.



→ When primary winding is connected with AC-source, then current "I_1" flows through the winding and produces an alternating flux (ϕ).

→ This alternating flux passes through magnetic core and links with secondary winding.

→ According to faradays law of electromagnetic mutual induction principle, an emf (i.e mutual induced emf(e_2)) is induceds in the secondary winding.

→ This secondary induced emf causes the current "I_2" and drives the load.

Like this, transformer transfers the power from one circuit other circuit without electrical connection.

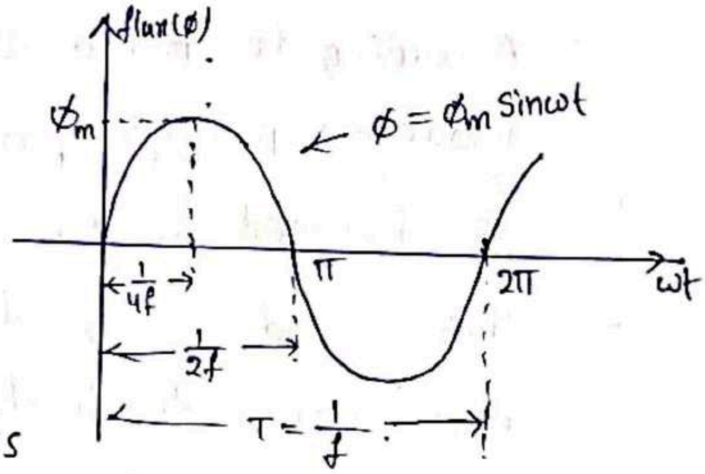
Q:- Explain why the transformer will not works for d.c supply?

A:- If d.c supply is given to the primary of transformer, then their is no transformer action, why because "d.c supply having frequency zero, so their is no alternating fluxes, and no-leakage reactance." if d.c supply is given them primary winding draws very high current, then transformer burn-out (or) exploision will be takes place.

EMF- equation of Transformer

When the primary winding is excited by an alternating voltage 'V_1', it circulates alternating current producing an alternating flux 'ϕ'.

The waveform for alternating flux 'ϕ' can drawn as for time period '2π'.



Let ϕ = alternating flux

ϕ_m = maximum flux

N_1 = No. of primary turns

N_2 = No. of Secondary turns

E_1 = primary induced emf in RMS

E_2 = Secondary induced emf in RMS

f = frequency of supply.

→ According to Faraday's law of electromagnetic induction the average emf induced ~~per~~ in each turn is proportional to the average rate of change of flux.

∴ Average emf per turn = Average rate of change of flux

$$\text{i.e} \quad \frac{d\phi}{dt} = \frac{\text{change in flux}}{\text{Time required for change in flux}}$$

In above ~~above~~ figure initial flux ($\phi = 0$) and after "1/4th" cycle the fluxes are maximum i.e 'ϕ_m', so

i.e $$\frac{d\phi}{dt} = \frac{\phi_m - 0}{(1/4f)} = 4f\phi_m \text{ wb/sec}$$

So, Average emf per turn = $4f\phi_m$ volts. i.e $\text{emf}/_{\text{turn}} = 4f\phi_m$

→ The RMS value of induced emf per turn

$$\text{emf}/_{\text{turn}} = 1.11 \times 4.f\ \phi_m$$

i.e $$E = 4.44\ f\ \phi_m$$

→ If primary winding has 'N_1' no. of turns, then RMS value of induced emf in primary

i.e $$\boxed{E_1 = N_1 \times 4.44 f\ \phi_m} \text{ volts}$$

Simillarly, in secondary

$$\boxed{E_2 = N_2 \times 4.44 f\ \phi_m} \text{ volts.}$$

Transformation ratio (K)

If transformer having primary induced emf (E_1) and secondary induced emf (E_2), then

i.e $$K = \frac{E_2}{E_1}$$ $\because E_2 \propto N_2$ & $E_1 \propto N_1$

and $$K = \frac{N_2}{N_1}$$ $\because E_2 = V_2$ & $E_1 = V_1$

and $$K = \frac{V_2}{V_1}$$ * i.e $$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = K = \frac{I_1}{I_2}}$$

problems:- ① The maximum flux density in the core of 250/3000 volts, 50 Hz single phase transformer is 1.2 weber per square meter. If the emf per turns is 8 volts determine primary and secondary turns and area of the core.

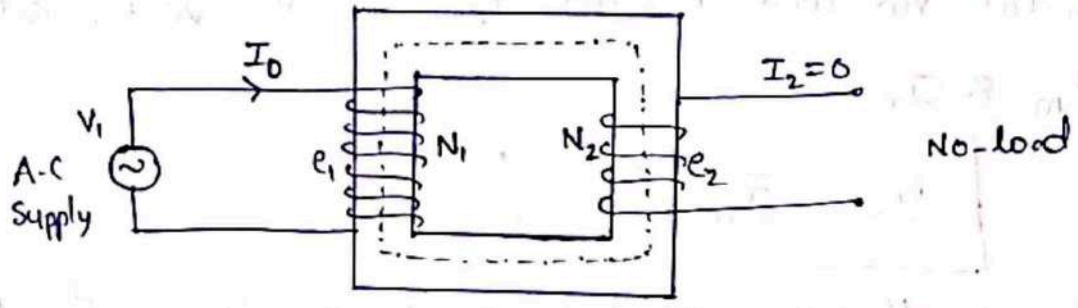
P② The number of turns on the primary and secondary windings of a single phase transformer are 350 and 35 respectively. If the primary is connected to a 2.2 KV, 50 HZ, determine the secondary voltage.

Comparision between core type and shell-type transformer

Core type transformer	Shell-type transformer
1. The windings surround the core and placed on the side limbs	1. The core surrounds the winding and is placed on central limb.
2. Laminations is in L, I, U strips formatts.	2. Laminations sheet is in long strips in shape of E & I
3. Two limbs exist	3. Three limbs exist
4. Requires more copper matorial	4. Requires less copper
5. Requires more insulation	5. Less insulation require
6. Equal distribution of flux on the limbs	6. Unequal flux distribution of flux in the limbs.
7. More loss exists	7. Less loss exists
8. High output achived	8. Less output can be achieved.
9. Easy to maintain	9. Difficult to maintain
10. Natural cooling possible	10. Cooling mechanism exists.

Practical Transformer on No-load

The practical transformer with no-load is shown in figure.



When transformer is on No-load, then secondary current is zero, but practical transformer has hysteresis and eddy current loss because it is excited by AC-source which causes alternating flux. Due to small internal resistance in winding of transformer it ~~have~~ causes a small amount of primary copper loss. At this the current drawn by primary is called No-load current (I_0).

→ This no-load input current has two components

→ Wattless component :(I_m) : The magnetizing current (I_m) is the purely reactive component of I_0, that lags V_1 by 90°, which is produce the magnetic flux.

$$\text{i.e} \quad I_m = I_0 \sin \phi_0$$

→ Wattful component :-(I_c) :- The power component (I_c) which supplies the total losses of transformer under no-load condition

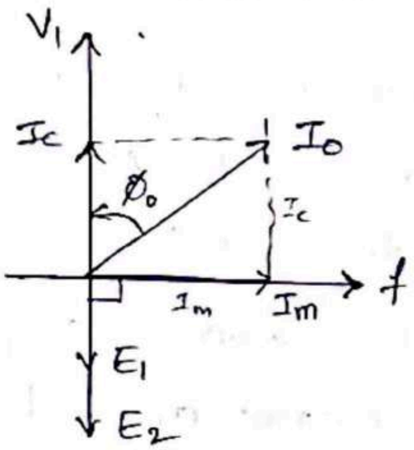
i.e $I_c = I_0 \cos\phi_0$

This I_c is in phase with 'V_1'

→ The total no-load current 'I_0' is the vector addition of I_m & I_c

$$\boxed{\bar{I_0} = \bar{I_m} + \bar{I_c}}$$

→ The phasor diagram of transformer at no-load is



→ From the above phasor diagram, magnitude of no-load current

$I_0 = \sqrt{I_m^2 + I_0^2}$ & "$\cos\phi_0$" is No-load power factor

→ The total power input on no-load is

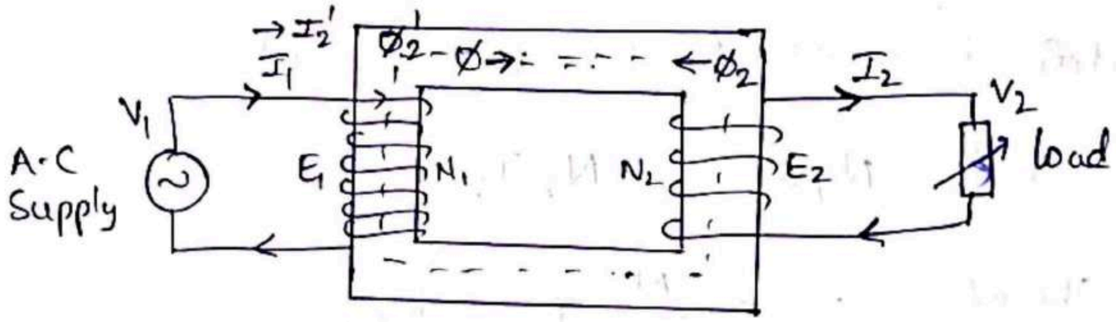
$$W_0 = V_1 I_0 \cos\phi_0 = V_1 I_c = P_i \text{ (Iron losses)}$$

→ Where 'I_0' is ~~co~~ very small, hence primary copper loss is negligible.

→ Hence power input 'W_0' on no-load always reprecent the iron losses as copper loss is negligible.

Transformer ON-load :-

The practical transformer connected with load is shown as below figure.



When primary winding of the transformer is connected to AC Source, then V_1 induces emf E_2 in Secondary by transformer action. When secondary winding is connected with load then 'I_2' flows in winding.

→ The current I_2 flowing through Secondary winding produces flux "ϕ_2", which opposes ϕ.

→ Then main flux 'ϕ' is decreases, then E_1 decreases then current drawn by primary is "I_2'", which producess additional flux 'ϕ_2'' which opposes ϕ_2

→ This I_2' neutralizes ϕ_2, the flux is maintained constant, hence transformer is flux constant machine.

→ The secondary flux ϕ_2 is developes the mmf is '$N_2 I_2$' and ϕ_2' flux produces mmf "$N_1 I_2'$" these mmf are get balanced, the flux in transformer is maintained constraint for load condition

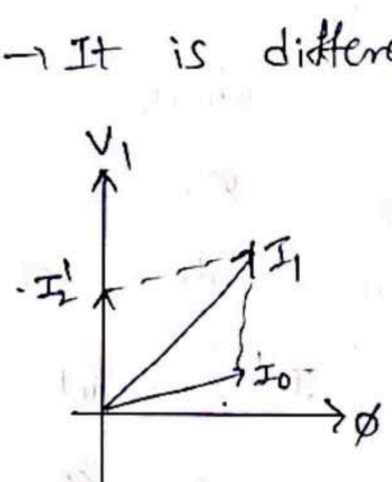
i.e $N_1 I_2' = N_2 I_2$

Therefor $I_2' = \frac{N_2}{N_1} I_2 = k I_2$

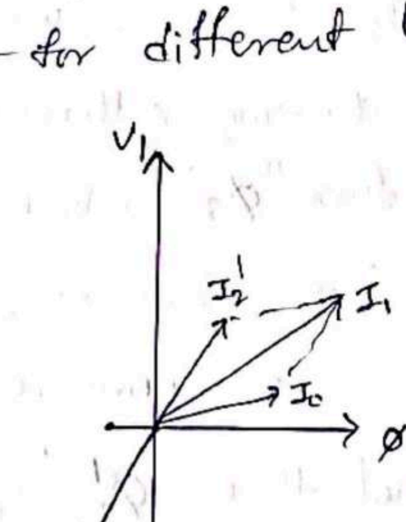
→ When a transformer is loaded, the primary current I_1 has two components

i.e $\bar{I}_1 = \bar{I}_0 + \bar{I}_2$

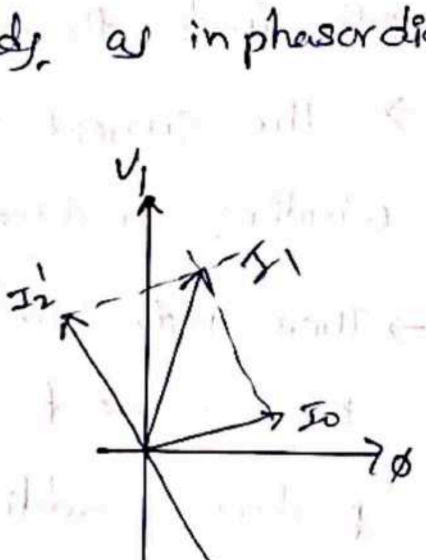
→ It is different for different loads, as in phasor diagram



Resistive-load



Inductive-load



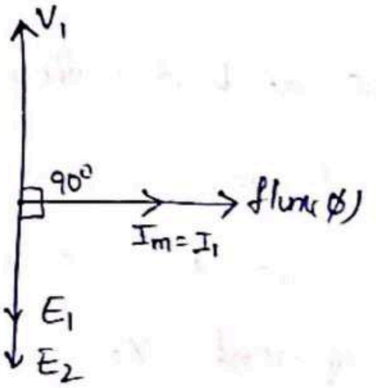
Capacitive-load

Ideal Transformer

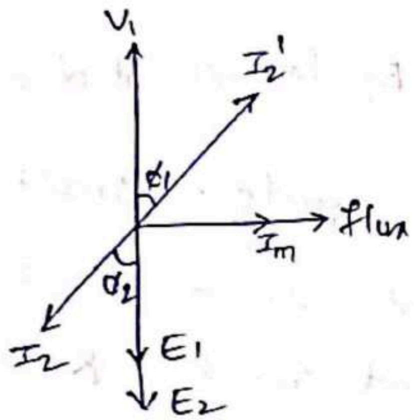
A transformer is said to be ideal transformer if it satisfies following properties

- → It has "no losses
- → Its windings (i.e primary & Secondary) have "zero resistance
- → Leakage flux is zero i.e 100% flux produced by primary links with the secondary.
- → Permeability of core is so high.
- → It has 100% efficiency.
- → Magnetic coupling (K) = 1

Phasor diagrams for ideal transformer



Ideal transformer at No-load



Ideal transformer at load.

In ideal transformer voltage drops in primary and secondary are zero, because resistance is zero. and E_2 is equal to V_2.

Equalent Circuit of Transformer :-

The equalent circuit of a transformer is a circuit with the combination of various resistances and reactances of the primary and secondary windings, which exactly ~~perp~~ perform like a transformer. It can be drawn a) below.

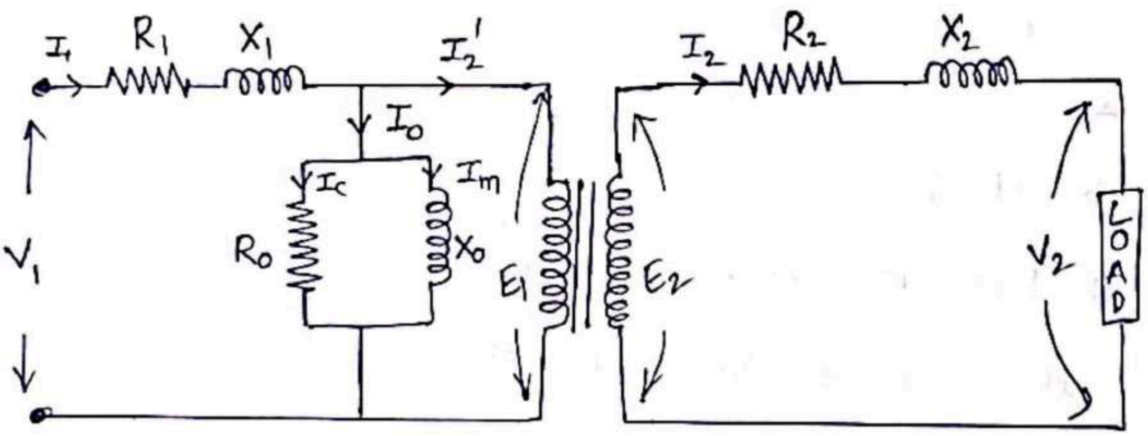


Fig :- Equalent Circuit of a Transformer at Load condition

→ In equalent circuit of transformer, it has no-load current I_0 are I_m & I_c which are flows through no-load reactive & active components X_0 & R_0

where $R_0 = \frac{V_1}{I_c}$ and $X_0 = \frac{V_1}{I_m}$

→ In equalent circuit of transformer has leakage reactances X_1 & X_2 w.r.to primary & secondary windings, which represent leakage flux

→ Winding resistance R_1 & R_2 to reprecent the copper losses $I_1^2 R_1$ & $I_2^2 R_2$ in the primary and secondary windings. respectively.

→ When load is connected, I_2 current ~~then~~ flows and it causes voltage drop across R_2 & X_2, then

additional current $I_2' = I_2 K$.

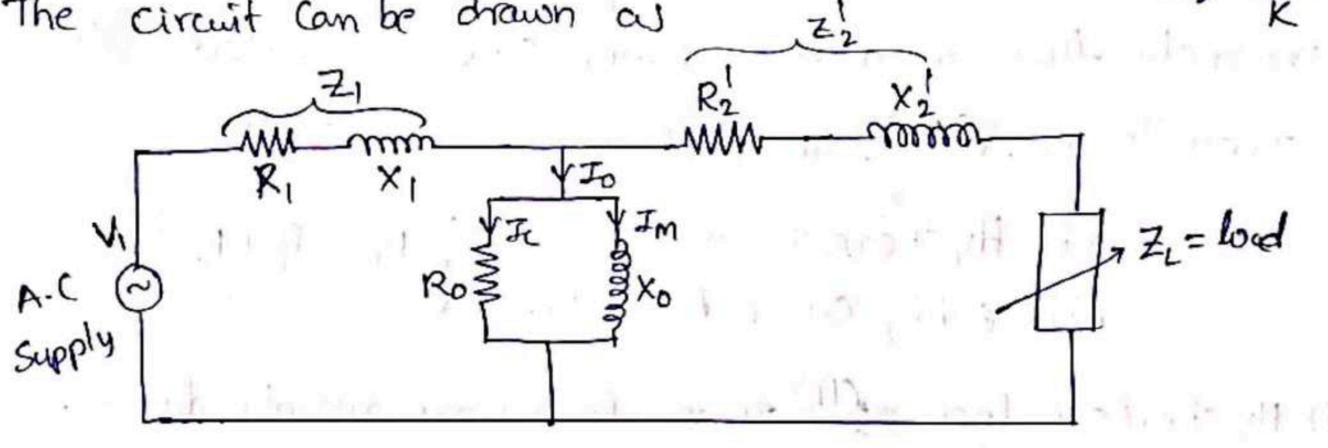
Equalent Circuit of transformer when ~~reffered to~~ Secondary-parameters reffered to primary Side

→ Then

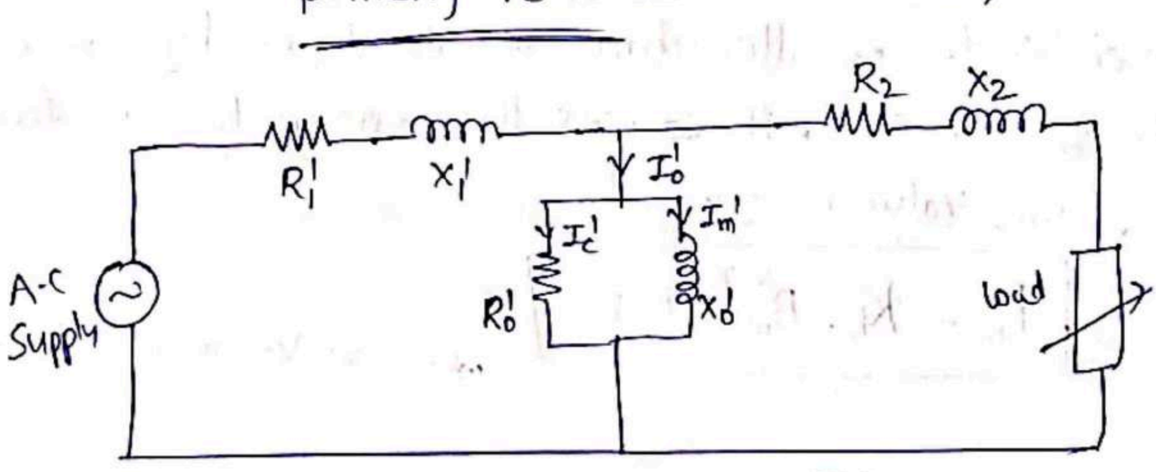
$$R_2' = \frac{R_2}{k^2}, \quad X_2' = \frac{X_2}{k^2}, \quad Z_2' = \frac{Z_2}{k^2} \quad \& \quad I_2' = kI_2$$

$$E_2' = \frac{E_2}{K}$$

The circuit can be drawn as



Equalent Circuit of Transformer when primary reffered to secondary Side :-



where

$R_1' = k^2 R_1$

$X_1' = K^2 X_1$

$E_1' = kE_1$

Losses in Transformer

→ Losses in transforboer can be classified as

Transformer Losses

Types

1. Constant losses i.e Core (or) Iron losses
   - Hysteresis loss
   - Eddy Current loss
2. Variable losses i.e copper losses
3. Stray losses
4. Dielectric loss

① Core (or) Iron losses (P_i)

The losses which are produced by alternating magnetic flux in a transformer core is called "Core or Iron losses. (P_i). These losses are two types

(i) Hysteresis losses.
(ii) Eddy current losses.

$$\boxed{P_i = P_h + P_e}$$

(i) Hysteresis losses (P_h):- These losses are mainly due to alternating flux in transformer core when transformer core is magnetization and de-magnetization takes place. The each cycle of alternating flux developes hysteresis loop in transform core, it causes the energy loss in form of heat. This value is given by

$$\boxed{P_h = K_h . B_m^{1.67} . f\ V}$$

where V=Volume of the core.

(ii) Eddy current loss : (P_e)

An induced emf in the core causes the current called eddy current, this eddy current circulates in transformer core and ~~dev~~ causes "I^2R" losses. The losses due to eddy current in transformer core is called Eddy current losses.

i.e $\boxed{P_e = K_e B_m^2 f^2 t^2 v}$ where t = thickness of sheets.

These constant losses can be reduced (or) minimised by using high-grade silicon steel lamination sheets.

(2) Copper losses (P_c)

The losses due to winding resistances of transformer are called as "copper losses". The total copper loss.

$$P_c = I_1^2 R_1 + I_2^2 R_2$$

(3) Stray losses :- The losses that occure in the transformer due to the leakage of magnetic flux are called stray losses. Thes losses are very less percentage, so these are neglisible

(4) Dielectric loss :- The losses due to ~~o~~ the insulating material for transformer are called as "Dielectric loss". This loss can be ~~effect~~ the efficieny of transformer.

Efficiency of The transformer

The efficiency of the transformer can be defined as its the ratio of the output power to the input power

i.e $\eta = \frac{\text{output power}}{\text{Input power}}$ (or) $\frac{\text{Power output}}{\text{Power Input}}$

(or) $$\eta = \frac{\text{outpute power}}{\text{Output power} + \text{Total losses}}$$

$$\eta = \frac{\text{Power output}}{\text{Power output} + P_i + P_{cu}}$$

by basis power equations

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_{2}^2 R_{eq}} \qquad \because P_{cu} = I^2 R$$

If the 'VA' rating of the transformer is $V_2 I_2$ then

$$\eta = \frac{(\text{VA rating}) \cos\phi_2}{(\text{VA rating}) \cos\phi_2 + P_i + I_2^2 R_{eq}}$$

Let $n = \frac{\text{Actual load}}{\text{Full load}}$ i.e fraction of Load, then

$$\eta = \frac{n \times (\text{VA rating}) \cos\phi_2}{n (\text{VA rating}) \cos\phi_2 + P_i + n^2 P_{cu}}$$

$$\boxed{\eta\% = \frac{n (\text{VA rating}) \cos\phi_2}{n (\text{VA rating}) \cos\phi_2 + P_i + n^2 P_{cu}} \times 100}$$

Condition for maximum efficiency (η_{max}).

In a transformer the output power is less than input power, because it has the losses.

i.e Power output = Power input − Losses

$$P_o = P_i - P_{Loss} \qquad \because P_{loss} = P_i + P_{cu}$$

$$P_i = P_o + (P_i + P_{cu}).$$

→ The load current at which efficiency attains maximum value is denoted by 'I_{2max}' and the maximum efficiency denoted as "η_{max}".

→ The efficiency is a function of load i.e load current I_2 assuming $\cos\phi_2$ is constant, and secondary voltage 'V_2' also assumed as constant.

