Basic Electrical Engineering

Current: It is defined as the rate of flow of electrical charge with respect to time which is given by

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

it's unit is : Ampere(A)

Electric potential:

The virtue of work can possible done due to accumulation of electrical charges is called electric potential.

It is given by

$$\boxed{V = \frac{\text{Work}}{\text{Charge}} \text{ or } \frac{W}{Q}}$$

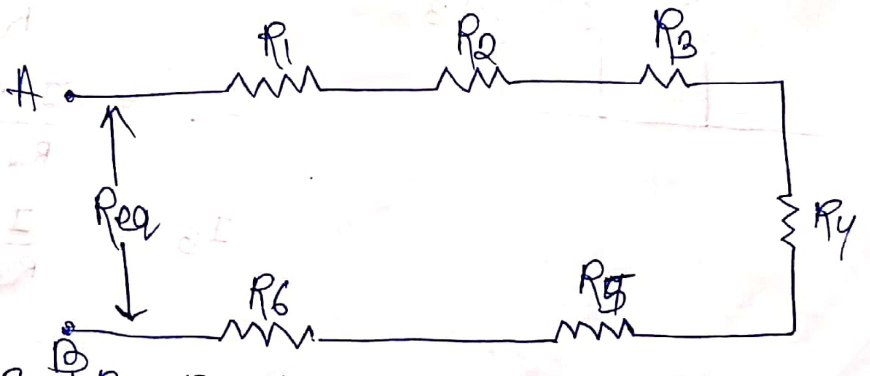
it's unit is volt(V).

Resistance:-

It is a physical property of matter that opposes the flow of electric current through it this is called resistance.

It's unit is ohm(Ω).

Series Combination of Resistance:

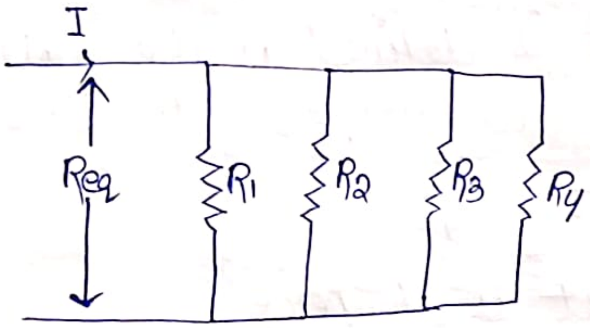


$$R_{eq} = R_1 + R_2 + R_3 + R_4 + R_5 + R_6$$

Parallel combination of Resistance :-

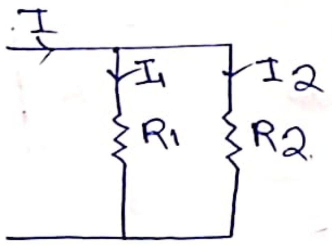
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}$$



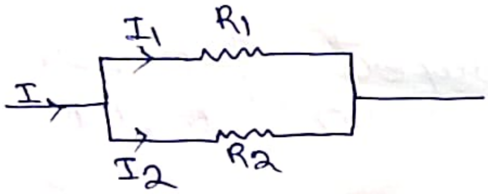
Current Division :

current division is only applicable in parallel combination.



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

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



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

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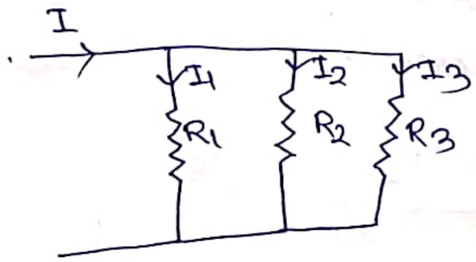


$$I_1 = \frac{I \times R_{eq}}{R_1 + R_{eq}}$$

$$I_2 = \frac{I \times R_{eq}}{R_2 + R_{eq}}$$

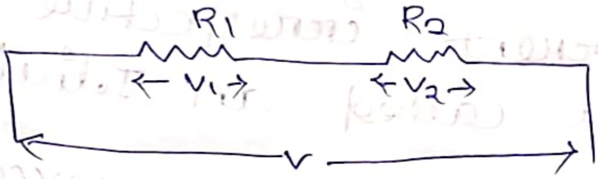
$$I_3 = \frac{I \times R_{eq}}{R_3 + R_{eq}}$$

Voltage Division:

Voltage division is only applicable in series combination

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

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

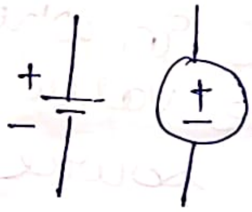


Idial Voltage Source:

A voltage source that maintence constant terminal voltage irrespective of variation in the load current is called an Idial voltage source.

