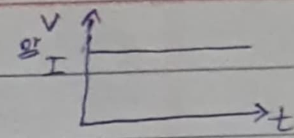
Diode → Anode → Cathode   anode ← cathode

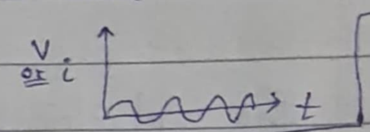
(on) short circuit (R=0)   (off) open circuit (R=∞)

DC Circuit

↳ magnitude & direction remains constant with time



AC Circuit → mag & dir changes with time



DC circuit → only R & source of energy, no L or C cuz they are freq dependent but DC circuit has const freq

Network → Maybe open or closed path

Circuit → Circuit always closed path

Circuit Element

Energy Source → Current or Voltage

Basic Circuit Parameter → R (Resistance), L (Inductor), C (capacitor)

Ⓡ Resistance → Opposes flow of current in circuit
→ Only basic circuit parameter which dissipates energy in form of heat.

rheostat (variable)

* Ohm's law → $V = IR$ ⇒ $I = \frac{V}{R}$
* for open circuit, $R = \infty$
* for short circuit, $R = 0$

Unit → ohm (Ω)

Ⓛ Inductor → Stores & releases energy but doesn't dissipate it

Voltage across inductor, $e = L\frac{dI}{dt}$ ⇒ $I = \frac{1}{L}\int e\,dt$

variable

Energy across inductor $= \frac{1}{2}LI^2$ (Magnetic energy)

Inductive reactance $x_L = \omega L = 2\pi\nu L$ [$\nu = f$ = frequency no. of cycle per second]

L = Inductance   Unit → Henry (H).

Ⓒ Capacitor → $I = \frac{dq}{dt}$, $q \propto V$ ⇒ $q = CV$ ⇒ $\boxed{V = \frac{q}{C}}$

Energy $= \frac{1}{2}CV^2$ (electrical energy) C = Capacitance

capacitive reactance $x_c = \frac{1}{\omega C}$ unit → Farad (F)

DC Circuit

Electrical Circuit - The electrical circuit may consist of one or more source of energy & no. of electrical parameters (RLC) connected in different ways.

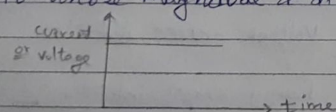
Network / Circuit Terminology.

① Network

* Any arrangement of the various electrical energy Sources along with the different circuit element is called an electrical network / circuit.

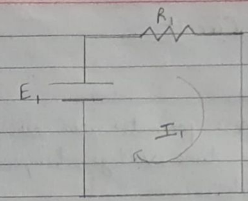
* The DC circuit consists of only resistance and DC source of energy and circuit analysis means to find a current through or voltage across any branch of the circuit

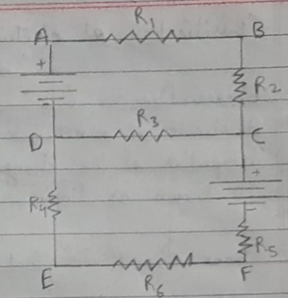
* DC circuit is a circuit whose magnitude & direction is constant w.r.t time.



② Network Element

* Any individual circuit element with two terminal which can be connected to other





i) Branch - * A part of the network which connects the various points of the network with one another is called a branch.

* AB, BC, CD, DA etc are various branch

* A branch may consist more than one element.

ii) Junction - * A point where three or more branches meet is called a junction point.

* Point C & D are junction point

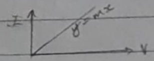
iii) Node * A point at which two or more elements are joined together is called node.

* Sometimes, junction points are also the nodes of the network.

* A, B, C etc are nodes

iv) Mesh or loop - A set of branches forming a close path

Classification of electrical Circuit



1> **Linear Circuit**

* A circuit or a network whose parameter are always constant irrespective of the change in time; voltage, temperature etc is known as linear network.

* Linear Circuit is that circuit which obeys ohm's law.

2> **Non-Linear Circuit**

* Non-linear circuit is that circuit which does not obey ohm's law.

3> **Bilateral Circuit**

* A circuit whose characteristics behaviour is same irrespective of the direction of current through various elements of it, is called bilateral circuit.

eg → Transmission lines

4> **Unilateral Circuit**

* A circuit whose characteristic behaviour changes with respective to the direction of current through various elements of it, is called Unilateral circuit.

eg → diodes

"Electric load is combination of RLC which demands current".

Energy Sources

There are basically two types of energy sources:

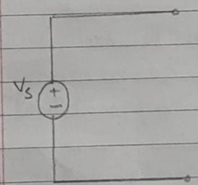
1> Voltage Source
2> Current Source

these are further classified as:

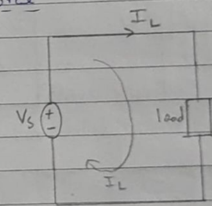
i> Ideal Source
ii> Practical Source

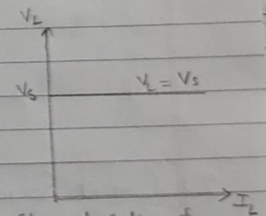
1> Voltage Source

i> Ideal Voltage Source



Symbol of DC voltage source





Characteristics of ideal voltage source

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

* Internal resistance of ideal voltage source is equal to zero i.e $\boxed{R_{se} = 0}$.

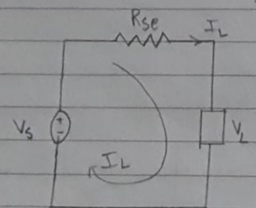
ii) Practical voltage Source

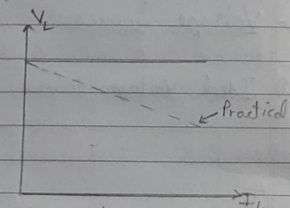
* Practically, every voltage Source has small internal resistance in Series with the voltage source and represented by R_{se}.

* Because of the R_{se}, voltage across terminals decreases slightly with increase in current and it is given by the expression,

$$\boxed{V_L = V_s - I_L R_{se}}$$

↳ voltage across resistance





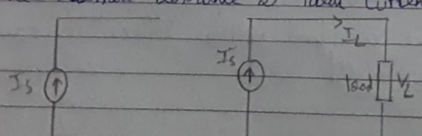
Voltage drop across the resistance

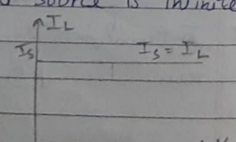
2) Current Source

i) Ideal current source

* Ideal current source is defined as which gives constant current at its terminal irrespective of the voltage appearing across its terminal.

** * The internal resistance of ideal current source is infinite $\boxed{R_{SH} = \infty}$

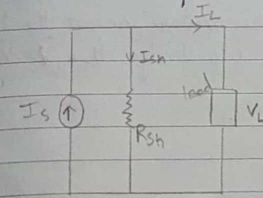


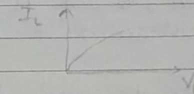


characteristics of ideal current source

ii) Practical current source

* Practically, every current source has high internal resistance which is connected in parallel with current source and represented by R_{SH}





Resistance

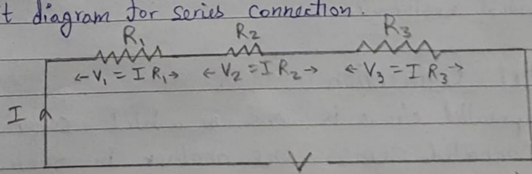
Connections of resistance

1) Series connection (series circuit)
2) Parallel connection (parallel circuit)

1) Series Connection

* A series circuit is one in which several resistances are connected one after the other such connection is also called end to end connection or cascade connection.
· There is only one path for the flow of current.

* Circuit diagram for series connection:



* A series circuit consist R_1, R_2, R_3 and the combination of this is connected across source of voltage (V) volts and the current flowing through all of them is (I) ampere

* Let V_1, V_2 and V_3 be the voltage across the terminals of resistance R_1, R_2 and R_3 respectively then $\boxed{V = V_1 + V_2 + V_3}$ → (1)

According to ohm's law,

$$V_1 = I R_1$$
$$V_2 = I R_2$$
$$V_3 = I R_3$$

and $V = I R$

Putting value of V, V_1, V_2, V_3 in eq (1)

$$IR = IR_1 + IR_2 + IR_3$$

$$\therefore \boxed{R = R_1 + R_2 + R_3}$$

* Characteristics of series circuit:

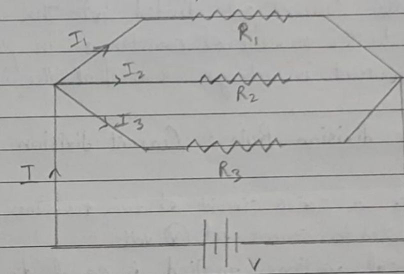
i) The same current flows through each resistance.

ii) The supply voltage (V) is the sum of the individual voltage drop across the resistance.

iii) The equivalent resistance is equal to the sum of the individual resistance

2) Parallel Connection

* The parallel circuit is one in which several resistances are connected across one another in such a way that one terminal of each is connected to form a junction point while the remaining ends are also joined to form another junction point.



* In parallel connection, the three resistances R_1, R_2 and R_3 are connected in parallel and this combination is connected across a source of voltage (V)

On applying ohm's law, $V = I_1 R_1$, $V = I_2 R_2$, $V = I_3 R_3$

and current $I = I_1 + I_2 + I_3$ — (1)

Total voltage of circuit is $V = IR$

Putting value of I, I_1, I_2, I_3 is eq^n (1)

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

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

* Characteristics of parallel circuit:

i) The same potential difference / voltage gets across all the resistance connected in parallel.

ii) The total current gets divided into the number of path equal to the number of resistances in parallel and the total current is always sum of all the individual currents

Voltage division Rule & Current division Rule

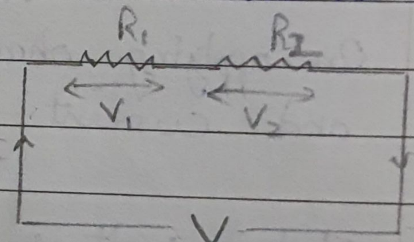
Voltage division rule - Consider a series circuit of two resistors R_1 and R_2 connected to source of V volts

The total voltage applied is equal to the sum of voltage drop, V_1 and V_2 i.e $V = V_1 + V_2$

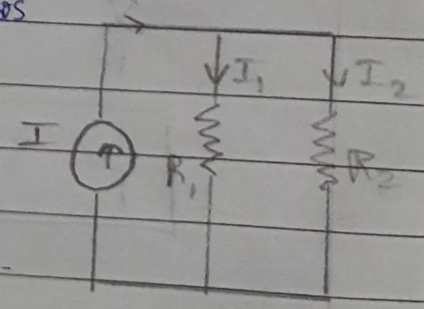
Using Voltage division rule, $V_1 = \text{total voltage} \times \dfrac{R_1}{\text{total resistance}}$

i.e $\boxed{V_1 = V \times \dfrac{R_1}{(R_1 + R_2)}}$

and voltage $\boxed{V_2 = V \times \dfrac{R_2}{(R_1 + R_2)}}$



Current division rule - Consider a parallel circuit of two resistors R_1 & R_2 and the total current of circuit is I where $I = I_1 + I_2$



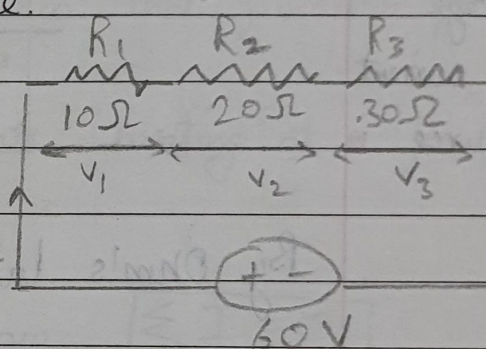
Using current division rule, $I_n = \text{total current} \times \dfrac{\text{opposite resistance}}{\text{total resistance}}$

$\therefore$ Current $\boxed{I_1 = I \times \dfrac{R_2}{(R_1 + R_2)}}$ → opp side ka resistance

and $\boxed{I_2 = I \times \dfrac{R_1}{(R_1 + R_2)}}$

Q) Find the voltage across three resistance.

Sol $\because R_1, R_2$ and R_3 are in series



$\therefore R = R_1 + R_2 + R_3$

$R = (10 + 20 + 30)\Omega$

$\boxed{R = 60\,\Omega}$

By ohm's law, $V = IR$

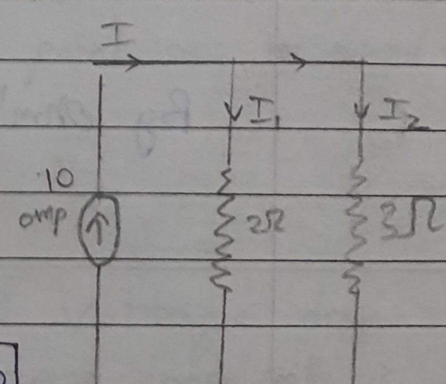
$$I = \frac{V}{R} = \frac{60}{60} = 1 \text{ ampere}$$

$V_1 = I R_1 = 1 \text{ ampere} \times 10\,\Omega = 10$ volt

$V_2 = I R_2 = 1 \text{ ampere} \times 20\,\Omega = 20$ volt

$V_3 = I R_3 = 1 \text{ ampere} \times 30\,\Omega = 30$ volt

Q) find value of current I_1 & I_2.



Sol By current division rule,

$I_1 = I \times \dfrac{R_2}{(R_1 + R_2)} = 10 \times \dfrac{3}{5}$

$\boxed{I_1 = 6 \text{ amp}}$

$I_2 = I \times \dfrac{R_1}{(R_1 + R_2)} = 10 \times \dfrac{2}{5} = \boxed{4 \text{ amp}}$

ohm's law = when all physical cond are const (temp & pressure), $V \propto I$

Current Source = Parallel resistors

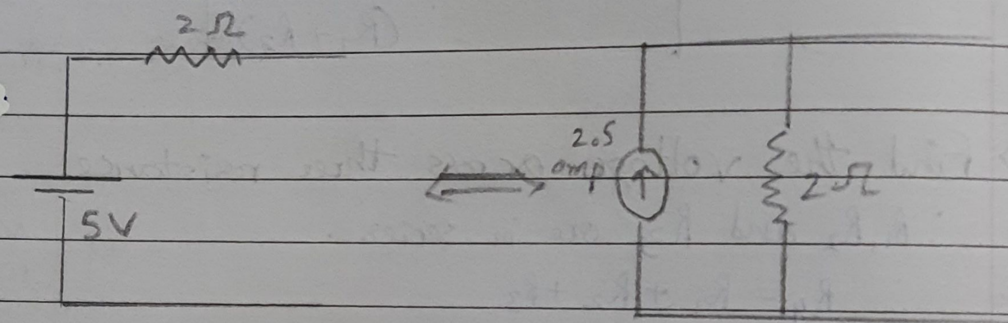
Voltage Source = Series resistors

** Source Conversion/ Transformation

When voltage source is converted into a current source or current source is converted into voltage source, it is called Source conversion / transformation

eg →

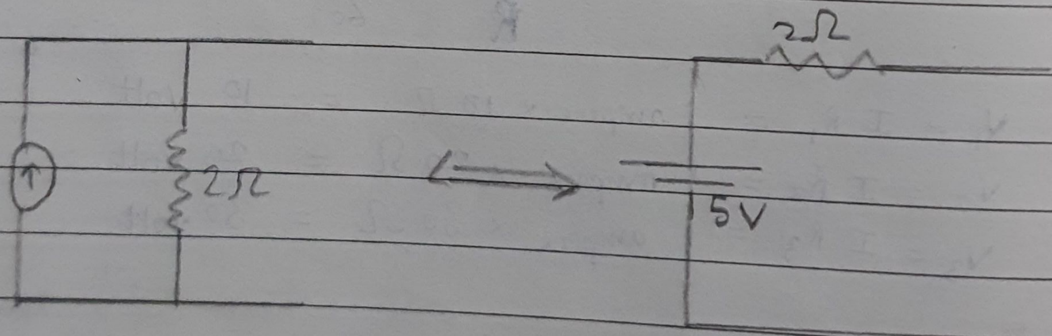
Voltage into current Source



By Ohm's law, $V = IR$

$$I = \frac{V}{R} = \frac{5}{2} = \boxed{2.5 \text{ amp}}$$

Current into voltage Source



By ohm's law, $V = IR = 2.5\,(2)$

$$\boxed{V = 5\,V}$$

emf | electro motive force → responsible for flow of current
↳ voltage / Potential diff

Camlin Page
Date / /

★ Kirchoff's Law

1) Kirchoff's Current law (KCL) Nodal analysis
2) Kirchhoff's Voltage law (KVL) Mesh analysis

① Kirchhoff's Current Law

Incoming current = Outgoing current

* The total current flowing towards a junction point is equal to the total current flowing away from that junction point

OR

* The algebraic sum of all the currents meeting at a junction point is always zero.

* Mathematical form of kirchhoff's current law, $\boxed{\sum I = 0}$

* The application of kirchhoff's current law is Nodal analysis.

* Sign convention for KCL:
  → Current flowing towards a junction point are assumed to be positive
  → Current flowing away from a junction point are assumed to be negative

② Kirchhoff's Voltage Law

* In any network, the algebraic sum of voltage drop across the circuit element of any closed loop/path is equal to the algebraic sum of the e.m.f in the path.

Diffs b/w KVL & KCL
* eq^n in KVL = no. of loops
  eq^n in KCL = $(n-1)$ n = no. of nodes
* KVL → closed loop necessary

OR

* The algebraic sum of all of the branch voltages around any closed path or closed loop is always zero.

* Mathematical form of KVL is $\boxed{\Sigma V + IR = 0}$
  or $\boxed{\Sigma V = 0}$

* The application of KVL is Loop / Mesh analysis

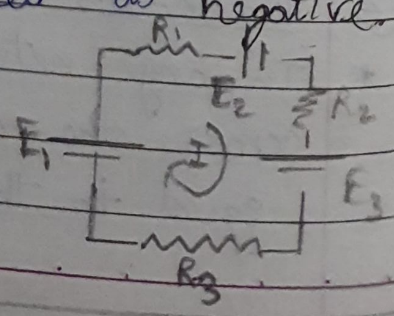
* Sign convention for KVL:
  → When current flows through a resistance, the voltage drop occurs across the resistance, the polarity of this voltage drop always depends on direction of the current, the current always flows from higher potential to lower potential.

  → Potential rise : travelling from negative to positively marked terminal must be considered as positive.