→ So condition for maximum efficiency is

$$\frac{d\eta}{dI_2} = 0$$

We have $\eta = \dfrac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2}$ $\qquad \because \dfrac{d}{dx}\left(\dfrac{u}{v}\right) = \left(\dfrac{u'v - uv'}{v^2}\right)$

So

$$= (V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2)(V_2 \cos\phi_2) - (V_2 I_2 \cos\phi_2).(V_2 \cos\phi_2 + 0 + 2I_2R_2) = 0$$

Let common "$V_2 \cos\phi_2$" and cancel it, then

$$\Rightarrow V_2 I_2 \cancel{\cos\phi_2} + P_i + I_2^2 R_2 - V_2 I_2 \cancel{\cos\phi_2} - 2 I_2^2 R_2 = 0$$

$$\Rightarrow \quad P_i - I_2^2 R_2 = 0$$

$$\boxed{P_i = I_2^2 R_2}$$ i.e condition for maximum efficiency

i.e $\boxed{\text{Iron losses} = \text{Copper losses}}$

$$\boxed{P_i = P_{cu}}$$

Voltage Regulation :-

The voltage regulation of transformer can be defined as ~~change in the~~ ratio of change in secondary voltage when the transformer load is reduced from full load to no-load to the full load secondary voltage

~~wh~~ if V_2 = Secondary voltage at full load

V_{02} = Secondary voltage at no-load

$$\therefore \text{Voltage Regulation} = \frac{V_{02} - V_2}{V_2}$$

$$\boxed{\% \text{ Voltage Regulation} = \frac{V_{02} - V_2}{V_2} \times 100}$$

→ If we have $V_2 = I_2 X_{02} \sin\phi$

$$V_{02} = I_2 R_{02} \cos\phi$$

Then

$$\% V.R = \frac{I_2 R_{02}\cos\phi \pm I_2 X_{02}\sin\phi}{V_2}$$

for inductive load = +Ve
Capacitive load = −Ve

$$= \frac{I_2 R_{02}\cos\phi}{V_2} \pm \frac{I_2 X_{02}\sin\phi}{V_2}$$

→ The Regulation will be zero when power factor angle $\phi = \tan^{-1}\left(\frac{-R_{02}}{X_{02}}\right)$

where '−ve' indicates that zero regulation occurs at leading power factor.

→ Regulation will be maximum when angle

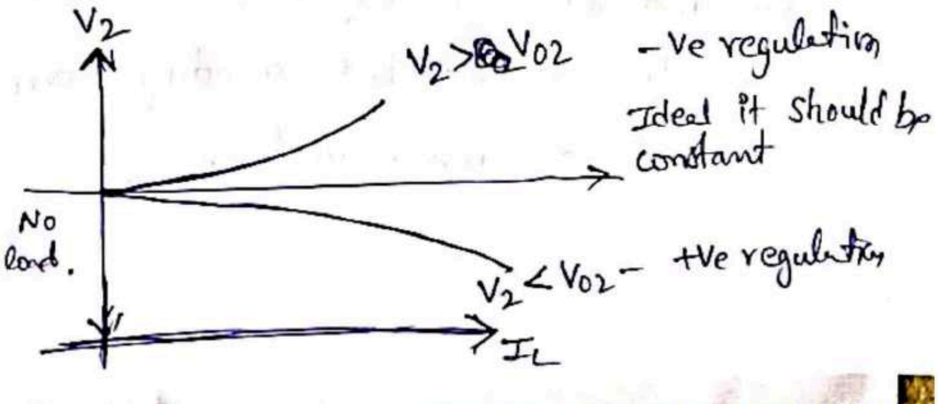
$$\phi = \tan^{-1}\left(\frac{X_{02}}{R_2}\right)$$

Maximum Regulation occurs at " lagging power factor.

→ Voltage Regulation of transformer on an average is about 4%

→ For consumers View Regulation should be kept as possible

→ It can be shown as



Auto-transformer :-

An auto-transformer is a special type of single-phase transformer, consisting of single winding woun-on a laminated core. Here, some part of this single winding acts as the primary winding and some part acts as the secondary winding.

→ The number of turns of the primary and secondary windings can be varied using switch contact. Since the output voltage of the auto-transformer can be varied.

→ So, it also called as VARIAC (VARIable A) (or) voltage regulator.

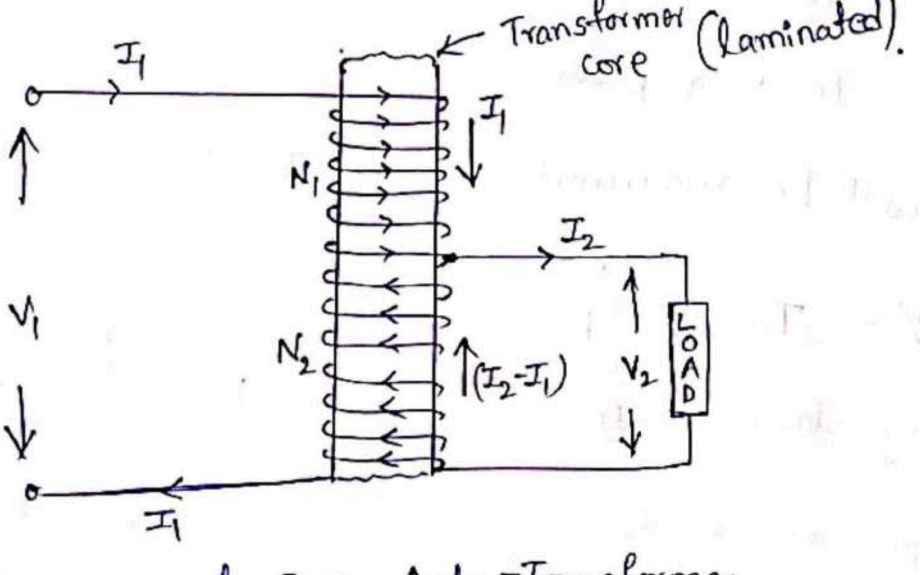


Diagram of Basic Auto-Transformer

→ In two-winding transformer, the windings (primary & secondary) are magnetically coupled and electrically isolated, but in auto transformer 'both windings' are connected electrically as well as magnetically.

→ A ~~part of~~ single continous winding is common to primary and secondary windings. These windings are wound on a silicon steel laminated core.

→ To ~~vary~~ regulate the voltage of the auto-transformer we have a tapping brush which is moving on windings of transformer.

Operation of Single-phase Auto transformer :-

The working of an auto-transformer is similar to ~~that of~~ a two-winding transformer, A-T/F shown below.

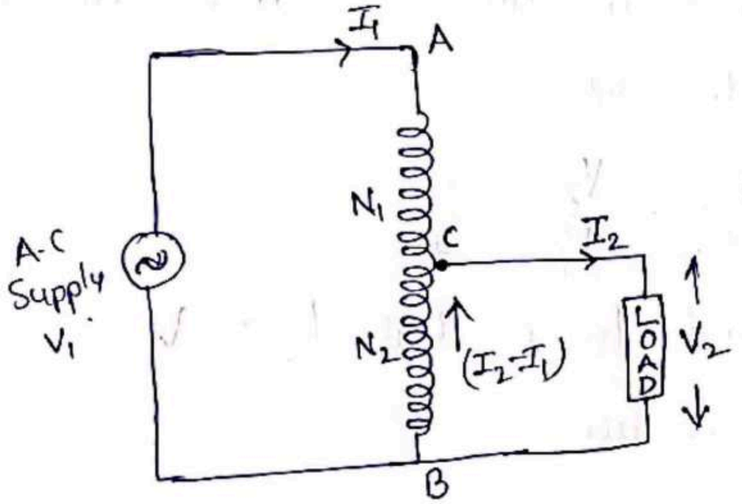


Diagram of Auto-Transformer

In above diagram, the AB is the primary winding of transformer and 'CB' is secondary winding where the tapping is provided.

When a supply voltage V_1 is applied to the primary winding AB, an alternating flux set up in the core due to which an induced emf 'E_1' is devoloped. Since the secondary winding is a part of the primary winding, a part of the induced emf E_1, is taken in to which the load is connected.

→ Let E_2 be the induced emf in the secondary winding

→ This induced emf drives the current in the secondary winding and hence the load connected to it.

→ As in an ordinary transformer, the transformation ration is turn ratio as

$$K = \frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

→ The power delivered to load is $P_L = V_2 I_2$

→ But in Auto transformer

$$\boxed{P_{Auto} = V_2 I_2 (1-k)}$$

→ & The power conducted directly is $\boxed{P = K V_2 I_2}$

→ When $N_1 > N_2$ → is Stepdown Transformer

$N_1 < N_2$ → is Step-up Transformer.

Advatages of Auto-Transformer

- It provides continous varrying voltage
- There is lot of saving in copper requirement
- It is in small size
- It is more efficient and hase better regulation
- Has low leakage flux
- Loss is Low
- It is mostly used for starter
- Very cheap and more economical.

Applications of Auto Transformer :-

- For starting rotating machine like induction motor, synchronous motors.
- As regulating transformer
- As voltage booster to raise voltage in an AC-feeder
- It is used as balance coil in order to provide neutral coil in 3-wire System.
- For interconnecting systems which are working with same voltage.

Three-Phase Transformer Connections (3-ϕ)

Three-phase transformer :-

The transformer used to supply (or) transfer large amount of power to "three-phase connections, to meet the required demand power economically, is called a "3-ϕ Transf In power systems it's used in different stages for stepping up ~~and~~ or stepping down higher voltages.

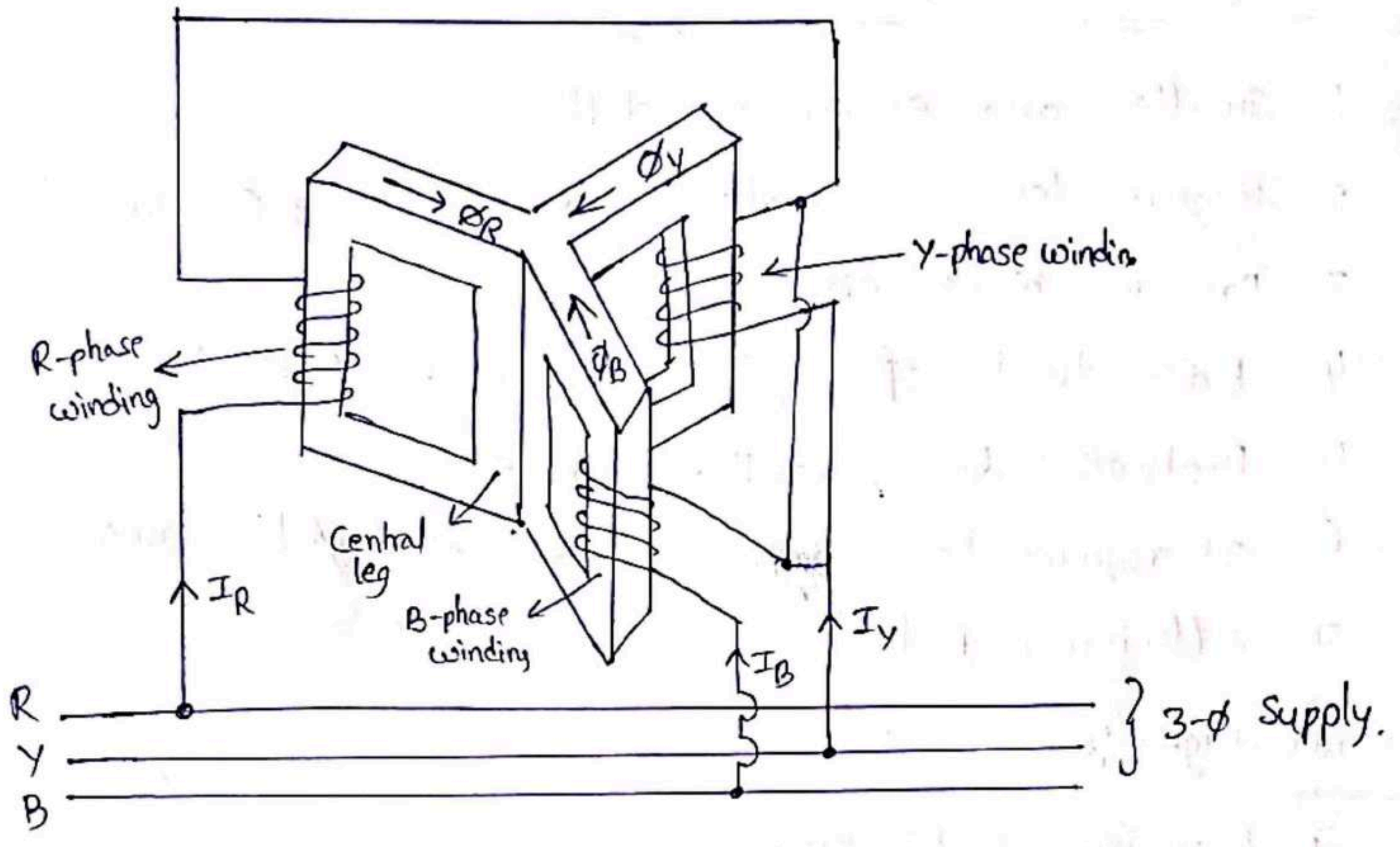
→ For the construction of 3-ϕ transformer, we have two methods
① → Using a bank of three single phase transformers
② → Using a single-three phase transformer.

→ By based ~~by~~ on type of the core, we have two types of 3-ϕ transformers as

ⓐ Core type three-phase transformer
ⓑ shell type three-phase transformer.

Working of a Three-phase Transformer :-

Consider that the primary of a three-phase transform are connected in star on the cores, which are displayed by 120°, each other, as shown in figure below. For simplification ~~only~~ purpose, only primary windings are connected to A.C suppl



When the primary windings are excited by 3-ϕ supply, current I_R, I_Y & I_B flow through its respective windings, which produces the magnetic fluxes ϕ_R, ϕ_Y & ϕ_B in cores. Since centre leg is common for all the cores, the sum of all three fluxes is carried by it. These fluxes induce an emf in primary winding based on the principle of transformer, an emf is induced in ~~r~~ its respective windings. The emf in secondary winding drives the currents to the load connected to it. In this way 3-ϕ transformer is ~~transform~~ transfer the 3-ϕ power.

Advatages of Three-phase transformer :-

1. Smaller and easier to install
2. Require less core material and it is more economical
3. Provides higher efficiency
4. Easier to transport, it's weight is relatively less
5. Protective device installation is easier
6. It require less space comparing with 1-ϕ transformer.
7. Efficiency is high

Dis advatages :-

1. Repairing cost is more
2. When it is self-cooled, it's capacity reduces.

Three-phase Transformer Connections :-

→ The windings of 3-ϕ transformers may be connected in Star (Y) or Delta (Δ) in the same manner of as three 1-ϕ transformers.

→ We have 4-ways of connections for 3-ϕ transforme

1. Star (Y) - Star(Y) connection (Y-Y).
2. Delta - Delta connection (Δ-Δ)
3. Star - Delta connection (Y-Δ)
4. Delta - Star connection (Δ-Y)

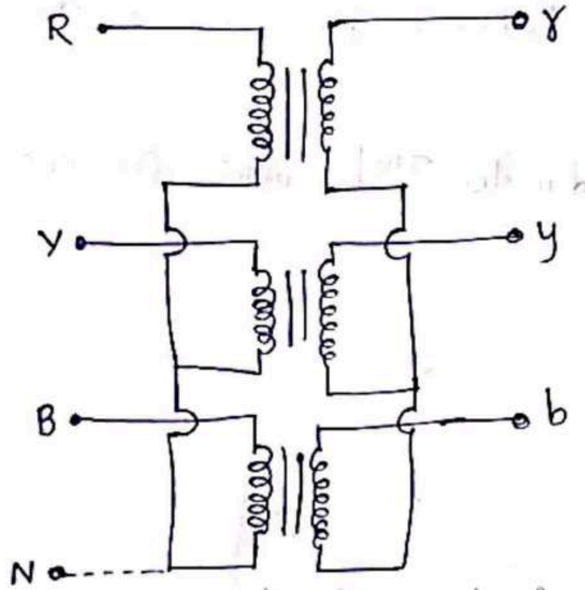
① Star-Star Connection (Y-Y) :-

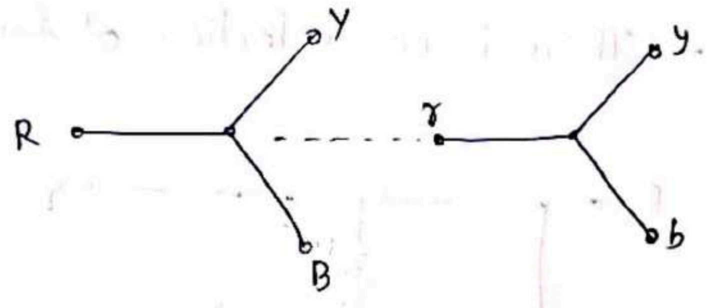
In this connection both the primary and secondary windings are connected in star, as shown below.

→ It gives line voltages $\sqrt{3}$ times phase voltage.

→ In this connection, there is no-phase angle difference between the line voltages of primary and secondary windings.

→ It is economical for small high voltage transformers as the number of turns per phase and the amount of insulation required is less.





0° angular displacement.

Advatages:-

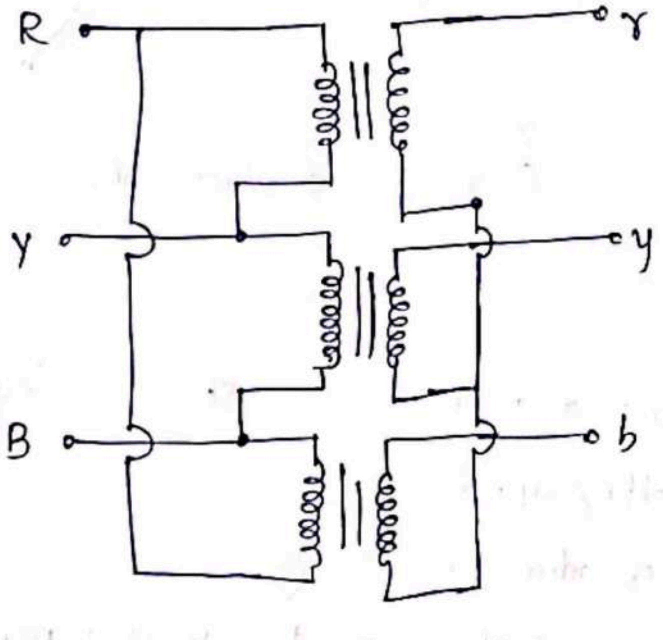
① Requires less number of turns and insulation stress is less.
2. Economical for medium-voltage applications
3. Mechanical strength of the windings is stronger
4. Can be used in 3-ϕ-4-wire system, as the neutral point is available.

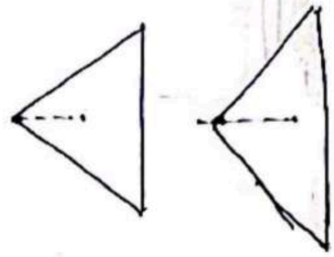
(iii) Disadvatages:-

1. If unbalanced load is connected, its performance is poor.
2. When an alternator is connected, then secondary voltage is having the third harmonic ~~present~~ distortion.

(2). Delta-Delta Connection (Δ-Δ)

→ The primary and secondary windings are connected in delt
→ The number of turns required per phase and the required insulation is more when compared to star-star connection.
→ It is used in "large transformers" for any type of load.
→ There is no-phase displacement between primary and secondary voltages
→ There is no-distortion of flux due to 3rd harmonic currents.





0° angular displacement.

Advatages:-

1. Unbalanced load can be used in this connection.

2) Less windings cross-section and hence it is economical for low voltage transformers

3. Continously supply can be provided, for a bank of three single phase transformers

Dis advatags :-

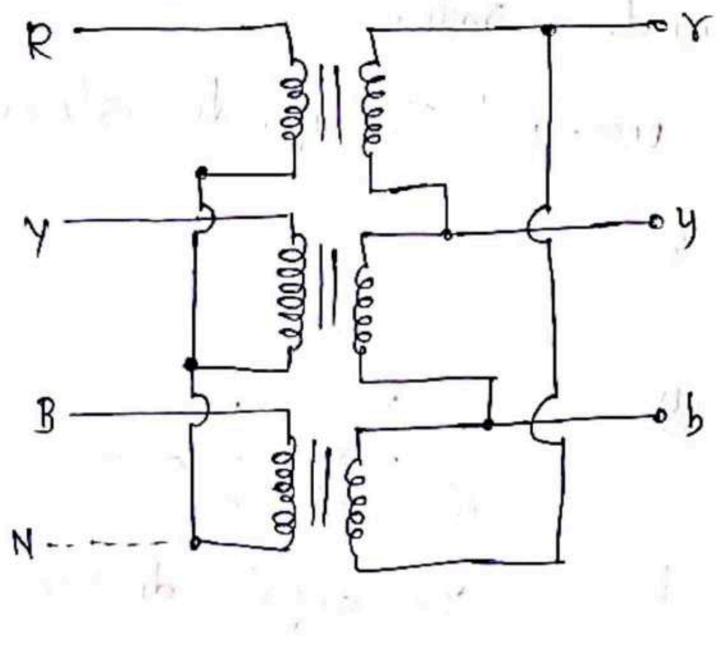
It is not suitable for a three-phase four-wire system due to the absence of neutral point.

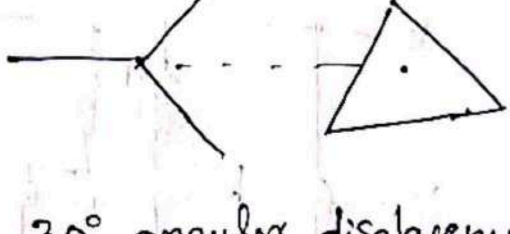
(3) Star-Delta connection :- (Y-Δ)

In this connection primary windings are connected in star with neutral grounded and secondary windings are connected in delta.

→ In this type, the ratio of primary to secondary line voltages is $\sqrt{3}$ times the transformation ratio.

→ This connection is used for "Step-down transformers".





30° angular displacement

Advatages!-

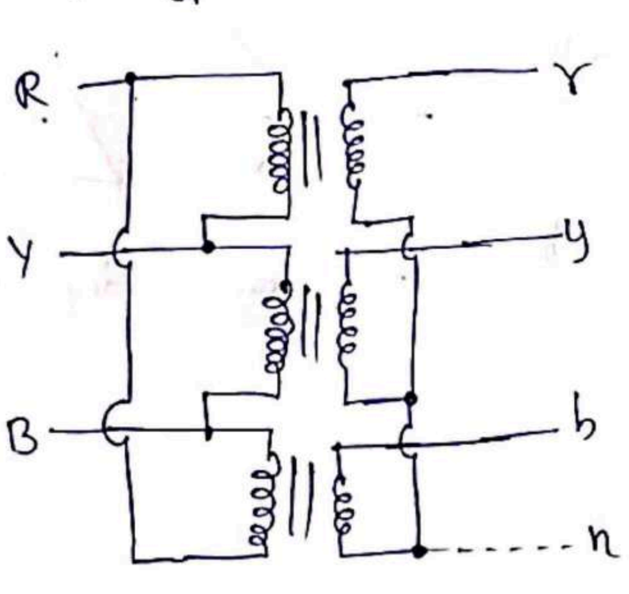
→ Requires less no.of turns
→ More economical for large and high voltage transformers
→ Distortion is avoided
→ Unbalanced load can be connected to the transformer

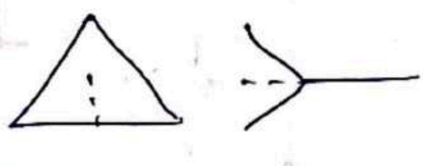
Disadvatages!-

→ A phase shift exists between the primary & secondary windi
→ It can't be used in parallel with Y-Y & Δ-Δ connection

(4) Delta-Star connection (Δ-Y).

→ In this connection, the primary windings are connected in delta and the secondary windings are connected in star with neutral ground.
→ In this type, the primary to secondary voltages is $\frac{1}{\sqrt{3}}$ times the transformation ratio.
→ This type connection used in "Step up-transformers".





30° angular displacement

Advatages :-

→ winding ~~cs~~ cross-section area is less in primary side due to delta connection.

→ No-distortion in system.

→ ~~It~~ ~~is~~ can be used in 3-ϕ, 4-wire power system.

→ Economical as cost is saved due to less insulation.

→ Unbalanced load can be connected.

Disadvatages :-

→ Phase shifts exists between primary and secondary voltages

→ It cannot be used in parallel with star-star (or) delta-delta connected transformer.

UNIT IV

ELECTRICAL MACHINES

UNIT-IV

Electrical Machines

DC-Machines:-

Two types — DC-Generator
— DC-Motor.

* DC-motors are classified into two types

① Separately excited DC-motor

② Self excited dc motor

(i) DC - series motor
(ii) DC - shunt motor
(iii) DC - compound motor

Construction of DC-Machine:-

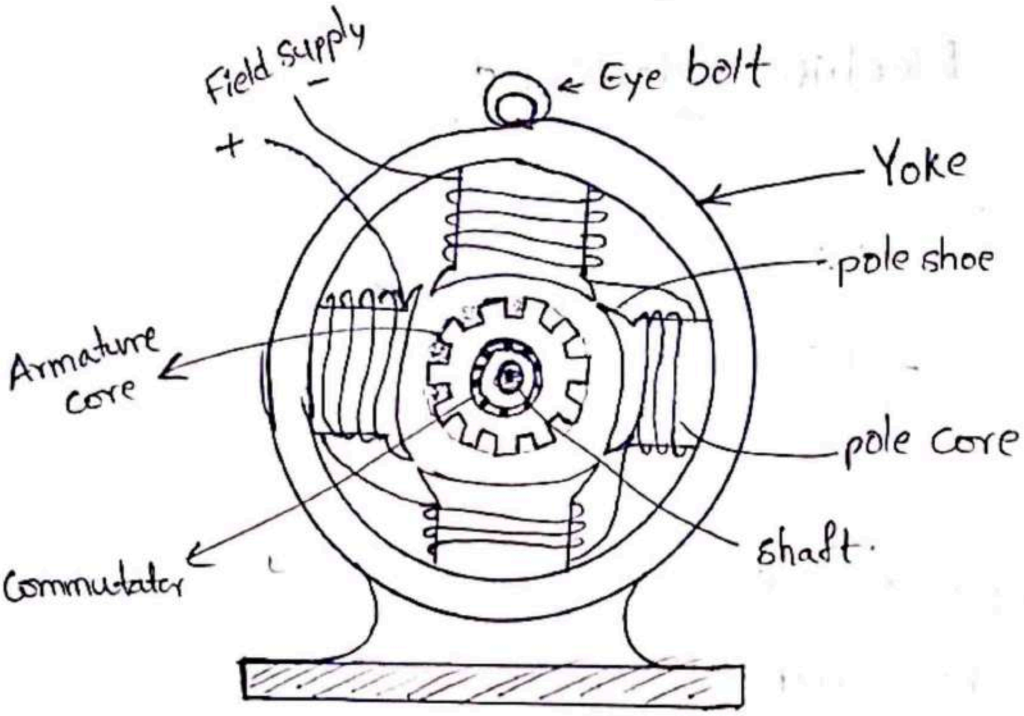
The construction for DC-motor and DC-generator is same, it consists of the following parts.