Its internal resistance doesn't exist or are treated as zero.

symbol



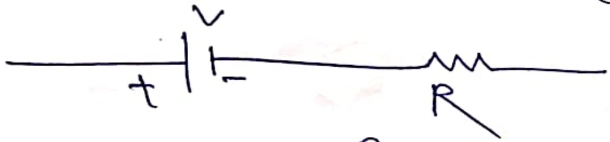
DC voltage source

efficiency is 100%.

AC voltage source.

Practical Voltage Source:

A voltage source in which internal resistance is not zero is called as practical voltage source.



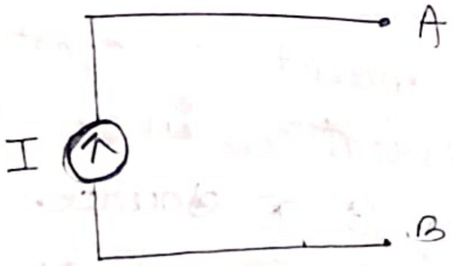
Symbol.

(4) Dt. 20.8.19

Ideal Current Source.

A current source that maintence constant out put current irrespective of variation in load is called an Idial Current Source.

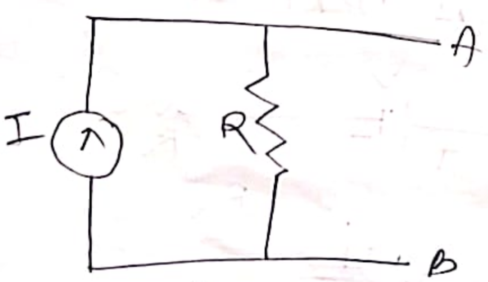
For ideal current source internal resistance 'R' has a very high value tending to infinite.



Practical Current Source

A current source in which internal resistance has a finite value is treated as a Practical current source.

✓ A current source and resistance always connect in parallel.

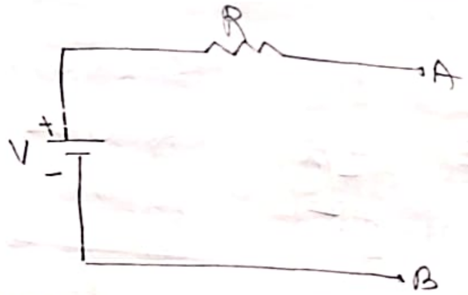


✓ Ammeter connected in parallel.
Volt meter connected in series.

5

A voltage source and resistance always connected in series.

Source Conversion



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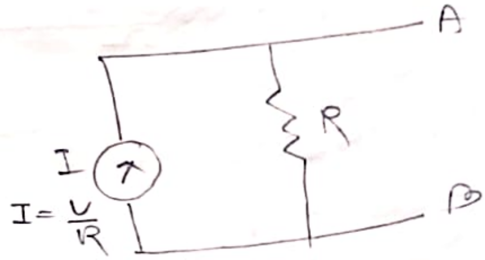


$V = IR$

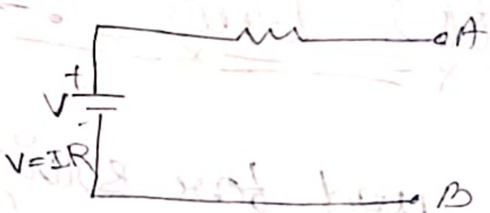
$\Rightarrow I = \frac{V}{R}$

* Replacing a practical voltage source by an equivalent practical current source or viseversa is known as source conversion.