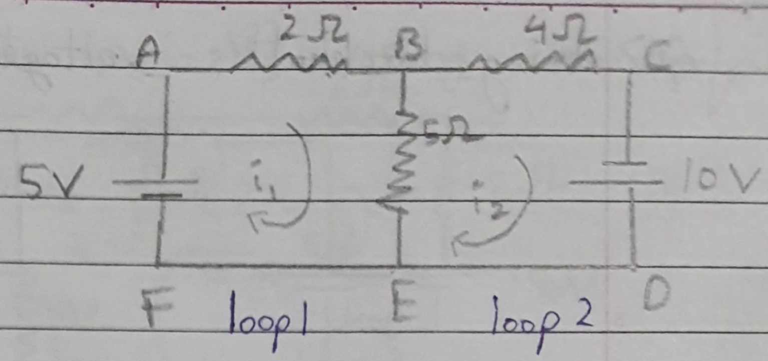
  → Potential drop : travelling from positive to negatively marked terminal must be considered as negative.

eg →

$$\Sigma V = +E_1 - IR_1 - E_2 - IR_2 - E_3 - IR_3 = 0$$



Q> Find current i_1 and i_2



loop①, $+5V - 2i_1 - 5(i_1 - i_2) = 0$

$$5V - 2i_1 - 5i_1 + 5i_2 = 0$$

$$\boxed{-7i_1 + 5i_2 + 5 = 0} \quad (1)$$

loop②, $+10 - 5(i_2 - i_1) - 4i_2 = 0$

$$10 - 5i_2 + 5i_1 - 4i_2 = 0$$

$$\boxed{5i_1 - 9i_2 + 10 = 0} \quad (2)$$

$$-35i_1 + 25i_2 + 25 = 0$$

$$35i_1 - 63i_2 + 70 = 0$$

$$-38i_2 + 95 = 0$$

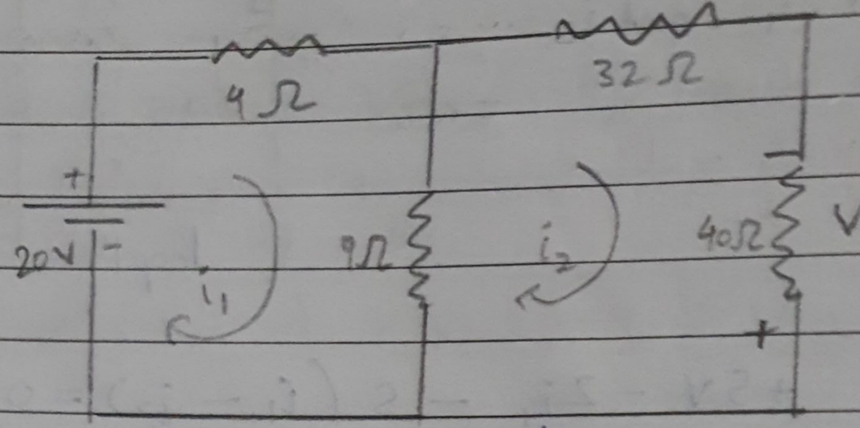
$$\boxed{i_2 = \frac{95}{38} \text{ amp}}$$

$$5i_1 = 9i_2 - 10$$

$$i_1 = \frac{1}{5}\left[9 \times \frac{95}{38} - 10\right] = \frac{1}{5}\left[\frac{855-380}{38}\right] = \frac{475}{190} = \frac{95}{38}$$

$$\boxed{i_1 = \frac{95}{38} \text{ amp}}$$

Q> Using Kirchhoff's voltage law, find voltage V.



loop 1 loop 2

loop 1, $20 - 4i_1 - 9(i_1 - i_2) = 0$

$20 - 4i_1 - 9i_1 + 9i_2 = 0$

$\boxed{-13i_1 + 9i_2 + 20 = 0}$ (1)

loop 2, $-9(i_2 - i_1) - 32i_2 - 40i_2 = 0$

$-9i_2 + 9i_1 - 72i_2 = 0$

$+9i_1 - 81i_2 = 0$

$\cancel{i_2 = \frac{9i_1}{17}}$

$9i_1 = 81i_2$

$\boxed{i_1 = 9i_2}$ (2)

∴ eq(1) becomes,

$-117i_2 + 9i_2 + 20 = 0$

$-108i_2 = -20$

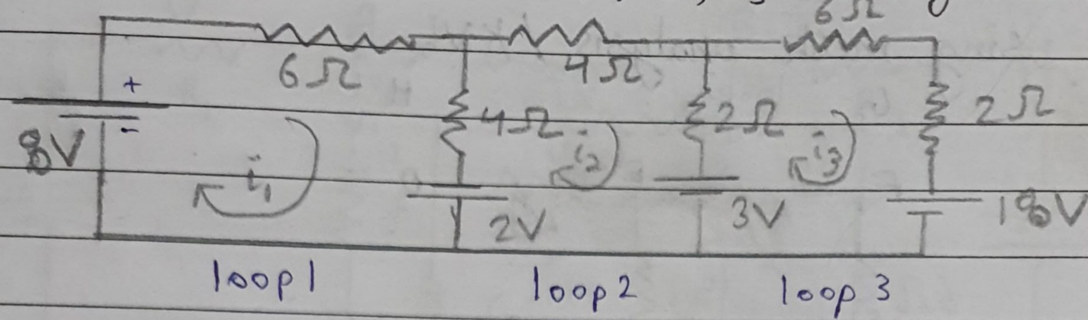
$\boxed{i_2 = 0.185 \text{ amp}}$

∵ $V = 40i_2$

$V = 40(0.185)$

$\boxed{V = 7.4 \text{ volt}}$

Q> Calculate the mesh current i_1, i_2, i_3 using mesh analysis



Sol) Using KVL,

loop 1, $+8 - 6i_1 - 4(i_1 - i_2) + 2 = 0$

$-6i_1 - 4i_1 + 4i_2 + 10 = 0$

$\boxed{-10i_1 + 4i_2 + 10 = 0}$ — (1)

loop 2, $-2 - 4(i_2 - i_1) - 4i_2 - 2(i_2 - i_3) - 3 = 0$

$-5 - 4i_2 + 4i_1 - 4i_2 - 2i_2 + 2i_3 = 0$ — (2)

$\boxed{4i_1 - 10i_2 + 2i_3 - 5 = 0}$ (2)

loop 3, $+3 - 2(i_3 - i_2) - 6i_3 - 2i_3 - 18 = 0$

$-15 - 2i_3 + 2i_2 - 8i_3 = 0$

$\boxed{2i_2 - 10i_3 - 15 = 0}$ — (3)

Solving eq (2) & (3)

$4i_1 - 10i_2 + 2i_3 - 5 = 0$

$+10i_2 - 50i_3 - 75 = 0$

$4i_1 - 48i_3 - 80 = 0$ — (4)

Solving eq (1) & (2)

$-25i_1 + 10i_2 + 25$

$4i_1 - 10i_2 - 5 + 2i_3 = 0$

$-21i_1 + 20 + 2i_3 = 0$ — (5)

On Solving (4) & (5)

$\boxed{i_1 = 0.8 \text{ amp}}$

from (4),

$i_3 = \frac{i_1 - 20}{12}$

$\boxed{i_3 = -1.6 \text{ amp}}$

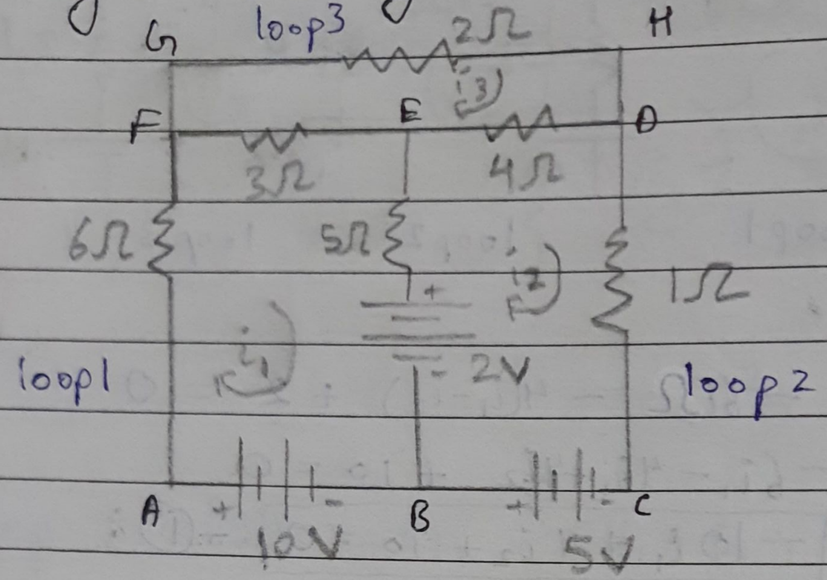
From (1),

$i_2 = \frac{5}{2}(i_1 - 1)$

$\boxed{i_2 = -0.5 \text{ amp}}$

0.8, -0.5, -1.6

Q) Calculate the current in each branch of network using mesh analysis / KVL



Using KVL,

loop 1, $-6i_1 - 3(i_1 - i_3) - 5(i_1 - i_2) - 2 + 10 = 0$

$-6i_1 - 3i_1 + 3i_3 - 5i_1 + 5i_2 + 8 = 0$

$\boxed{-14i_1 + 5i_2 + 3i_3 + 8 = 0}$ — (1)

loop 2, $+2 - 5(i_2 - i_1) - 4(i_2 - i_3) - 1i_2 + 5 = 0$

$-5i_2 + 5i_1 - 4i_2 + 4i_3 - 1i_2 + 7 = 0$

$\boxed{5i_1 - 10i_2 + 4i_3 + 7 = 0}$ — (2)

loop 3, $-2i_3 - 3(i_3 - i_1) - 4(i_3 - i_2) = 0$

$-2i_3 - 3i_3 + 3i_1 - 4i_3 + 4i_2 = 0$

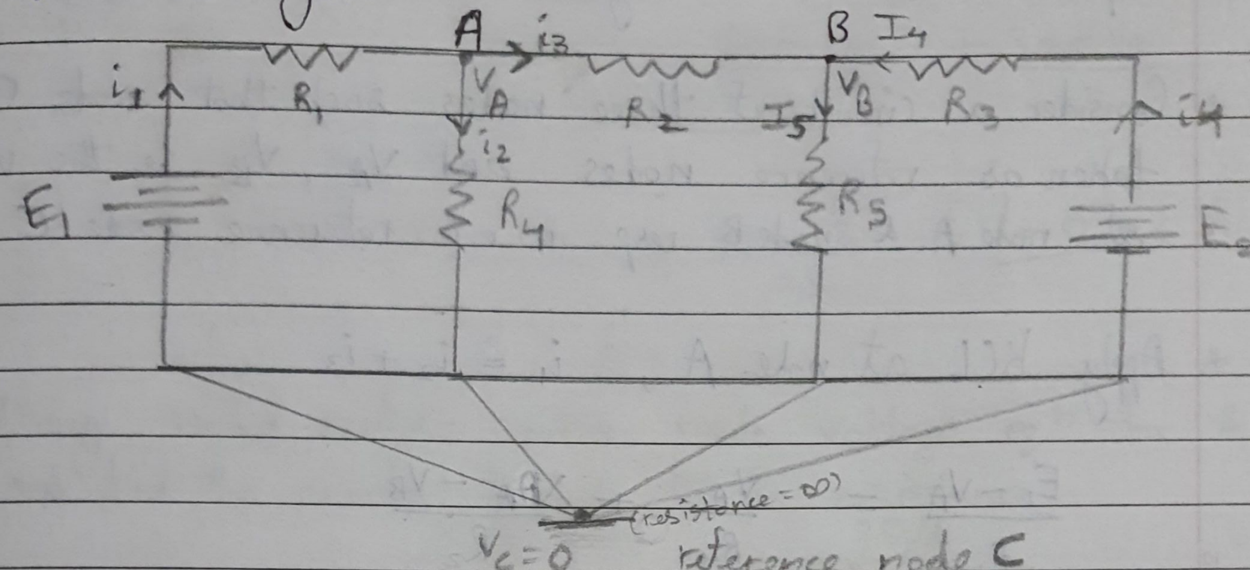
$\boxed{3i_1 + 4i_2 - 9i_3 = 0}$ — (3)

From eq (1), (2) & (3)

$\boxed{i_1 = 1.64 \text{ amp}, \quad i_2 = 2.12 \text{ amp}, \quad i_3 = 1.49 \text{ amp}}$

→ Circuit mai node ko count karke KCL lagate hai = Nodal analysis
→ Calc of nodal analysis is easier than mesh analysis

** Nodal Analysis



* For application of node voltage theorem (KCL) one of the node is taken as reference or zero potential or datum node and the potential difference between each of the other & the reference node is expressed in terms of an unknown voltage. (V_A, V_B)

* At every node KCL is applied assuming the possible direction of branch current.

* Node voltage theorem reduces the no. of equations to be solved to determine the unknown quantities.

* If there are (n) no. of nodes there shall be (n−1) no. of nodal eqⁿ in terms of (n−1) no. of unknown variables or nodal voltages

Explanation of nodal analysis:

* Consider a circuit of three nodes such that node C is taken as reference nodes and V_A, V_B be the voltages of node A & node B resp w.r.t reference node C.

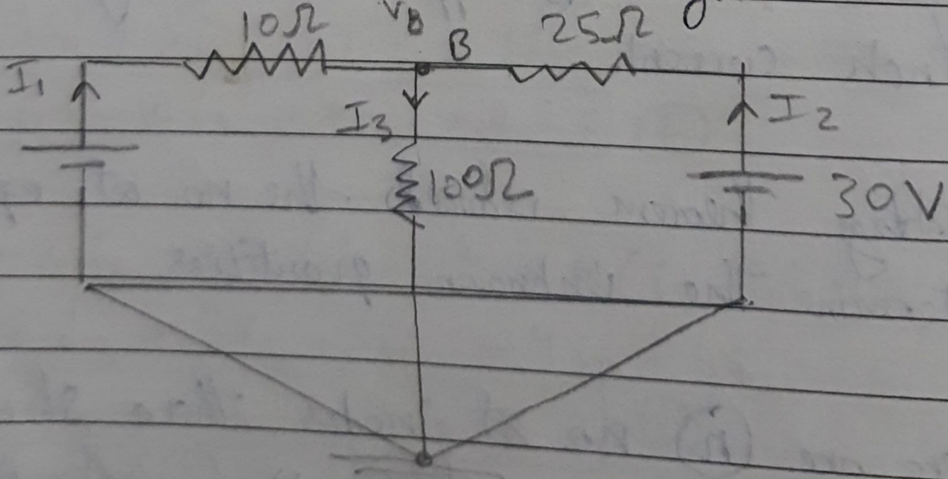
* Apply KCL at node A, $i_1 = i_2 + i_3$

$$\frac{E_1 - V_A}{R_1} = \frac{V_A}{R_4} + \frac{V_A - V_B}{R_2}$$

Apply KCL at node B, $i_5 = i_4 + i$

$$\frac{E_2 - V_B}{R_3} + \frac{V_B - V_A}{R_2} = \frac{V_B}{R_5}$$

Q> Using Nodal analysis, write node voltage eq^n for the circuit and find the current through $25\,\Omega$ resistance.



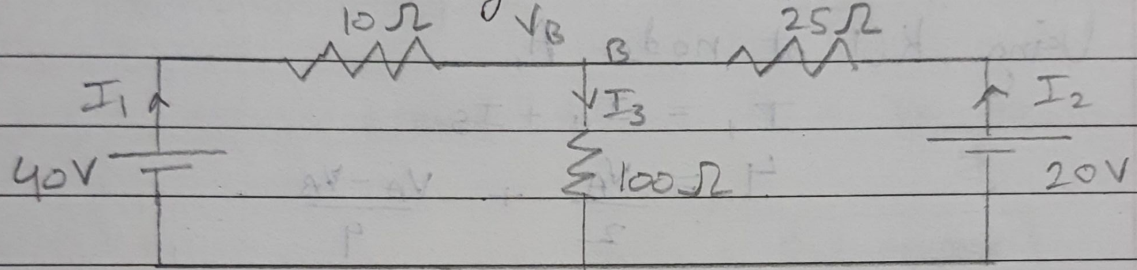
Applying KCL at node (B), $I_3 = I_1 + I_2$

$$\frac{V_B}{100} = \frac{60 - V_B}{10} + \frac{30 - V_B}{25}$$

$$\boxed{V_B = 48\,V}$$

$$I_2 = \frac{30 - V_B}{25} = \frac{30 - 48}{25} = \boxed{-0.72\ A}$$

Q) Using nodal analysis write node voltage eq^n for the circuit and find the current through 25 Ω resistance.



6) Applying KCL at node (B), $I_3 = I_1 + I_2$

$$\frac{V_B}{100} = \frac{40 - V_B}{10} + \frac{20 - V_B}{25}$$

$$\frac{V_B}{100} = \frac{1000 - 25V_B + 200 - 10V_B}{250}$$

$$5V_B = 2000 - 50V_B + 400 - 20V_B$$

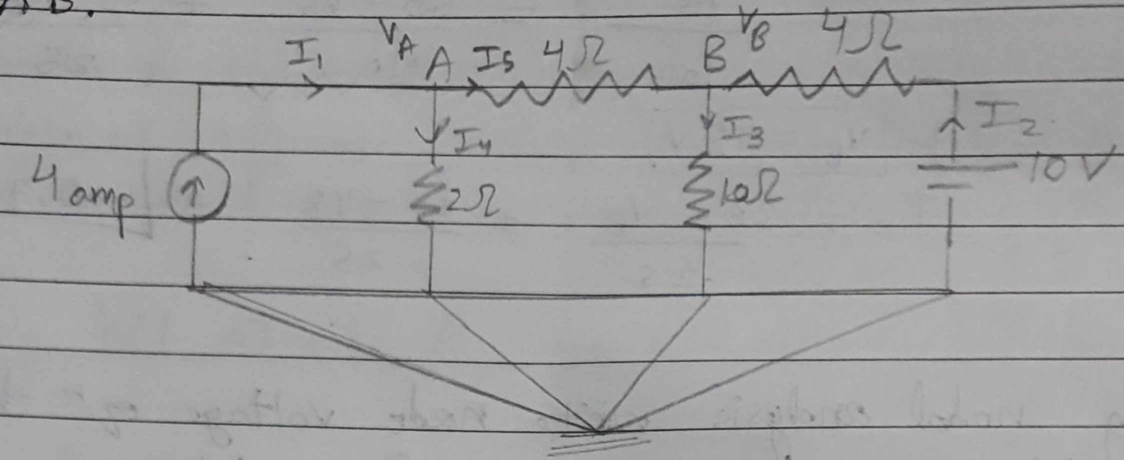
$$75V_B = 2400$$

$$\boxed{V_B = 32\ \text{volt}}$$

Current through 25 Ω, $I_2 = \frac{20 - V_B}{25} = \frac{20 - 32}{25} = \frac{-12}{25}$

$$\boxed{I_2 = -0.48\ A}$$

Q) Using nodal analysis determine current through branch AB.



Using KCL at node A,

$$I_1 = I_4 + I_5$$

$$4 = \frac{V_A}{2} + \frac{V_A - V_B}{4}$$

$$4 = \frac{2V_A + V_A - V_B}{4}$$

$$16 = 3V_A - V_B$$

$$\cancel{V_B = \frac{3V_A}{16}} \qquad \boxed{V_A = \frac{16 + V_B}{3}}$$

Using KCL at node B,

$$I_5 + I_2 = I_3$$

$$\frac{V_A - V_B}{4} + \frac{10 - V_B}{4} = \frac{V_B}{10}$$

$$\frac{V_A - V_B + 10 - V_B}{4} = \frac{V_B}{10}$$

$$\frac{V_A - 2V_B + 10}{2} = \frac{V_B}{5}$$

$$5V_A - 10V_B + 50 = 2V_B$$

$$5V_A - 12V_B + 50 = 0$$

$$\frac{5(16 + V_B)}{3} - 12V_B = -50$$

$$\frac{80 + 5V_B - 36V_B}{3} = -50$$

$$80 - 31V_B = -150$$

$$-31V_B = -230$$

$$\boxed{V_B = 7.4 \text{ volt}}$$

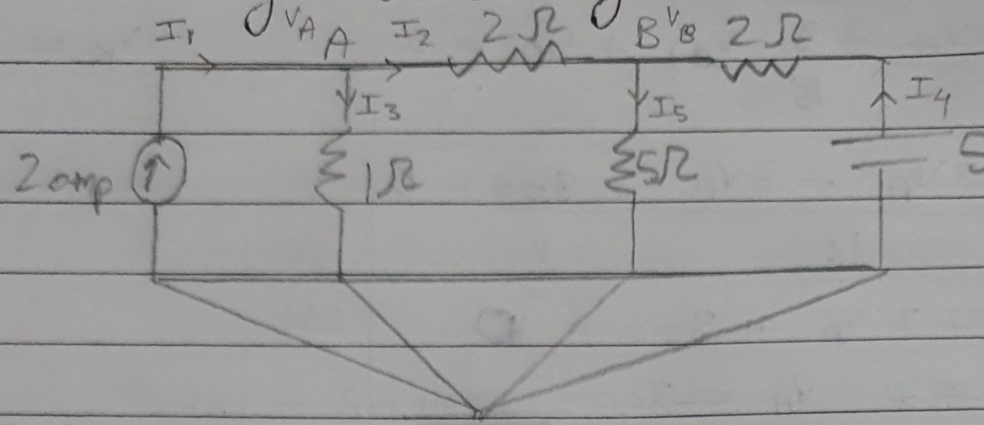
$$V_A = \frac{16 + V_B}{3} = \frac{16 + 7.4}{3}$$

$$\boxed{V_A = 7.8}$$

Current through branch AB is $I_S = \frac{V_A - V_B}{4} = \frac{7.8 - 7.4}{4} = \frac{0.4}{4}$

$$\boxed{I_S = 0.1 \text{ ampere}}$$

Q> Determine the current through branch AB through circuit using nodal analysis.



Using KCL at node A, $I_1 = I_2 + I_3$

$$2 = \frac{V_A - V_B}{2} + \frac{V_A}{1}$$

$$2 = \frac{V_A - V_B + 2V_A}{2}$$

$$4 = 3V_A - V_B \quad -(1)$$

$$\boxed{V_A = \frac{4 + V_B}{3}}$$

Using KCL at node B, $I_2 + I_4 = I_5$

$$\frac{V_A - V_B}{2} + \frac{5 - V_B}{2} = \frac{V_B}{5}$$

$$\frac{V_A - V_B + 5 - V_B}{2} = \frac{V_B}{5}$$

$$5V_A - 10V_B + 25 = 2V_B$$

$$5V_A - 12V_B = -25$$

eq(1),
$$36V_A - 12V_B = 48$$

$$\underset{-}{} \quad \underset{+}{} \quad \underset{-}{}$$

$$-31V_A = -73$$

$$V_A = \frac{73}{31}$$

$$\boxed{V_A = 2.35 \text{ volt}}$$

from (1),

$$V_B = 3V_A - 4$$

$$V_B = 3(2.35) - 4 = 7.05 - 4$$

$$\boxed{V_B = 3.05 \text{ volt}}$$

Current through branch AB is $I_2 = \frac{V_A - V_B}{2}$

$$I_2 = \frac{2.35 - 3.05}{2} = \frac{-0.7}{2}$$

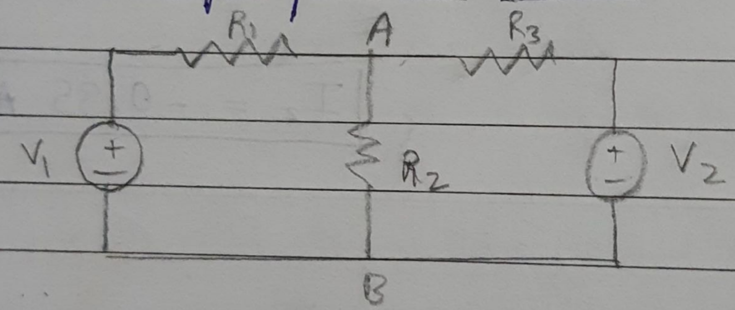
$$\boxed{I_2 = -0.35 \text{ A}}$$

linear & bilateral
atleast 2 energy sources
total response / effect = algebraic sum of individual effects
$I = I_1 + I_2 + I_3 + \ldots$

IMP Super Position Theorem

Super Position Theorem states "In any multi source network consisting of linear bilateral element, the voltage across or current through any given element of the network is equal to the algebraic sum of the individual voltages or currents, produced independently across or in that element by each source acting independently when all the remaining sources are replaced by their respective internal resistance

Explanation of Super position theorem



Consider a network having two voltage sources V_1, V_2 lets calculate the current in branch AB of the network using Super position theorem.