① Yoke on Magnetic frame

② Pole core and pole shoes

③. Field winding

4. Armature core and windings
5. Commutators
6. Brushes
7. Bearings
8. End covers
9. Shaft.



① Yoke (or) Magnetic frame :- It is outer frame of DC-machine. It provides the mechanical support to the poles core and pole shoes of machine. In large machines it is made up of cast steel and in small machines it is made up of cast iron. The important fuctions of this yoke is

→ It provides support to pole core and pole shoe.

→ It provides low reluctance path for the flux of field

→ It protects inner parts of the machine.

②. Pole core and pole shoes:-

The pole core and pole shoe's are fixed to the magnetic frame or Yoke with the help of bolts. The thin cast steel

~~on~~ iron with ~~on~~ without laminations is used to make pole core and pole shoes.

→ The pole core carries the field winding and pole shoe gives a particular shape to enlarges the area of armature core to come across fluxes.

3. Field winding :-

→ It is the exciting winding, which is placed on pole core to produce the required magnetic field. It always requires a relatively small DC-power to produce the required strong magnetic field. It is wound on all pole cores in a series connection.

4. Armature core and windings

The rotating component of the DC-motor is called "Armature" and it consists of a liminated cylinder called "Armature core" placed over the shaft.

→ Armature core is the drum (or) Cylindrical component fixed to the rotating shaft in a DC-motor.

→ it provides a place for conductor in slots

→ Provides a low reluctance path for the magnetic flux.

It is made up of "Silicon steel material

→ The armature windings ~~is~~ are the insulated conductors made up of steel wire are placed in the armature slots.

→ This armature windings are two types

(i) Lap winding

(ii) Wave winding.

⑤ Commutators :-

→ Commutator is a cylindrical - wedge shaped hard-drawn copper bars (or) segments, which rotates along with the armature. It performs particular functions

(i) It collects currents from armature conductors and also supplies current to them

(ii) It converts alternating current to direct current in generators

(iii) It converts direct current to alternating current in motors.

⑥. Brushes :-

It is set of carbon brushes attached to rotating armature via commutator, connecting the external circuit. The main purpose of brushes is to tap the electrical power generated in the rotating machine.

(7) Bearings :-
Fitting a high carbon steel ball on roller bearings in the machine to make machine smooth rotation and reducing frictional losses.

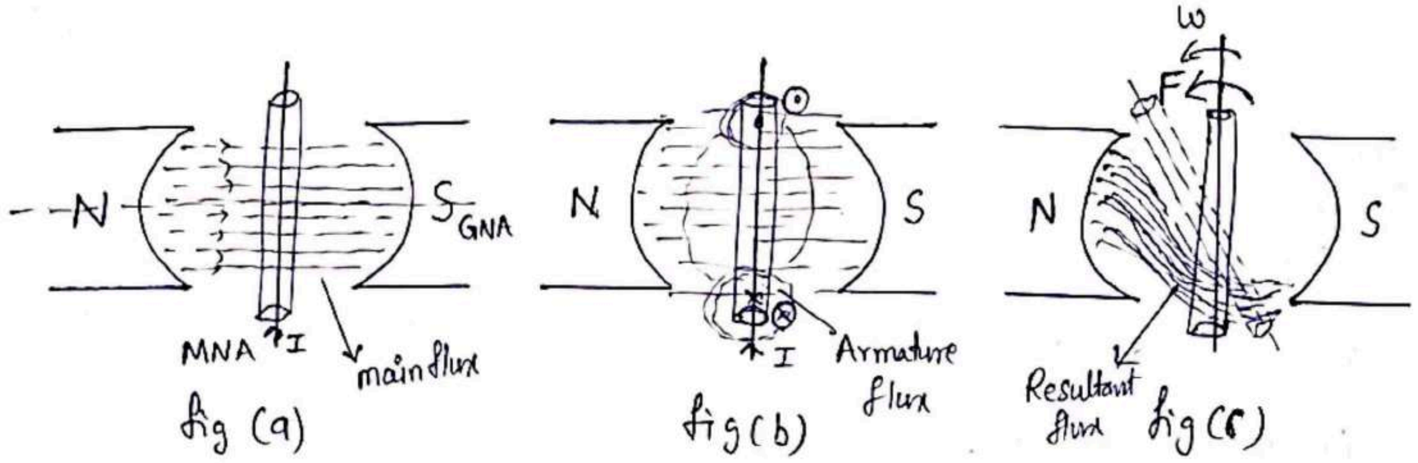
(8). End covers :- It is compunents attached to the yoke ends and which provide support to the bearings is called "end covers.

(9) Shaft :- It is madeup of a mild steel which is having maximum breaking strength. It is transfers mechanical power to mechanical loads.

Working principle of DC-~~machine~~ motor

Motor works on Lorentz principle, it states that" whenever current carrying conductor placed in a magnetic field it experiences mechanical force (i.e torque), then it starts to rotates.

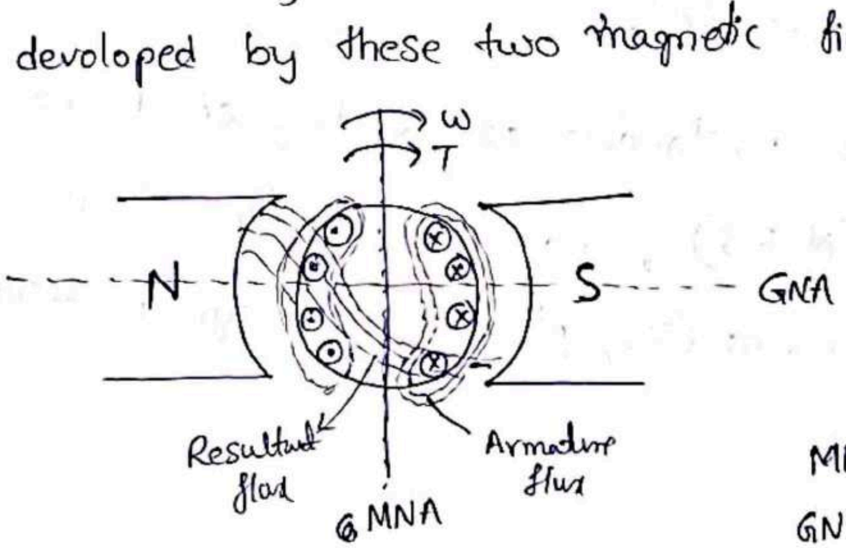
For understanding of working of dc-motor, consider a 2-poles (N & S), and a conductor which is carrying ~~condu~~ the current (I), placed in a magnetic field as shown below.



When the field windings wound on the poles are excited by a dc-source, the poles get magnetized and a strong magnetic field is produced. In that field, if conductor is placed, it creates the own magnetic field i.e weak magnetic field. Here due to the interaction between these two fields resultant field is produced as shown in fig(C).

The resultant field causes rotation of armature conduction, the direction of conductor can be found by Flemming Left Hand Rule (FLHR).

The working of DC-motor can be explained by DC-motor mmf devoloped by these two magnetic fields as shown



MNA → magnetic Neutral axis
GNA → Geometrical neutral axis

As shown above figure, if the DC-motor having 'z' no.of conductors and produces resultant flux, it causes "mmf" i.e resultant mmf, which developes resultant force (F_r), which ratates the armature conductors.

The electromagnetic torque developed in the armatur conductors will be continouous if the direction of current in each conductor (or) coil side changes when i crosses the magnetic neutral axis (MNA). This reversal of direction of current can be achieved busing a commutator and it helps in developing a continuous torque.

** Back Emf in a DC-Motor

When a DC-source is used to excite the armature conductor, which is placed in the main magnetic field, a electromagnetic torque is developed, then DC-motor starts rotating. Due to the rotation of armature, the armature conductors cut the magnetic flux of the main magnetic field, hence an emf induced in armature conductors. This emf opposes the cause

produces, this induced emf known as "Back emf (E_b)".
This emf is induced in the armature due to the generator action, its magnitude is given by the same ~~as~~ expression as that of the generated emf in a DC-generator, i.e

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

where
ϕ = magnetic flux
Z = Total no. of conductors
N = Speed of motor
P = No. of poles
A = No. of parallel paths
if $A = P$ for lap winding
$A = 2$ for wave winding.

Equivalent circuit of DC-Motor

The equivalent circuit of a DC-motor armature is shown as

In a DC-motor, the current flows from the line into the against the voltage generated in the armature, using KVL in circuit, then

$$V = E_b + I_a R_a + V_b$$

If the drop across the brushes is negligible, we get

$$V = E_b + I_a R_a$$

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

Multiplying with 'I_a', then

$$V I_a = E_b I_a + I_a^2 R_a$$

where $P_i = V I_a \rightarrow$ input power

$P_m = E_b I_a \rightarrow$ Mechanical power

$P_c = I_a^2 R_a \rightarrow$ copper loss in the armature.

Characteristics of separately excited DC-motor

We have different types of characteristics

- → Torque (T_a) and Armature current (I_a)
- → Speed (N) and Armature Current (I_a)

} Electrical characteristics

- → Torque (T_a) and Speed (N) → Mechanical characteristics.

We have the relations

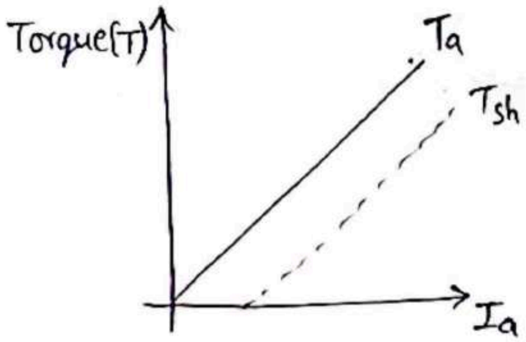
Torque $T = 9.55 \times \dfrac{E_b I_a}{N} \rightarrow T \propto I_a$

and $E_b = \dfrac{\phi Z N P}{60 A} \rightarrow T \propto \dfrac{1}{N}$

& $N \propto \dfrac{V - I_a R_a}{\phi} \Rightarrow N \propto \dfrac{1}{I_a}$

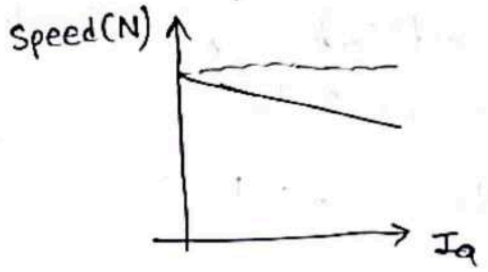
(i) T Vs I_a characterstics:-

Since the field winding in a DC-motor is excited by the constant supply voltage 'V', the current through the field winding I_{sh} constant, w.r.to that torque constant with change the constant armature current 'I_a'



(ii) N Vs I_a Characterstics:-

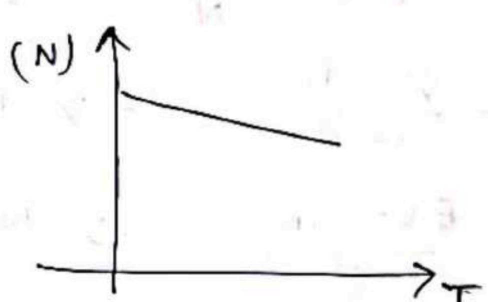
We know that $N \propto E_b$, so $N \propto V - I_aR_a$, when I_a increases, then 'I_aR_a' drop increases, then automatically speed decreases, so



drooping characterstics.

(iii) T Vs N characterstics:- From the torque equation

$T \propto \frac{1}{N}$, so that



Speed control of DC-motors

The speed equation of a DC-motor is given by

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

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

→ The speed control of DC-shunt motors, we have the methods

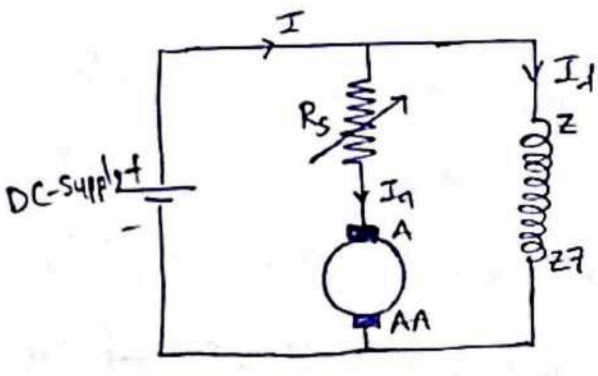
(a) Armature Resistance control method

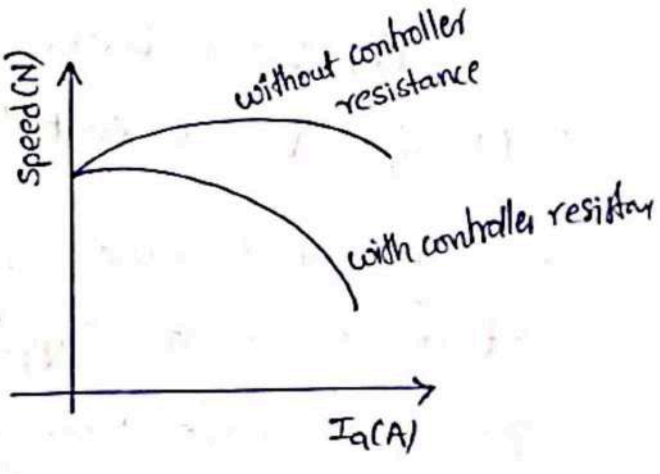
(b) Flux control method

(c) Applied Voltage method

(a) Armature Resistance control method :-

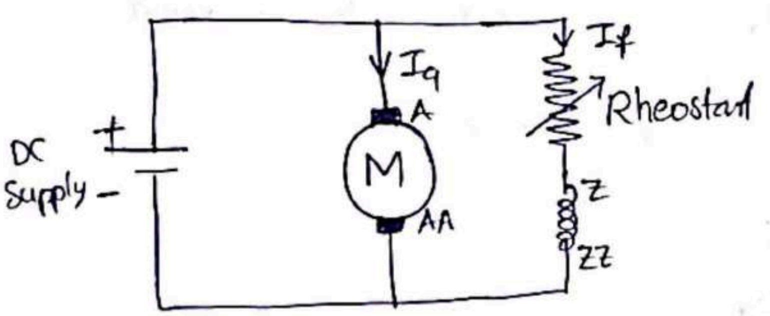
In this method, connecting a series resistance (R_s) to the motor, we can control speed of DC-shunt motor, as shown in fig.

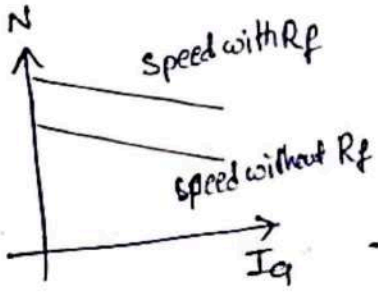


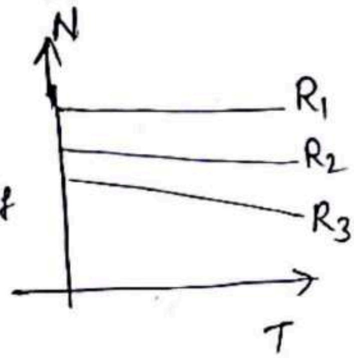


We know that $N \propto (V - I_a R_a)$, from this $N \propto \frac{1}{R_a}$, when R_a increases, then I_a decreases, w.r.to that speed will be reduces.

(b) Flux control method :- This method is used to control of the speed of a DC-shunt motor, above the rated speed, by reducing the field flux, since $N \propto \frac{1}{\phi}$. In this method a variable resistance element called " shunt field rheostart is connected in series with shunt field winding, as shown in fig







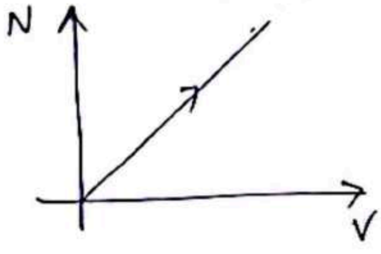
(c). Applied voltage control method :-

We have two different voltage control methods as

(i) Multiple voltage control

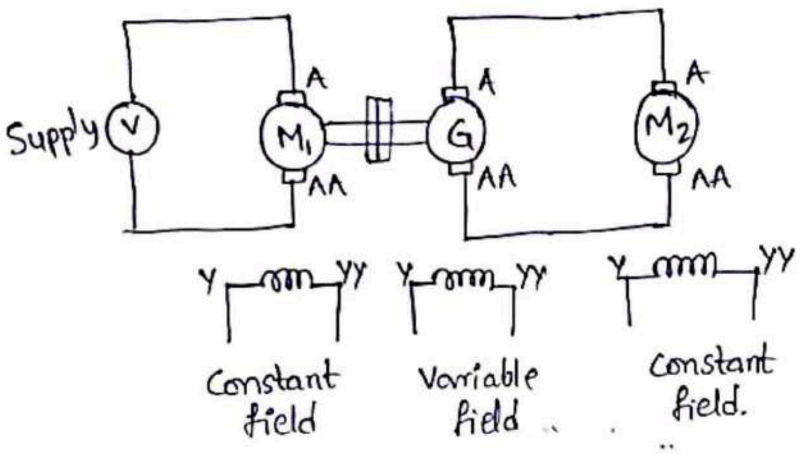
(ii) Ward-Leonard System.

(i) Multiple Voltage Control :- In this method, a suitable arrangement is made in such away that the field winding gets a constant supply voltage and armature winding gets a variable voltage. The different voltages that can be used for exciting armature winding are obtained using a switch-gear. We know that $N \propto V$, so



(ii) Ward - Leonard System :-

The arrangement of ward-leonard system to control the speed of a DC-Shunt motor is shown in figure below.



In this method, M_2 DC-Shunt motor speed has to be controlled, M_1 can be either AC (or) DC-motor with constant speed which is coupled directly to generator "G".

The output of G_1 is fed as the input to the armature of motor M_2. The field winding of M_2 is given by a constant DC-Supply voltage. Therefore, varying the generator output can vary the supply voltage applied to armature of M_2. The generator output can be varied using a field regulator. Smooth controlling can be possible by using this method.

Construction of three phase Induction motor:-

4-①

* The three phase induction motor consists of two main parts, namely.

1) The part carrying three phase windings, which is stationary called stator.

2) The part which rotates and is connected to the mechanical load through shaft called rotor.

1. Stator:- The stator has a laminated type of construction made up of stampings which are 0.4 to 0.5mm thick.

* The stampings are slotted on its periphery to carry the stator winding. The stampings are insulated from each other. Such a construction essentially keeps the iron losses to a minimum value.
* The number of stampings are stamped together to build the stator core.
* The slots on the periphery of the stator core carries a three phase winding, connected either in star or delta. This three phase winding is called stator winding. It is wound for definite number of poles.
* The radial duts are provided for the cooling purpose. The Fig Q. 35.1 shows a stator lamination.

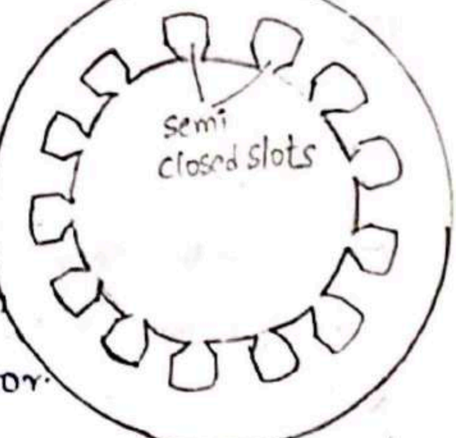


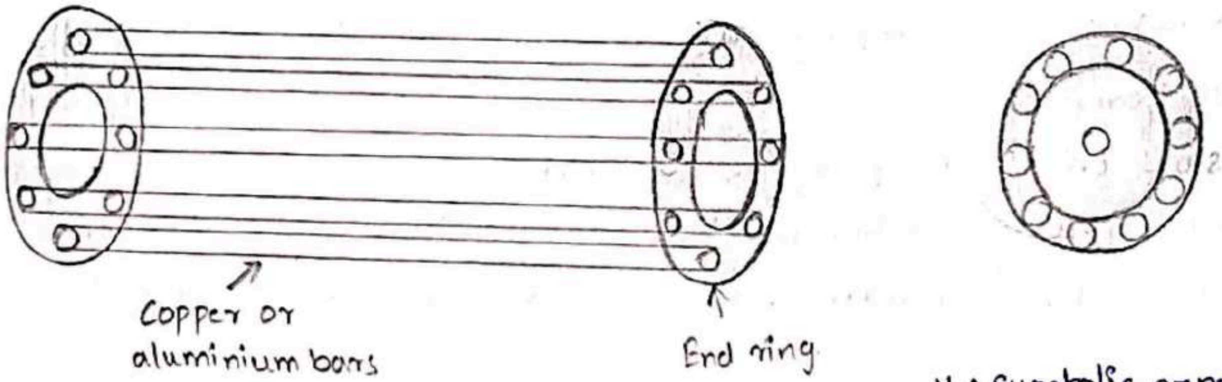
Fig. Q.35.1 Stator lamination

2) Rotor:- The rotor is placed inside the stator.

* The air gap between stator and the rotor is 0.4mm to 4mm.
* The two types of rotor constructions which are used for induction motor are, a. squirrel cage rotor and b. slip ring or phase wound rotor.

a) Squirrel cage rotor:-

* The rotor core is cylindrical and slotted on its periphery.
* The rotor consists of uninsulated copper (or) aluminium bars called rotor conductors. The bars are placed in the slots.
* These bars are permanently shorted at each end with the help of conducting copper ring called end ring. The bars are usually brazed to the end rings to provide good mechanical strength.
* The entire structure looks like a cage, forming a closed electrical circuit. so the rotor is called squirrel cage rotor The construction is shown in the Fig. Q.35.2.



(b) Symbolic representation

(a) Cage type structure of rotor

b) Slip Ring Rotor (or) phase wound Rotor:-

* In this type of construction, rotor winding is exactly similar to the stator.
* The rotor carries a three phase star (or) delta connected, distributed winding, wound for same number of poles as that of stator.
* The rotor construction is laminated and slotted, The slots contain the rotor winding.
* The three ends of three phase winding, available after connecting the winding in star (or) delta, are permanently connected to the slip rings.
* with the helps of slip rings, the external resistances can be added in series with each phase of the rotor winding. This

arrangement is shown in the Fig Q.35.3

4-②

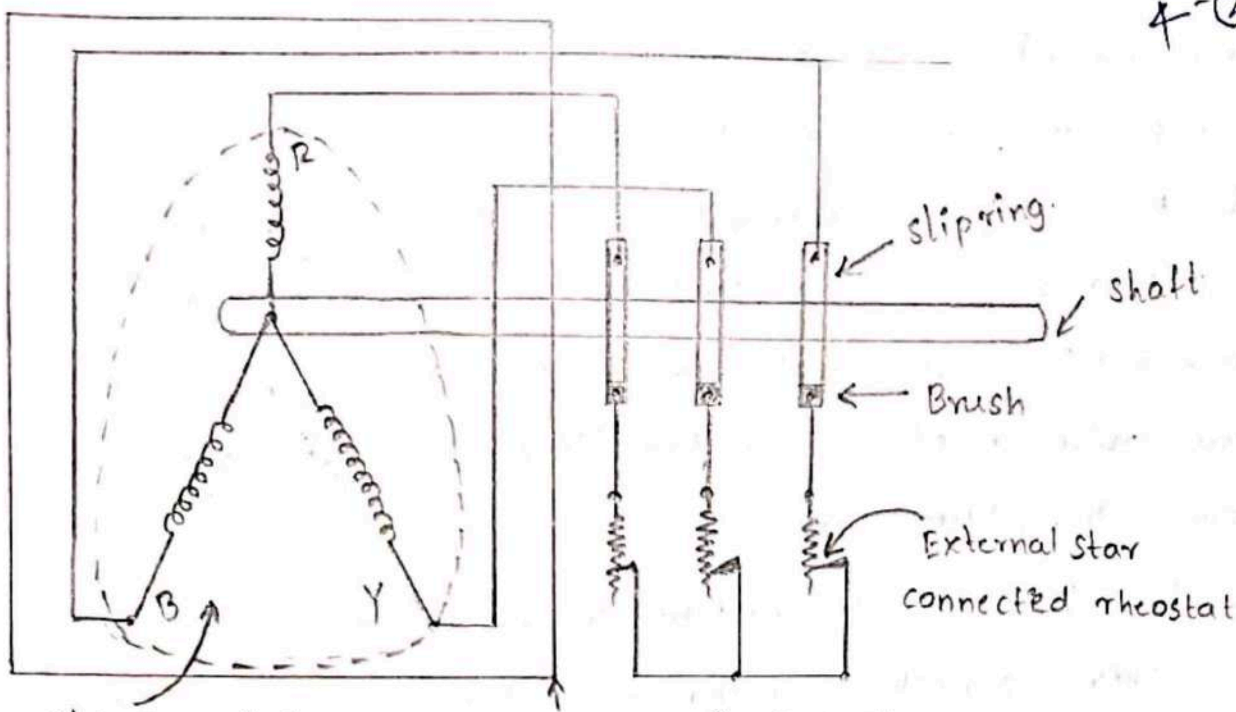


Fig. Q.35.3 Slip rings or wound rotor.