* The magnitude of current source will be

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

≡

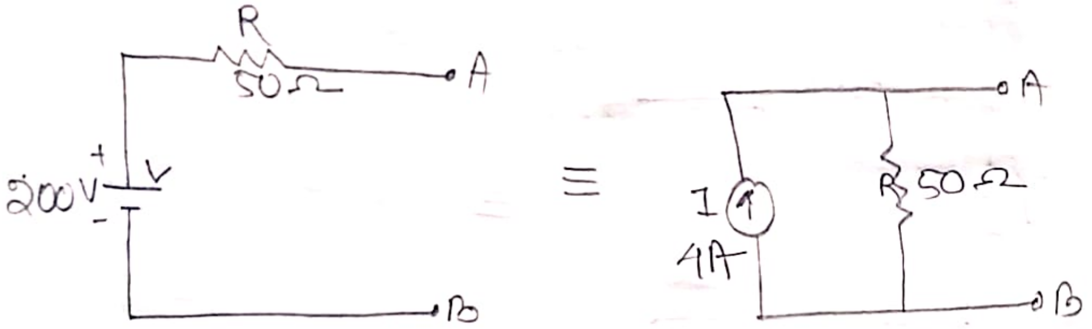


* The magnitude of voltage source will be

$$\boxed{V = IR}$$

6 problem 1: By drawing proper circuit diagram Explain the source conversion If the given datas are $V = 200V$ and $R = 50\Omega$?

Ans



Here $V = 200V$

and $R = 50\Omega$

from Ohm's Law ⇒ $V = IR$

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

$= \frac{200}{50}$

$= 4A$

Kirchoff's Laws :⇒

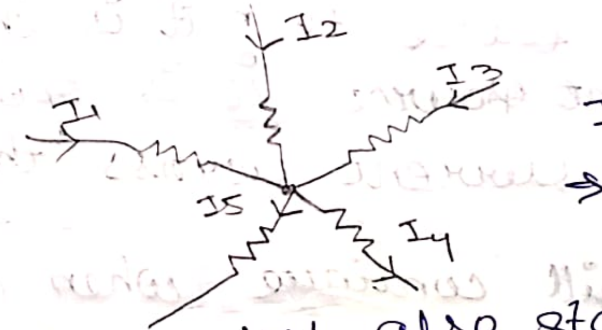
* It is used for solving electrical network problems.
* These laws are useful for determinding the currents and voltages in different sections of electrical networks when circuit contains one or more active elements (voltage source & current source) and number of passive

elements (resistance, inductance, Capacitance)

* Kirchhoff's Law is of two types
1. Kirchhoff's current Law (KCL)
2. Kirchoff's voltage Law (KVL)

Kirchoff's Current Law

Defn:- It is otherwise known as junction Law
this law states that at a given instant the algebric sum of all currents ~~meeti~~ ~~and jo~~ or a junction ~~ng~~ at a given node in a network is zero.



$$I_1 + I_2 + I_3 - I_4 - I_5 = 0$$

$$\Rightarrow I_1 + I_2 + I_3 = I_4 + I_5 \quad \text{--(1)}$$

from eqn (1) KCL also states that the algebric sum of all the currents meeting at a node or a junction at a given instant is equal to be the algebric sum of all the currents leaving the same node or junction.

from eqn KCL

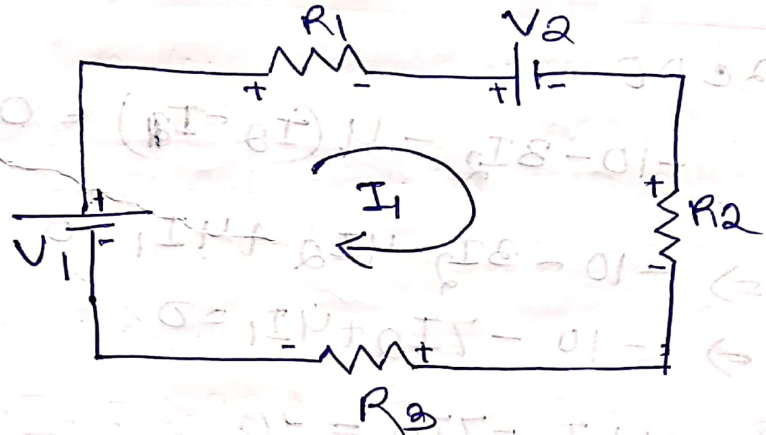
From

1. 6.40/80

0.04

Kirchoff's Voltage Law (KVL)

It states that the algebric sum of voltages around a closed path of any electrical network at a given instant is zero.