Step 1) * According to super position theorem consider each source independently. Let the source* V_1 volts act independently at this time the other source must be replaced by internal resistance.

* But ∵ internal resistance of V_2 is not given, the

Current source ka response ... voltage / current

Note ★ If the internal resistance of source is unknown then the independent voltage sources must be replaced by short circuit while the independent current source must be replaced by an open circuit.

Source V_2 must be replaced by short circuit.

Obtain I_{AB} due to only source V_1.

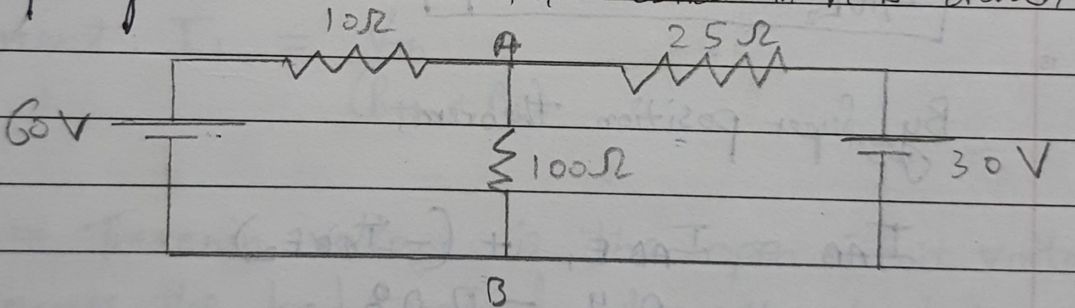
step 2> Now consider source V_2 volts alone with V_1 replaced by a short circuit to obtain the current through branch AB.

Obtain I_{AB} due to only V_2.

step 3> According to super position theorem, the total current through branch AB is the sum of the currents produced by each source acting independently.

$$I_{AB} = I_{AB} \text{ due to } V_1 + I_{AB} \text{ due to } V_2$$

Q> Using super position theorem, find current in AB branch.



Ans Due to E_1 i.e 60V

$$I_{total\,E_1} = \frac{E_1}{R_{total}} = \frac{60}{10 + \frac{(100 \times 25)}{100+25}} = \frac{60}{30}$$

$$\boxed{I_{total\,E_1} = 2 \text{ amp}}$$

Using current division ; $I_{100\Omega \text{ due to } E_1} = \frac{I_{total\,E_1}}{R_{total}} \times 25\,\Omega$

$$I_{100\Omega \text{ due to } E_1} = \frac{2}{\cancel{500}\ \cancel{125}_{5}} \times \cancel{25}$$

$$I_{100\Omega \text{ due to } E_1} = 0.4 \text{ amp}$$

Due to E_2 i.e 30V

$$I_{total E_2} = \frac{E_2}{R_{total}} = \frac{30}{25 + \left(\frac{100 \times 10}{110}\right)} = \frac{30}{34.09}$$

$$\boxed{I_{total E_2} = 0.88 \text{ amp}}$$

By current division rule,

$$I_{AB E_2} = \frac{I_{total E_2} \times 10}{R_{total}} = \frac{0.88 \times 10}{110}$$

$$\boxed{I_{AB E_2} = 0.08 \text{ amp}}$$

By Super position theorem,

$$I_{AB} = I_{AB E_1} + (-I_{AB E_2})$$

$$= 0.4 - 0.08$$

$$\boxed{I_{AB} = 0.32 \text{ amp}}$$

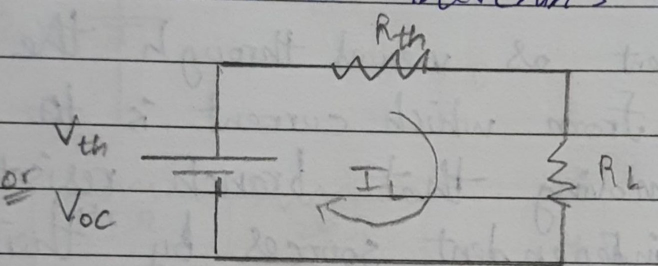
V_{th}, R_{th} ka R_L ke sath series mae circuit ko th circuit kehete hai

Sare energy sources ko deactivate karne par jo resistance milta hai we R_{th} kehta hai

IMP ★★★ Thevenin's Theorem

Thevenin's theorem states that "Any two terminal linear bilateral network can be replaced by their equivalent circuit and that equivalent circuit consists of one thevenin's voltage V_{th} or V_{oc} (open circuit voltage) in series with R_{th} (thevenin's resistance) & R_L (load resistance).

Equivalent circuit of thevenin's theorem:-



load current, $I_L = \dfrac{V_{th}}{(R_{th} + R_L)}$

Note → ① V_{th} = Thevenin voltage is the open circuit voltage that appears across the load terminal when the load is removed or disconnected

② R_{th} = Thevenin's equivalent resistance is equal to the resistance of the network looking back into the low terminal

Easiest → KVL

Jab Load resistance ko remove karte hai tab V_{th} milta hai

R_{th} nikalne ke liye imaginary current flow karate hai

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Date / /

Steps to apply thevenin's theorem:

Step 1> Remove the branch resistance (load resistance) through which current is to be calculated.

Step 2> Calculate the voltage across these open circuited terminals by using any of the network simplification techniques. This is V_{th} or V_{oc}.

Step 3> i) Calculate Requivalent as viewed through the two terminals of the branch from which current is to be calculated by removing that branch resistance and replacing all independent sources by their internal resistance.

ii) If the internal resistances are not known then replace voltage sources by short circuit (ideal voltage source) and independent current sources (ideal current source) by open circuit.

Step 4> Draw the thevenin's equivalent showing source V_{th} with the resistance R_{eq} or R_{th} in series.

Step 5> Reconnect the branch resistance (load resistance). The required current through the branch is given by

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

i.e load current.

$\frac{1}{4} + \frac{1}{24} = \frac{24 \times 4}{24+4} = \frac{96}{28}$

Q) Find the thevenin's equivalent across 16 Ω resistor and hence find the current through it

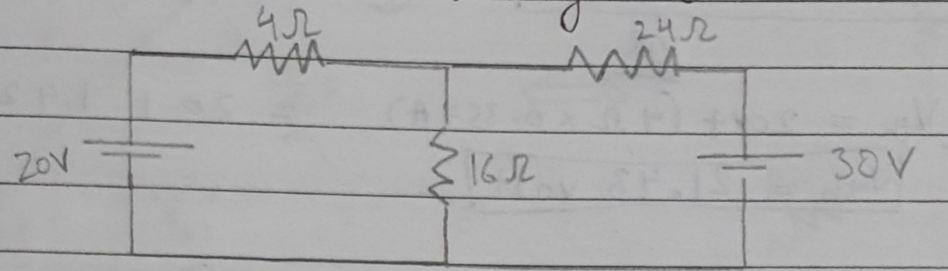


Fig 1

⇓

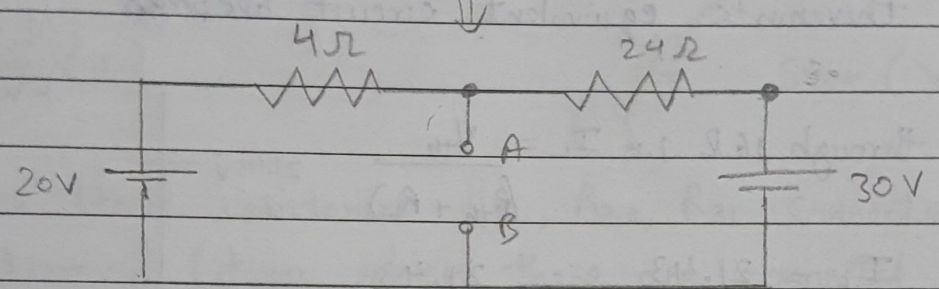
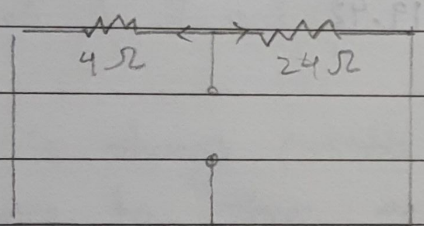


Fig 2

For R_{th},



4Ω and 24Ω are in parallel

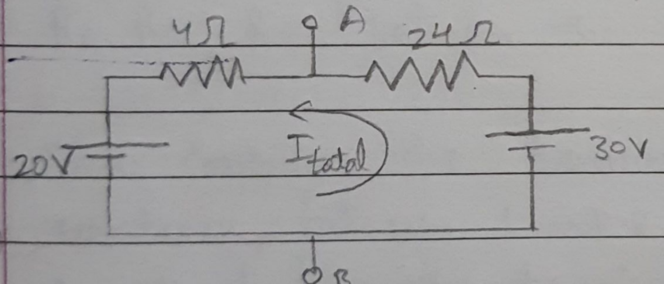
$\therefore \frac{1}{R_{th}} = \frac{1}{4} + \frac{1}{24}$

$\frac{1}{R_{th}} = \frac{24+4}{24 \times 4} = \frac{28}{96}$

$R_{th} = \frac{96}{28}$

$\boxed{R_{th} = 3.42\ \Omega}$

(current from high to low potential)



Applying KVL in fig 3

~~I_{total}~~ $+30 - 24I - 4I - 20 = 0$

$10 - 28I = 0$

$I = \frac{10}{28}$

$\boxed{I_{total} = 0.357\ A}$

$V_{th} = 30 - (24 \times 0.357) = 30 - 8.568$

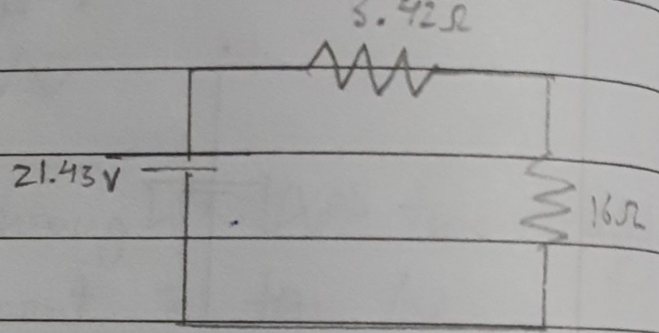
$\boxed{V_{th} = 21.43 \text{ volt}}$

OR

$V_{th} = 20V + (4\,\Omega \times 0.357\,A) = 20 + 1.428$

$\boxed{V_{th} = 21.43 \text{ volt}}$

$\therefore$ The thevenin's equivalent circuit becomes

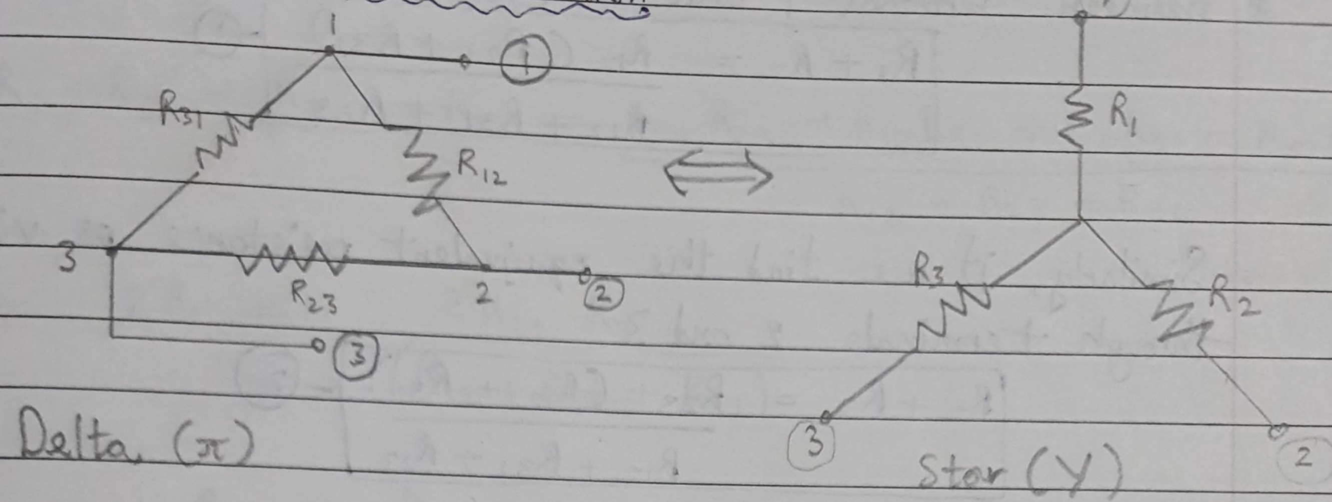


Load Current through 16Ω i.e. $I_L = \dfrac{V_{th}}{(R_{th} + R_L)}$

$I_L = \dfrac{21.43}{3.42 + 16} = \dfrac{21.43}{19.42}$

$\boxed{I_L = 11.03\,A}$

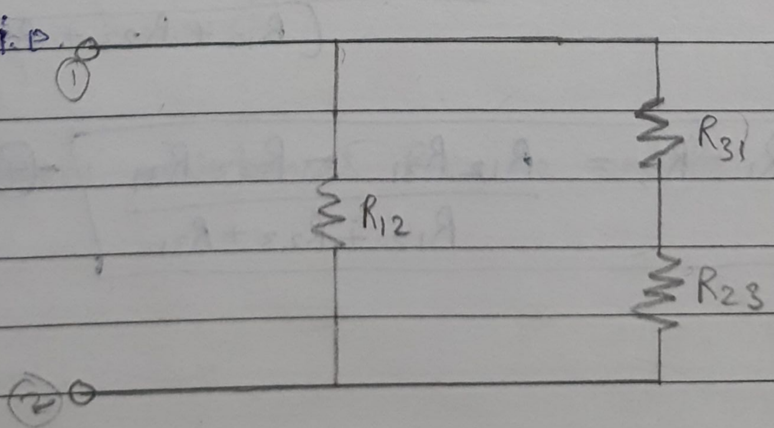
Delta - Star transformation



* Consider three resistances R_{12}, R_{23}, R_{31} connected in delta, the terminal between which these are connected in delta are named as 1, 2 and 3.

* Now it is always possible to replace these delta connected resistance by three equivalent star connected resistance, R_1, R_2, R_3 between the same terminals 1, 2 and 3.

* Now consider the terminals 1 and 2 let's find equivalent resistance between 1 and 2 we can redraw the network as viewed from the terminals 1 and 2 without considering terminal 3. i.e.



$R_{12} \parallel (R_{31} + R_{23})$

* Between terminal 1 and 2, the resistance is $R_1 + R_2$

$$\boxed{R_1 + R_2 = \frac{R_{12}(R_{23} + R_{31})}{R_{12} + R_{31} + R_{23}}} \quad -(1)$$

Similarly, if we find the equivalent resistance as viewed through terminals 2 and 3

$$\boxed{R_2 + R_3 = \frac{R_{23}(R_{12} + R_{31})}{R_{12} + R_{31} + R_{23}}} \quad -(2)$$

Similarly, equivalent resistance as viewed through terminals 1 and 3,

$$\boxed{R_1 + R_3 = \frac{R_{31}(R_{23} + R_{12})}{R_{12} + R_{31} + R_{23}}} \quad -(3)$$

Subtract eq (2) from eq (1)

$$R_1 + R_2 - R_2 - R_3 = \frac{R_{12}(R_{23} + R_{31})}{(R_{12} + R_{31} + R_{23})} - \frac{R_{23}(R_{12} + R_{31})}{(R_{12} + R_{31} + R_{23})}$$

$$R_1 - R_3 = \frac{R_{12}R_{23} + R_{12}R_{31} - R_{12}R_{23} - R_{23}R_{31}}{(R_{12} + R_{23} + R_{31})}$$

$$\boxed{R_1 - R_3 = \frac{R_{12}R_{31} - R_{23}R_{31}}{R_{12} + R_{23} + R_{31}}} \quad -(4)$$

$$\frac{1}{R_1+R_2} = \frac{1}{R_{12}} + \frac{1}{R_{31}+R_{23}}$$

$$\frac{1}{R_1+R_2} = \frac{R_{31}+R_{23}+R_{12}}{R_{12}(R_{31}+R_{23})}$$

Adding eq (3) & (4)

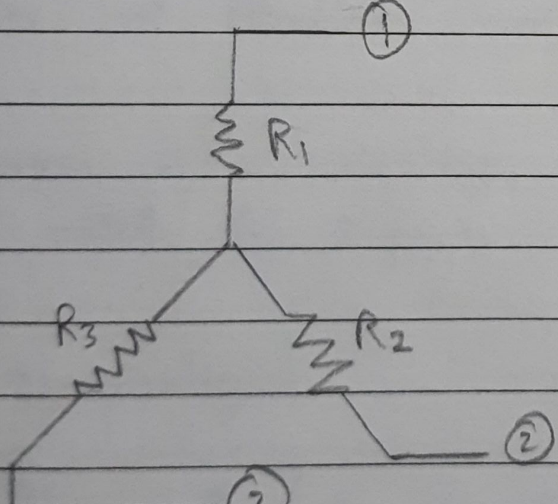
$$R_1+R_3 + R_1 - R_3 = \frac{R_{31}R_{23} + R_{12}R_{31} + R_{12}R_{31} - R_{23}R_{31}}{R_{12}+R_{23}+R_{31}}$$

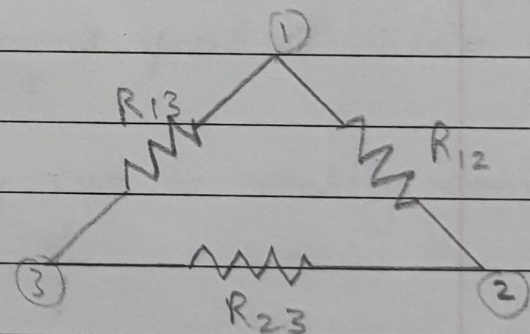
$$\cancel{2}R_1 = \frac{2R_{12}R_{31}}{(R_{12}+R_{23}+R_{31})}$$

$$R_1 = \frac{R_{12}R_{31}}{\Sigma R}$$

Similarly, $R_2 = \dfrac{R_{21}R_{23}}{\Sigma R}$ and $R_3 = \dfrac{R_{31}R_{32}}{\Sigma R}$

Star to Delta transformation





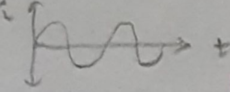
Consider the three resistances R_1, R_2 and R_3

AC quantity → Direction & mag of voltage/current changes with time

graph → sinosoidal wave

$i = I_m \sin \omega t$ ↳ max

alternating quantity → small letters → v, i

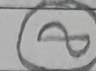


$v = V_m \sin \omega t$
$v = V_m \sin \theta$
$v = V_m \sin 2\pi f t$

Unit - 2

A C Circuit

AC Quantity - An alternating ~~current~~ quantity is a value which changes periodically both in magnitude and direction

Symbol of AC quantity : 

Advantages of AC:

i) The voltage in AC system can be rised or lowered with the help of a device called transformer.
In a DC system rising & lowering of voltage is not so easy.

ii) AC electrical motors are simple in construction, cheaper and require less attention from maintainance point of view.

iii) Whenever it is necessary, AC supply can be easily converted to obtain DC supply

★★ AC terminologies

Instantaneous Value - The value of an alternating quantity at a particular instant is known as instantaneous value and is represented by v, i.

WaveForm - The graph of instantaneous value of an alternating quatity plotted against time is called its waveform.

Cycle- * Each repetation of a set of positive & negative instantaneous values of the alternating quantity is called a cycle.

* One cycle corresponds to 2π radians or 360°

Time period (T)- * The time taken by an alternating quantity to complete its one cycle is known as its time period, denoted by T seconds.

* After every T seconds the cycle of an alternating quantity repeats.

Frequency- * The number of cycles completed by an alternating quantity per second is known as its frequency and denoted by f and measured in 'cycles per second' which is known as Hertz.

* Relationship b/w time period & frequency is $\boxed{f = \frac{1}{T} \text{ Hz}}$

Amplitude- The maximum value attained by an alternating quantity during positive and negative half cycle is called its amplitude & it is denoted by E_m or I_m

***

Effective/ root mean sq. (rms) value - The effective or RMS value of an alternating current is given by that steady current (DC) which when

Date / /

flowing through a given circuit for a given time produces the same amount of heat as produced by the alternating current which when flowing through the same circuit for the same time.

** Form factor (K_f) - The form factor of an alternating quantity defined as the ratio of RMS value to the average value.

i.e $$\boxed{K_f = \frac{\text{RMS value}}{\text{Average value}}}$$ (of voltage/current)

For sinosoidal quatity, $\boxed{K_f = 1.11}$

Crest/Peak factor - The peak factor of an alternating quantity is defined as ratio of maximum value to RMS value.