* In the running condition, the slip rings are shorted.

Working principle of three phase induction motor:-

Induction motor works on the principle of electromagnetic Induction.

* When a three phase supply is given to the three phase stator winding, a rotating magnetic field of constant magnitude is produced. The speed of this rotating magnetic field is synchronous speed, N_s r.p.m.

$N_s = \frac{120f}{P}$ = speed of rotating magnetic field.

* This rotating field produces an effect of rotating poles around a rotor.
* At this instant rotor is stationary and stator flux R.M.F. is rotating. so its obvious that there exists a relative motion between the R.M.F and rotor conductors.
* Whenever conductor cuts of flux, e.m.f gets induced in it. So e.m.f gets induced in the rotor conductors called rotor induced e.m.f
* As rotor forms closed circuit, induced e.m.f circulates through

rotor called rotor current

* Any current carrying conductor produces its own flux. so rotor produces its flux called rotor flux.

* The two fluxes, stator flux and the rotor flux interact with each other such that on one side of rotor conductor, two fluxes are in same direction hence add up to get high flux area while on other side, two fluxes cancel each other to produce low flux area

* As flux lines act as stretched rubber band, high flux density area exerts a push on rotor conductor toward low flux density area. so rotor conductor experiences a forces due to interaction of the two fluxes.

* As all the rotor conductors experiences a force, the overall rotor experiences a torque and starts rotating.

* According to Lenz's law the direction of induced current in the rotor is so as to oppose the cause producing it.

* The cause of rotor current is the induced e.m.f. which is induced because of relative motion present between the rotating magnetic field and the rotor conductors.

* Hence to oppose the relative motion i.e, to reduce the relative speed, the rotor experiences a torque in the same direction as that of R.M.F. and tries to catch up the speed to rotating magnetic field.

Slip of Induction motor:-

The differentebetween the speed of rotating magnetic field and the actual rotor speed is called slip speed i.e. $N_S - N$ = slip speed of the motor.

$$\boxed{\therefore \text{ slip speed} = N_S - N}$$

* slip of the induction motor is defined as the difference between the synchronous speed (N_S) and actual speed of rotor i.e. motor (N) expressed as a fraction of the synchronous speed (N_S). This is also called absolute slip (or) fractional slip and is denoted as 's'.

Thus, $$\boxed{\text{slip, } S = \frac{N_S - N}{N_S} \quad \text{and } \% \ S = \frac{N_S - N}{N_S} \times 100}$$

Torque equation of three phase inductor motor:-

The torque developed by the rotor is directly proportional to

i, rotor current

ii, rotor E.m.f

iii, power factor of the rotor circuit

$$T \propto E_2 I_2 \cos\phi_2$$

Rotor current $I_2 = \frac{SE_2}{Z_2} = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$

$\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$; $T = \frac{KSE_2^2 R_2}{R_2^2 + (SX_2)^2}$

Starting Torque i.e. at $S = 1$ (slip)

$SE_2 = E_2$, $SX_2 = X_2$

So starting Torque is given by

$$T_S = KE_2 I_2 \cos\phi_2$$

$$T_S = K E_2 \times \frac{E_2}{\sqrt{R_2^2 + X_2^2}} \times \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$$

$$T_S = \frac{kE_2^2 R_2}{(R_2^2 + X_2^2)}$$

Generally, the startor supply voltage is constant (V), so that flux set up by the stator also fixed, This in turn means that the Emf induced in the Rotor will be constant, so.

$$T_S = \frac{K_1 R_2}{(R_2^2 + X_2^2)}$$

$$T_S = \frac{K_1 R_2}{Z_2^2} \quad (\because K_1 = kE_2^2)$$

Condition for maximum starting Torque :-

Torque Equation is

$$T_S = \frac{K_1 R_2}{(R_2^2 + X_2^2)} \quad \text{——} (1)$$

Differentiating (1) w.R.T R_2 and Equate to zero

$$\frac{dT_S}{dR_2} = 0$$

$$\text{So} \Rightarrow \quad K_1 \left[\frac{(R_2^2 + X_2^2) - R_2(2R_2)}{(R_2^2 + X_2^2)^2} \right] = 0$$

$$R_2^2 + X_2^2 - 2R_2^2 = 0$$

$$R_2^2 + X_2^2 = 2R_2^2$$

$$R_2^{\cancel{2}} = X_2^{\cancel{2}}$$

$$\boxed{R_2 = X_2}$$

→ This is the condition for maximum starting Torque

Hence, the starting Torque will be maximum

when Rotor Resistance / phase = Stand still Rotor Reactance

Torque -slip characteristics:-

The torque slip characteristics are divided mainly into Three region

i, Low slip Region i.e, Lightly Loaded conditions:-

Here Rotor speed (N_r) is almost Equal to synchronous speed of Rotating magnetic field (N_s)

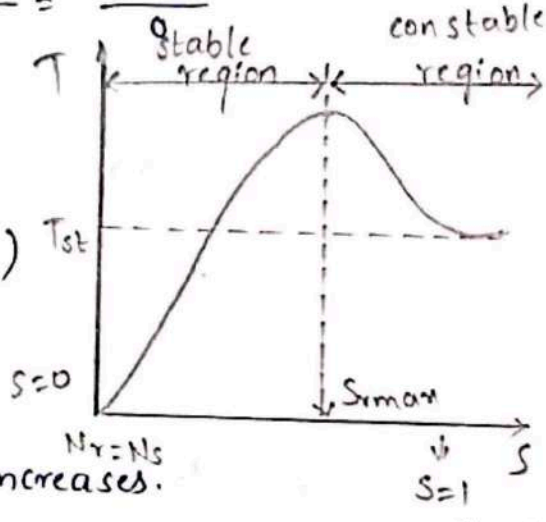
$N_r \simeq N_s$, so slip $s = \frac{N_s - N_r}{N_s} = \frac{N_s - N_s}{}$

$s = 0$

So, $sx_2^2 << R_2^2$

$T_s = \frac{KSE^2R_2}{R_2^2 + (sx_2)^2}$ $(sx_2 << R_2)$

So $\boxed{T_s \propto s}$



Torque varies Linearly with slip increases.

ii, Medium slip:- In this Region Torque attain a maximum value i.e at $R_2 = x_2$

iii, High slip Region:- (i.e motor is fully Loaded)

$N_r < N_s$, The slip value increases (0-1)

so $(sx_{20})^2 >> R_2^2$, from Torque Equation

$\boxed{T \propto 1/s}$ → Torque varies Non-Linear i.e decreases with increases in slip(s)

Application of I.M:-

i, Squirrel cage Induction motors have "moderate starting Torque" and constant speed characterstics preferred for Driving fans, water pumps, grinders, Lalte machines, printing machines, drilling machines.

ii, slip ring Induction motors have "high starting Torque, hence they are preferred for Lifts, hoists, elevators, cranes, compressors,

Applications of three phase Induction motor:-

i, Squirrel cage type of motors having moderate starting torque and constant speed characteristics preferred for driving fans, blowers, water pumps, grinders, lathe machines, printing machines, drilling machine.

ii, slip ring induction motors can have high starting torque as high as maximum torque. Hence they are preferred for lifts, hoists, elavators, cranes, compressors.

Losses in three phase:-

The various losses taking place in three phase induction motor are,

1) Stater losses:- These include copper losses and iron losses.

2) Roter losses:- In running copper condition, rotor frequency is very small hence iron losses are negligible. Hence only rotor copper losses are considered.

3) Mechanical losses:- These include friction and windage losses.

$$\boxed{\therefore \quad P_{out} = P_m - \text{Mechanical losses}}$$

Types of Single phase Induction motors:-

Name the starting methods for single phase Induction motors.

Depending upon the methods of producing rotating stator magnetic flux, the single phase induction motors are classified as,

1) split phase induction motor.

2) capacitor start induction motor.

3) Capacitor start capacitor run induction motor.

4) Shaded pole induction motor.

~~Slip~~ Split phase Induction motor:-

This type of motor has single phase stator winding called main winding. In addition to this, stator carries one more winding called auxiliary winding (or) starting winding.

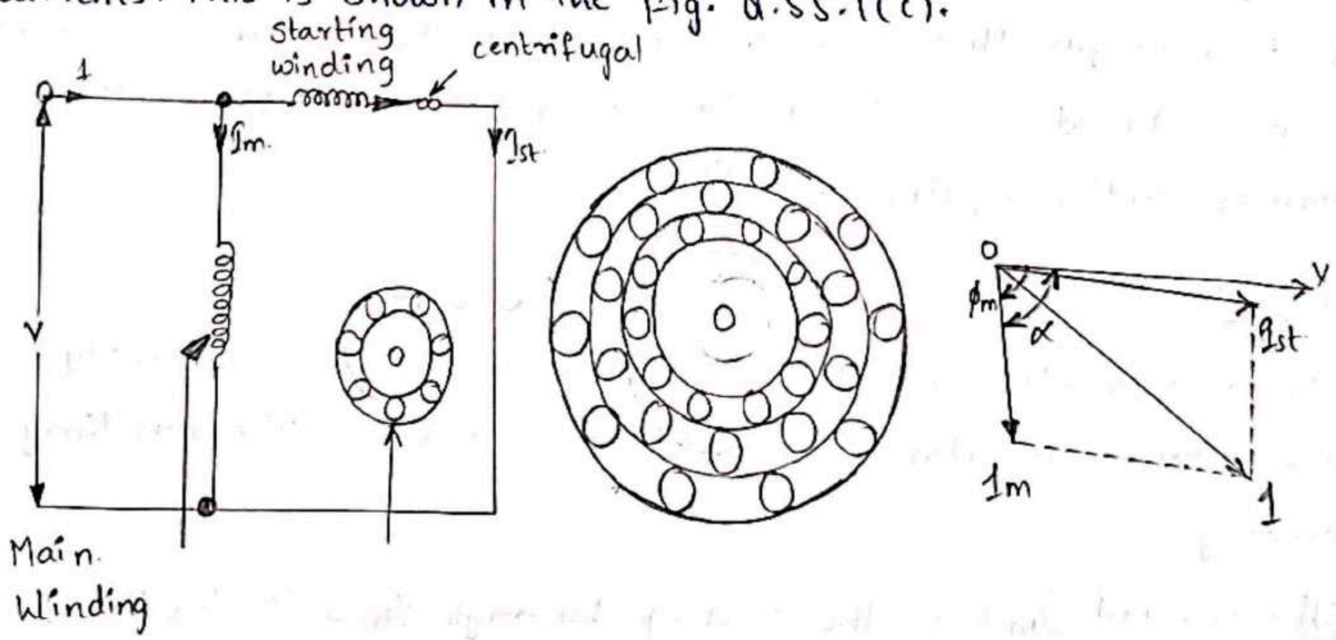
* The auxiliary winding carries a series resistance such that its impedance is highly resistive in nature. The main winding is inductive in nature.

Let I_m = current through main winding.

and I_{st} = current through auxiliary winding.

* As main winding is inductive, current I_m lags voltages V by a large angle ϕ_m while I_{st} is almost in phase in V as auxiliary winding is highly resistive.

* Thus there exists a phase difference of α between the two currents and hence between the two fluxes produced by the two currents. This is shown in the Fig. Q.55.1(c).



(a) Circuit diagram (b) Representation (c) phasor diagram

* The resulant of these two fluxes is a rotating magnetic field. Due to this, the starting torque which acts only in one direction is produced to make the motor self starting.

* The auxiliary winding has a centifugal switch in series with it when motor gathers a speed upto 75 to 80%. of the synchronous speed, centifugal switch gets opened mechanically and in running condition auxiliarly winding remains out of the circuit. so motor runs only on stator winding.

* The torque-speed characteristics of split phase motor is shown in the Fig. Q.55.2.

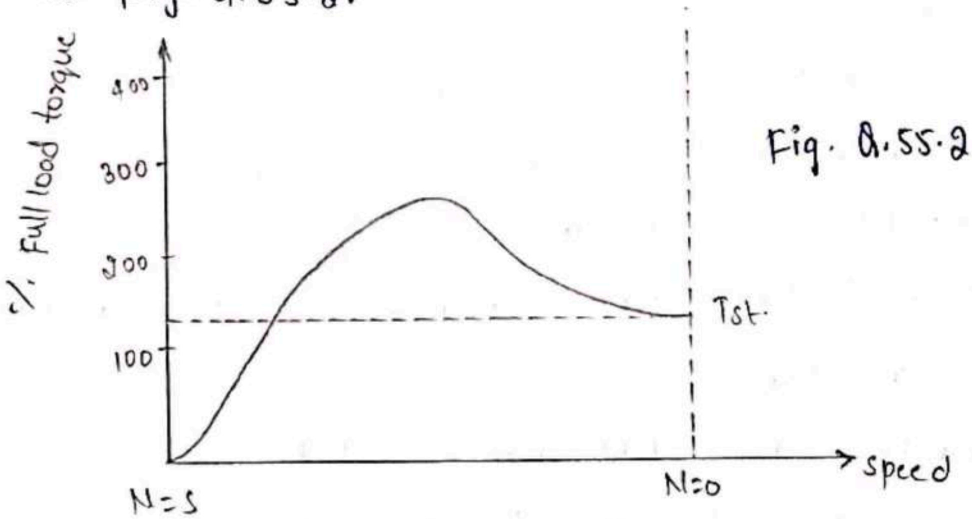


Fig. Q.55.2

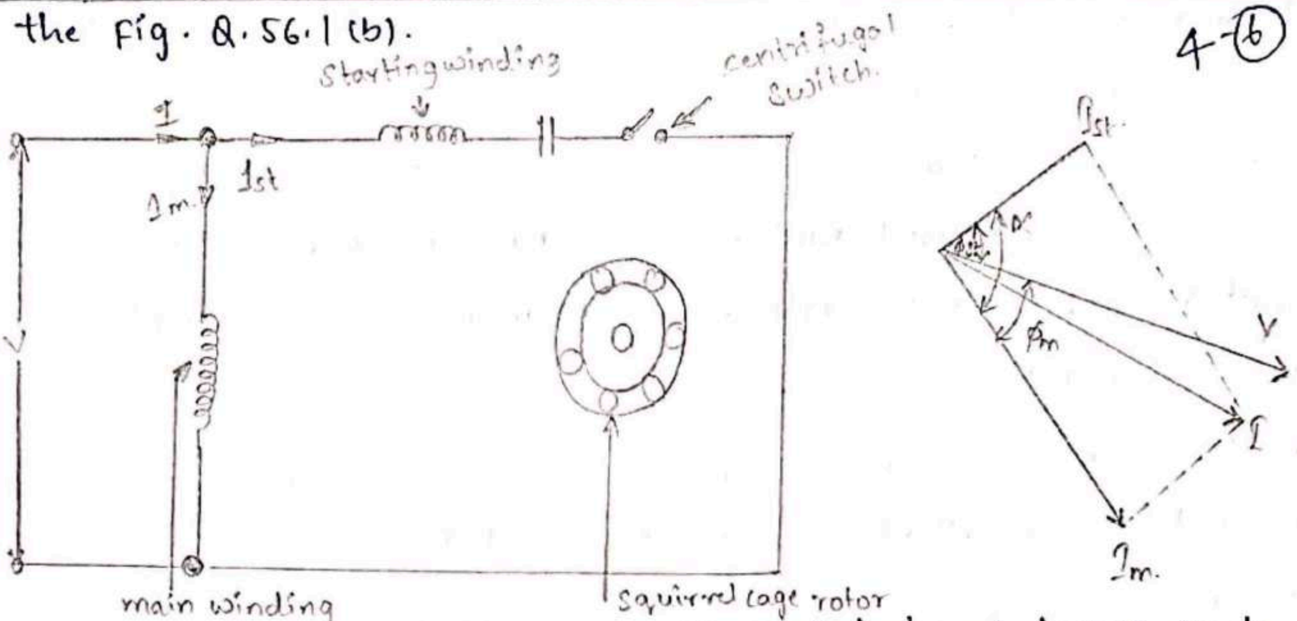
Applications:- These motors have low starting current and moderate starting torque. These are used for easily started loads like fans, blowers, grinders, centrifugal pumps, washing machines, oil burners, office equipments etc.

Capacitor start single phase induction motor:-

* The construction of capacitor start motor is shown in Fig Q.56.1 (a) A capacitor is connected in series with the auxiliary winding.

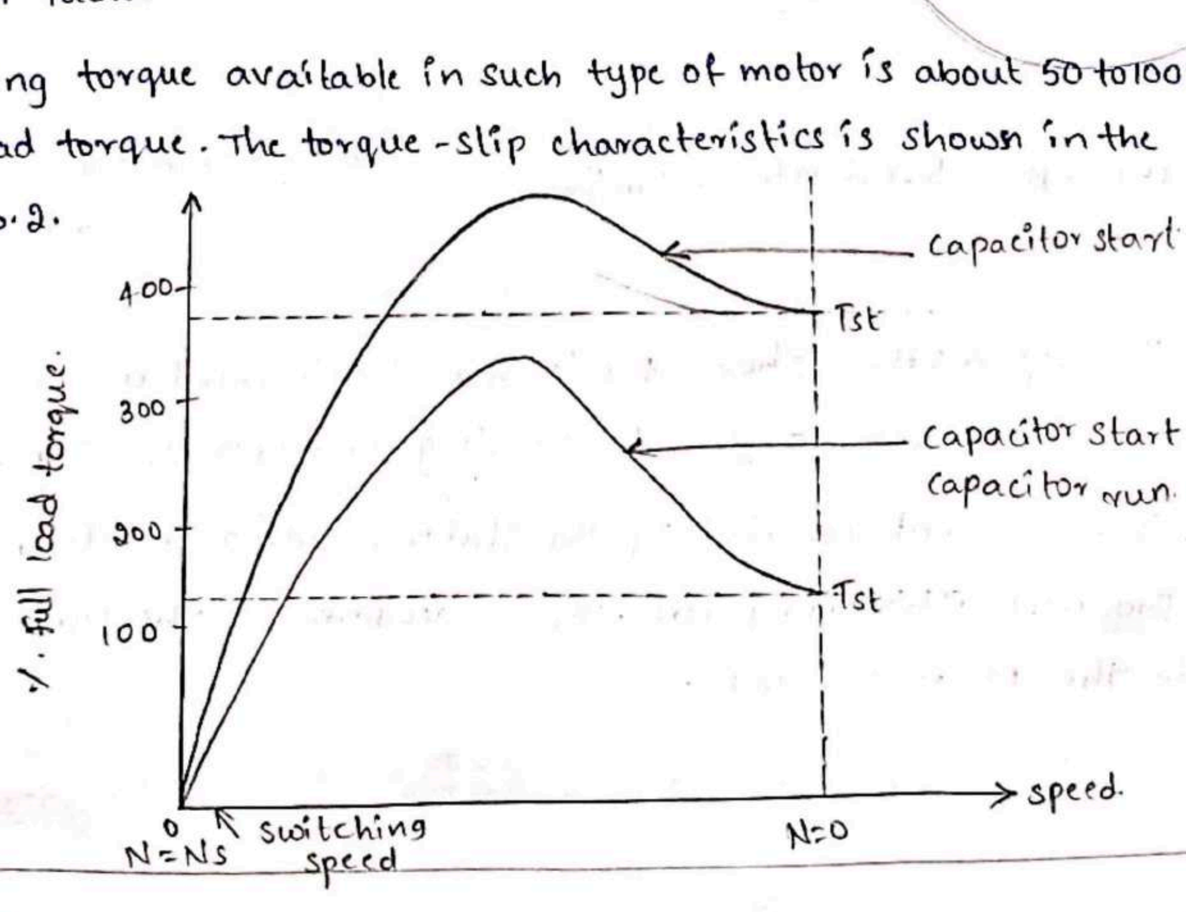
* The current I_m lags the voltage by angle ϕ_m while due to capacitor the current I_{st} leads the voltage by angle ϕ_{st}. Hence there exists a large phase difference between the two currents which is almost 90°, which is an ideal case. The phasor diagram is shown

in the Fig. Q.56.1 (b).



* The starting torque is ~~por~~ porportional to 'α' and hence such motors produce very high starting torque.
* When speed approaches to 75 to 80% of the synchronous speed, the starting winding gets disconnected due to operation of the centrifugal switch. The capacitor remains in the circuit only at start hence it is called capacitor start motors.
* In case of capacitor start capacitor run motor, there is no centrifugal switch and capacitor remain parmenently in the circuit. This improves the power factor.

The starting torque available in such type of motor is about 50 to 100% of full load torque. The torque-slip characteristics is shown in the Fig. Q.56.2.

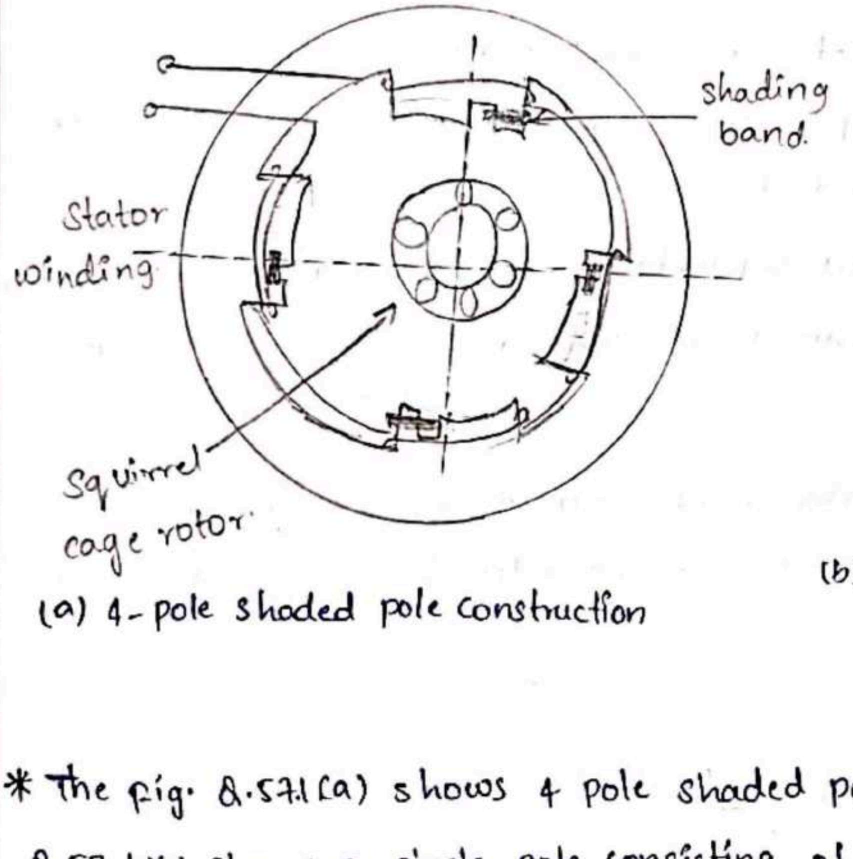


Applications:- These motors have high starting torque and hence are used for hard starting loads. These are used for compressors, conveyors, grinders, fans, blowers, refrigerators, air conditions etc. These are most commonly used motors. The capacitors start capacitor run motors are used in ceiling fans, blowers and air-circulators.

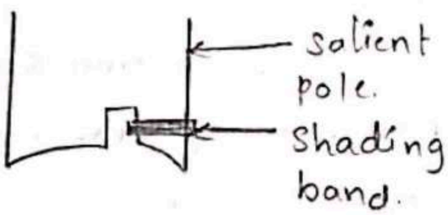
Shaded pole:-

* This type of motor consists of a squirrel cage rotor and stator consisting of salient poles i.e. projected poles.

The poles are shaded i.e. each pole carries a copper band on one of its unequally divided part called shading band.