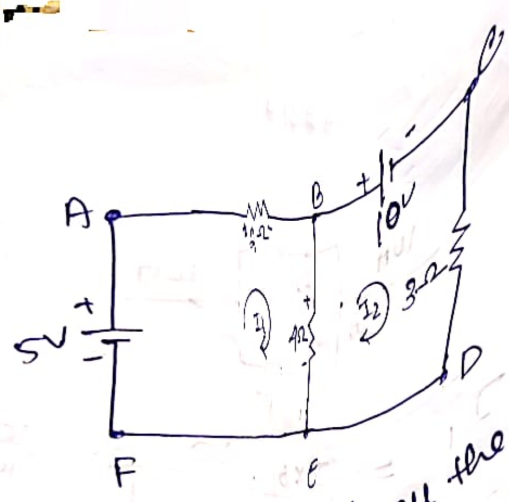


$$+V_1 - IR_1 - V_2 + IR_2 - IR_3 = 0$$

$$\Rightarrow V_1 - V_2 = IR_1 + IR_2 + IR_3 \quad \ldots (1)$$

From the eqn (1) the Alternative statement of KVL which says that the algebric sum of all source voltages at a given instant is equal to the algebric sum of all voltage drops across the passive elements in any closed loop of a network.

Q.1



find the currents flowing in all the branches and voltage drop across the 4Ω

appling KVL.

In ABEF loop

$5V - 2I_1 - 4(I_1 - I_2) = 0$

$\Rightarrow 5V - 2I_1 - 4I_1 + 4I_2 = 0$

$\Rightarrow 5V - 6I_1 + 4I_2 = 0$

$\Rightarrow \cancel{4I_2}\ 6I_1 - 4I_2 = 5$ ---- (1)

Again In BCDE

$-10 - 3I_2 - 4(I_2 - I_1) = 0$

$\Rightarrow -10 - 3I_2 - 4I_2 + 4I_1 = 0$

$\Rightarrow -10 - 7I_2 + 4I_1 = 0$

$\Rightarrow 4I_1 - 7I_2 = 10$ ---- (2)

Solving eq(1) & (2)

$24I_1 - 16I_2 = 20$

$24I_1 - 42I_2 = 60$

(−) (+) (−)

$26I_2 = -40$

$\Rightarrow I_2 = -40/26$

$6I_1 - 4 \times (-1.53) = 5$

$\Rightarrow 6I_1 + 6.12 = 5$

$\Rightarrow 6I_1 = -1.12$

$\Rightarrow I_1 = -0.18\,A$ at a given instant is zero

~~$I_2 - I_1$~~

$I_2 = -1.53A$ (from B to C)

$I_1 = -0.18\,A$ (from B to A)

~~4Ω~~ 4 $I_2 - I_1 = -1.53 + 0.18$

$= -1.35\,A$ from (B to E)

voltage drop across $4\Omega = -1.35 \times 4$

$= -5.40\,V$

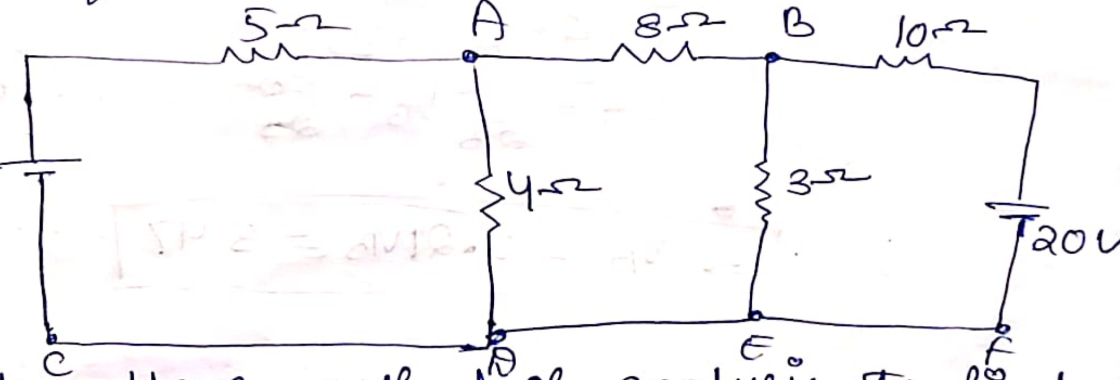
Dt. 27.08.19

Nodal Analysis

The node equation method is ~~best~~ based directly on Kirchoff's current law.