It is represented by K_p

$$\boxed{K_p = \frac{\text{Maximum value}}{\text{RMS value}}}$$

The numerical value of peak factor for sinsoidal quatity is $\boxed{K_p = 1.414}$

Representation of AC quantity (voltage & current)

Instantenous value i.e $v = V_m \sin\theta$
of voltage $= V_m \sin\omega t$
$= V_m \sin 2\pi f t$

Instantaneous value, $i = I_m \sin\omega t$
of current

phasor & phasor difference) → diff in phasor of two AC quantities

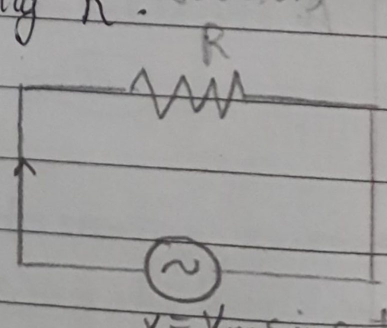
Note :-
For Purely sinosoidal quantity, $\boxed{\text{RMS value} = \frac{1}{\sqrt{2}} \text{ Maximum value}}$

Types of AC circuit :-
1) Single phase (ϕ) AC circuit
2) Three phase AC circuit

(1) Single phase AC circuit

i) Single phase AC circuit Consisting only R : (resistor)

Consider a simple circuit consisting of a pure resistance (R) ohms connected across a voltage $\boxed{v = V_m \sin\omega t}$



According to ohm's law, current, $\boxed{i = \frac{v}{R} = \frac{V_m \sin \omega t}{R}}$ — ①

Maximum value of alternating current is $\boxed{I_m = \frac{V_m}{R}}$, when $\sin \omega t = 1$.

Putting value of $\frac{V_m}{R} = I_m$ in eq ①

$$\boxed{i = I_m \sin \omega t} \quad -②$$

★→ It indicates that current is in phase with the voltage applied. There is no phase difference b/w the two.

Power : The instantaneous power in AC circuit can be obtained by taking product instantaneous value of current and instantaneous value of voltage.

i.e

$$\begin{aligned} p &= v \times i \\ &= V_m \sin \omega t \times I_m \sin \omega t \\ &= V_m I_m \sin^2 \omega t \\ &= V_m I_m \left(\frac{1 - \cos 2\omega t}{2} \right) \end{aligned}$$

$$\boxed{p = \frac{V_m I_m}{2} - \frac{V_m I_m \cos 2\omega t}{2}} \quad -③$$

From eq ③, it is clear that the instantaneous power consist

Sinosoidal wave ki avg value hamesha 0 hoti hai

Q> Draw waveform for voltage current power for purely resistive circuit

of two components:

* a) Constant component i.e $V_m I_m$
  or const power

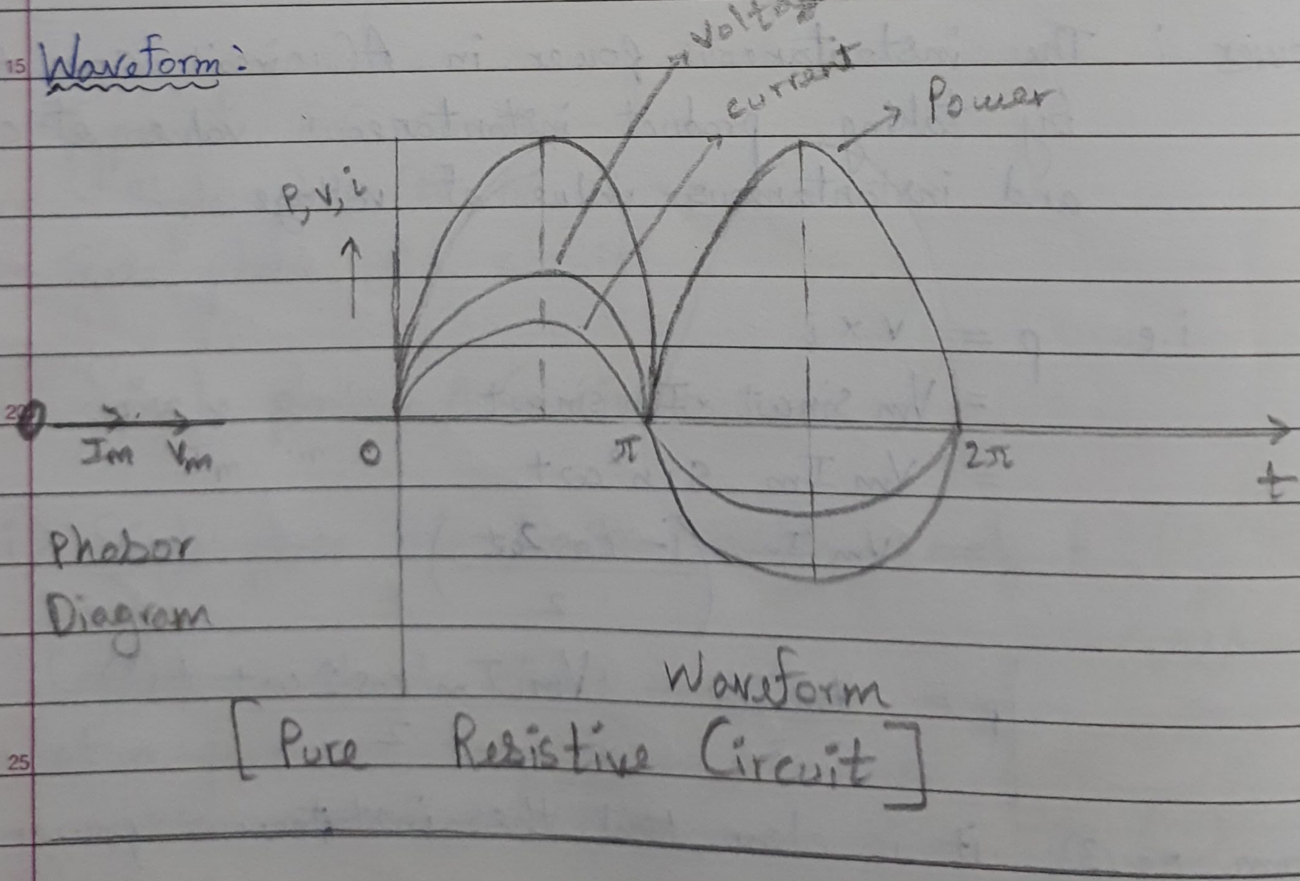
* b) Fluctuating component i.e $V_m I_m \cos 2\omega t$
  or fluctuating power

Now, the average value of fluctuating cosine component of double frequency is zero over one complete cycle. So average power consumption over one cycle is equal to the constant power component.

i.e $P_{avg} = \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}}$

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

Waveform:

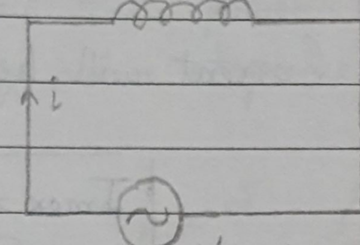


Waveform
[Pure Resistive Circuit]

Magnetic motive force MMF = N I → current
N ↓ no. of turns

Imp ii) Single phase AC circuit consisting only L : (inductor) → unit Henry

Consider a circuit which consists of a pure inductor of (L) Henry connected across a voltage $\boxed{v = V_m \sin\omega t}$



$v = V_m \sin\omega t$

★ When alternating current (i) flows through an inductor (L) it sets a alternating magnetic field around the inductance.

This changing flux links the coil & due to self inductance emf gets induced in the coil and this emf opposes the applied voltage and the self induced emf in coil is given by

$$\boxed{e = -L\frac{di}{dt}} \quad (1)$$

at all instant applied voltage v is equal & opposite to the self induced emf i.e

$$\boxed{v = -e = L\frac{di}{dt}}$$

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

$$di = \frac{V_m}{L}\sin\omega t\, dt \quad (2)$$

Integrating eq (2)

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

$$i = \frac{V_m}{\omega L}(-\cos\omega t)$$

$$i = \frac{V_m}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right) \quad -(3)$$

Current will be Maximum when $\sin\left(\omega t - \frac{\pi}{2}\right) = 1$

$$\boxed{I_{max} = \frac{V_m}{\omega L}}$$

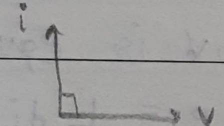
where $\omega L = X_L$ i.e Inductive reactance $\rightarrow$ unit = ohm

$$\therefore \boxed{I_m = \frac{V_m}{X_L}}$$

Putting $\frac{V_m}{\omega L}$ in eq (3)

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

★ → For purely inductive circuit . Current lags voltage by 90°



Power: The expression for instantaneous power can be obtained by

$$p = v \times i$$

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

$$= V_m \sin \omega t \; I_m \cos \omega t$$

$$p = \frac{V_m I_m}{2} \sin 2\omega t$$

$\rightarrow$ sin aur cos ke terms ka avg 0 hota hai

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

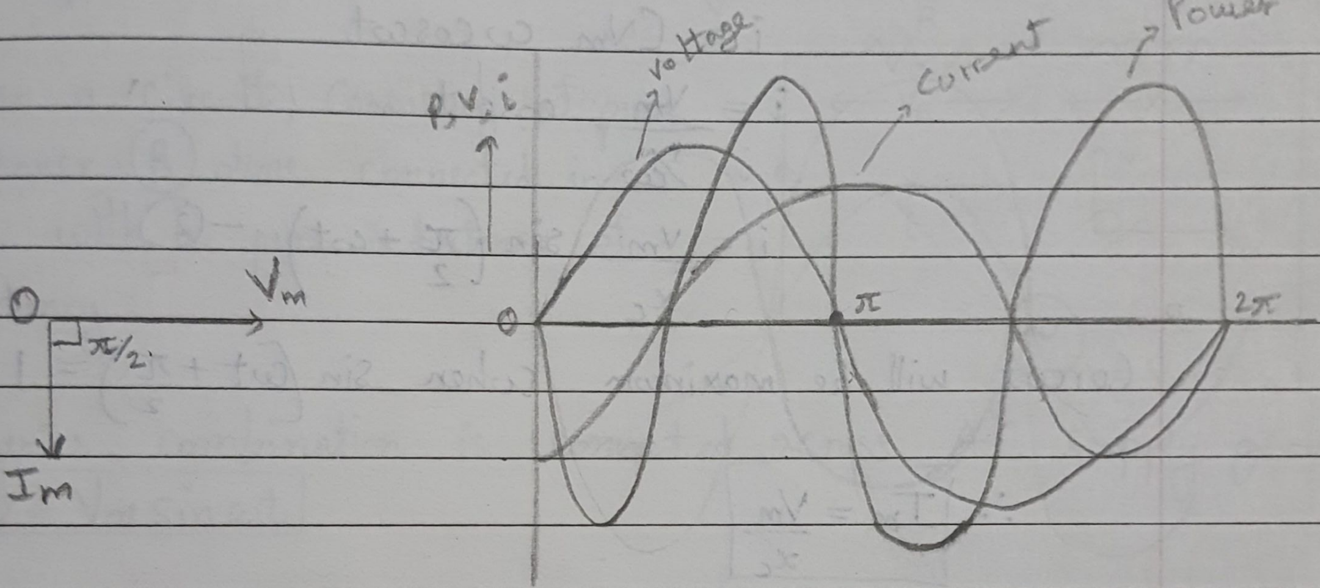
Purely inductive circuit kabhi energy consume nahi karta

stored magnetic energy $= \frac{LI^2}{2}$

+ve → stores energy

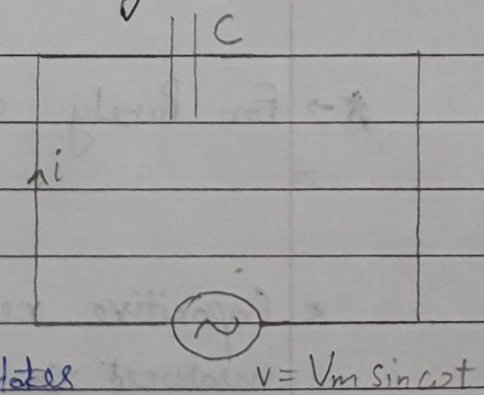
−ve → releases energy

It can be observed that for positive cycle energy gets stored in magnetic field established due to the increasing current and during negative half cycle this power is returned back to the supplier so the average value of power in purely inductive circuit is equal to 0.



Phasor Diagram & Waveform of Pure Inductive Circuit

iii) Single Phase AC circuit which consists only C :



Consider a circuit consisting of a pure capacitor of (C) farad connected across a voltage $\boxed{v = V_m \sin \omega t}$.

The current (i) charges capacitor C.

The instantaneous charge (q) on the plates of capacitor is given by :

$$\boxed{q = CV} \quad (1)$$

$$q = CV_m \sin \omega t$$

Now, Current is rate of flow of charge

i.e $i = \frac{dq}{dt}$

Putting value of q, $i = \frac{d}{dt} C V_m \sin \omega t$

$$i = C V_m \omega \cos \omega t$$

$$i = \frac{V_m}{1/\omega C} \cos \omega t$$

$$i = \frac{V_m}{X_C} \sin\left(\frac{\pi}{2} + \omega t\right) \quad -(2)$$

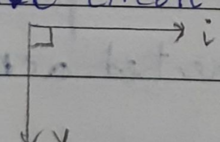
Current will be maximum when $\sin\left(\omega t + \frac{\pi}{2}\right) = 1$

$$\therefore \boxed{I_m = \frac{V_m}{X_C}}$$

Putting value of I_m in eq (2)

$$\boxed{i = I_m \sin\left(\omega t + \frac{\pi}{2}\right)}$$

* → For Purely capactive circuit, current leads voltage by 90°



(phasor diagram)

* Capacitive reactance of circuit $X_C = 1/\omega C = \frac{1}{2\pi f C}$ and measured in ohms

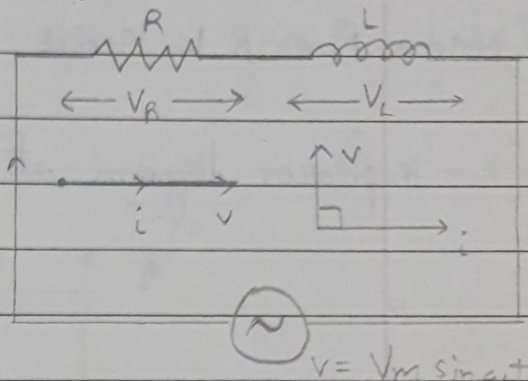
Power: Instantaneous power i.e $p = v \times i$

$$p = V_m \sin \omega t \times I_m \sin\left(\omega t + \pi/2\right)$$

$$p = \frac{V_m \sin\omega t \; I_m \cos\omega t}{2}$$

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

IMP iv) **Single phase AC circuit consisting R & L in Series**



Consider a circuit, consisting of pure resistance (R) ohms connected in series with a pure inductance of (L) Henry.

The series combination is connected across AC supply given by $\boxed{v = V_m \sin\omega t}$

Circuit draws a current I then there are two voltage drops : a) Voltage drop across R i.e $\boxed{V_R = IR}$
b) Voltage drop across L i.e $\boxed{V_L = I X_L}$

Phasor sum / vector sum of voltage

$$\vec{V} = \vec{V_R} + \vec{V_L}$$

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

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

$$\frac{\vec{V}}{I} = \sqrt{R^2 + X_L^2}$$

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

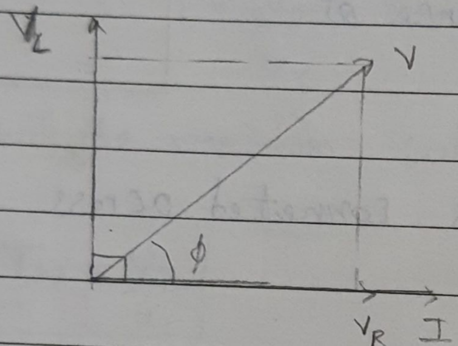
Z = impedence → opposes flow of current = ohm

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

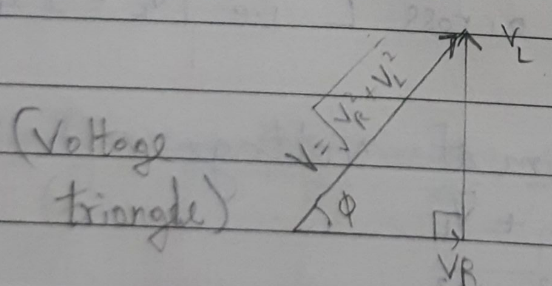
where,
Z is Impedence which ~~is defined~~ opposes the current in AC circuit and its unit is ohm

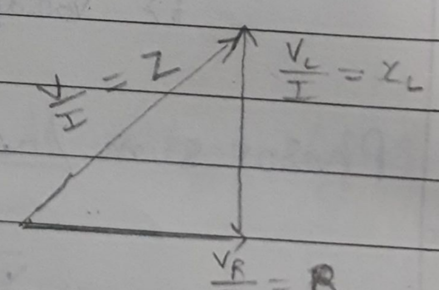
Note → For R L series circuit, Impedence $\boxed{Z = \sqrt{R^2 + X_L^2}}$

* phasor diagram of RL circuit :



Imp * Voltage triangle & Impedence triangle :





→ If all sides of voltage triangle are divided by current, we get a triangle called impedence triangle

⇒ From this impedence triangle, the component of X_L and R is given by $\boxed{R = Z\cos\phi}$ $\boxed{X_L = Z\sin\phi}$

1 active power → useful work
2 reactive power → wasteful power
3 apparent power → sum of above two

$\omega = 2\pi f \rightarrow$ freq → +ve & -ve half cycle
↳ avg power = 0

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★ Power of Series RL Circuit :

Instantaneous power

$$p = v \times I$$

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

$$\cancel{p = V_m \sin \omega t \times I}$$

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

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

Avg value of power

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

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

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

$$\boxed{P_{avg} = V_{rms} I_{rms} \cos \phi}$$

where, $\cos \phi$ is the power factor

Imp Imp Different power in AC circuit

Apparent power (S) - It is defined as product of RMS value of voltage and current. It is denoted by (S) and measured in Volt Ampere (V-A)

$$\boxed{S = V \times I}$$

Active power (P) - ★ Active / true / useful power is defined as the product of the applied voltage and the active component of the current.
★ It is the power which is dissipated by the resistor.

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

It is measured in kilo watt (kW).

Reactive Power (Q) - * It is defined as product of applied ~~&~~ voltage & the reactive component of the current. ~~It~~

It is an imaginary power & represented by (Q) & measured in (KVAR) kilo volt ampere reactance

* It is stored by Inductor.

$$\boxed{Q = VI\sin\phi}$$

⇒ Total power $\boxed{S = \sqrt{P^2 + Q^2}}$

Power factor ($\cos\phi$)

* It is defined cosine angle between voltage & current.

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

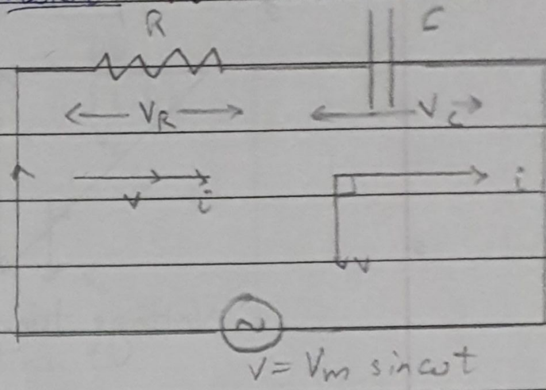
OR

* Power factor ($\cos\phi$) is the ratio of resistance to impedence.

Note⇒ Power factor varies from 0 to 1. [preferable 0.8 to 0.9]

v) Single phase AC circuit which consist R & C

Consider a circuit, consisting of pure resistance (R) ohms connected in series with a pure capacitor of (C) farad.