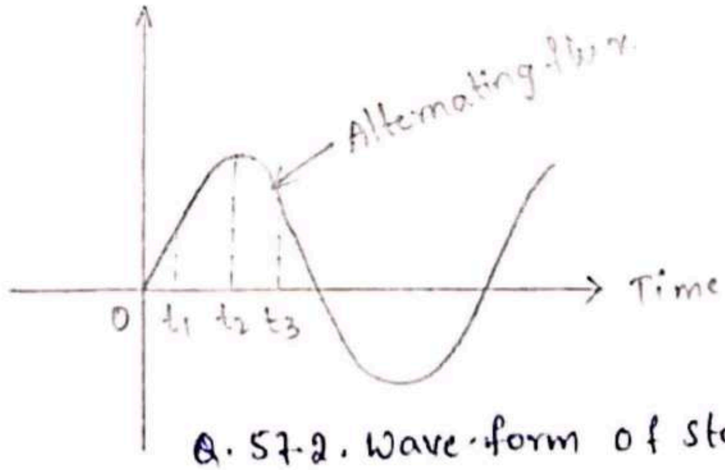


(a) 4-pole shaded pole construction



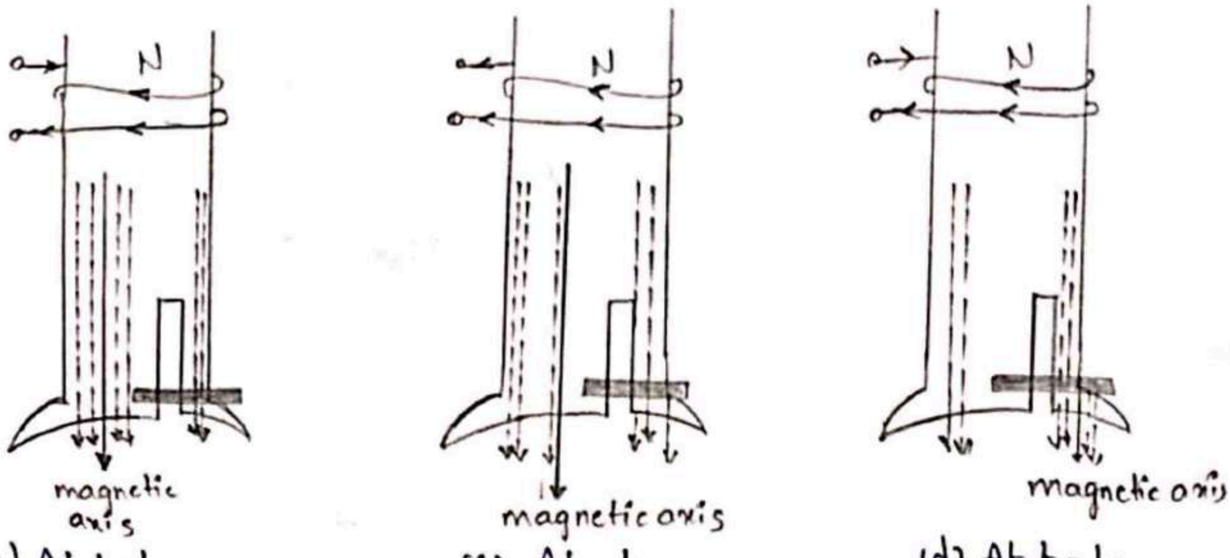
(b) Salient pole with shading band.

* The fig. Q.57.1(a) shows 4 pole shaded pole construction while Fig. Q 57.1(b) shows a single pole consisting of copper shading band.
* The current carried by the stator winding is alternating and produces alternating flux. The wave form of the flux is shown in the Fig. Q.57.2(a)



Q. 57.2. Wave form of stator flux.

* At instant $t = t_1$, rate of rise of current and hence the flux is very high. Due to the transformer action, large e.m.f gets induced in the copper shading band. This circulates current through shading band as it is short circuited, producing its own flux. According to Lenz's law, the direction of its current is so as to oppose the cause i.e, rise in current. Hence there is crowding of flux in nonshaded part while weakening of flux in shaded part, overall magnetic axis shifts in nonshaded part as shown in the fig Q.57.2(b)
* At instant $t = t_2$, rate of rise of current and hence the rate of change of flux is almost zero. Hence there is very little induced e.m.f in the shading ring. Hence the shading ring flux is also negligible. Hence the main flux distribution is uniform and magnetic axis lies at the centre of the pole face as shown in fig. Q.57.2(c)
* The torque speed characteristics is shown in the fig. Q.57.3.



(b) At $t = t_1$ (c) At $= t_2$ (d) At $t = t_3$

Applications:-

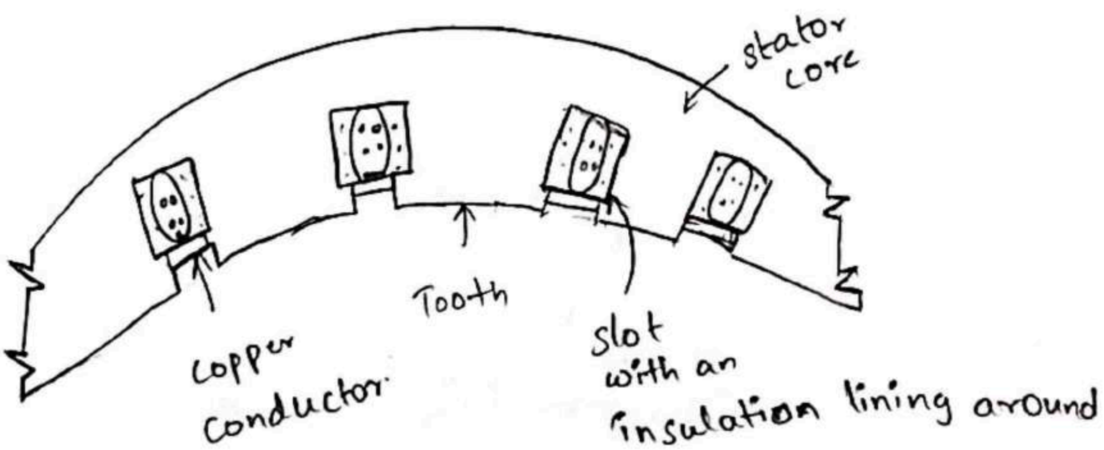
* These motors are cheap but have very low starting torque, low power factor and low efficiency. These motors are commonly used for the small fans, toy motors, advertising displays,. film projections, record players, gramophones, hair dryers, photocopying machines etc...

Construction of synchronous generator:-

* In synchronous generators i.e, alternators the stationary winding is called 'stator' while the rotating winding is called 'Rotor'.

1) Stator:- The stator is a stationary armature. This consits of a core and the slots to hold the armature winding.

* The stator core uses a laminated construction. It is built up of special steel stampings insulated from each other with varnish (or) paper. The laminated construction is basically to keep down eddy current looses.
* The entire core is fabricated in a frame made of steel plates. The core has slots on its periphery for housing the armature conductors.
* ventilation is maintained with the help of holes casted in the frame
* The section of an alternator stator is shown in the Fig. Q.61.1.

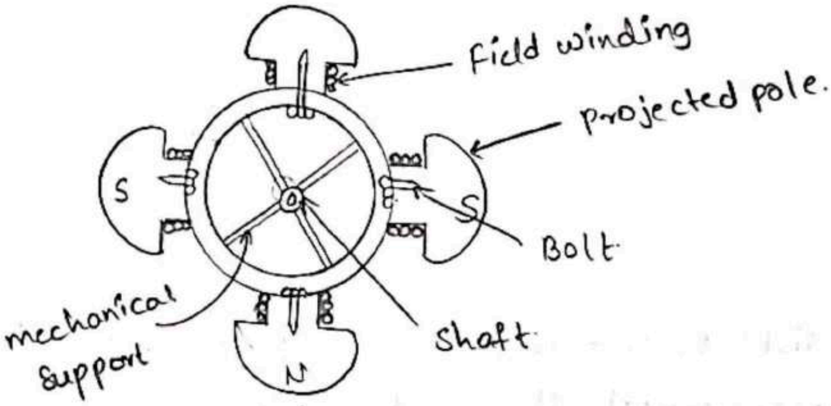


2) Rotor :- There are two type of rotors used in alternators, 4-(8)

i, Salient pole are projected pole type :-

* This is also called projected pole type as all the poles are projected out from the surfaces of the rotor.

* The poles are built up of thick steel laminations. The poles are bolted to the rotor as shown in the Fig. Q.61.2



* The pole face has been given a specific shape as discussed earlier in case of d.c. generators. The field winding is provided on the pole shoe.

* These rotors have large diameters and small axial lengths.

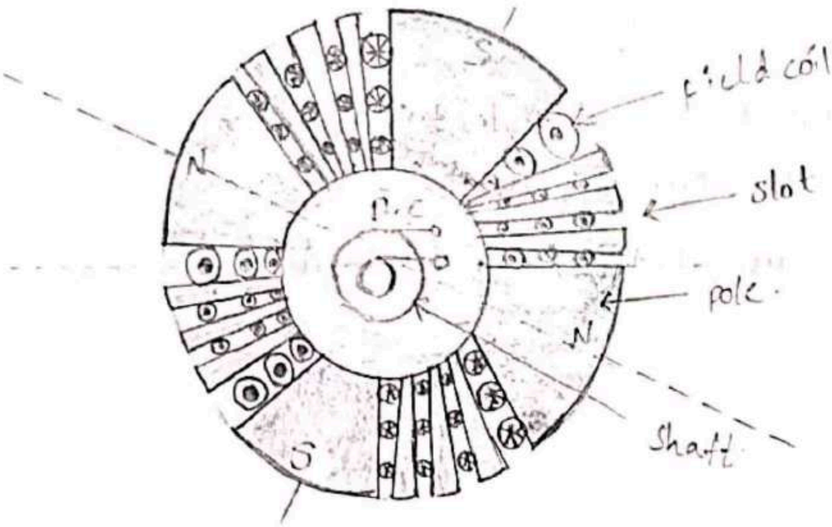
* As mechanical strength of salient pole type is less, this is preferred for low speed alternators ranging from 125 r.p.m to 500.r.p.m

* The prime movers used to drive such rotor are generally water turbines and I.C. engines.

ii, Smooth cylindrical or non salient type :-

* This is also called non salient type (or) non-projected pole type of rotor.

* The Fig. Q.61.3 shows smooth cylindrical type of rotor.

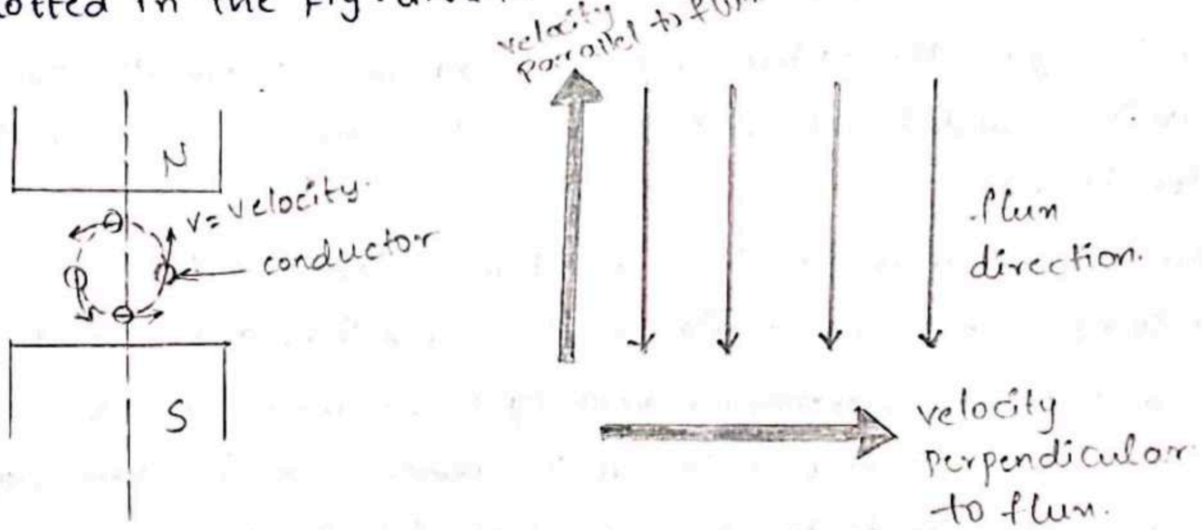


* The rotor consists of smooth solid steel cylinder, having numbers of slots to accommodate the field coil. The slots are covered at the top with the help of steel (or) manganese wedges.
* The unslotted portions of the cylinder itself act as the poles. The poles are not projecting out and the surface of rotor is smooth which maintains uniforms air gaps between stator and the rotor.
* These rotors have small diameters and large axial lengths. This is to keep peripheral speed within limits.
* The main advantage of this type is that these are mechanically very strong and thus preferred for high speed alternators ranging between 1500 to 3000 r.p.m... such high speed alternators are called 'turboalternators'.
* The prime moves used to drive such type of rotors are generally steam turbines, electric motors.

Working principle of Alternators:- 4-(9)

Principle of operation of synchronous generator:-

* The alternators i.e, synchronous generators work on the principle of electromagnetic induction. When there is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors.
* consider a relative motion of a single conductor under the magnetic field produced by two stationary pole. The magnetic axis of the two poles produced by field is vertical, shown dotted in the fig. Q.62.1.



* Let conductor starts rotating from position 1. At this instant, the entire velocity component is parallel to the flux lines. Hence there is no cutting of flux lines by the conductor. Hence induced e.m.f. in the conductor is also zero.
* As the conductor moves from position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that, e.m.f gets induced in the conductor. The magnitude of such an induced e.m.f. increases as the conductor moves from position 1 towards 2.
* At position 2, the entire velocity component is perpendicular to the flux lines. Hence there exists maximum cutting of the flux lines. And at this instant, the induced e.m.f in the conductor

is at its maximum.

* As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

* As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

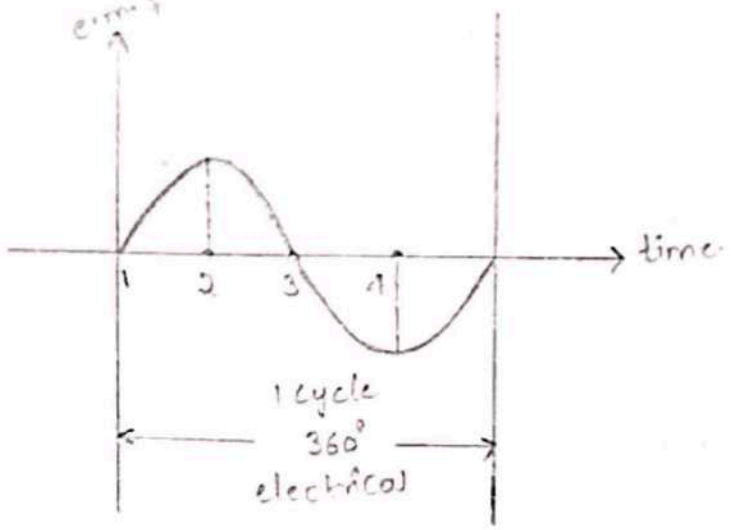
* As the conductor moves from position 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. But the direction of velocity component now is opposite to the direction of velocity component existing during the movement of the conductor from position 1 to 2. Hence an induced e.m.f in the conductor increases but in the opposite direction.

* At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines.

* Again from position 4 to 1, induced e.m.f decreases and finally at position 1, again becomes zero. This cycle continues as conductor rotates at a certain speed.

* So if we plot the magnitudes of the induced e.m.f against the time, we got an alternating nature of the induced e.m.f as shown in the Fig. Q.62.2.

* Thus for 2 pole alternator, one mechanical revolution corresponds to one electrical cycle i.e. 360° electrical of an induced e.m.f



* In a 4 pole alternator, for one revolution of the conductor, we get the two electrical cycles of the induced e.m.f. due to flux distribution due to 4 poles.

* In general, one mechanical revolution of rotor = $\frac{P}{2}$ cycles of e.m.f. electrically.

* As speed is N r.p.m., in one second, rotor will complete $\left(\frac{N}{60}\right)$ revolutions.

* But electrical cycles / sec = frequency = f

$\therefore$ frequency f = (No. of electrical cycles per revolution) X (No. of revolutions per second)

$\therefore \quad f = \frac{P}{2} \times \frac{N}{60}$ i.e., $f = \frac{PN}{120}$ Hz (cycles per sec)

* So there exists a fixed relationship between three quantities, the number of poles P, the speed of the rotor N in r.p.m and f the frequency of an induced e.m.f in Hz (hertz)

* The speed of the alternator at which it produces induced e.m.f. at the rated frequency for P numbers of poles is called synchronous speed N_s

So, $\boxed{N_s = \frac{120f}{P}}$

Where f = Required rated frequency

Ex:-

* A 12 pole alternator is coupled to an engine running at 500 rpm. It supplies a 3 phase induction motor having full load speed at 1440 rpm. Find % slip and number of poles of the motor.

Ans:- For an alternator, $P = 12$, $N_s = 500$ r.p.m.

$$N_s = \frac{120f}{P} \quad \text{i.e,} \quad f = \frac{500 \times 12}{120} = 50\,Hz$$

For an Induction motor,

$$N_{FL} = 1440 \text{ r.p.m.}$$

$$\therefore \text{Nearest } N_s = 1500 \text{ r.p.m} = \frac{120f}{P}$$

$$\therefore \quad P = \frac{120 \times 50}{1500} = 4 \quad \text{.... poles of motor}$$

$$\therefore \quad \% s = \frac{N_s - N}{N_s} \times 100 = \frac{1500 - 1440}{1500} \times 100 = 4\%.$$

UNIT V

ELECTRICAL INSTALLATIONS

UNIT-5

ELECTRICAL INSTALLATION:-

Switchgear:- In electrical power system, switchgear refers to the device used for switching, controlling and protecting the electrical circuits and components.

Essential Features of Switch Gear:-

The essential features of protective devices are:-

i) **Complete reliability:-** It is the most important feature, which all the protective devices should have, in the power system. If a fault occurs in any part of the power system, then the protective device should operate in such a way that the faulty section gets isolated from the other part of the power system.

ii) **Absolutely discrimination:-** clear and accurate descrimination between the faulty section and healthy section is required to isolate the faulty section.

iii) **Quick operation:-** The time taken by the protective device to isolate the faulty section must be minimum so that other parts of the system do not get damaged.

(iv) **provision for manual control:-** Even if the protective device can be made automatic, there should be a provision for manual control to carry out the necessary operations when the automatic control fails.

Components of Switch Gear:-

The switch gear comprises of wide range of components whose primary functions are switching and interrupting currents during both normal and faulty conditions. The basic components of switch gear; switches, fuses, circuit breakers, relays and other equipment.

i, **Switch:-** The device which is used to open (or) close an electrical circuit in a most conventional way is called switch. It can be operated at any condition of the circuit. The main disadvantage of the switch is that it cannot interrupt the current occuring due to faulty condition. The switches are classified as air and oil switches based on the medium where the contacts are opened.

(ii) **Fuse:-** A simple protective device used to protect the cables and electrical equipment under overload and short circuit conditions is called fuse. It consists of a small piece or thin strip of wire which melts when fault current flows through it for a sufficient time. Hence, the circuit gets protected from the fault current.

iii, **protective relay:-** In the power system, a device which continuously monitors the electrical quantities like current and voltage to sense the faulty condition is called protective relay. The main function of protective relay is to send the information about the faulty condition to the circuit breaker.

iv, **circuit breaker:-** A switching device, which can be used to make or break a circuit manually, automatically or with the help of remote control, under different conditions i.e., normal and faulty conditions, is known as a circuit breaker. In this ~~chap~~ chapter, some of the types of circuit breaker are discussed in detail.

→ * **Fuse:-** A fuse is a short piece of wire or metal or thin strip which is inserted in series to the circuit. when the fault current flows through the fuse for a sufficient time, it melts and thus isolates the circuit.

—* Desirable characteristics of fuse element materials:

The desirable characteristics of the material used in the fuse to have satisfied performance are:

1) low melting point e.g.., tin, lead
2) high conductivity e.g.., silver, copper
3) least effect to oxidation eg.., silver
4) affordable eg...., lead, tin, copper

—* Important Terms.

The following are the terms which are required in fuse analysis:

i) Current rating of fuse element:- It is the amount of current which the fuse element can carry under normal operation without overheating or melting. It depends on temperature rise in fuse holder, fuse material and surroundings of the fuse

~~ii) Fusing factor:~~

ii) Fusing current:- It is the minimum current at which the fuse element melts or blows away and isolates the healthy portion of the power system. It is higher than the current rating of fuse element.

iii) Fusing factor:- It is the ratio of the fusing current to the current rating of fuse element and its value is always greater than 1.

iv) Prospective current:- It is the RMS value of the fault current which is obtained by replacing the fuse with the conductor of negligible resistance.

v) cut-off current:- It is the maximum value of fault current obtained before the fuse element melts.

vi) Pre-arcing time:- The time taken to cut off the fault current from its commencement is known as pre arcing time.

vii) Arcing time:- The time taken to extinguish the arc after the pre-arcing time is known as arcing time

viii) Total operating time:- It is the summation of pre-arcing and arcing time

ix) Breaking capacity:- The RMS value of the maximum prospe-ctive current which a fuse can deal at rated voltage is known as breaking capacity.

—* Advantages and Disadvantages of fuse:-

The advantages and disadvantages of fuse are given below:

* Advantages:-

1) Cheapest form of protection device
2) Requires no maintenance
3) Operation of fuse is completely automatic
4) Easily breaks the large amount of fault current
5) pollution free protection device i.e,...., does not create any smoke or noise
6) suitable for over-current conditions due to its inverse current-time characteristics.
7) Requires less time in isolating the faulty part of the circuit.

* Disadvantages:

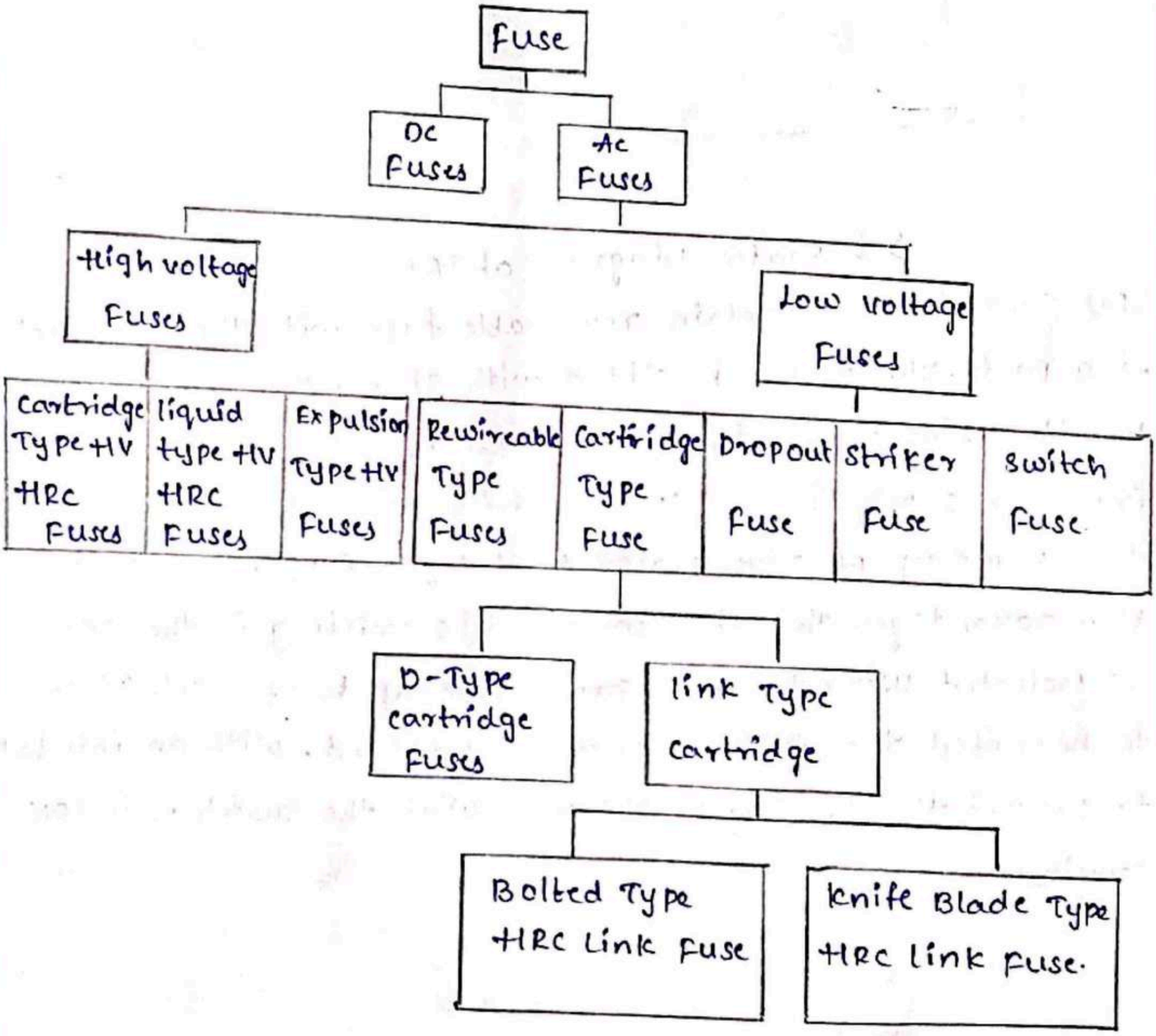
1) Rewiring or replacing a fuse takes a considerable time
2) Discrimination between fuses connected in series is not possible
3) co-relation of the characteristics of fuse with the protected device is not always possible

Classification of Fuses:-

The general classification of fuses is shown in fig. 5.2.