The advantages is that a minimum number of equations needed to be written to determine the unknown quantities

Q// 1.

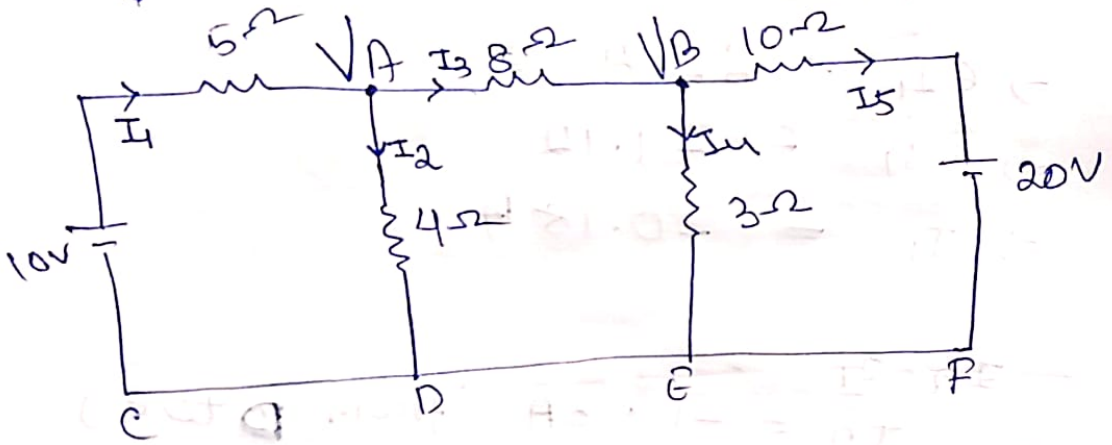


Apply the node voltage method of analysis to find
a) The voltage across terminal A and B
b) Current through 8Ω resister of the circuit in the fig

Ans (16)

~~volt~~

(reference node (C, D, E, F))



$I_4 = \cancel{I_2 + I_3}$

Step 1

Considering node 1: VA

Appling Kirchoff's current law at node 1, V_A

$$I_1 = I_2 + I_3$$

$$\Rightarrow \frac{10 - V_A}{5} = \frac{V_A}{4} + \frac{V_A - V_B}{8}$$

$$\Rightarrow \frac{10 - V_A}{5} = \frac{2V_A + V_A - V_B}{8}$$

$$\Rightarrow 80 - 8V_A = 15V_A - 5V_B$$

$$\Rightarrow 80 = 23V_A - 5V_B$$

$$\Rightarrow V_A - \frac{5}{23} V_B = \frac{80}{23} \quad \text{----}$$

$$\boxed{\Rightarrow V_A - 0.21V_B = 3.47} \quad \text{----(1)}$$

Step-2

Considering node 2, V_B

$I_3 = I_4 + I_5$

appling KCL at node 2, V_B

$$I_3 = I_4 + I_5$$

$$\Rightarrow \frac{V_A - V_B}{8} = \frac{V_B}{3} + \frac{V_B + 20}{10}$$

$$\Rightarrow \frac{V_A - V_B}{8} = \frac{10V_B + 3V_B + 60}{30}$$

$$\Rightarrow \frac{V_A - V_B}{8} = \frac{13V_B + 60}{30}$$

$$\Rightarrow 30V_A - 30V_B = 104V_B + 480.$$

$$\Rightarrow 30V_A - 30V_B - 104V_B + 480 = 0$$

$$\Rightarrow 30V_A + 134V_B + 480 = 0$$

$$\Rightarrow V_A + \frac{134}{30}V_B + \frac{480}{30} = 0$$

$$\Rightarrow V_A + 4.46V_B + 16 = 0$$

$$\Rightarrow V_A - 4.46V_B = -16 \quad \ldots (2)$$

solving eqn (1) & (2)