The series combination is connected across AC supply given by $\boxed{v = V_m \sin\omega t}$

Circuit draws a current (I) due to which there are two voltage drops i.e. $\boxed{V_R = IR}$

b) Voltage drop across C i.e $\boxed{V_C = I x_C}$

Phasor sum / vector sum of voltage

$$\vec{V} = \vec{V_R} + \vec{V_C}$$

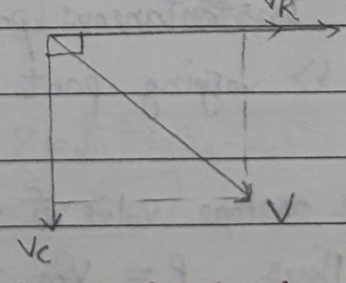
$$V = \sqrt{V_R^2 + V_C^2}$$

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

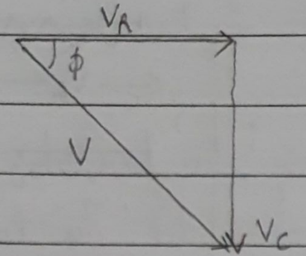
$$\frac{V}{I} = \sqrt{R^2 + x_C^2}$$

$\therefore$ Impedance i.e $\boxed{Z = \sqrt{R^2 + x_C^2}}$ where, $x_C = \frac{1}{\omega C}$

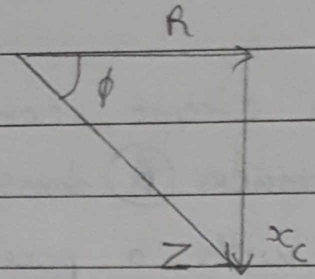
* Phasor diagram of RC circuit :



* Voltage & impedence triangle for RC circuit:



Voltage triangle



Impedence triangle

→ From impedence triangle, the component of x_c & R is given by

$$\boxed{R = Z\cos\phi} \qquad \boxed{x_c = Z\sin\phi}$$

→ In R-C series circuit current I leads voltage V by an angle ϕ which is given by $\boxed{\phi = \tan^{-1}\frac{x_c}{R}}$

* Power of series RC circuit:

$$P = VI$$

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

$$= \frac{V_m I_m}{2}\left[2\sin\omega t \sin(\omega t + \phi)\right]$$

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

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

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

∴ Instantaneous power consist of two parts a) Constant part $= \frac{V_m I_m}{2}\cos\phi$

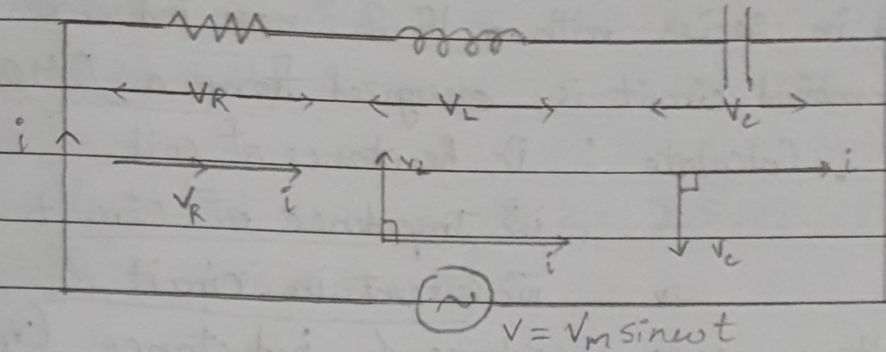
b) Varying part $= \frac{V_m I_m}{2}\cos(2\omega t + \phi)$

The average value of varying power component over a complete cycle is zero.

Thus, $P = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos\phi \Rightarrow \boxed{P = V_{RMS} \cdot I_{RMS} \cdot \cos\phi}$

where, $\cos\phi$ is power factor.

Imp vi) Single phase AC circuit which consists R, L & C in series



* Consider a circuit consisting of resistance (R) ohm pure inductance (L) Henry and capacitance (C) farad connected in series with each other across AC supply

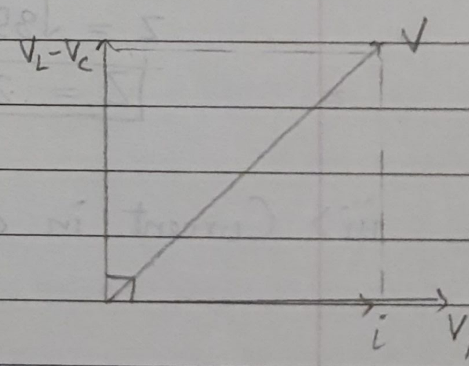
* The AC supply is given by $\boxed{v = V_m \sin \omega t}$
The circuit draws a current I, due to the current I there are different voltage drop across R, L & C which are given by

Voltage drop across resistance $V_R = IR$
Voltage drop across inductor $V_L = I x_L$
Voltage drop across capacitor $V_C = I x_C$

~~Phasor~~ · Total voltage $V = \sqrt{(V_R)^2 + (V_L - V_C)^2}$

$$\frac{V}{I} = \sqrt{R^2 + (x_L - x_C)^2}$$

Impedence i.e $\boxed{Z = \sqrt{R^2 + (x_L - x_C)^2}}$



Note → Impedence of series RLC circuit $Z = \sqrt{R^2 + (x_L - x_C)^2}$ & power factor $\boxed{\cos\phi = \frac{R}{Z}}$ and $\boxed{\tan\phi = \frac{x_L - x_C}{R}}$

Q) A coil of inductance 0.08 Henry and negligible resistance is connected in series with a 15 Ω non inductive resistance. The combined circuit is energized from a 240 volt 50 Hz supply. Calculate : $x_L = 2\pi f L$

i) Reactance of coil

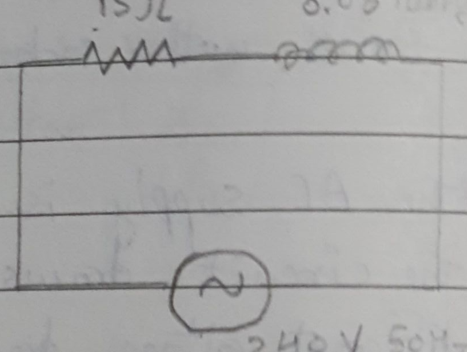
ii) Impedence of circuit $Z = \sqrt{R^2 + x_L^2}$

iii) Current in circuit $I = \frac{V}{Z}$

iv) Voltage across resistance & inductance (V_R, V_L) IR, IX_L

v) Power absorbed by circuit. $P = VI\cos\phi$

vi) Power factor of circuit $\cos\phi = R/Z$



i) Reactance of coil i.e $x_L = 2\pi f L$

$$x_L = 2 \times \pi \times 50 \times 0.08$$

$$\boxed{x_L = 25.13 \text{ ohm}}$$

$R = 15\,\Omega$, $L = 0.08\,H$

$V = 240\,V$, $f = 50\,Hz$

ii) Impedence of circuit

i.e $Z = \sqrt{R^2 + x_L^2}$

$$Z = \sqrt{(15)^2 + (25.13)^2}$$

$$Z = \sqrt{225 + 631.51}$$

$$Z = \sqrt{856.51}$$

$$\boxed{Z = 29.26 \text{ ohm}}$$

iii) Current in circuit. i.e $I = \frac{V}{Z} = \frac{240}{29.26}$

$$\boxed{I = 8.20 \text{ A}}$$

iv) Voltage across resistance & inductance

$$V_R = IR = 8.2 \times 15$$

$$\boxed{V_R = 123 \text{ volt}}$$

* $$V_L = I X_L = 8.2 \times 25.13$$

$$\boxed{V_L = 206.06 \text{ volt}}$$

v) Power absorbed by circuit i.e $P = VI \cos\phi$

$$P = 240 \times 8.2 \times 0.51$$

$$\boxed{P = 1003.68 \text{ watt}}$$

vi) Power factor of circuit i.e $\cos\phi = \frac{R}{Z}$

$$\cos\phi = \frac{15}{29.26}$$

$$\boxed{\cos\phi = 0.51}$$

Single phase → ek wire, ek neutral
3 phase system → 3 bindings → more superior

(2) Three phase AC circuit

* In an electrical/power system there are certain loads which require poly-phase supply. Phase means branch, circuit or bindings while poly means 'many'. So such application need a supply having many AC voltages present in it simultaneously.
  Such a system is called poly phase system.

* To develop poly phase system the binding is divided into number of phases required. In each section a separate AC voltage gets induced. So there are many independent AC voltages present equal to the number of phases of bindings.

* The various phases of bindings are arranged in such a way that the magnitude & frequencies of all these voltages is same. But they have definite phase difference w.r.t. each other.

* If binding is divided into three coils then three separate AC voltages will be available having same magnitude & frequency ~~per~~ but they will have a phase difference of 120° w.r.t each other $\left[\frac{360°}{n} = \frac{360°}{3} = 120°, \; n = \text{no. of phases}\right]$

Such a supply system is called Three phase AC system

3phase → Less losses ∴ more efficiency
↳ less material req to build → more economically

Advantages of 3 phase system:

i> To transmit a specific power over a specific distance at given rated voltage, 3 ϕ system needs less conductor material as compared to 1 ϕ system.

ii> The size of 3 ϕ system operated machine is less than machine operated at single phase having same output rating.

iii> In 3 ϕ power supply system, the less voltage drop occurs from source to load points

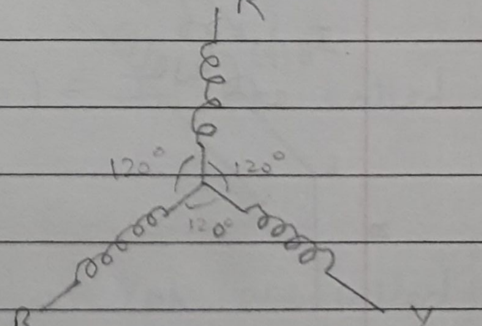
iv> A 3 ϕ system can transmit more power as compared to 1 ϕ system.

v> The efficiency of 3 ϕ operated devices & appliance is higher than 1 ϕ machines.

vi> Three phase machines are less costly & more efficient.

vii> If a fault occurs on a 1 ϕ line, the whole system will have to shut down. In case of 3 ϕ single line fault, the other two lines provide power supply to other single phase load points connected to them.

Generation of three phase Voltage System:



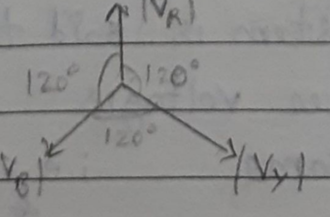
Representation of three phase AC voltage

$e_R = E_m \sin \omega t$

$e_Y = E_m \sin (\omega t - 120°)$

$e_B = E_m \sin (\omega t - 240°)$

Phasor diagram of balanced three phase AC system



Same magnitude of voltages
same phase diff i.e. 120°

Voltage b/w any two branches = line voltage
$I_R = I_B = I_Y = I_L$ ∵ balanced system

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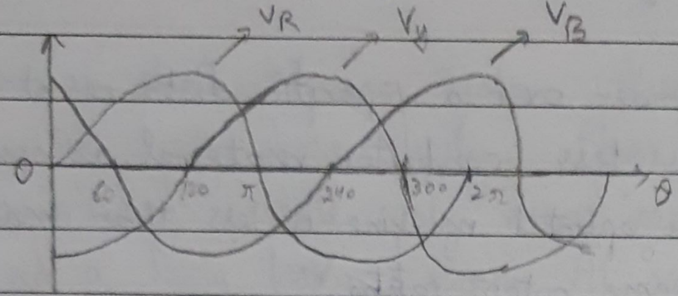
waveform of three phase AC voltages

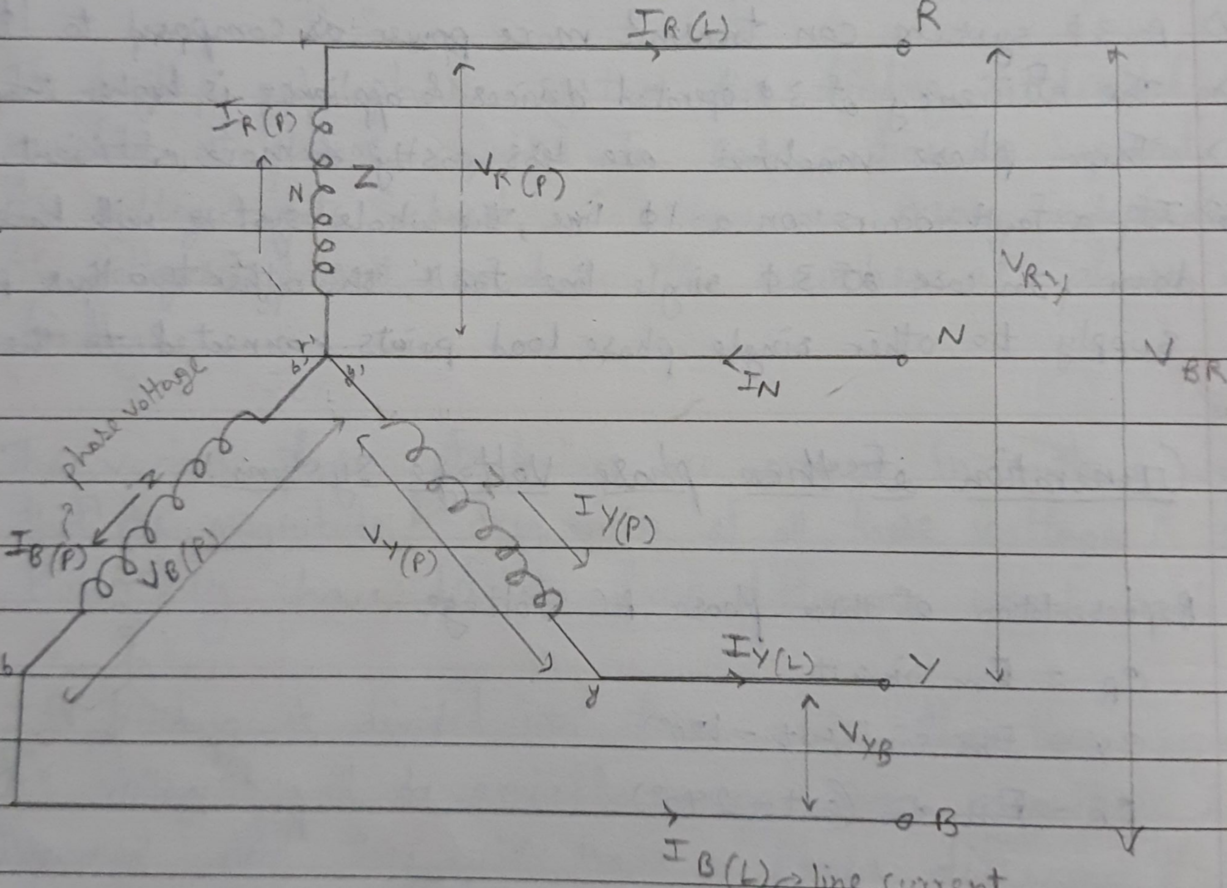


$V_R = V_m \sin \omega t$

$V_Y = V_m \sin(\omega t - 120°)$

$V_B = V_m \sin(\omega t - 240°)$

Star connection of three phase AC circuit



Three-phase balanced system

A three phase system is said to be balanced only if:

i) Magnitude of three voltages V_R, V_Y & V_B (and currents I_R, I_Y, I_B) are same i.e $\boxed{|V_R| = |V_Y| = |V_B|}$ & $\boxed{|I_R| = |I_Y| = |I_B|}$ values phase voltage = voltage of coil with neutral

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where I_R, I_Y, I_B are the Rms values of current flowing in three coils.

ii> Phase angle b/w every two adjacent voltages (& currents) is 120°.

phase sequence - The order in which the voltages will reach their maximum values is known as phase sequence.
The voltage V_R attains maximum value first, it is followed by V_Y & V_B
∴ The phase sequence is R, Y, B

Types of three Phase connection:
There are two types of 3 phase connection
i> Star Connection
* Currents $|I_{R(P)}| = |I_{Y(P)}| = |I_{B(P)}| = I_P$ are called phase currents.
* Currents $|I_{R(L)}| = |I_{Y(L)}| = |I_{B(L)}| = I_L$ are called line currents.

* Voltages $|V_{RN}| = |V_{YN}| = |V_{BN}| = V_{ph}$ are called phase voltages.

* Voltages $|V_{RY}| = |V_{YB}| = |V_{BR}| = V_L$ are called line voltages.

electric quantities → voltage, current, power

In this connection the three coils are interconnected such that their similar ends are joined together to form a neutral point. which is known as Star point (N)

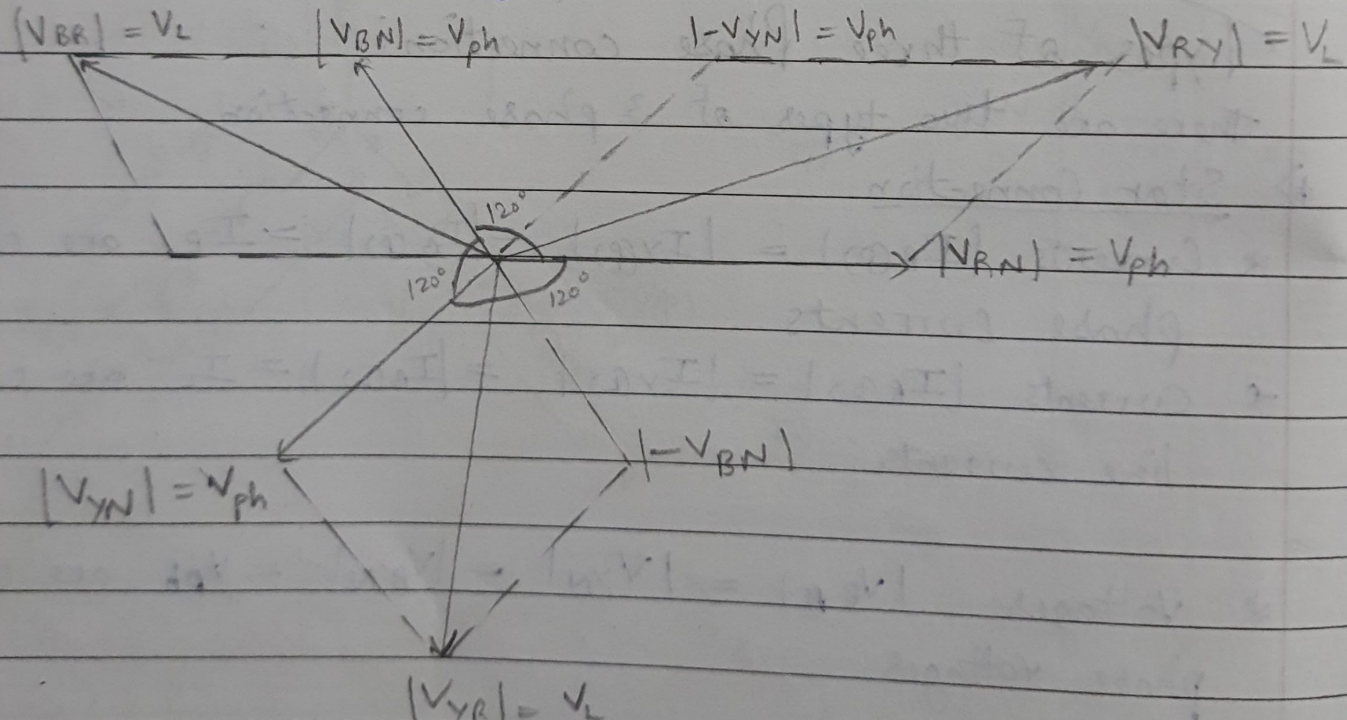
Relation b/w line & phase quantities in three phase star connection:

It can be seen that $I_L = I_{ph}$ in star connection

We know, $\bar{V}_{RY} = |\bar{V}_{RN}| - |\bar{V}_{YN}|$

Similarly, $\bar{V}_{YB} = |\bar{V}_{YN}| - |\bar{V}_{BN}|$

and $\bar{V}_{BR} = |\bar{V}_{BN}| - |\bar{V}_{RN}|$



Jahan par bhi power poocha hai wahan par assume kare active power poocha hai

agar ques mae kuch specified na ho toh assume kare line value hai

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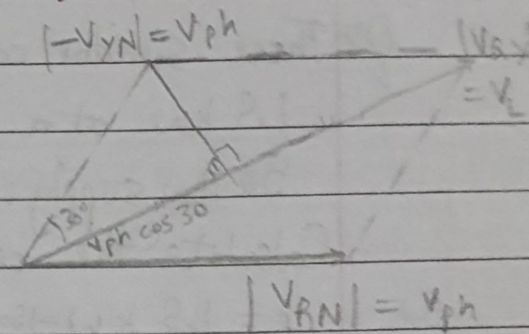
$V_L = 2 V_{ph} \cos 30^\circ$

$= 2 V_{ph} \frac{\sqrt{3}}{2}$



$$\boxed{V_L = \sqrt{3}\, V_{ph}}$$

and $\boxed{I_L = I_{ph}}$

Power i.e. $\boxed{P = 3 V_{ph} I_{ph} \cos\phi}$

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

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

Q) In a star connected alternator, the EMF generated in each phases is 3810 V. Calculate: i) The line voltage & ii) The total power output when current in each phase is 300 A. & power factor is 0.8 lagging.

Sol $V_{ph} = 3810$ V

$I_L = I_{ph} = 300$ A, $\cos\phi = 0.8$ lagging

$V_L = ?$

$P = ?$

In ~~Y con~~ Star connection, $V_L = \sqrt{3} V_{ph} = \sqrt{3}(3810)$

$$\boxed{V_L = 6600 \text{ V}}$$

$P = \sqrt{3} V_L I_L \cos\phi = \sqrt{3}(6600)(300)(0.8)$

$$\boxed{P = 2743.57 \text{ kW}}$$

Q7 Three similar coils connected in star take a total power of 1.5 kW at a power factor of 0.2 lagging from a 3 ϕ 400 V 50 Hz supply.
Calculate the resistance & inductance of each coil

Sol $P = 1.5\ kW = 1500\ W$, $V_L = 400$ volt
$\cos\phi = 0.2$ lagging $R = ?$
$f = 50\ Hz$ $L = ?$

For star connection, $P = \sqrt{3}\ V_L I_L \cos\phi$

$$I_L = \frac{1500}{\sqrt{3} \times 400 \times 0.2} = \frac{15000}{138.56}$$

$$\boxed{I_L = I_{ph} = 10.82\ A}$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}}$$

$$\boxed{V_{ph} = 230.94\ V}$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{230.94}{10.82}$$

$$\boxed{Z_{ph} = 21.34\ \Omega}$$

$$\cos\phi = \frac{R_{ph}}{Z_{ph}} \quad \#$$

$$R_{ph} = Z_{ph} \cos\phi = 21.34 \times 0.2$$

$$\boxed{R_{ph} = 4.26\ \Omega}$$

$$Z_{ph} = \sqrt{R_{ph}^2 + x_{Lph}^2}$$

$$x_{Lph} = \sqrt{Z_{ph}^2 - R_{ph}^2} = \sqrt{(21.34)^2 - (4.28)^2}$$

$$\boxed{x_{Lph} = 20.91\,\Omega}$$

$$x_{Lph} = 2\pi f L_{ph} \qquad \because \boxed{x_L = \omega L}$$

$$L_{ph} = \frac{x_{Lph}}{2\pi f}$$

$$\boxed{L_{ph} = 0.0665\ H}$$

Q> Three coils each having a resistance of 20 Ω & inductive reactance of 50 Ω are connected in star to a 400 Ω 3 ϕ 50 Hz supply. Calculate:

i> Line current. ii> Power factor iii> Power supplied

magnet → substance that attracts iron
mag field → jitna area tak magnet apna magnetism show karta hai
line of force → magnetic flux → weber / flux density = $B = \Phi/A$ = weber/m^2 = tesla

Unit-3

Magnetic Circuit & Transformer

Magnet - Magnet is something which attracts iron substance.