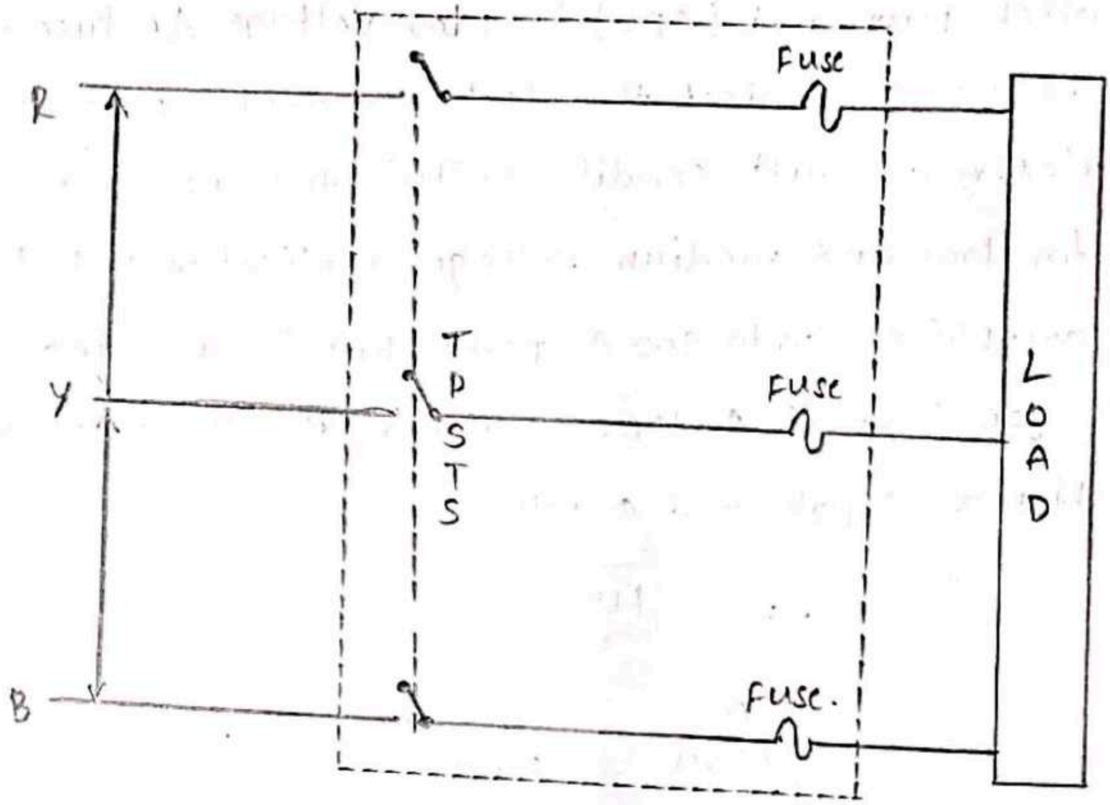
→* **Switch Fuse unit (SFU):-**

The switch fuse unit (SFU) is a low voltage AC fuse unit which is used to protect the electrical device or equipment from different fault conditions. This fuse is most commonly used for low and medium voltage applications. Rating of SFU varies from 30 to 800 Amperes. But the making capacity of SFU goes high till 46kA. In general the SFU is availables as 3 pole and 4 pole



classification of Fuse

unit. SFU has the capability of withstanding till the fault Current reaches 3 times full load Current.



Schematic Diagram of SFU

SFU consists of porcelain rewireable fuse with their conduct-ing parts. The switch is fitted with strong side operating handle using which the circuit ~~the~~ is made or isolated from the supply. In this SFU, the different contacts existing in it is made up of silver plated electrolytic copper due to its own advantages. The other components existing in the SFU is protected using the enclosure made up ~~to~~ of steel. It is to be noted that the enclosure is provided, with an interlock to prevent the opening of the unit when the switch is in ON condition.

→ * **Switch Fuse Unit (SFU):**- A fuse is a protective device which acts quickly. In abnormal condition, it blows and disconnects the circuit from the supply. Thus it provides circuits protection by destroying itself.

* A switch is used to isolate the circuit from the supply purposely for repair and maintenance. Generally it is manually operated.

* A unit which consists of the combinations of fuse and switch together is called switch fuse unit. It is shown in Fig. Q.21.

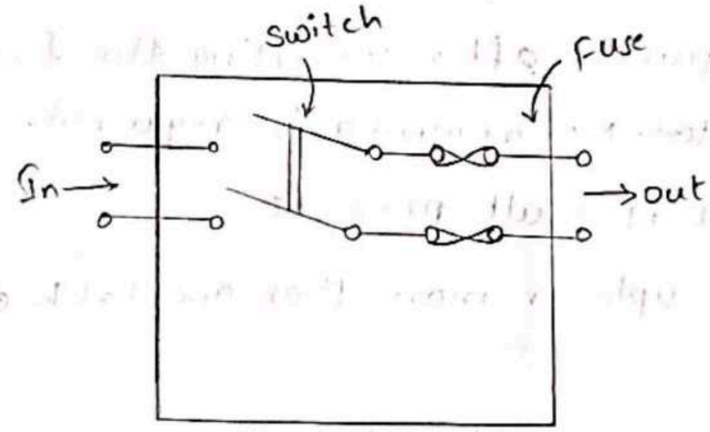


Fig. Q.2.1 switch fuse unit.

* The advantage of such switch fuse unit are,
i) The number of joints in the circuit get reduced.
ii) Due to compact construction, less space is required.
iii) Easy from handling point of view.

→ * **Miniature circuit Breaker (MCB):**-

* A miniature circuit breaker is an electromechanical device which makes and breaks the circuit in normal operation and disconnects the circuit under the abnormal condition when current exceeds a preset value.

* MCB is a high fault capacity current limiting, trip free, automatic switching device with thermal and magnetic operation to provide protection against overload and short circuit.

* It is necessary to use MCB because of its following features

1) Its operation is very fast and opens in less than one milli-second.

2) No tripping circuit is necessary and the operation is automatic.

3) provides protection against overload and short circuit without noise, smoke or flame.

4) It can be reset very quickly after correcting the fault, just by switching a button. No rewiring is required.

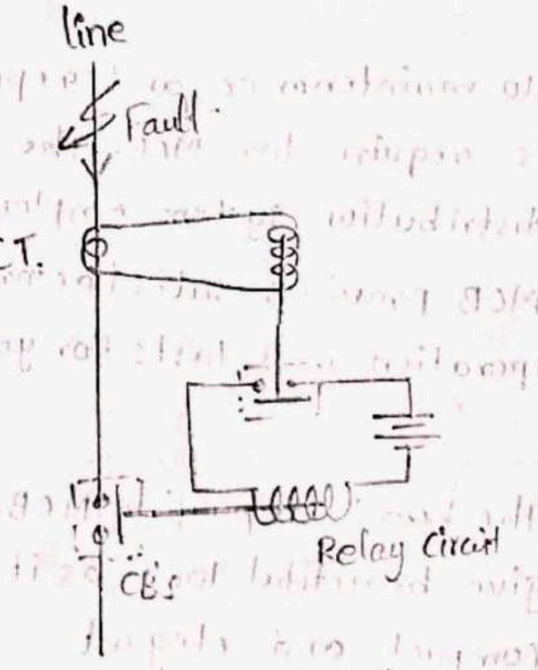
5) It can not be reclosed if fault persists.

6) The mechanical life is upto or more than one lakh operating cycle.

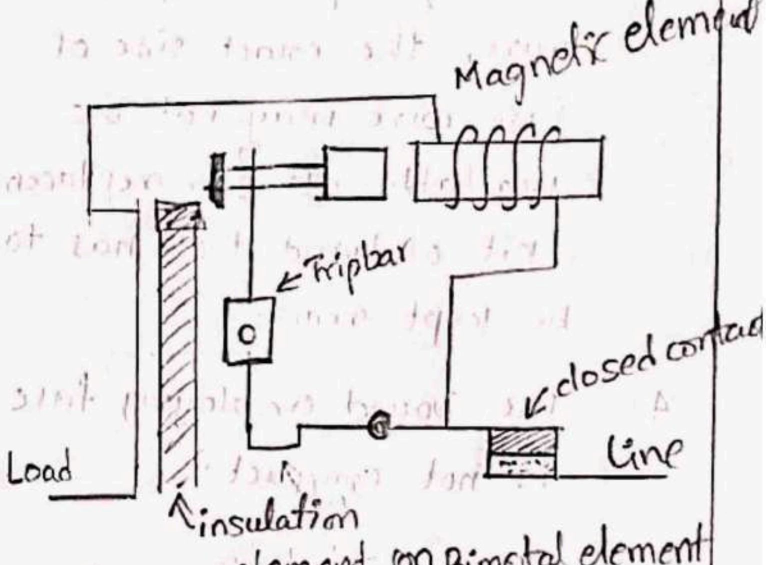
* Hence now a days MCBs are used rather than rewirable fuse.

* Generally MCBs are rated for a.c voltage of 240 V for single phase, 415 V for three phase or 220 V d.c. The current rating available is from 0.5A to 63 A. It is available as single pole (SP), Double pole (DP), Tripple pole (TP) with short circuit breaking capacity from 1KA to 10KA with a rated frequency.

* A typical view of MCB and its practical appearance is shown in Fig. below.



Equalent Circuit of CB's



Basic diagram of MCB's

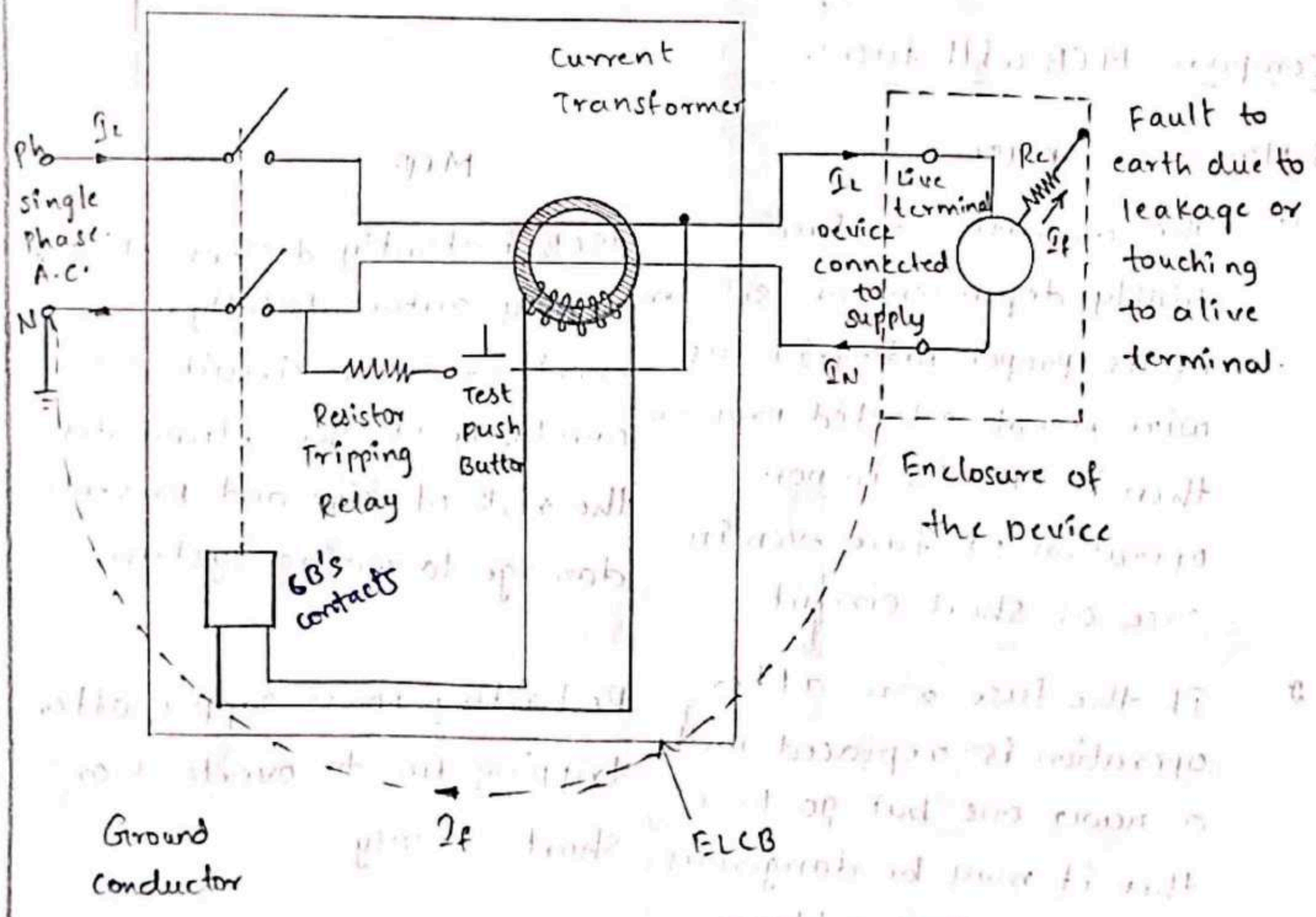
Compare MCB with fuse:-

S.No.	Fuse	MCB
1.	The operation of fuse is highly dependent on selection of its proper rating. If fuse wire is not selected properly then it results in non operation of fuse even in case of short circuit.	MCB instantly disconnects the supply automatically in the event of short circuit (or) overload. It thus eliminates the risk of fire and prevents damage to wiring system.
2.	If the fuse wire after operation is replaced with a newer one but go loose then it may be dangerous. Also to replace a blown fuse in ~~button~~ between	Restarting power supply after tripping due to overload or short is easy.

	current carrying points is dangerous specially in dark.	
3.	During replacement of fuse wire, the exact size of fuse wire may not be available. Also for replacement a kit of hand tools has to be kept ready	No maintenance and repairs is require for MCB. The distribution system employing MCB provides satisfactory operation and lasts for years.
4.	The board employing fuse is not compact.	The board employing MCBs give beautiful look as it is compact and elegant.

—* Earth Leakage Circuit Breaker (ELCB):-

* The schematic of ELCB is as shown in the fig Q.5.1



As shown in the Fig. Q.51 ELCB consists of a small current transformer surrounding live and neutral wire. The secondary winding of current transformer is connected to relay circuit which can trip the circuit breaker which is connected in the circuit.

under normal conditions, the current in line and neutral conductor is same so the net current ($I_L - I_N$) flowing through the core is zero. Eventually there will not be any production of flux in the core and no induced e.m.f. so the breaker does not trip.

* If there is a fault due to leakage from live wire to earth or a person by mistake touching to the live terminal then the net current through to the core will no longer remain as zero but equal to $I_L - I_N$ or I_f which will set up flux and emf in C.T. As per the present value, the unbalance in current is detected by C.T. and relay coil is energized which will give tripping signal for the circuit breaker. As C.T. operates with low value of current, the core must be very permeable at low flux densities.

* Thus ELCB provides protection against electric shock when a person comes in contact with live parts. resulting in flow of current from body to earth.

* A properly connected ELCB detects such small currents in milliamperes flowing to earth through human body or earth wire and breaks the circuit to reduce the risk of electrocution to humans.

* There are certain situations where leakge current can flow through the metal bodies of appliances, when person touches to such appliances. Thus person can get a shock.

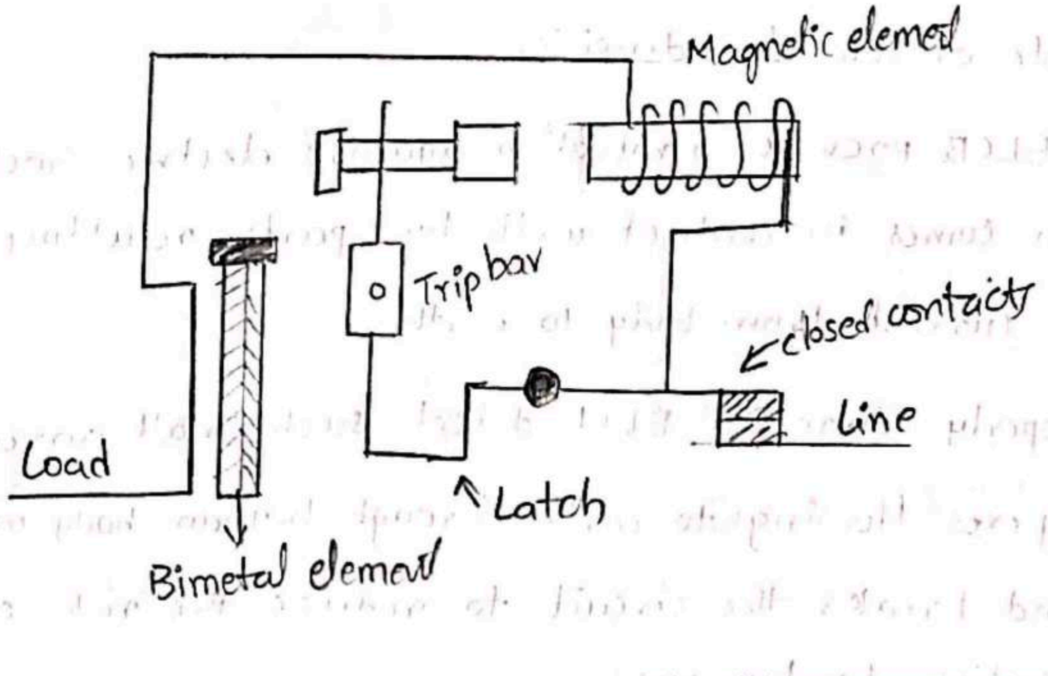
* Similarly there is risk of fire due to such earth leakage currents.

* Thus a protective device is necessary which ~~say~~ can sense small leakage current and disconnect the circuit from supply. Such a device is called earth leakage circuit breakers (ELCB).

1) provides protection to a human against the electric shock.
2) Detects very small leakage currents.
3) Reduces the Risk of fire due to hot spots.
4) Saves electrical energy due to leakage.
5) Energy conservation can be achieved.

—* Moulded Case Circuit Breaker (MCCB):-

* MCCB is similar to MCB but used when the load currents exceed the capabilities of MCB. It is used for circuits having current ranges from 63A to 3000A.



* Its working is based on thermal mechanism. It has a bimetallic contact which expands and contracts when there are changes in temperature. under normal condition, the contacts are closed allowing current to pass. under over load or short circuit condition, current exceeds its safe value. Due to this, heat is generated and the contacts are opened to interrupt the circuit.

* Due to the interruption of high current, there is arc formation. Hence in MCCB there are arc extinguishers which suppress the arc.

* There is a disconnection switch, with the help of which, the MCCB can be operated manually.

* ~~pratic~~ practically it has adjustable trip settings and hence it can be used for high current applications.

* It can be easily reset after the fault rectification. Thus it provides operational safely and convenience.

* All the operating parts of MCCB are covered within a plastic moulded housing made in two halves. The two halves are joined together to form the whole structure.

* The basic difference between MCB and MCCB is the current rating. Hence MCCBs are used for industrial and commercial applications such as main feeder protection, generator and motor protection, capacitor bank protection, welding application and applications which require adjustable trip setting.

* MCCBs are used for high current protection such as,

1) Generator protection
2) Main feeder protection

3) motor protection

4) Capacitor bank protection

5) Welding applications

6) Applications which need adjustable current trip setting.

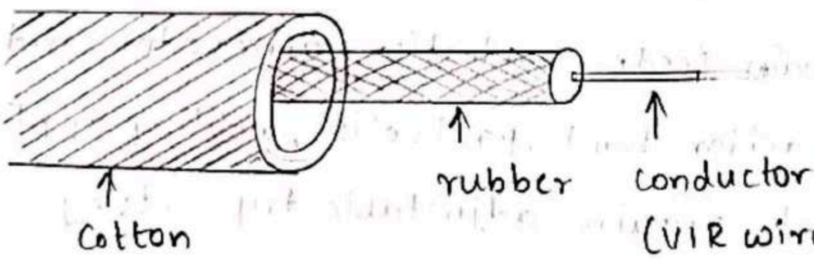
—* Types of wires:-

1) vulcanised India Rubber wires (V.I.R)
2) Cab Tyre sheathed wires (C.T.S)
3) poly vinyl chloride wires (P.V.C)
4) Flexible wires.

* The various type of wires which are used for various wirining schemes are:

1) Vulcanised India Rubber wires (V.I.R.):-

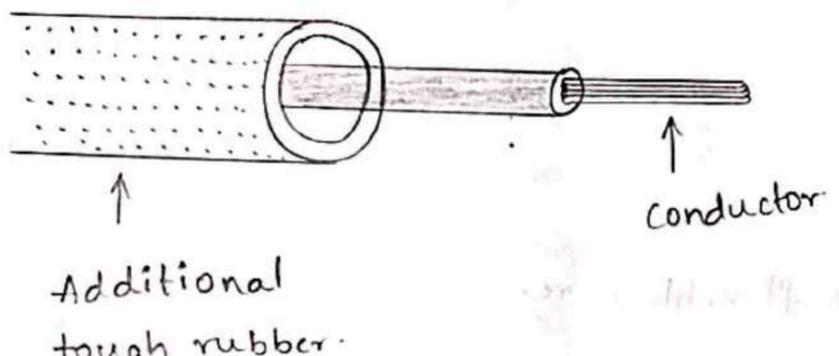
* This type of wire consists tinned conductor coated with rubber insulation. This is further covered with protective cotton and bitumen compound and finally finished with wax. This makes it moisture and heat resistant. These are always single core wire. Though are covered with a cotton layer it has tendency to absorb moisture and hence rarely used, now a days.



(VIR wire)

2) Cab Tyre Sheathed wires (C.T.S.)

In this type, ordinary rubber insulated conductors are provided with an additional tough rubber sheath. The wire is also known as Tough Rubber sheathed (T.R.S) wire. It provides additional insulation and along with that a protection against moisture, chemical fumes and wear and tear. These are also available in single core, double core and three core varieties.



3) Poly Vinyl Chloride wires (P.V.C):-

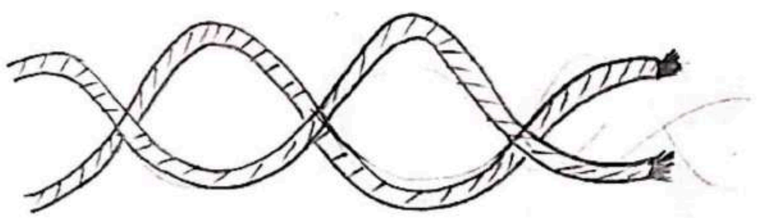
These are most commonly used wires. These have conductors with p.v.c insulation. p.v.c has following characteristics:

1) It is nonhygroscopic and moisture proof.
2) It is tough and hence durable.
3) Resistant to corrosion.
4) It is chemically inert.
5) As it is tough so additional converging is not required.

The only disadvantages is, it softens at highs temperature and hence it avoided where extreme of temperature may occur. eg. in heating appliances.

4) Flexible wires:-

* These are used very commonly in domestic wiring or fire for wiring or for wiring of temporary nature.
* It consist of two seperately insulated stranded conductors. The insulation is mostly rubber. more commonly available in parallel (or) twisted twins.
* Due to its flexible nature, the handling of these wire become very easy.



Twisted twin flexible wire.

—* Types of Cables:-

* An underground cable is defined as the groups of individually insulated one or more conductors which is put together and finally provided with number of layers of insulation to give proper mechanical support.
* The Fig. Q.12.1 shows the general construction of a cable. The cable shows is single conductor underground cable- Its various parts are,

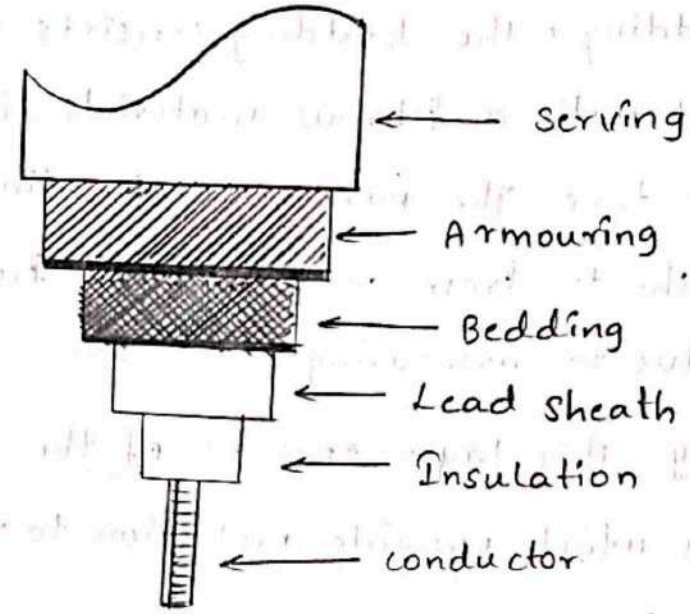


Fig. Q.12.1 General construction of a cable.

1) Conductor (or) Core:- This section consists of single conductor or more than one conductor. The conductors are also called cores. A cable with three conductors is called three core cable. The conductors used are aluminium or annealed copper. The conductors are stranded conductors in order to provide flexibility to the cable.

2) Insulation:- Each conductor or core is covered by insulation of proper thickless. The commonly used insulating materials are varnished cambric, vulcanized bitumen and impregnated paper.

3) Metallic sheath:- The insulated conductors are covered by lead sheath or aluminium sheath. This provides the mechanical protection but mainly restricts moisture and other gases to each to the insulation.

4) Beddings:- The metallic sheath is covered by another layer called bedding. The bedding consists of paper tape compounded with a fibrous materials like jute strands or hessian tape. The purpose of bedding is to protect the metallic sheath from corrosion and from mechanical injury resulting due to armouring.

5) Armourings:- This layer consists of the layers of galavized steel wires which provide protection to the cable from the mechanical injury.

6) Serving:- The last layer above the armouring is serving. It is a layer of fibrous material like jute cloth which protects the armouring from the atmospheric conditions.

* The type of cable is basically decided on the voltage level for which it is manufractured and the material used for the insulation such as cotton, paper, rubber etc.

* Based on voltage level, the various types of cables are,

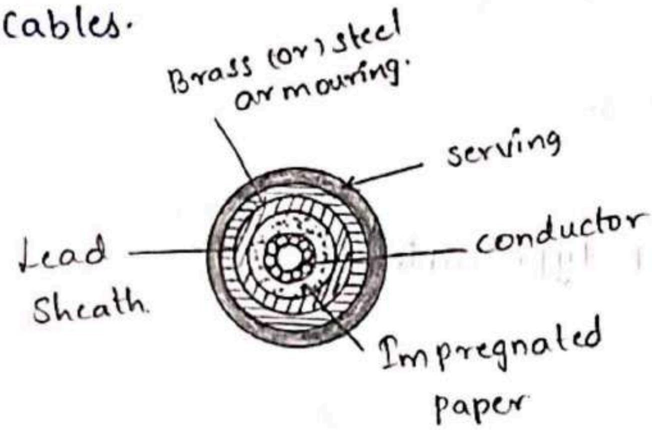
1. Low Tension (L.T) cables:- used for the voltage levels upto 6.6 KV.