$$V_A - 0.21V_B = 3.47$$

$$\underline{\overset{(-)}{}V_A \overset{(+)}{-} 4.46V_B = \overset{(+)}{-16}}$$

$$4.25V_B = 19.47$$

$$\Rightarrow V_B = \frac{19.47}{4.25}$$

$$= \underline{\underline{4.58\ V}}$$

$V_A - 0.21 \times 4.58 = 3.47$ (Putting value V_B in eqn 1)

$$\Rightarrow V_A - 0.961 = 3.47$$

$$\Rightarrow V_A = \underline{\underline{4.431\ V}}$$

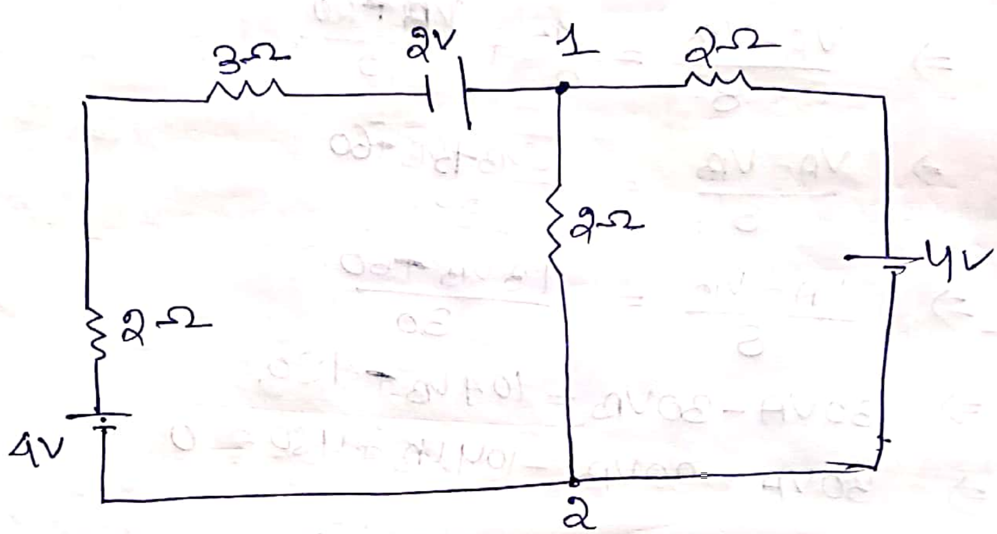
$$V_{AB} = V_A - V_B = 4.431 - 4.58 = -0.14\ V$$