Magnetic Field - Magnetic field is defined as the region around a magnet ~~in which~~ within which the influence of magnet can be experienced ~~is called magnetic fi~~

Magnetic flux (Φ) - The total no. of line of force existing in a particular magnetic field is called Magnetic flux or lines of force can be called lines of magnetic flux.
It is denoted by ϕ and its unit is Weber
where, $\boxed{1 \text{ weber} = 10^8 \text{ line of force}}$

Magnetic flux density (B) - It can be defined as the flux passing per unit area. It is denoted by B and measured in weber per m^2 or tesla (weber/m^2)

$$B = \mu_0 \mu_r H \quad \text{or} \quad B = \frac{\Phi}{a}$$

Magnetic field (H) intensity - It can be defined as the force experienced by a unit N pole when placed at any point in a magnetic field.
It is denoted by (H) & measure in $\frac{\text{Newton}}{\text{weber}}$

and the mathematical expression for magnetic field intensity is

$$\boxed{H = \frac{NI}{l} = \frac{AT}{m}}$$

ampere turn / metre

Force experienced by this unit N pole is mag field intensity.

Airgap is to avoid saturation gap
MMF sets up ϕ in mag circuit

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Magneto motive force (MMF) - * It is defined as the driving force which sets up magnetic flux in the magnetic circuit.

* Mathematically it is expressed as $\boxed{MMF = N \times I}$
where N is no. of turns & I is current in ampere
* Its unit is Ampere turn. (AT)

Reluctance - * Opposition by the material to the set up of flux is called reluctance or it is defined as the resistance offered by the material to the ~~flow~~ set up of magnetic flux through it.

* It is denoted by (S)
* Mathematical representation of $\boxed{S = \dfrac{l}{\mu_0 \mu_r a}}$

where, μ_0 is absolute ~~permittivity~~ permeability
μ_r is relative permeability
l is length
a is cross-sectional area

Note → * Permeability is defined as the ability or ease with which the magnetic material forces the magnetic flux through a given medium.

* There are two types of permeability:
a> Absolute permeability
b> Relative permeability

Relationship b/w magneto motive force (MMF), magnetic flux (ϕ) and reluctance (S).

Magneto motive force i.e MMF = ϕS

$\therefore$ Magnetic flux i.e $\phi = \frac{MMF}{S}$

$$\phi = \frac{NI}{\frac{l}{\mu_0 \mu_r a}}$$

$$\boxed{\phi = \frac{NI \, \mu_0 \mu_r a}{l}}$$

Leakage Flux - Flux which does not flow their proper path is called Leakage flux

Fringing - When flux is spread out at the edges of airgap is called fringing

Leakage coefficient - The ratio of total flux to the useful flux is called leakage coefficient.

IMP

[Similarity & Dissimilarity b/w electric & magnetic circuit in tabular form]

Also comparison

flux → set up
current → flows

mag field ko rotate karna - tough job
∴ coil ko rotate karate hai

Faraday's law of Electromagnetic Induction

first law → Whenever the no. of magnetic line of force (magnetic flux) linking with a coil or circuit changes, an EMF gets induced in that coil or circuit.

second law → The magnitude of the induced EMF is directly proportional to the rate of change of flux linkage.

i.e. $emf \propto \frac{d\phi}{dt}$

$$\left[\begin{array}{l} \phi \propto i \\ \phi = Li \end{array}\right]$$

$$emf = L\frac{di}{dt}$$

Nature of induced emf :-

Depending on the nature, two types of induced emf are :-

i) Dynamically induced emf
ii) Statically induced emf

Dynamically induced emf - Induced emf which is due physical movement of coil/ conductor w.r.t flux or movement of magnet w.r.t stationary coil conductor is called Dynamically/rotational induced emf.

Statically induced emf - The changes in flux line w.r.t coil can be achieved without physically moving the coil or the magnet.

such induced emf in a coil which is without physical movement of coil or a magnet is called statically induced emf.

Lenz's Law

It states that "The direction of an induced emf produced by the ~~EMF is~~ electromagnetic induction is such that it sets up a current which always opposes the cause that is responsible for inducing the EMF.

<Fleming's right & left hand rule>

Q> An iron ring of mean circumference 1m is uniformly wound with 400 ~~tons~~ turns of wire when a current of 1.2 A is passed through the coil, a flux density of 1.15 weber/m^2 is produced in the iron. Find the relative permeability of iron under this circumference.

Sol Given, length i.e $l_i = 1\,m$

$\boxed{\mu_0 = 4\pi \times 10^{-7}}$

no. of turns i.e $N = 400$

Current i.e $I = 1.2\ A$

Flux density i.e $B = 1.15\ wb/m^2$

we know, $B = \mu_0 \mu_R H$

$B = \mu_0 \mu_R \dfrac{NI}{l}$

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$$\mu_R = \frac{Bl}{\mu_0 N I}$$

$$\mu_R = \frac{1.15 \times 1}{4\pi \times 10^{-7} \times 400 \times 1.2}$$

$$\mu_R = \frac{1.15}{6028.8 \times 10^{-7}}$$

$$\mu_R = 0.00019075 \times 10^{7}$$

$$\boxed{\mu_R = 1907.5}$$

Q) A cast steel electromagnet has an air gap length of 3mm and an iron path of length 40 cm. Find the no. of ampere turns necessary to produce a flux density of 0.7 Wb/m^2 in the gap. Assumed Ampere turns/m of flux path length for cast steel material is 600 AT/m. Neglect leakage and fringing.

Sol Given, $l_i = 40\ cm = 40 \times 10^{-2}\ m$, $l_g = 3mm = 3 \times 10^{-3}\ m$

$B = 0.7\ \frac{weber}{m^2}$, $H_i = 600\ \frac{AT}{m}$

$$\therefore H = \frac{AT}{l_i}$$

$\therefore$ Ampere turn for iron $(AT)_i = H \times l_i$

$$= 600 \times 40 \times 10^{-2}$$

$$\boxed{(AT)_i = 240\ AT}$$

For air gap; $B = \mu_0 \mu_r H_g$

$$H_g = \frac{B}{\mu_0 \mu_r} = \frac{0.7}{4\pi \times 10^{-7} \times 1}$$

$H_g = \cancel{3 \times 10}$

$$\boxed{H_g = 0.0557 \times 10^{-7}\ \frac{AT}{m}}$$

$$(AT)_g = H_g \times l_g = 0.0557 \times 10^{-7} \times 3 \times 10^{-3}\ m$$

$$(AT)_g =$$

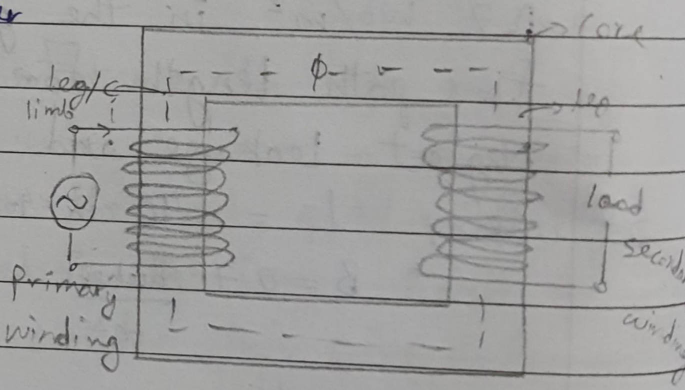
Total ampere turn =

TRANSFORMER

* Transformer is a static device which transfer energy from one circuit to another circuit without change in frequency.

* Transformer works on Faraday's law of electromagnetic induction

Basic Construction – * Basic construction of transformer Consists of :: One Core and two windings.



* When one winding is connected to supply or Source, it is called primary winding.

And the winding which is connected to the load is called Secondary winding.

* The primary winding has (N_1) number of turns while Secondary winding has (N_2) number of turns.

* Primary & secondary winding, both are electrically isolated but magnetically coupled.

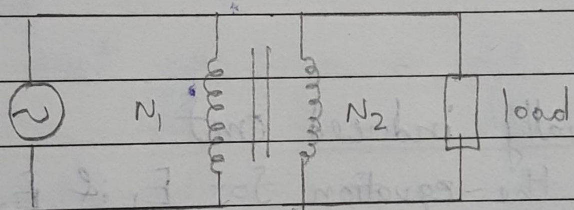
Parallel lines = magnetically coupled

Working principle - * When primary winding is excited by an alternating voltage, it circulates an alternating current. This current produces an alternating flux ϕ which completes its path through common magnetic core as shown dotted.

* As the flux is alternating, according to faraday's law of electromagnetic induction, mutually induced emf gets developed in the secondary winding.

* If now load is connected to a secondary winding, this emf ~~rides~~ drives a current to it.

Symbolic representation -



Types of Transformer - On basis of construction : core
shell

On basis of ~~power~~ voltage : step up
step down

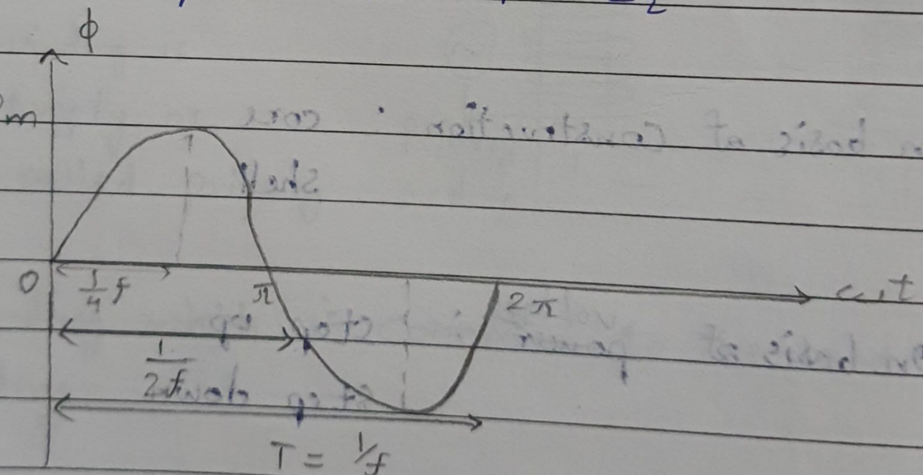
On basis of power : distribution
Power

Imp EMF equation of transformer

* When the primary winding is excited by an alternating voltages (V_1), it circulates alternating current producing an alternating flux (ϕ)
The primary winding has (N_1) number of turns.

* The alternating flux ϕ linking with the primary winding itself induces an emf in it denoted as (E_1).
The flux links with secondary winding through the common magnetic core, it produces induced emf (E_2) in the secondary winding.

* This is mutually induced emf.
Let us derive the equation for E_1 & E_2



* The primary winding is excited by purely sinosoidal alternating voltage. Hence, the flux produced is also sinosoidal in nature having maximum value of (ϕ_m)

* The various quantities which affects the magnitude of the induced emf are:
  i) flux = ϕ
  ii) Maximum value ~~number~~ of flux = ϕ_m
  iii) N_1 = no. of turns in Primary ~~secondary~~ winding
  iv) N_2 = no. of turns in secondary winding
  v) f = Frequency of supply voltage.
  vi) E_1 = RMS value of induced emf in primary side
  vii) E_2 = RMS value of induced emf in secondary side

From Faraday's law of electromagnetic induction, the average emf induced in each turn is proportional to the average rate of change of flux.

$$\text{Average emf per turn} = \frac{d\phi}{dt} \quad \text{—(1)}$$

Putting value of $\frac{d\phi}{dt}$ ∴ $\frac{d\phi}{dt} = \frac{\phi_m - 0}{\frac{1}{4f}} = 4f\phi_m$

$$\boxed{\text{Average emf per turn} = 4f\phi_m} \quad \text{—(2)}$$

As ϕ is sinosoidal the induced emf in each turn of both the winding also sinosoidal in nature.

For sinosoidal quantity, form factor $= \frac{\text{RMS value}}{\text{Avg value}} = 1.11$

RMS value = 1.11 · Avg Value.

RMS value of induced emf per turn = 1.11 × Avg value of induced emf per turn

$$\boxed{\text{RMS value of induced emf per turn} = 4.44 f\phi_m}$$

core lamination to avoid eddy current lose

There are N_1 number of primary turns. Hence the RMS value of induced Emf of primary denoted as E_1 is

$$\boxed{\begin{aligned} E_1 &= 4.44\, N_1 f \phi_m \\ \text{Similary} \quad E_2 &= 4.44\, f \phi_m N_2 \end{aligned}}$$

In general, ~~this is~~ ~~called~~ EMF ~~of~~ equation of transformer is

$$\boxed{E = 4.44\, f \phi_m N}$$

⇒ Transformation ratio ⇒ $\boxed{\dfrac{E_2}{E_1} = \dfrac{V_2}{V_1} = \dfrac{N_2}{N_1} = \dfrac{I_1}{I_2} = k}$

where k is the transformation ratio

~~Ideal Condition for transformer~~:

* If $N_2 > N_1$ then $k > 1$ and $E_2 > E_1$ and transformer is called step-up transformer.

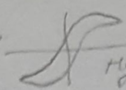
* If $N_2 < N_1$ then $k < 1$ and $E_2 < E_1$ and transformer is called step-down transformer.

Ideal Condition for transformer

A transformer is said to be ideal if it satisfies following properties.

i) It has no loses.
ii) Its windings have 0 resistance.
iii) Leakage flux should be zero, 100% flux produced by primary

iron loss - voltage → core → No load loss/Core loss → Hysteresis & eddy current loss
copper loss - current → winding

→ use stainless steel to avoid →  Hysteresis loss loop BH curve
Hysterisis loss → rapid magnetization of core
molecules collide → heat

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gives hysteresis loss

binding links with the secondary binding.

* Permeability of core is so high that negligible current is required to ~~establish~~ stablize the flux in it.

Volt Ampere Rating

* Transformer rating is specified as the product of voltage and current and called Volt-Ampere rating.
* Mathematical Volt-Ampere rating,

$$\text{KVA rating of transformer} = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$$

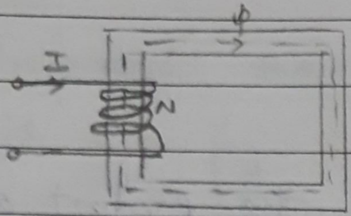
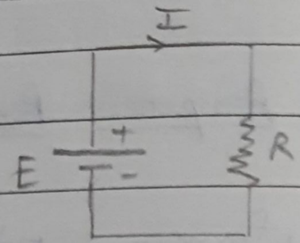
* If V_1 & V_2 are the terminal voltages of primary & secondary then from specified KVA rating full load currents of primary and secondary winding will be decided. (I_1 & I_2)
* This is the safe maximum current limit which transformer can carry

$$I_1 \text{ at full load} = \frac{\text{KVA rating} \times 1000}{V_1}$$

$$I_2 \text{ at full load} = \frac{\text{KVA rating} \times 1000}{V_2}$$

Comparison Between Magnetic & Electric Circuits

Similarities

	Magnetic Circuit	Electric Circuit
Circuit		
Definition	The closed path followed by magnetic flux is called magnetic circuit.	The closed path followed by an electric current is called an electric circuit.
Driving Force	MMF is required to establish flux ϕ in the magnetic circuit & is measured in ampere-turns (AT) or amperes	EMF is required to cause flow of current in an electric circuit & is measured in volts.
Response	Flux, $\phi = \frac{\text{Driving Force}}{\text{Magnetic reluctance}} = \frac{AT}{S}$ webers	Current, $I = \frac{\text{Driving force}}{\text{Electric resistance}} = \frac{E}{R}$ amperes.
Impedance a) For series circuits	Reluctance, $S = \frac{l}{\mu_0 \mu_r a} = \frac{l}{\mu a} \frac{AT}{Wb}$ $S = S_1 + S_2 + S_3 + ---$	Resistance, $R = \rho \frac{l}{a}$ ohms $R = R_1 + R_2 + R_3$

b) For parallel circuits	$S = \frac{1}{1/S_1 + 1/S_2 + 1/S_3 + ---}$	$R = \frac{1}{1/R_1 + 1/R_2 + 1/R_3 + ---}$
Admittance	Permeance $= \frac{1}{\text{Reluctance}}$ in $\frac{Wb}{AT}$	Conductance $= \frac{1}{\text{Resistance}}$ in siemens
Proportionality Constant	Reluctivity $= \frac{1}{\text{Permeability}} = \frac{1}{\mu}$ in $\frac{m}{H}$	Resistivity, $\rho = \frac{1}{\text{conductivity}}$ in ohm-metre
Density	Flux density, $B = \mu \times$ magnetic field intensity $= \mu H$ is tesla or Wb/m^2	Current density, $J = \frac{\text{Electric field intensity}}{\rho}$ in $\frac{A}{m^3}$
Field intensity	Magnetic field intensity, $H = \frac{MMF}{l} = \frac{NI}{l}$ in $\frac{AT}{m}$	Electric field intensity $= \frac{E}{l}$ in $\frac{V}{m}$
Drop	MMF drop $= \phi \times$ reluctance $= \phi S$	Voltage drop $= I \times$ Resistance $= IR$.

Dissimilarities

Magnetic Circuit	Electric Circuit
i) Flux does not actually flow in a magnetic circuit.	i) Current does flow in an electric circuit.
ii) Flux can pass through air.	ii) Current would not flow through air until an arc is struck.

[Magnetic circuit]	[Electric circuit]
iii> Permeability does not largely vary from material and there is hardly any material which can act as an insulator to the magnetic flux.	iii> Conductivity varies largely from material to material so much so that some materials are insulators to electric current and ~~some~~ Some are very good conductors.
iv> For a particular temperature the permeability depends upon the flux density (or total flux.)	iv> For a particular temperature, conductivity (or resistivity) is constant and independent of current strength.
v> Residual flux persists after removal of mmf.	v> The current is reduced to zero after removal of source of emf.
vi> There is no waste of energy due to reluctance in the magnetic circuit and, therefore, energy is required only to create the magnetic flux but not to maintain it.	vi) In an electric circuit, resistance causes heat to be generated resulting in waste of energy and therefore, energy is required as long as the current flows.

Imp Q1> A single phase transformer has 350 primary & 1050 secondary turns. The primary is connected to 400 volt 50 Hz AC supply if the net cross-sectional area of the core is 50 cm². Calculate
i> Maximum value of the flux density in the core
ii> The induced emf in secondary winding.

Sol $V_1 = E_1 = 400$ volt

$f = 50\ Hz$

$a = 50\ cm^2 = 50 \times 10^{-4}\ m^2$

$N_1 = 350, \quad N_2 = 1050$

i> $E_1 = 4.44\ \phi_m f N_1$

$\cancel{\phi}\ B_m \times a = \dfrac{\cancel{4.44}\ E_1}{4.44 \times f \times N_1}$

$B_m = \dfrac{400}{4.44 \times 50 \times 350 \times 50 \times 10^{-4}}$

$B_m = \dfrac{0.000102960}{10^{-4}}$

$B_m = \dfrac{1.02 \times 10^{-4}}{10^{-4}}$

$$\boxed{B_m = 1.02\ \frac{Wb}{m^2}}$$

ii> $\dfrac{N_2}{N_1} = \dfrac{E_2}{E_1}$

$E_2 = \dfrac{1050 \times 400}{350}$

$$\boxed{E_2 = 1200\ \text{volt}}$$

Q> A 10 KVA transformer having 50 no. of turns on primary and 10 no. of turns on secondary is connected to 440 volt 50 Hz supply. Calculate:

i> Secondary voltage on no load.

ii> Full load primary & secondary current

iii> Maximum value of flux in the core.