2. Medium tenstion cables:- Used for 11 kV level and are called belted cables.

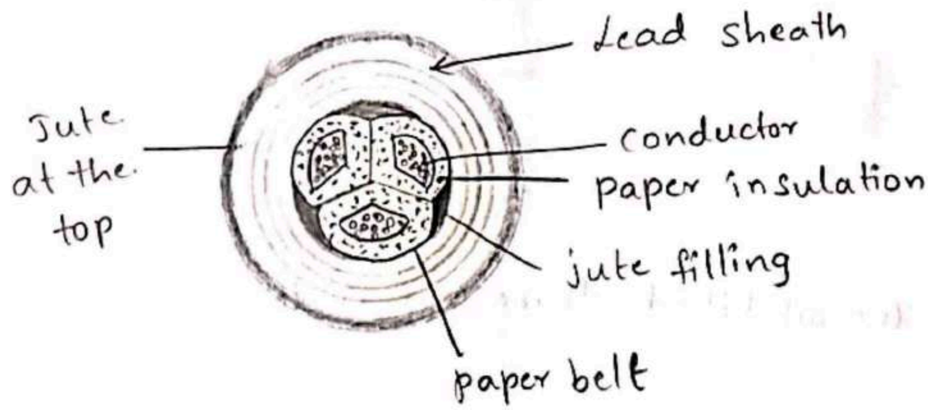
3. High tension cables:- used for 22 kV and 33 kV levels. These are screened type cables and further classified as: i) H type cables and ii) S.L. cables i.e, separate lead screened cables.

4. Extra high tension cables:- used for voltage levels more than 33 kV. These are pressure cables which are further classifed as: i) oil filled cables and ii) Gas pressure cables.

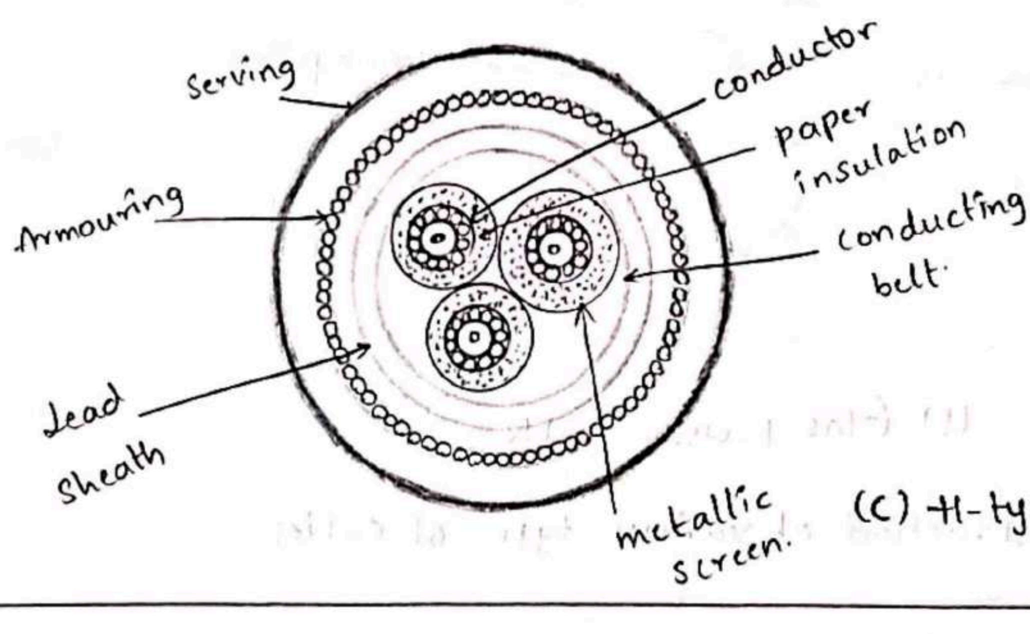
* The fig Q13.1 shows the constructional details of various types of cables.



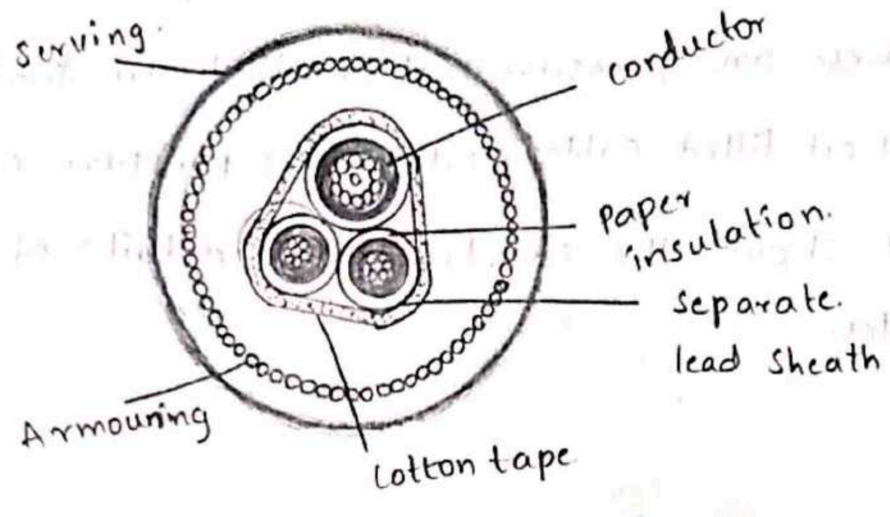
(a) Single Core L.T. Cable.



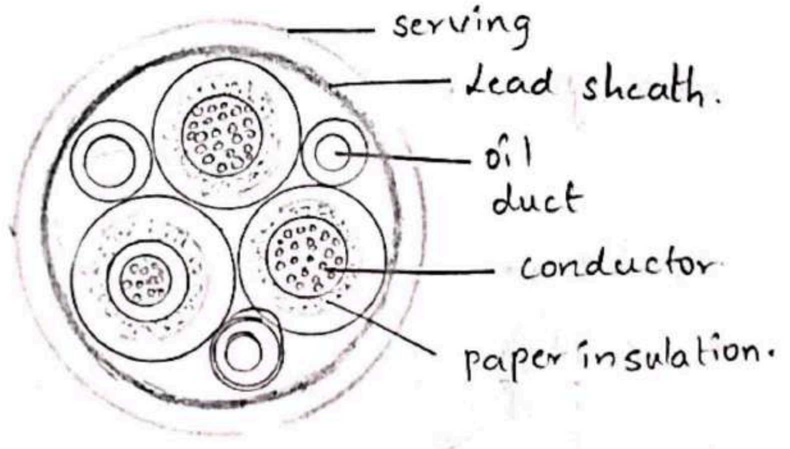
(b) Belted 3 core cable.



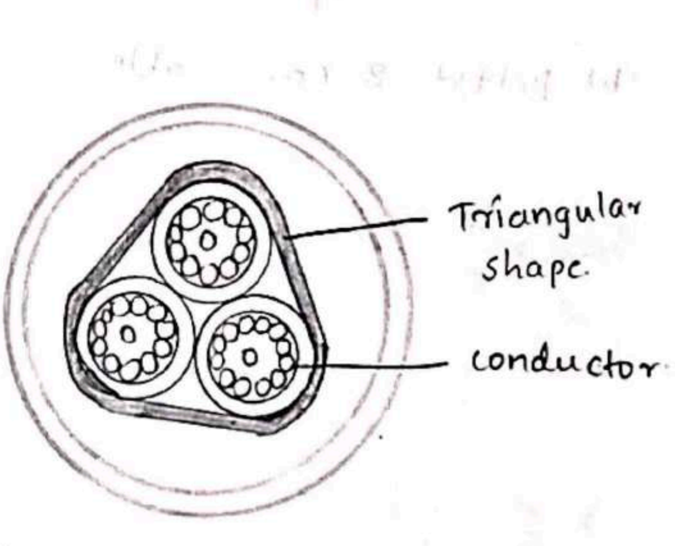
(C) H-type Cable.



(d) S.L. type cable.



(e) oil filled three core cable.



(f) Gas pressure cable.

Fig. Q.13.1 construction of various types of cables.

* Based on the cores, the various types of cables are,
(i) Single core (ii) Two core and (iii) Three core cables.

* The advantages are,

1. Require less maintenance.
2. The voltage drop is less than overhead lines.
3. Not affected by lightning, storms and other weather conditions.
4. Beauty of towns and cities gets maintained.
5. Possibility of accidents is less.
6. possibility of faults is less.

* The limitations are,

1. Initial cost is very high.
2. The size is more hence installation is difficult and costly
3. Insulation cost is high.
4. Long distance transmission is not possible.

* For distribution of power in town and cities which are thickly populated areas.
* For providing power to areas where overhead lines are not permitted.
* For electrification of areas where beauty is required to be maintained such as gardens, hotels, educational builidings etc.
* For supplying mining machines in mining industries.

* used in power networks.

* specials cables are used in switch control, relay and instrumentation panels of power switch gear.

—* Importance of Earthing:-

* The connection of electrical machinery to the general mass of earth, with a conducting material of very low resistance is called "**earthing**" or "**grounding**".

* consider a machine which is not earthed. It is operated at supply voltage V.

* If a person touches to the outer part of the machine then as long as insulating of the machine is perfect, person will, not get a shock. The insulation resistance of perfect insula-tion is infinite.

* But if there is some fault and insulation becomes weak or if one of the windings is touching to the cover of the machine then insulation resistance becomes zero. If person touches to such a machine, current flows through the body resistance is small, current through the body is high so that the person receives a shock.

* To avoid such a situation, the body of the machine is connected to the earth with a very low resistance. This is called earthing.

* If machine is earthed an person touches to a faulty machine then body resistance and earthing resistance

appears to be in parallel.

* As earthing resistance is very small than the resistance of the body hence almost entire current flows through earthing connection.

* Thus current through the body of the person is almost zero and person doesnot receive any shock.

* Similarly due to earthing, the tall buildings, structures and other machines are protected from high voltage in over-head lines and the atmospheric lightening as high voltage and lightening as high voltage and lightening gets discharging to earth through earthing connection.

* Due to earthing the line voltage is maintained at constant value.

* Hence earthing is necessary for all domestic appliances, machines, buildings and structures, equipments power stations etc.

1) plate earthing.
2) Pipe earthing.
3) Rod earthing.
4) Earthing through water main
5) Horizontal strip earthing.

Plate Earthing

(1) * The earth connection is provided with the help of copper plate or Galvanized Iron (G.I) plate. The copper plate size is 60cm x 60cm x 3.18 mm while G.I. plate size is not less than 60cm x 60cm x 6.3mm. The G.I plates

are commonly used now-a-days. The plate is embedded 3 meters (10 feet) into the ground. The plate is kept with its face vertical.

* The plate is surrounded by the alternate layer of coke and salt for minimum thickness of about 15cm. The earth wire is draw through G.I. pipe and is perfectly bolted to the earth plate. The nuts and bolts must be of copper plate and must be of galvanized iron for G.I. plate.

* The earth lead used must be G.I wire or G.I strip of sufficient cross-sectional area to carry the fault current safely. The earth wire is drawn through G.I. pipe of 19mm diameter, at about 60cm below the ground.

* The G.I. pipe is fitted with a funnel on the top. In order to have an effective earthing, salt water is poured periodi-cally through the funnel.

* The earthing efficiency, increases with the increases of the plate area and depth of embedding. If the resistivity of the soil is high, then it is necessary to embed the plate vertically at a greather depth into the ground.

* The only disadvantage of this method is that the discon-tinuity of the earth wire from the earthing plate below the earth can not be observed physically. This may cause misleading and may result into heavy losses under fault conditions.

* The schematic arrangement of plate earthing is shown in the fig. Q.18.1

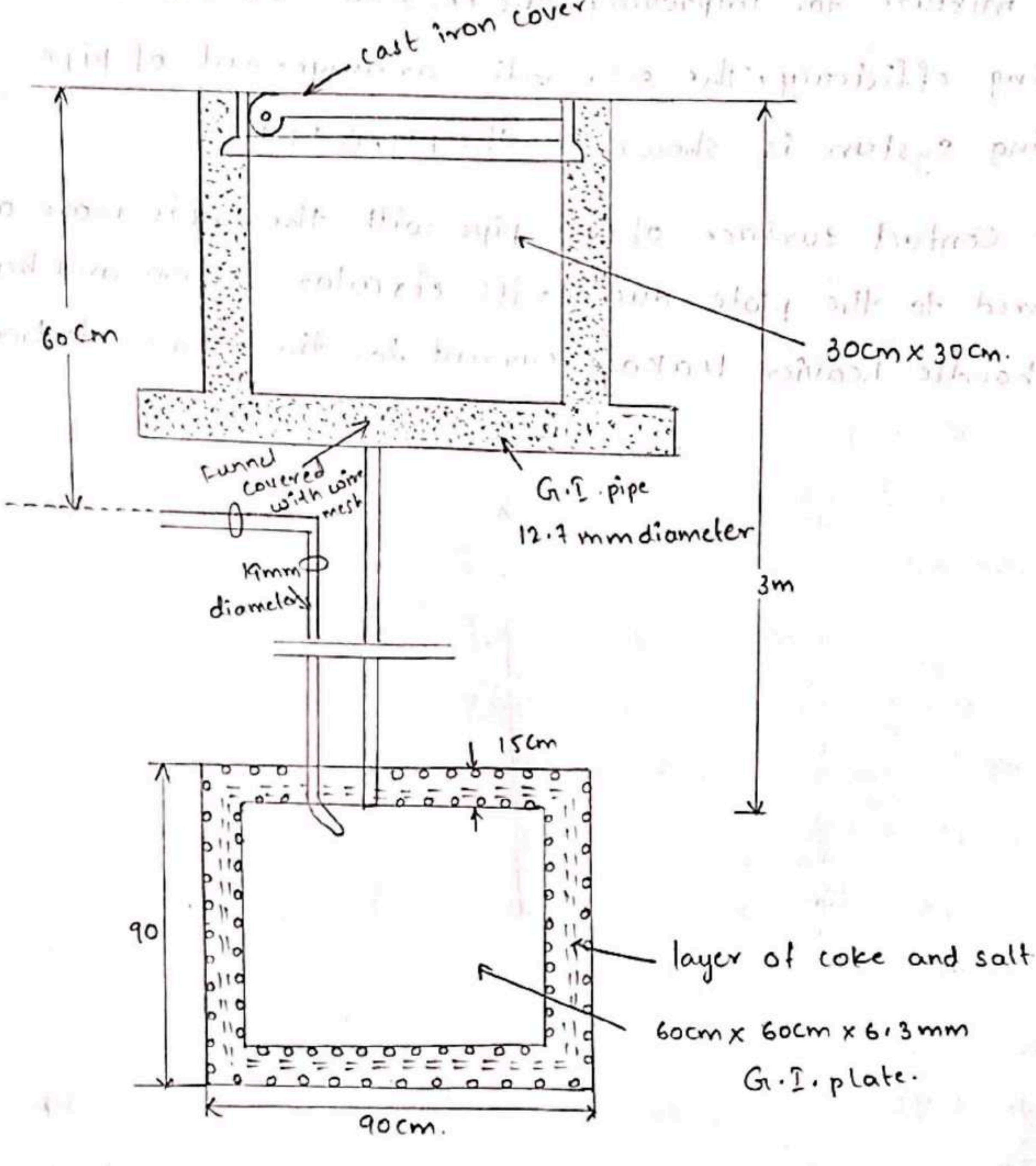


Fig. Q.18.1 plate earthing.

② Pipe earthing

* In this method of earthing a G.I. pipe of 38mm diameter and 2 meter (7 feet) length is embedded vertically into the ground. This pipe acts as an earth electrode. The depth depends on the condition of the soil.
* The earth wires are fastented to the top section of the pipe above the ground level with nut and bolts.

* The pit area around the pipe is filled with salt and coal mixture for improving the condition of the soil and earthing efficiency. The schematic arrangement of pipe earthing system is shown in the fig. Q.19.1

* The contact surface of G.I pipe with the soil is more as compared to the plate due to its circular section and hence can handle heavier leakage current for the same electrode size.

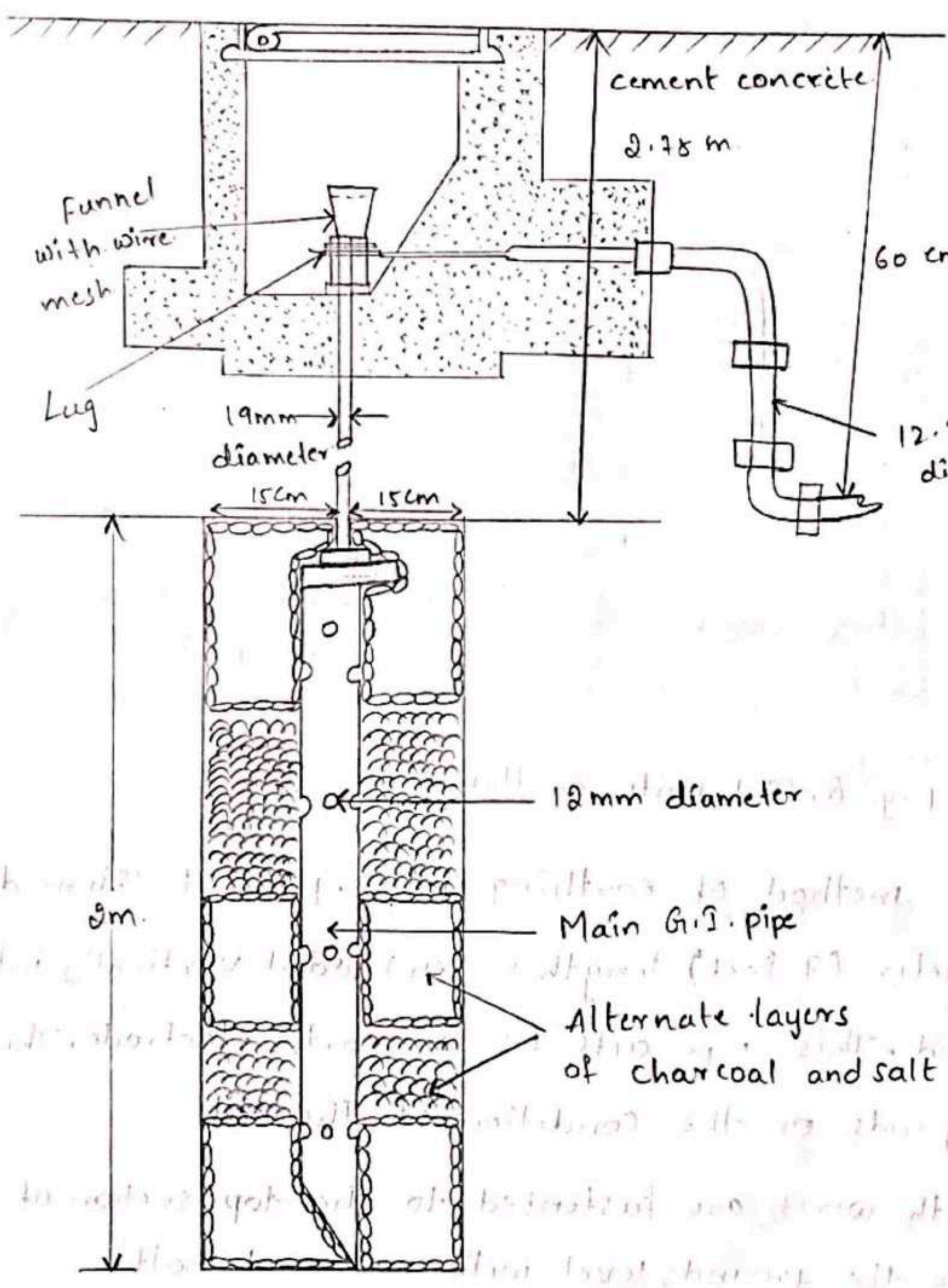


Fig. Q.19.1 pipe earthing.

* According to Indian standard, the pipe should be placed at a depth of 4.75m. Impregnating the coke with salt decreases the earth resistance. Generally alternate layers of salt and coke are used for best results.

* In summer season, soil becomes dry. In such case salt water is poured through the funnel connected to the main G.I. pipe through 19mm diameter pipe. This keeps the soil wet.

* The earth wires are connect. to the G.I. pipe above the ground level and can be physically inspected from time to time. These connections can be checked for performing continuity tests. This is the important advantage of pipe earthing over the plate earthing. The earth lead used must be G.I. wire of sufficient cross-sectional area to carry fault current safely. It should not be less than electrical equivalent of copper conductor of $12.97\ mm^2$ cross-sectiona area.

* The only disadvantage of pipe earthing is that the embedded pipe length has to be increased sufficiently in case the soil specific resistivity is of high order. This increases the excavation work and hence increased cost. In ordinary soil condition the range of the earth resistance should be 2 to 5 ohms.

* In the places where rocky soil earth bed exists; horizontal strip earthing is used. this is suitable as soil excavation required for plate or pipe earthing is difficult in such places. for such soils earth resistance is between 5 to 8 ohms

* Types of Batteries:-

S.No.	Type of battery	Applications.
1.	Lead acid battery	In automobiles for starting and lighting, battery electric vehicles, backup operations like rail road signals, air traffic controls and critical systems in submarines, for lights and fans in trains etc...
2.	Nickel - cadmium battery	In railways for lighting and air conditioning systems, for starting engines and provide emergency power supply in millitary aeroplanes and helicopters, in movie cameras and photoflash, in electric shaver, variety of cordless electronic devices etc.
3.	NiMH battery (Nickel metal hydride)	cellular phones, portable computers. and laptops, digital cameras, electronic toys, providing emergency supply to various electronic instruments etc.
4.	Lithium battery (Lithium ion)	consumer products such as camcorders, calculators, electric razors, medical equipments, portable radios, in traction.
5.	SMF battery [sealed maintenance Free]	ups systems, telecommunications. equipments, fire alarms and security systems, office automation equipments, etc...

* **Important characteristics for Batteries**:- The various important characteristics for batteries are.

1. **Nominal voltage**:- It is indicated on a battery depending on the amount of cells connected in series. It is the open circuit voltage of a battery.
2. **Battery capacity (or) battery life**:- It is specified in ampere-hours (Ah).

* It indicates the amount of electricity which a battery can supply at the specified discharge rate till its voltage falls to a specified value.

* Mathematically product of discharge current (I_D) in amperes and the time for discharge (T_D) in hours till voltage falls to a specified value is the capacity of a battery

$$\boxed{\therefore \text{ Battery capacity} = I_D \times T_D \text{ (Ah)}}$$

3. **Specific gravity of electrolyte**:- More the specific gravity of electrolyte, more is the battery capacity. It decides internal resistance of a battery.
4. **Specific energy**:- The battery capacity expressed in watt-hour per kg weight is called specific energy. It is also called gravimetric energy density of a battery.
5. **Electrical characteristics**: These characteristics include, the charging and discharging curves for a battery. It is the graph of terminal voltage against charging or discharging time in hours at normal rate. The Fig. Q.21.1 shows such curves for

a ~~sp~~ typical battery. From the given charging and discharging curves, the time of discharge for a specified voltage level can be obtained.

6. Battery efficiency:- It is defined as the ratio of the output during discharging to the input required during charging, to regain the original state of the battery.

* It is commonly called ampere-hour efficiency or quantity efficiency and denoted as η_{Ah}.

$$\eta_{Ah} = \frac{\text{Amp-hours on discharge}}{\text{Amp-hours on charge}}$$

$$\therefore \quad \boxed{\% \eta_{Ah} = \left[\frac{\text{current} \times \text{Time on discharge}}{\text{current} \times \text{Time on charge}}\right] \times 100}$$

* For lead acid battery, it is about 80% to 90%.

—* Calculations for Energy Consumption:-

* The total electrical energy consumption is the addition of electrical energy consumption of various domestic appliances or industrial machinery.

* To calculate the consumption of an electrical appliance, following factors are required,

1. capacity of electrical appliance in watts.
2. Numbers of hours for which appliances is in use in one day.
3. Numbers of days per month or years as per the required energy calculation.

* Mathematically energy consumption of an appliance is given by,

$$\frac{\begin{bmatrix}\text{Capacity of}\\ \text{appliance in W}\end{bmatrix} \times \begin{bmatrix}\text{Number of}\\ \text{hours/ day}\end{bmatrix} \times \begin{bmatrix}\text{Number of}\\ \text{days / month}\end{bmatrix}}{1000} = \text{kWh per month}$$

* The division of 1000 is to express energy consumption in kWh i.e, units [1 unit = 1 kWh].

* Addition of such energy consumptions of all the appliances, total energy consumptions per month can be obtained.

* But practically an energy meter is installed which directly measures the total energy consumption of a house or industry.

* Thus for pratical energy consumption calculation we need,

1. Energy meter reading at the start of counting period.
2. Energy meter reading at the end of counting period.
3. Number of days in a counting period which is generally a month.

∴ Total energy consumption per month = Final reading in kWh after a month - Initial reading in kWh.

* To find the consumption for one year, the energy consumption per day is multiplied by 365 days.