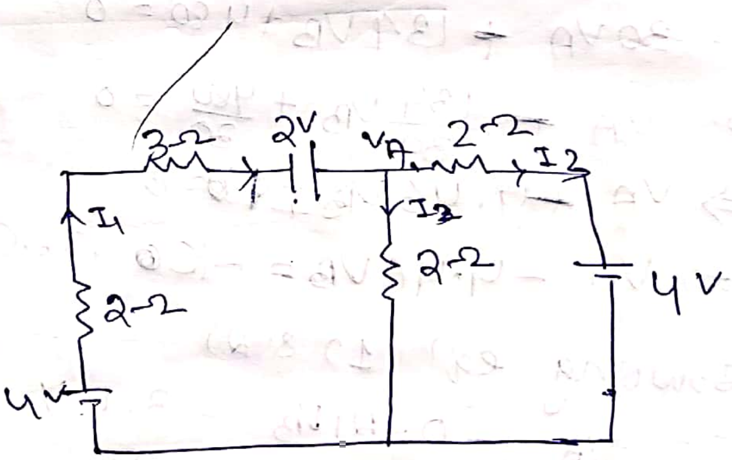
$V_{BA} = 0.14V$

b) current across the $8\Omega = \frac{0.14}{8}$

$= 0.017 A$

2b





$I_1 = I_2 + I_3$

$\Rightarrow \frac{4+2-V_A}{3+2} = \frac{V_A}{2} + \frac{V_A-4}{2}$

$\Rightarrow \frac{6-V_A}{5} = \frac{V_A+V_A-4}{2}$

$\Rightarrow \frac{6-V_A}{5} = V_A - 2$

$\Rightarrow 6 - V_A = 5V_A - 10$

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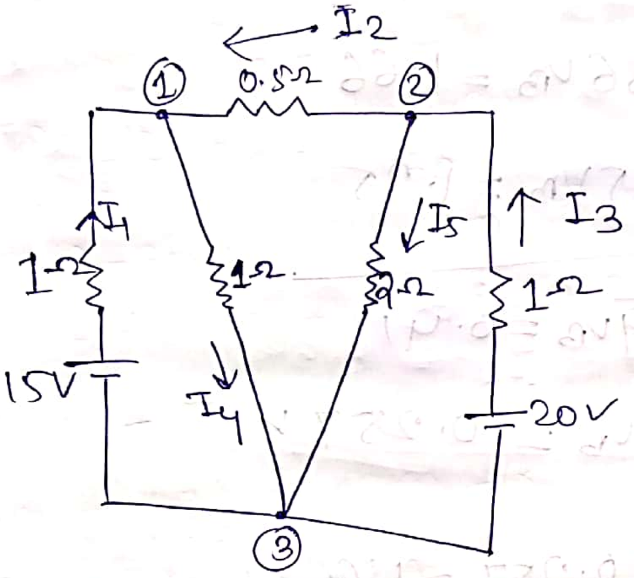
$\Rightarrow \quad 6V_A = 16$

$\Rightarrow V_A = 2.66\ V$

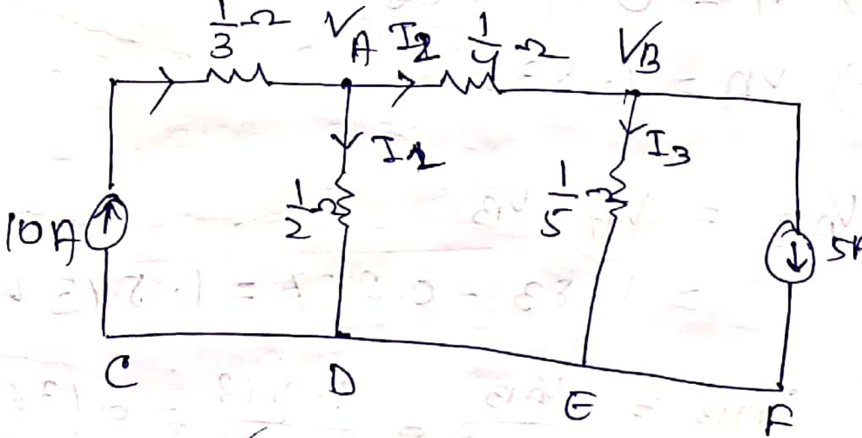
current through 3Ω is I_1

$$I_1 = \frac{6 - V_A}{5} = \frac{6 - 2.66}{5} = \frac{3.34}{5} = 0.66\ A$$

3)



4)



$$10 = \frac{V_A}{\frac{1}{2}} + 4V_A - 4V_B$$

$\Rightarrow 10 = 2V_A + 4V_A - 4V_B$

$\Rightarrow 10 = 6V_A - 4V_B$

$\Rightarrow \quad V_A = 0.66V_B \Rightarrow V_A - 0.66V_B = 1.66$

Considering V_B

$I_2 = I_3 + 5$

$\Rightarrow 4V_A - 4V_B = 5V_B + 5$

$\Rightarrow 4V_A - 9V_B = 5$

$\Rightarrow V_A - 2.25V_B = 1.25$ ...②

$$\cancel{V_A} - 0.66V_B = 1.66$$
$$\underset{(-)}{\cancel{V_A}} \underset{(+)}{-} 2.25V_B = \underset{(-)}{1.25}$$

$1.59V_B = 0.41$

$\Rightarrow V_B = 0.257\,V$

$V_A - 0.66 \times 0.257 = 1.66$

$\Rightarrow V_A = 0.17 = 1.66$

$\Rightarrow V_A = 1.83V$

a) $V_{AB} = V_A - V_B$

$= 1.83 - 0.257 = 1.573\,V$

b) $I_{AB} = \dfrac{V_{AB}}{0.25} = \dfrac{1.573}{0.25} = 6.136A$ (A→B)