Sol $N_1 = 50$, $N_2 = 10$, $V_1 = 440$ V, $f = 50$ Hz

~~kV~~

i> $$\frac{N_2}{N_1} = \frac{V_2}{V_1}$$

$$V_2 = \frac{10 \times 440}{50}$$

$\boxed{V_2 = 88 \text{ volt on no load}}$

ii> $$I_1 = \frac{\text{KVA rating} \times 1000}{V_1} = \frac{10 \times 1000}{440} = \boxed{22.7\ A}$$

$$I_2 = \frac{\text{KVA rating} \times 1000}{V_2} = \frac{10 \times 1000}{88} = \boxed{113.6\ A}$$

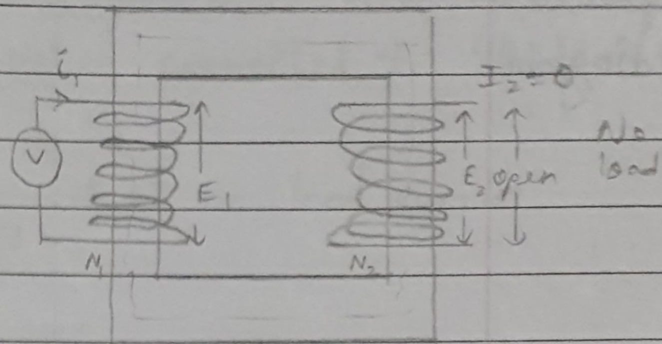
iii> $$E_1 = 4.44\, \phi_m f N_1$$

$$\phi_m = \frac{E_1}{4.44 f N_1} = \frac{440}{4.44 \times 50 \times 50}$$

$\boxed{\phi_m = 0.039 \text{ weber}}$

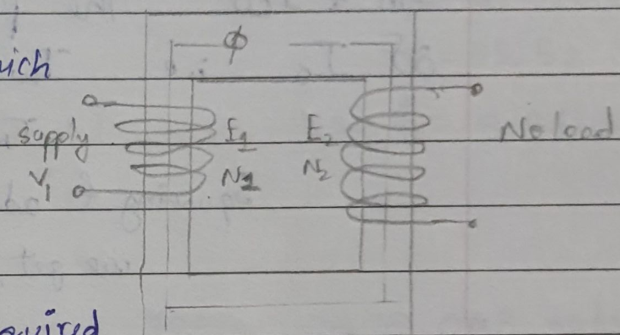
IMP **Transformer on no load**

Consider a transformer on ~~the~~ no load. The supply voltage is V_1 and as it is on no load so secondary current $I_2 = 0$



~~Phasor diagram of transformer at no load~~

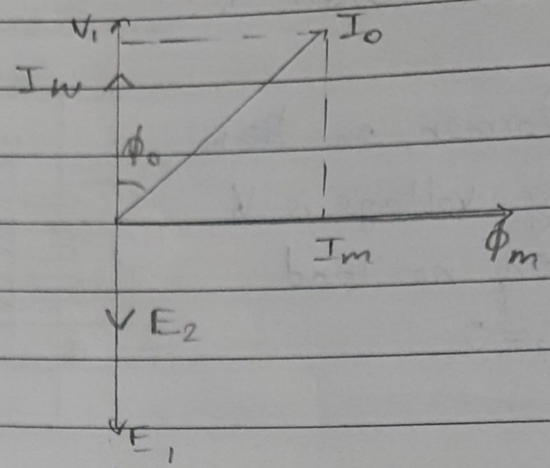
The primary draws the current I_0 which is no load input load, has two components : i) A purely reactive component (I_m) called magnetizing component of no load current required to produce the flux, this is also called watt less component.



ii) An active component (I_w) which supplies total loses under no load condition called useful component of no load current

Note:- Primary current under no load condition has to supply the iron loses (Hysteresis losses + Eddy current loses) and a very small amount of copper loses which is ~~ne~~ negligible working component $= I_w = I_c =$ core component

phasor diagram:



The total no load current I_0 is the vector addition of I_m & I_w. The phasor diagram shows ~~that~~ the two component of I_0 i.e $I_w = I_0 \cos\phi_0$ — (1)

$$I_m = I_0 \sin\phi_0 \quad \text{—} (2)$$

Squaring & adding eq (1) & (2) we get,

$$\boxed{I_0 = \sqrt{I_w^2 + I_m^2}}$$

and $\phi_0 =$ no load primary power factor angle.

The total power input on no load is denoted by W_0 and given by $\boxed{W_0 = V_1 I_0 \cos\phi_0}$ (3)

eq (3) is the iron loss at no load

Note: The Current I_0 is very small, about 3 - 5% of full load rated current. Hence, the primary copper losss is negligible and W_0 on no load always represents the iron losses.

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[Phasor diagram of transformer at load]

Q> The no load current of a transformer is 10 A at a power factor of 0.25 lagging when connected to 400 V 50 Hz supply.

Calculate : i> Magnetising component of no load current

ii> Iron losses.

iii> Maximum value of flux in core

Assume primary turns as 500.

Ans $I_0 = 10\,A$, $\cos\phi = 0.25$, $V_1 = 400$ volt, $f = 50$ Hz

ii> $W_0 = V_1 I_0 \cos\phi_0$ $\quad\quad \phi_0 = \cos^{-1}(0.25)$

$= 400\,(10)\,(0.25)$ $\quad\quad \phi_0 = 75.52$

$W_0 = 1000$ VA (Iron loses) $\quad\quad \sin\phi_0 = 0.96$

iii> $E_1 = 4.44 f \phi_m N_1$

$\phi_m = \dfrac{E_1}{4.44 f N_1} = \dfrac{400}{4.44 \times 50 \times 500} = \dfrac{400}{111000} = 0.003$ weber (Max flux)

i> $I_m = I_0 \sin\phi_0 = 10 \times 0.96$

$I_m = 9.6$ A (magnetising component of no load current)

Q> A single phase transformer of 3300/220 V 50 Hz takes a no load current of 0.8 ampere & 500 watt Calculate

1> Active & magnetising component of current

2> Its power factor

Sol $V_1 = 3300$ V, $I_0 = 0.8$, $W_0 = 500$, $V_2 = 220$ V

$W_0 = V_1 I_0 \cos\phi_0$

$\cos\phi_0 = \dfrac{W_0}{V_1 I_0} = \dfrac{500}{3300 \times 0.8}$

$\boxed{\cos\phi_0 = 0.18}$ $\phi_0 = \cos^{-1}(0.18) = 79.63$

$\sin\phi_0 = 0.98$

$I_w = I_0 \cdot \cos\phi_0 = 0.8 \times 0.18$

$\boxed{I_w = 0.144 \text{ A}}$

$I_m = I_0 \sin\phi_0 = 0.8 \times 0.98$

$\boxed{I_m = 0.784 \text{ A}}$

Q> A single phase 50 Hz transformer has 80 turns on Primary & 280 in secondary, the voltage applied across the primary winding is 240 V. Calculate:

i> Maximum flux density in core

ii> Induced emf in secondary winding

~~iii~~> Net cross sectional area of the core can be taken 200 cm^2.

Sol $f = 50$ Hz, $N_1 = 80$, $N_2 = 280$, $E_1 = V_1 = 240$ Volt

i> $B_m = \dfrac{E_1}{a \times 4.44 \times f \times N_1} = \dfrac{240}{200\times10^{-4} \times 4.44 \times 50 \times 80} = \dfrac{240}{3552\times10^{3}\times10^{-4}}$

$B_m = 0.67 \text{ wb/m}^2$

$\phi_m = B_m \times a = 0.67 \times \cancel{50}\ 200\times10^{-4} = 0.0134$ weber

ii> $E_2 = 4.44 f \phi_m N_2$

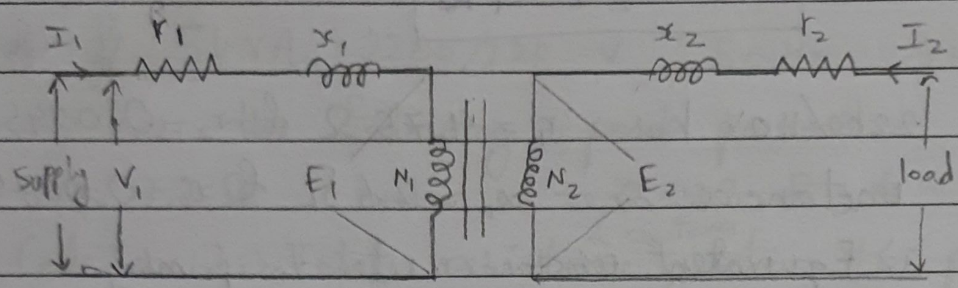
$= 4.44 \times 50 \times 0.0134 \times 280$

$E_2 = 832.9$ volt

winding is combo of resistance & inductance

$p \to S = 1/K^2$ $S \to P = K^2$

Imp. Equivalent circuit of a transformer



* Equivalent circuit is used to find equivalent resistance & equivalent reactance of the transformer.
* Equivalent resistance when secondary side refer to primary side.

It is denoted as $\boxed{r_2' = \frac{r_2}{K^2}}$ and equivalent reactance $\boxed{x_2' = \frac{x_2}{K^2}}$ where, $K = \frac{N_2}{N_1}$

* Total resistance & total reactance of transformer when secondary refer to primary is given by,

Total resistance, $r = r_1 + r_2'$

$$\boxed{r = r_1 + r_2 \times \frac{1}{K^2}}$$

Total reactance, $x = x_1 + x_2'$

$$\boxed{x = x_1 + x_2 \times \frac{1}{K^2}}$$

⇒ When primary refer to secondary side then total resistance, $r = r_2 + r_1'$ ⇒ $\boxed{r = r_2 + r_1 \times K^2}$

Total reactance, $x = x_2 + x_1'$

$$\boxed{x = x_2 + x_1 k^2}$$

Q> A 15 KVA 2200/110V has $r_1 = 4.75\ \Omega$ & $r_2 = 0.0045\ \Omega$ and leakage reactances are $x_1 = 2.6\ \Omega$ & $x_2 = 0.0075\ \Omega$
Calculate: i> Equivalent resistance refer to primary
ii> Equivalent resistance refer to Secondary
iii> Equivalent reactance refer to primary.
iv> Equivalent reactance refer to secondary.

Q> A single phase transformer 50 Hz 220/300V has a net cross-sectional area of the core is 400 cm² If the peak value of flux density in core is 1.24 wb/m². Calculate the Stable values for the number of turns on the primary and secondary winding.

Sol

$f = 50\ Hz$, $V_1 = E_1 = 220\ V$, $V_2 = E_2 = 300\ V$, $a = 400\ cm^2$

$B_m = 1.24\ wb/m^2$. $N_1 = ?$, $N_2 = ?$

$$B_m = \frac{\phi_m}{a} \Rightarrow \phi_m = B_m \times a$$

$$\phi_m = 1.24 \times 4 \times 10^2 \times 10^{-4}$$

$$\boxed{\phi_m = 4.96 \times 10^{-2}}$$

$$E_1 = 4.44\ \phi_m f N_1$$

$$N_1 = \frac{E_1}{4.44\ \phi_m f} = \frac{220}{4.44 \times 4.96 \times 10^{-2} \times 50} = \frac{220}{1101.12 \times 10^{-2}} = 0.1997 \times 10^{2}$$

Similarly, $N_2 = \dfrac{E_2}{4.44\ \phi_m f} = \dfrac{300}{4.44 \times 4.96 \times 10^{-2} \times 50} = \dfrac{300}{1101.12 \times 10^{-2}} = 0.2724 \times 10^{2}$

$\boxed{N_1 = 28 \quad , \quad N_2 = 27}$

Q) A ~~1φ~~ 5kVA 2200/220 V 50 Hz single phase transformer has the following ~~perd~~ parameter $r_1 = 3.4\,\Omega$ & $x_1 = 7.2\,\Omega$ and $r_2 = 0.028\,\Omega$ & $x_2 = 0.060\,\Omega$

Calculate : i) Total resistance & reactance refer to primary

ii) Total resistance & total reactance refer to secondary.

Sol KVA rating = 5 KVA , $V_1 = E_1 = 2200\,V$, $V_2 = E_2 = 220\,V$,

$f = 50\,H$, $r_1 = 3.4\,\Omega$, $x_1 = 7.2\,\Omega$

$r_2 = \cancel{7.2\,\Omega}\ 0.028\,\Omega$, $x_2 = 0.06\,\Omega$

i) Total resistance refer to primary

i.e $r = r_1 + r_2'$

$$r = r_1 + \frac{r_2}{K^2}$$

$$r = 3.4 + \frac{0.028}{\frac{1}{100}}$$

$$r = 3.4 + 2.8$$

$$\boxed{r = 6.2\,\Omega}$$

$$k = \frac{E_2}{E_1}$$

$$k = \frac{220\,V}{2200\,V}$$

$$\boxed{k = \frac{1}{10}}$$

Total reactance refer to primary

$$x = x_1 + x_2' = x_1 + \frac{x_2}{K^2} = 7.2 + \frac{0.06}{\frac{1}{100}} = 7.2 + 6$$

$$\boxed{x = 13.2\,\Omega}$$

ii) Total resistance refer to secondary

$$r = r_2 + r_1' = r_2 + r_1 K^2 = 0.028 + \frac{3.4}{100} = 0.028 + 0.034$$

$$\boxed{r = 0.062\,\Omega}$$

Total reactance refer to secondary

$$x = x_2 + x_1' = x_2 + x_1 K^2 = 0.06 + 7.2 \times \frac{1}{100}$$

$$x = 0.06 + 0.072$$

$$\boxed{x = 0.132\,\Omega}$$

Voltage regulation of a transformer (short notes)

Voltage regulation is defined as change in the magnitude of the secondary terminal voltage from no load to full ~~lod~~ load when primary voltage maintained constant.

Mathematical expression for voltage regulation:

Let E_2 = secondary terminal voltage on no load

and V_2 = secondary terminal voltage on given load.

the voltage regulation at given load can be expressed as

percentage voltage regulation $= \frac{E_2 - V_2}{V_2} \times 100$

Note → The secondary terminal voltage doesnot depend on the magnitude of the load current but

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also on the nature of power factor of the load

In terms of power factor, the voltage regulation can be expressed as

$$\% VR = \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100$$

equivalent

(+) sign for lagging power factor (inductive load)
(−) sign for leading power factor.

Q) 250/125 V 5 kVA single phase transformer has primary resistance of $r_1 = 0.2\ \Omega$ & reactance of $x_1 = 0.75\ \Omega$ and secondary resistance is $r_2 = 0.05\ \Omega$ & reactance of $x_2 = 0.2\ \Omega$. Determine : i) Its regulation while full load on 0.8 leading power factor.
ii) The secondary terminal voltage on full load at 0.8 leading power factor.

Sol KVA rating = 5 kVA, $r_1 = 0.2\ \Omega$, $x_1 = 0.75\ \Omega$,
$r_2 = 0.05\ \Omega$, $x_2 = 0.2\ \Omega$

Leading power factor, $\cos\phi = 0.8$ (i) % VR = ? (ii) V_2 on full load

$V_1 = 250$ V, $V_2 = 125$ V

$$k = \frac{V_2}{V_1} = \frac{125}{250} = \frac{1}{2}$$

$$R_{2e} = r_2 + r_1' = r_2 + r_1 k^2 = 0.05 + \frac{0.2}{4} = 0.05 + 0.05$$

$$\boxed{R_{2e} = 0.1\ \Omega}$$

$$X_{2e} = x_2 + x_1' = x_2 + x_1 K^2 = 0.2 + \frac{0.75}{4} = 0.2 + 0.18$$

$$\boxed{X_{2e} = 0.38\ \Omega}$$

$\because V_2 I_2 = kVA \times 1000$

$$I_2 = \frac{kVA \times 1000}{V_2} = \frac{5000}{125} = \cancel{\frac{1}{800}}$$

$$\boxed{I_2 = 40\ A}$$

$\cos\phi = 0.8$

$\phi = \cos^{-1}(0.8) = 36.86$

$\boxed{\sin\phi = 0.6}$

$$\%\,VR = \frac{I_2 R_{2e} \cos\phi - I_2 X_{2e} \sin\phi}{V_2} \times 100$$

$$\%\,VR = \frac{(40 \times 0.1 \times 0.8) - (40 \times 0.38 \times 0.6)}{125} \times 100$$

$$\%\,VR = \frac{(3.2 - 9.12)}{125} \times 100 = \frac{-5.92}{125} \times 100$$

$$\%\,VR = -0.0473 \times 100$$

$$\boxed{\%\,VR = -4.73}$$

transformer output to measure karne ke liye unit = KVA rating

CRGO → cold rod oriented steel

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~~Efficiency of a Transformer~~

Loses in a Transformer

In a transformer there exists two types of loses :

i) The core gets subjected to an alternating flux causing core loss.

ii) The windings carry current when transformer is loaded causing copper losses.

iron/core losses (P_i)

* Due to alternating flux set up in the magnetic core of the transformer, it undergoes a cycle of magnetization and demagnetization due to hyterisis effect there is loss of energy in this process which is called hysterisis loss.

Mathematical expression of hysterisis loss is given by,

$$\boxed{\text{Hysterisis loss} = K_h \times (B_m)^{1.67} f.V \text{ watt}}$$

where K_h = hysterisis constant depends of material.

B_m = Maximum flux density

f = frequency

V = Volume of the core

* The induced emf in the core tries to set up eddy currents in the core and hence responsible for the eddy current loses.

Mathematical expression for eddy current loss is,

$$\boxed{\text{Eddy current loss} = k_e B_m^2 f^2 t^2 \text{ watt}}$$

where, k_e = Eddy current constant,
t = thickness of core
B_m = Maximum value of flux density
f = frequency

* This is also called constant loses and denoted as P_i

* Hysterisis losses are minimized by using high grade core material like silicon steel having very low hysterisis loop ~~and~~

* Eddy current is minimized by manufacturing the core in the form of laminations.

Copper loss - P_{cu} * The copper loss are due to the power wasted in the form of I^2R loss due to the resistance of the primary and secondary winding.

* The copper loss depends on the magnitude of the current flowing through the windings.
This is also called, Variable losses.

* Total losses in a transformer = iron loss + Copper loss

$$\boxed{\text{Total Loss} = P_i + P_{cu}}$$

*** Efficiency of a transformer

Due to the losses in a transformer the output of the transformer is less than the input power supply.

Power input = power output + losses
= Power output + P_i + P_{cu}

The efficiency of any device is defined as the ratio of the power output to power input.
The efficiency of the transformer can be expressed as,

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

$$\eta = \frac{\text{Power output}}{\text{Power output} + P_i + P_{cu}}$$

Now, power output = $V_2 I_2 \cos\phi$
where, $\cos\phi$ = load power factor

The transformer supplies full load of current I_2 and with terminal voltage V_2
So, copper loss, $P_{cu} = I_2^2 R_2$

$$\therefore \boxed{\text{Efficiency i.e } \eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + I_2^2 R_2}}$$

max^{m} parameter ko find out karne ke liye expression ko differentiate karke zero se equate karte hai

$\cos\phi = \cos\phi_2$

For fractional load, the efficiency is given by

$$\boxed{\%\,\eta = \frac{n V_2 I_2 \cos\phi}{n V_2 I_2 \cos\phi + P_i + n^2 I_2^2 R_2}}$$

where, n = fraction by which load is less than full load

Condition for maximum efficiency:

* When a transformer works on a constant input voltage and frequency then efficiency varies with the load.

* As the load increases, the efficiency increases. At certain load it achieves the maximum value, if the transformer is loaded further the efficiency starts decreasing.

* The load current at which the efficiency attains maximum value is denoted as I_{2m} and maximum efficiency is denoted as η_{max}.

* The efficiency is a function of load or load current assuming $\cos\phi_2$ & V_2 is constant. So for maximum efficiency, $\frac{d\eta}{dI_2} = 0$ — (1) where $\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2}$

Putting value η in eq (1)

$$\frac{d}{dI_2}\left(\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2}\right) = 0$$

$$\frac{(V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2)(V_2 \cos\phi_2) - (V_2 I_2 \cos\phi_2)(V_2 \cos\phi_2 + 2 I_2 R_2)}{(V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2)^2} = 0$$

$$V_2^2 I_2 \cos^2\phi_2 + P_i V_2 \cos\phi_2 + V_2 I_2^2 R_2 \cos\phi_2 - V_2^2 I_2 \cos^2\phi_2 - 2 V_2 I_2^2 R_2 \cos\phi_2 = 0$$

$$P_i V_2 \cos\phi_2 - V_2 I_2^2 R_2 \cos\phi_2 = 0$$

$$P_i V_2 \cos\phi_2 = V_2 I_2^2 R_2 \cos\phi_2$$

$\boxed{P_i = I_2^2 R_2}$ i.e iron loss = Copper loss for max efficiency.

Note → Condition to achieve maximum efficiency is that copper loss is equal iron loss

★ Q) A 200 / 150 V 50 Hz single phase transformer is connected to a 200 volt 50 Hz supply with secondary winding open & primary winding 400 turns. Determine:

i) What is the value of maximum flux through the core.

ii) what is the peak value of flux if the primary voltage is

200 volt 25 Hz.

iii) What happens to no load current?

Sol $V_1 = 200V$, $V_2 = 50V$, $f = 50Hz$, $N_1 = 400$

i) $\phi_m = ?$

ii) $\phi_m = ?$ if $V_1 = E_1 = 200V$, $f = 25Hz$

i) $E_1 = 4.44 f \phi_m N_1$

$$\phi_m = \frac{E_1}{4.44 \times f \times N_1} = \frac{200}{4.44 \times 50 \times 400}$$

$$\boxed{\phi_m = 0.0022 \text{ weber}}$$

ii) $E_1 = 4.44 f \phi_m N_1$ if $f = 25Hz$

$$\phi_m = \frac{E_1}{4.44 \times f \times N_1} = \frac{200}{4.44 \times 25 \times 400}$$

$$\boxed{\phi_m = 0.0045 \text{ Wb}}$$

iii) The no load current is 2-4 % of full load current.