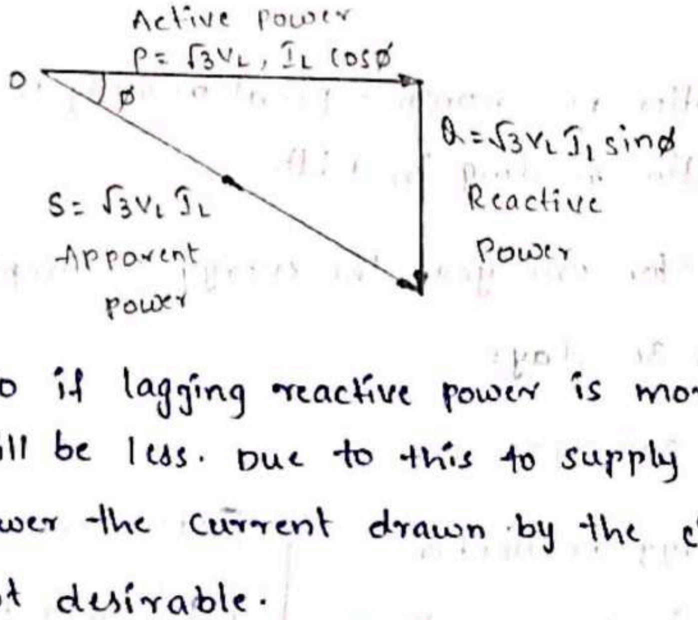
* For calculating energy savings use

$$\begin{matrix}\text{Energy saving}\\ \text{(kWh / year)}\end{matrix} = \begin{bmatrix}\text{365 x Energy consumption}\\ \text{Per day in previous day year}\end{bmatrix} - \begin{bmatrix}\text{energy consumption}\\ \text{Per current year}\end{bmatrix}$$

* By knowing energy consumption of each appliance and replacing bulbs by lower wattage bulbs if possible, saving in energy can be be achieved.

—* Power factor improvement and battery backup:-

* In a.c circuits the cosine of angle between voltage and current is called power factor. It is denoted as $\cos\phi$.
* The active power consumption in a.c. circuits is the product of voltage and the component of the current which is in phase with the voltage which is decided by the $\cos\phi$.
* Thus the power factor affects the active power consumption of the circuit.
* The power triangle for three phase circuit which is as shown in the Fig. Q.23.1. It is also called as KVA triangle.
* The power factor can be obtained as the ratio of active power to apparent power.
* If the lagging reactive power component is shown downwards. then the leading reactive power component is shown upwards.



$$\boxed{\cos\phi = \frac{\text{Active power}}{\text{Apparent power}}}$$

* So if lagging reactive power is more, ϕ will be more and $\cos\phi$ will be less. Due to this to supply same amount of active power the current drawn by the circuit will be more which is not desirable.
* If an additional load drawing leading reactive power is connected in parallel with the original load then leading reactive power is in opposite direction to lagging reactive power. So it partly neutralises the effect of lagging reactive

Power. Due to this, ϕ reduces and $\cos\phi$ increases. This reduces the current required to supply same amount of active Power will reduce.

* So lagging reactive power tries to lower the power factor while the leading reactive power increases the power factor.
* The main cause of low power factor is inductive loads. Such loads include,

(i) Transformers (ii) Induction motors (3 phase and single phase) (iii) Induction generators (iv) Domestic appliances and lighting load (v) High intensity discharge lighting (vi) Industrial induction furnaces etc...

* All these loads constitute a major portion of the power consumption while leading power factor loads are very less in number.
* Hence the overall power factor is very low.
* The various problems of low power factor are,

1. Lower is the power factor, higher is the load current for the same amount of active power.
2. The conductor size depends on the current. For higher current greater conductor size is required.
3. Higher conductor size increases the cost of the system.
4. Large current causes more copper losses (I^2R). This results into poor efficiency.
5. Large current causes large voltage drop (IZ) in transmission lines, alternators and transformers. This reduces the voltage available at the supply end. This results

into poor regulation of the various devices.

* <u>Power factor improvement</u>: The basic requirement to improve power factor is the leading reactive power loads. one of such loads is capacitors.

* Thus by connecting capacitor is parallel with the lagging power factor load, the overall power factor can be improved.

* consider a lagging power ~~load~~ factor load as shown in the Fig. Q.24.1 (a). The corresponding phasor diagram is shown in the Fig. Q.24.1 (b).

* Let I_1 be the current drawn at a lagging power factor angle of ϕ_1.

* To improve the power factor, a capacitor is connected across the load as shown in the Fig. Q.24.2.

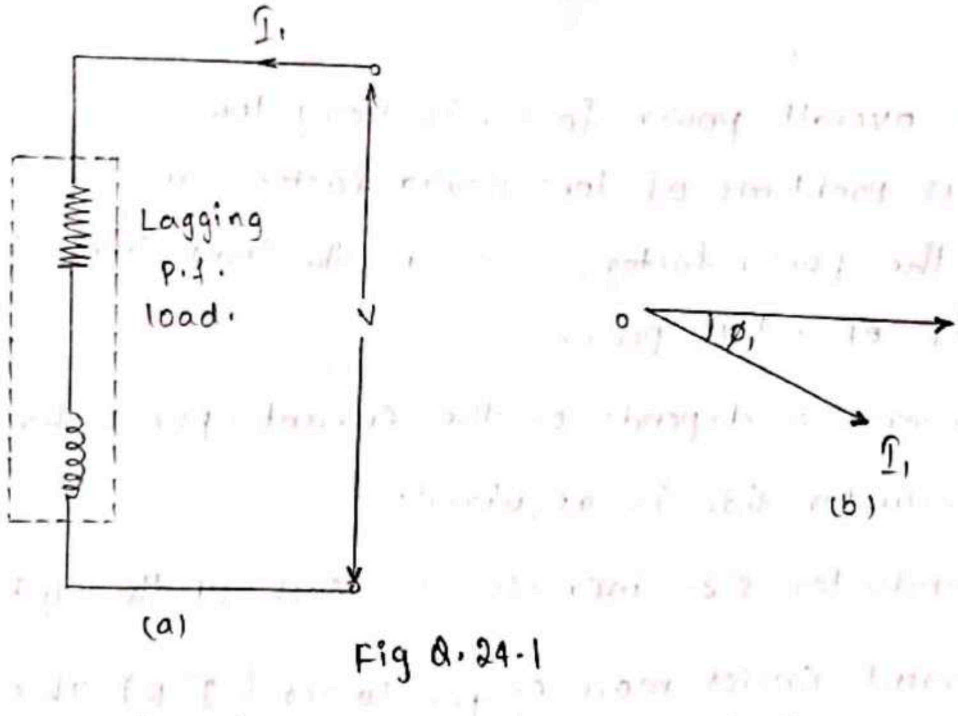


Fig Q.24.1

* The capacitor takes a leading current I_2, which leads voltage v by an angle of 90° as shown in the Fig. Q.24.2 (a).

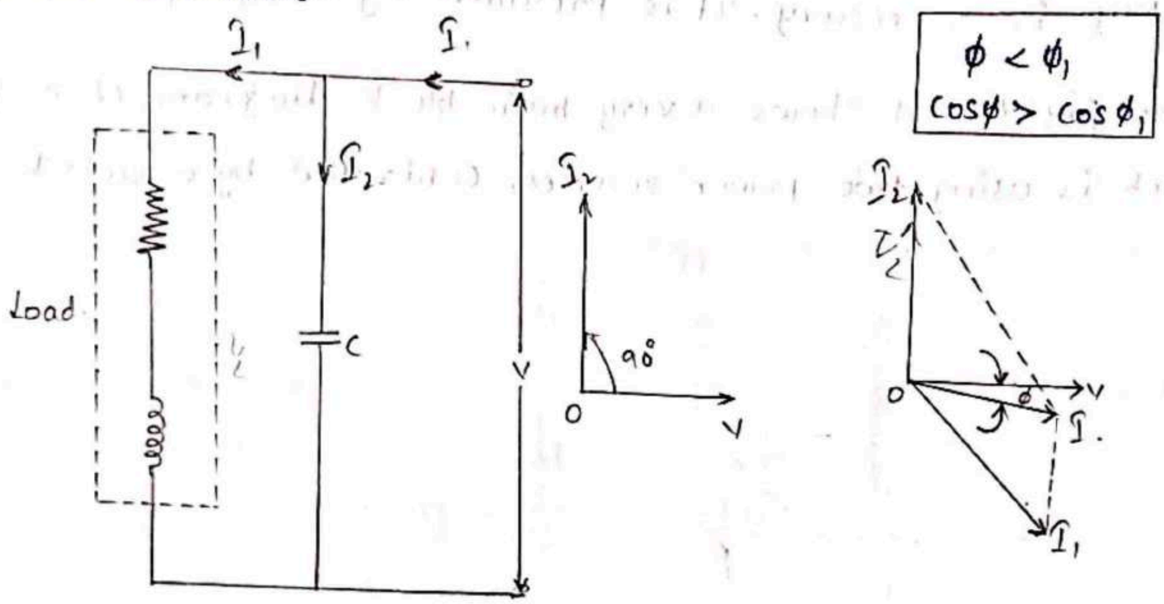
* This leading component of current I_2 tries to neutralize the lagging effect of I_1. Hence the resultant current becomes

as shown in the Fig Q.24.2(b).

* It can be seen that the effective power factor angle becomes ϕ. which is less than ϕ_1. Hence $\cos\phi$ is more than $\cos\phi_1$, thus there is improvement in the power factor of the system.

* The devices generally used to improve the power factor are,

1) Bank of Static Capacitors,
2) Synchronous condensers,
3) phase advancers.



—* **Battery Backups**— A battery backup device is an electronic device that supplies secondary power in the absence of the main power. It can also protect electronic hardware from power spikes and fluctuations.

The main battery backup device which is commonly used is called uninterruptible power supply [**UPS**].

Need of UPS:-

1. Most of the systems operate on a.c. supply, Thus a.c. supply failure causes periodical stoppage of the various systems.

2. Most of the modern systems use computers and micropr-occessors. Any interruption in the power supply may result into the loss of the work and may make system ineffecti-ve.

3. Many important places likes hospitals, temples, playing grounds, banks etc. require continuous supply for their efficient operation.

* To avoid all these adverse and serious situations, battery backup is necessary. It is provided by using ups.

* The Fig. Q.26.1 shows a very basic block diagram of an ups which is using two power sources, controlled by a switch.

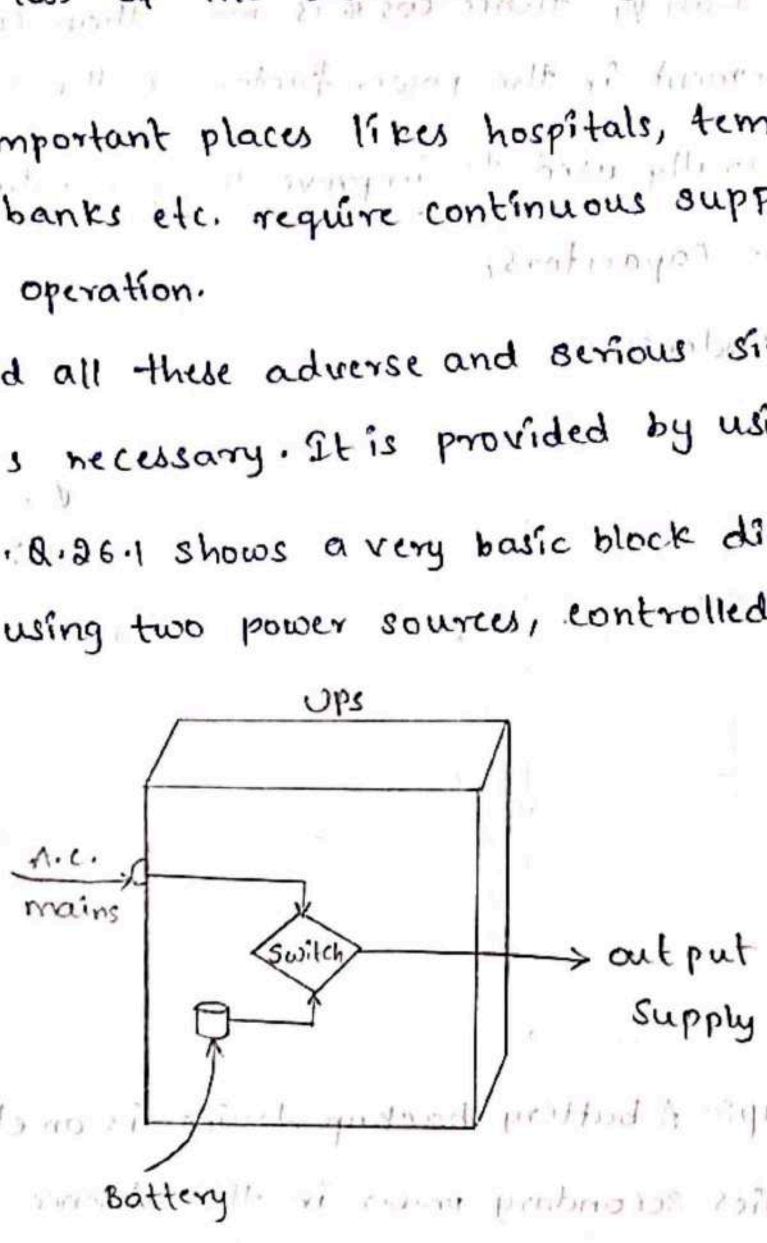


Fig. Q.26.1 Basic concept of Ups.

* The ups is designed so that there is one source of power, usede under normal conditions, known as.
Primary power source (usually a.c. mains) and other source that comes into action if the primary source is disrupted. This another sources is called the secondary power source. (usually battery). A switch is used as a controlling device. It changes from primary sources to secondary when it

detects that the primary source has failed. It automatica-lly switches back from the secondary power sources to the primary when it is detected that the primary source has returned to normal.

* The power available from mains is a.c. All batteries Provide d.c. Hence in UPS there UPS there is circuity to convert a.c to d.c for battery charging called a converter. Similarly there is a device converting d.c. from battery to a.c. as required by the load. This is called an inverter. These are important components of any UPS.

* The two types of UPS are: 1) on line UPS 2) off line UPS.

* The ON line UPS is also called true UPS. In this type of UPS, there are two power sources and a transfer switch that selects between them. The important feature of this UPS is that it uses the battery as its primary power source and a.c. mains power as its secondary power source.

* The Fig. Q.27.1 shows the block schematic of ON line UPS.

* under normal operations, the UPS is running off the battery while the line power runs the battery charger. The rectifier converts a.c. mains to d.c. and inverter converts d.c to a.c and is given to the load. Thus there are two conversions in this type of UPS hence it is called double conversion ON line UPS. As inverter is always working in normal conditions, it is also called inverter preferred. The normal operation path is shown by dark line in the Fig. Q.27.2.

* If the power goes out, the inverter and load continues to work on the battery. only the battery charger fails in such

a case. This path is shown in the Fig. Q.27.2 The time required by ups to transfor on battery is called transfer time which is important characteristics of ups. But in ON line

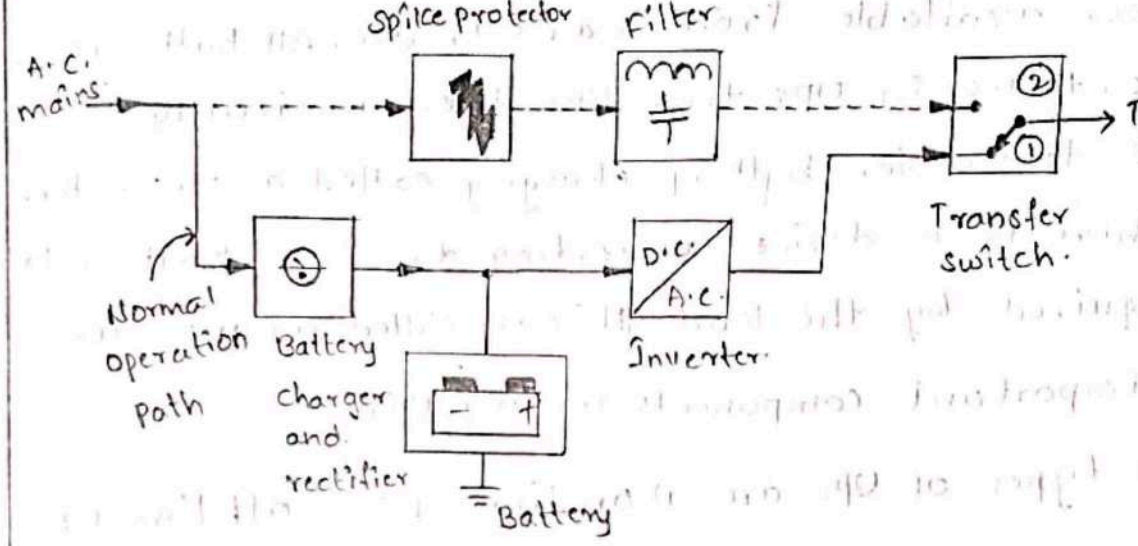


Fig. Q.27.1 Block schematic of ON line ups.

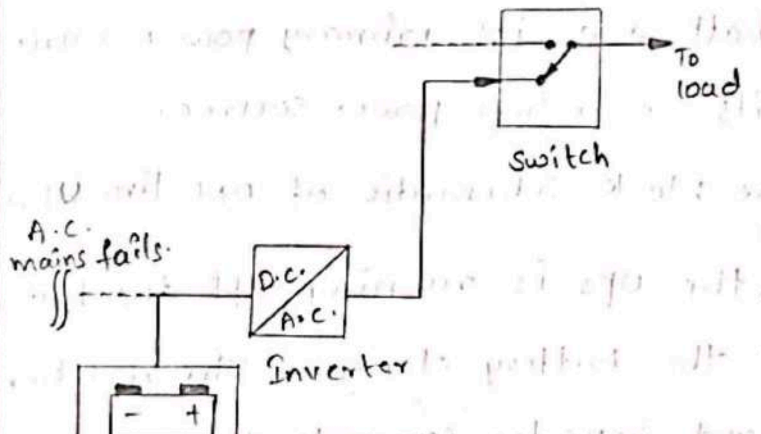


Fig. Q.27.2 Path when a.c. mains fails.

ups, there is no transfer time and ups instantly switches over to the battery when mains fails. The load keeps running without any kind of interruption. only beltery starts run down as there is no line power to charge it.

* Now let us understand the importance of the secondary power path. It is shown dashed in the Fig. Q.27.2. It comes into the action if the inverter fails. The transfer switch automatically changes from position 1 to position 2, to switch the load on a.c. mains. The spike protector protects the load from position 1 to position 2, to switch the load on a.c. mains. The spike protector protects the load from surges in line power and filters them out. In this switch over, transfer time is important which should be as small as possible. But in Practice, main power failures are much more common than the inverter failure.

* The important advantage of this UPS is, in normal condition the double conversion process totally isolates the output power from the input power. Any severe changes in main power affect the battery charger and not the output loads.

* The important consideration while designing ON line UPS is that converter (rectifier) and inverter are running 24 hours a day and so on. Hence quality of the components must be superior to avoid the inverter failure conditions. The size and cost of ON line UPS is more than other types of UPS.

* A part from cost, another disadvantage of ON line UPS is inefficiency. All the power reaching to the load is convered from a.c to d.c and back to a.c. Thus much of the power is dissipated as heat. This is happening all the time and not just when mains fails.

* The applications of ON line UPS are,
1) Network components such as gateways and bridges.
2) Tele communications systems.
3) voice mail and E-mails systems.
4) Test and diagnostic equipments.
5) Network Servers.
6) other critical electronic equipments.
* The ON line UPS are availables from 5000 VA upto hundreds of thousands of VA capacity.
* The OFF line UPS is also called Stand by UPS. In this type of UPS, the primary power source is the mains power and the secondary power sources is the battery.

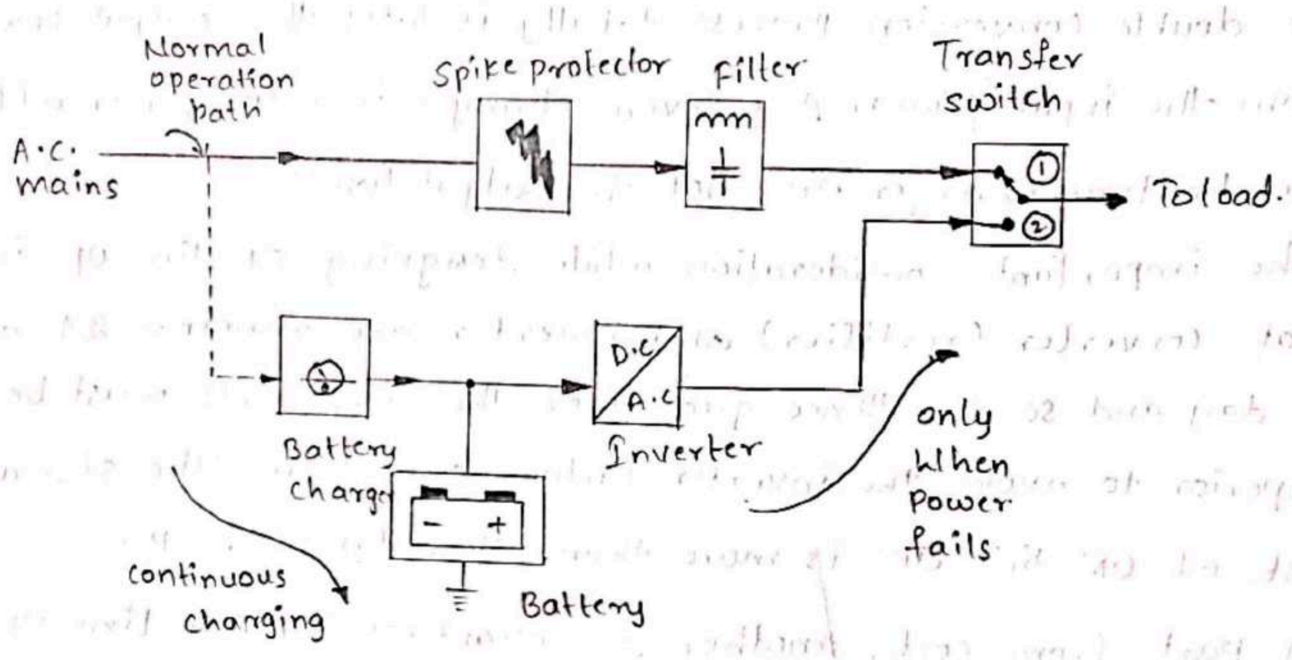


Fig. Q.29.1 Block Schematic of OFF line UPS.
* The Fig. Q.29.1 shows the blocks schematics of OFF line UPS.
* In this UPS, the battery and inverter are normally not supplying power to the load. The battery charger is using the line power to charge the battery but battery and inverter are waiting in standby mode till they are needed. Hence

the UPS is called standby UPS. As main line is primary Power source, it is also called line prefErred UPS.

* The spike protector and filter are used to filter the line noise and surges and to protect the loads from severs mains conditions.

* When the a.c. mains powers goes out, the transfer switch detects it and automatically switches from position 1 to 2. Thus battery starts supplying the load through inverter. This is shown in the Fig. Q.29.2 This path is similar to that of ON line.

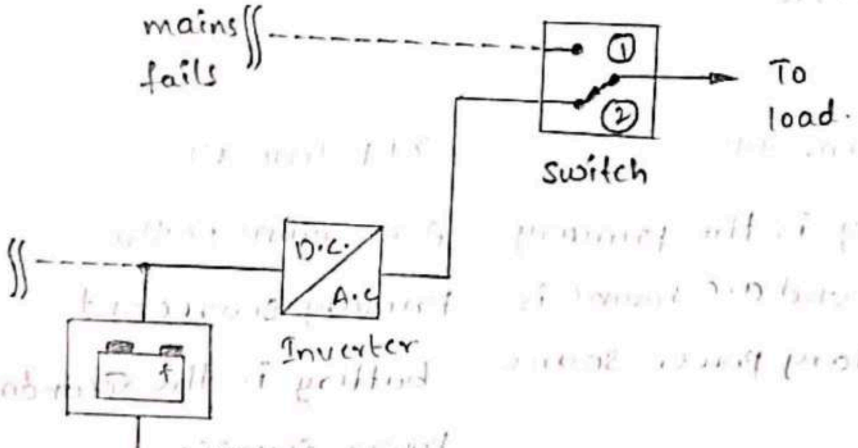


Fig. Q.29.2 path When a.c. mains fails.

UPS. The battery now starts run drown as there is no line power to charge it.

* As seen, every OFF line UPS requires a finite time to transfer the switch from position 1 to 2 and such a transfer can not happen instantly. This time is called transfer time or switch time. The units supplied from UPS have some holdup time means they can hold the power for fractions of seconds when mains fails.

Key point:- The transfer time of UPS must be much less than the holdup time.

* Thus transfer time is an important consideration in case of critical loads. The transfer time is in the range of ms to μs.
* The various applications of OFF line UPS are,

1) Work stations and peripherals.
2) Modems.
3) Office and home PCs.
4) Small desktop hubs.
5) Small business centers.
6) Switches

S.No	Parameter	ON line UPS	OFF line UPS.
1.	Operations	Battery is the primary source and a.c mains is secondary power source	A.c. mains is the primary source and battery is the secondary power source.
2.	Isolation	complete isolation between load and a.c. mains.	No isolation between load and a.c. mains.
3.	Reliability	Highest and transfer time is zero	Lower and transfer time is few m sec.
4.	Economy	High const	Low cost
5.	Size	Large size	Small size
6.	Efficiency	Less due to power dissipation	High efficiency.