Variac → voltage vary upto 240V

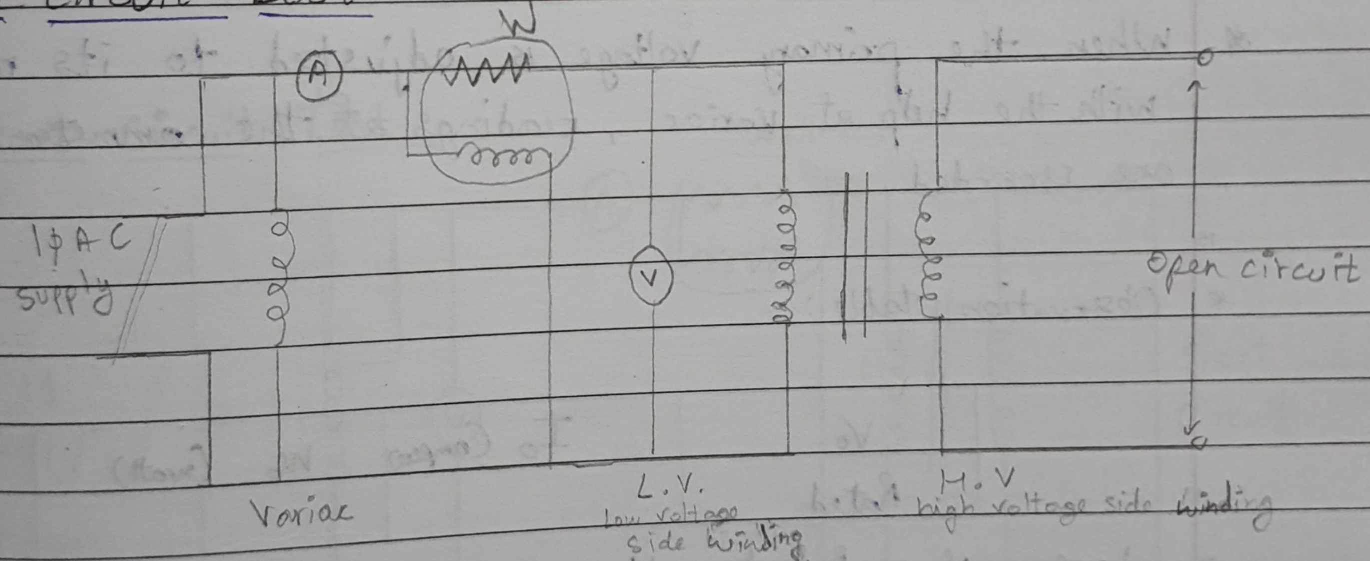
Wattmeter → measure power

** Test on a transformer

The efficiency and regulation of a transformer on any load condition can be predetermined by indirect loading methods.

In this method actual load is not used on a transformer but the equivalent circuit parameters of a transformer are determined by conducting these two tests:-

① Open circuit test



Experimental setup/circuit for open circuit test

* The transformer primary is connected to AC supply through ammeter, wattmeter and variac, the secondary of transformer is kept open. Usually low voltage side is used as primary and high voltage side as secondary to conduct open circuit test

* The primary is excited by rated voltage which is adjusted by the help of a variac. The wattmeter measures input power, ammeter measures input current & the voltmeter gives the value of rated primary voltage applied rated frequency.

* Some times a voltmeter maybe connected across secondary to measure secondary voltage which is $V_2 = E_2$ when primary is supplied with rated voltage as voltmeter's resistance is very high so secondary is created to be open circuit.

* When the primary voltage is adjusted to its rated value with the help of variac, readings of the ammeter, wattmeter are recorded.

* Observation table:

V_0	I_0 (ampere)	W_0 (watt)
Rated		

where, V_0 = Rated voltage
W_0 = Input power (iron loss)
I_0 = Input current = no load current

* Calculation: for open circuit test

We know that $\boxed{W_0 = V_0 I_0 \cos\phi_0}$

where, $\cos\phi_0$ = no load power factor & value of $\cos\phi$

is $\boxed{\cos\phi_0 = \dfrac{W_0}{V_0 I_0}}$

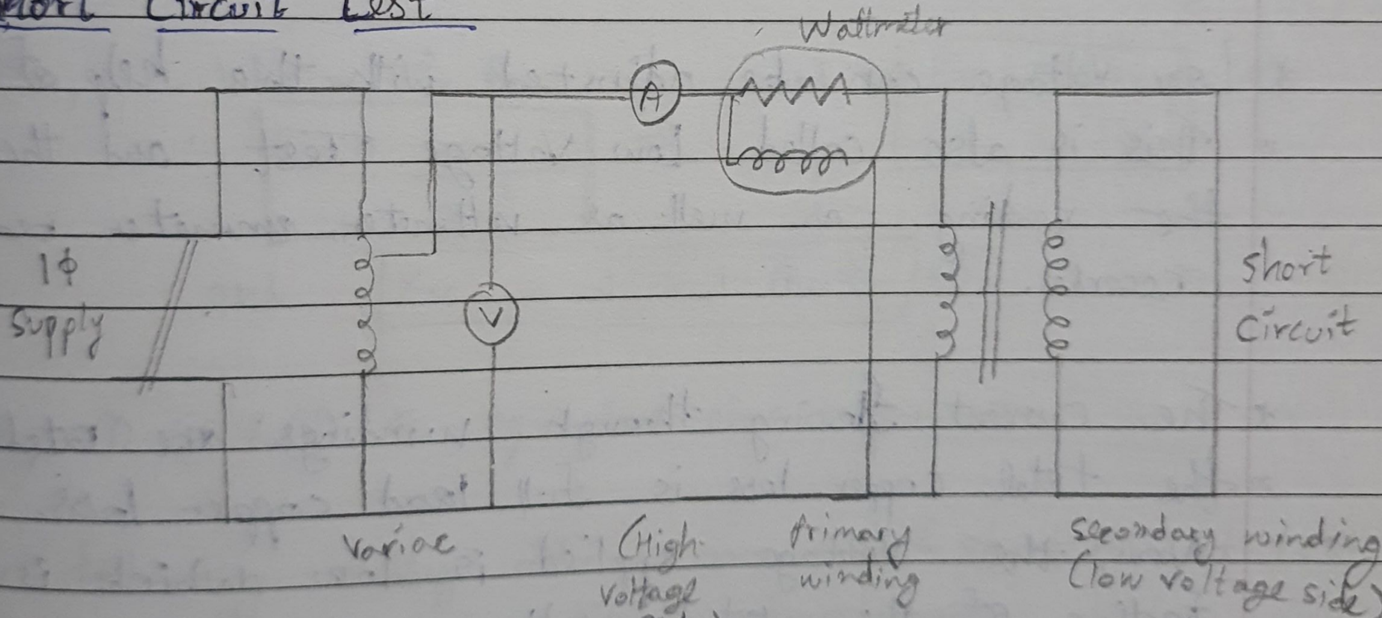
Once, $\cos\phi_0$ is known, we can calculate the value of I_w and I_m

$$I_w = I_0 \cos\phi_0$$
$$I_m = I_0 \sin\phi_0$$

Once I_w & I_m are known, we can determine circuit parameter R_0 & X_0

i.e $\boxed{R_0 = \dfrac{V_0}{I_w}\ \Omega}$ and $\boxed{X_0 = \dfrac{V_0}{I_m}\ \Omega}$

② **Short Circuit test**



* In this test, primary is connected to AC supply through variac, ammeter & voltmeter.

* The secondary is short circuited with the help of thick

copper wire as high voltage side is always low current side, it is convinient to connect high voltage side to supply and shorting the low voltage side.

* As secondary is shorted, its resistance is very small and on rated voltage it may draw very large current such large current can cause over heating & burning of transformer.

* To limit this short circuit current, primary is supplied with low voltage which is enough to cause rated current to flow through primary which can be measured by ammeter.

* Low voltage can be adjusted with the help of variac. This is also called Low Voltage Test and the wattmeter ~~the~~ reading as well as voltmeter, ammeter readings are recorded.

* The current flowing through windings are rated hence the total copper loss is full load copper loss. Now, the voltage applied is low which is a small fraction of the rated voltage

* The iron losses are function of applied voltage so the iron losses is reduced or considered as negligible hence the wattmeter reading gives full load copper losses

copper loss depends on load current

open test = no load = chota wala current

Observation table for short circuit test

V_{sc} (Volt)	I_{sc} (A)	W_{sc} (watt)
	Rated	Copper loss

Calculation

From short circuit test reading, we get.

$$\boxed{W_{sc} = V_{sc} I_{sc} \cos\phi_{sc}}$$

where, $\cos\phi_{sc} = \dfrac{W_{sc}}{V_{sc} I_{cs}}$ = short circuit power factor

Also, $W_{sc} = I_{sc}^2 R_{sc}$ and $\boxed{Z_{sc} = \dfrac{V_{sc}}{I_{sc}}}$ —②

$$\therefore \boxed{R_{sc} = \frac{W_{sc}}{I_{sc}^2}} \quad \text{—①}$$

and $\boxed{X_{sc} = \sqrt{(Z_{sc})^2 - (R_{sc})^2}}$ —③

Eq ①, ② & ③ is equivalent circuit parameter.

Q> The following reading obtained from open & short circuit test on 8 KVA 400/120 V 50 Hz transformer

O.C. Test : 120 V 4 A 75 watt (Iron loss)

S.C. Test : 9.5 V 20 amp 110 watt (copper loss)

Determine circuit parameters

Parts of rotating m/c
- Stator → stationary part
- Airgap b/w stator & rotator
- rotor → rotating part

DC m/c → generator, → motor

AC m/c → Induction motor 3φ, 1φ

Synchronous m/c → motor → alternator

Unit-4

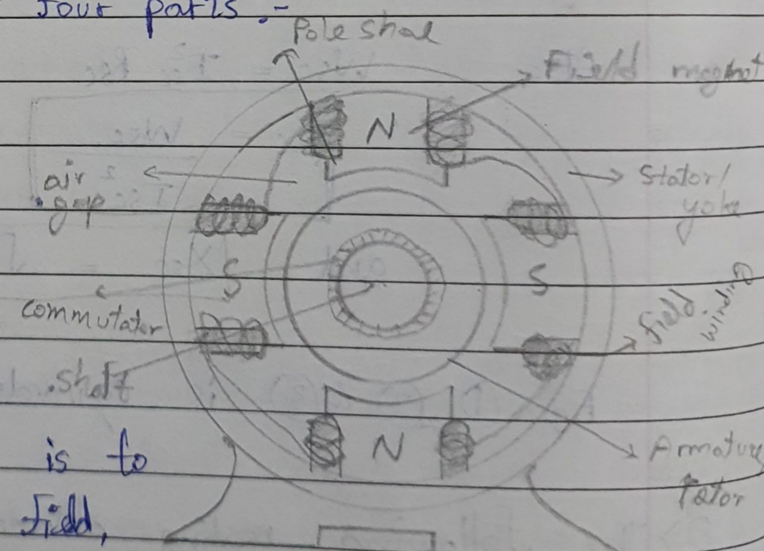
Basic Concepts of Rotating machine

Q> With the help of a neat diagram explain constructional details & function of each part of a DC machine.

Sol * A DC machine is an electromechanical energy conversion device (EMEC)

* DC machines are classified into two types:-
  i> DC generator
  ii> DC motor

Construction- DC machines consist of four parts:-
i> Field magnets
ii> Armature
iii> Brush & Brush gear
iv> Communicator



⇒ Field System
* The object of field system is to create a uniform magnetic field, within which the armature rotates.

* Field magnets consists of four given parts:-
i> Yoke ii> Pole cores iii> Pole <iv> Magnetising coils

Due to lack of rotating part → efficiency of transformer highest among devices.

rotating machine ⇒ iron loss + copper loss + windage loss + f...

~~Unit 4~~

~~Basic Concepts of~~

i) Yoke – Cylindrical yoke is usually used as a frame of the machine and carries the magnetic flux produced by the poles.

ii) Pole Cores – Pole cores are used to carry coils of insulated wires carrying the exciting current.

iii) Pole shoe – These are always laminated to avoid heating & eddy current losses caused by the fluctuations in the flux distribution on the pole face due to movement of armature ~~sto~~ slots and teeth.

iv) Magnetising coils – Coils are to provide the proper flux ~~by~~ through the armature to induce the desired potential difference.

⇒ **Armature**

* It is a rotating part of a DC machine and is built up in a cylindrical or drum shape.
* The purpose of armature is to rotate the conductors in the uniform magnetic field.
* It consists of coils of insulated wires wound around an iron & so arranged that electric currents are induced in these wires when the armature is rotated in a magnetic field.

① Yoke → mechanical support, provides low reluctance path

Poles → North pole, south pole →

field winding → provides necessary flux

④ armature → teeth, slots
conductors in slots
armature rotating part
cuts flux induces emf

* The armature core is made from high permeability silicon-steel stampings, each stamping being separated from its neighbouring one by thin paper or thin coating of varnish as insulation.

* A small air-gap exists between the pole pieces and the armature so that there will be no rubbing in the machine.

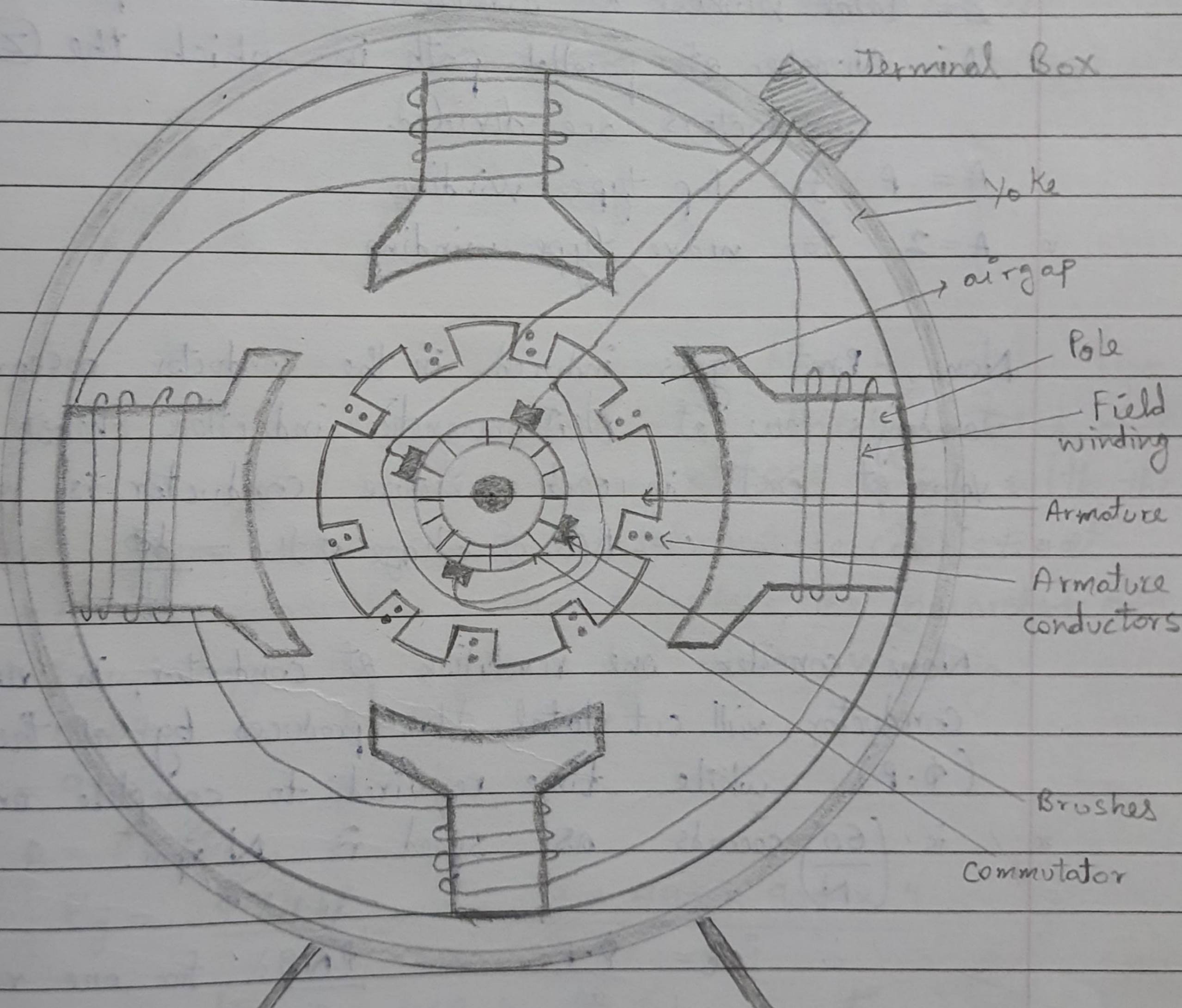
⇒ Commutator

The commutator is a form of rotating switch placed between the armature and the external circuit and so arranged that it will reverse the connections to the external circuit at the instant of each reversal of current in the armature coils.

* It provides the electrical connections between the rotating armature coils and the stationary external circuit
* As the armature rotates, it performs a switching action reversing the electrical connections between the external circuit and each armature coil in turn so that the armature coil voltages add together & result in a dc output Voltage.
* It also keeps the rotor or armature mmf stationary in space.

⇒ Brushes

The function of brushes is to collect current from the commutator and supply it to the external load circuit.



D.C Machine

Emf equation of DC machine

Let P = Number of Poles
ϕ = Flux produced by each pole in webers
N = Speed of armature in rpm (revolution per minute)
Z = Total number of armature conductors placed inside armature slots
A = Number of parallel path in which the Z number of conductors are divided.
$A = P$ for lap type winding. (High current)
$A = 2$ for wave type winding. (High volt)

Now, emf gets induced in the conductor according to Faraday's law of electromagnetic induction hence average value of emf in each armature conductor is

$$e = \text{Rate of change of flux} = \frac{d\phi}{dt}$$

Now consider one revolution of conductor, in one revolution conductor will cut total flux produced by all the poles as $(\phi \cdot P)$ while time required to complete one revolution is $\left(\frac{60}{N}\right)$ seconds as speed is N rpm.

$$\therefore \quad e = \frac{\phi \cdot P}{\frac{60}{N}} = \frac{\phi N P}{60} \quad \text{for one revolution}$$

This is the emf induced in one conductor.
Now, the conductor in one parallel path are always in series, there are total Z number of

$E_g \Rightarrow$ generated / induced emf for DC generator

$E_b \rightarrow$ Back emf for DC motar

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conductors with (A) parallel path.

Hence, $\frac{Z}{A}$ number of conductors are always in series and emf remains same across all the parallel paths.

So total emf induced in DC machine is

$$\text{Total emf} = \frac{\phi NP}{60} \times \frac{Z}{A}$$

OR

$$\boxed{E = \frac{\phi ZNP}{60A}}$$

Q> A 4 pole lap wound DC generator has a useful flux of 0.07 weber/pole. Calculate the generated emf when it is rotated at a speed of 900 rpm. with the help of prime mover (engine). Armature consists of 440 no. of conductors. Also calculate the generated emf if lap winding is replaced by wave winding.

Sol $\phi = 0.07$ $P = 4$

$N = 900$ $Z = 440$

i> $A = P = 4$

$$E_g = \frac{\phi ZNP}{60A} = \frac{0.07 \times 440 \times 900 \times 4}{60 \times 4}$$

$\boxed{E_g = 462 \text{ V}}$ (lap winding)

ii> $A = 2$

$$E_g = \frac{0.07 \times 440 \times 900 \times 4}{60 \times 2} \Rightarrow \boxed{E_g = 924 \text{ V}}$$

(wave winding)

Q) ~~Ent~~ A 6 pole wave wound DC generator has a useful flux of 0.05 weber/pole. Calculate generated emf when it is rotated with a speed of 1000 rpm with the help of prime mover. Armature consists of 400 number of Conductors. Also calculate the generated emf when the wave winding is replaced by lap winding.

Sol $P = 6$, $\phi = 0.05 \frac{wb}{Pole}$, $N = 1000$ rpm, $Z = 400$

i) For Wave winding, $A = 2$

$$E_g = \frac{\phi Z N P}{60 A} = \frac{0.05 \times \overset{200}{\cancel{400}} \times 100\cancel{0} \times \cancel{6}}{\overset{10}{\cancel{60}} \times \cancel{2}}$$

$$\boxed{E_g = 1000\ V}$$

ii) For lap winding, $A = 6$

$$E_g = \frac{\phi Z N P}{60 A} = \frac{0.05 \times 400 \times 1000 \times 6}{60 \times 6}$$

$$\boxed{E_g = 333.3\ V}$$

Excitation of DC Generator.

* Supplying current to the field winding is called excitation and the way of supplying the exciting current is called method of excitation.

* Depending on the method of excitation used, the DC generators are classified as:-

Shunt = parallel

i) Separately excited DC generator.
ii) Self excited DC generator

Separately Excited DC generator :-

In separately excited DC generator, a separate external DC supply is used to provide exciting current through the field winding.

Self excited DC generator :-

* The DC generator produces DC voltage, if this generated voltage itself is used to excite the field winding of the same DC generator then it is called self excited DC generator

* There are three types of self-excited DC generator:

1) Shunt generator
2) Series generator
3) Compound generator

Note → The field winding is also called exciting winding and current carried by the field winding is called an exciting current