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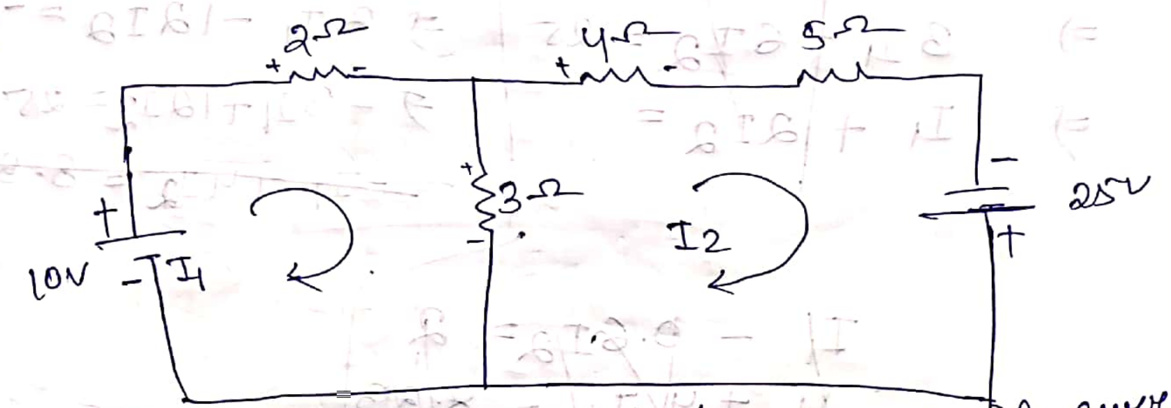
Mesh Analysis

* This method is effective for finding the branch currents and voltages across elements of an electrical network by the way of finding currents for each closed loops (mesh).
* It is applicable for Kirchoff's voltage law.

Q/ 1.



Apply the mesh current method to find the current through 3Ω and 4Ω resistor of the given circuit.

Ans

Appling KVL for loop (1)

$$+10 - I_1R_1 - 3(I_1 - I_2) = 0$$

$$\Rightarrow 10 - 2I_1 - 3I_1 + 3I_2 = 0$$

$$\Rightarrow 10 - 5I_1 + 3I_2 = 0$$

$$\Rightarrow -5I_1 + 3I_2 + 10 = 0$$

$$\Rightarrow 5I_1 - 3I_2 = 10 \quad \cdots (1)$$

$$\Rightarrow I_1 - 3/5 I_2 - 2 = 0$$

$$\Rightarrow I_1 - 0.6I_2 - 2 = 0 \quad (1)$$

$$\Rightarrow I_1 - 0.6I_2 = 2 \quad \cdots (1)$$

Appling for loop-2

$+25 - 3(I_2 - I_1) - 4I_2 - 5I_2 = 0$

$\Rightarrow 25 - 3I_2 + 3I_1 - 4I_2 - 5I_2 = 0$

$\Rightarrow 25 + 3I_1 - 12I_2 = 0$

$\Rightarrow 3I_1 - 12I_2 = -25$

$\Rightarrow -3I_1 + 12I_2 = 25$ ... (2)

~~$\Rightarrow -I_1 + 4I_2 = 8.33$~~

~~$\Rightarrow 25 - 3I_1 - 6I_2 = 0$~~

~~$\Rightarrow -3I_1 - 6I_2 = -25$~~

~~$\Rightarrow 3I_1 + 6I_2 = 25$~~

~~$\Rightarrow I_1 + 2I_2 =$~~

~~$I_1 - 0.6I_2 = 2$~~

~~$-I_1 + 4I_1 = 8.33$~~

The loop expression (1) & (2) may be arranged in a matrix form.

$$[R]\,[I] = [V]$$

$$\begin{bmatrix} 5 & -3 \\ -3 & 12 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 10 \\ 25 \end{bmatrix}$$

which can be solved by Cramer's Rule to get the unknown values of I_1 & I_2

For finding $I_1 = \dfrac{\begin{bmatrix} 10 & -3 \\ 25 & 12 \end{bmatrix}}{\begin{bmatrix} 5 & -3 \\ -3 & 12 \end{bmatrix}}$

$$I_1 = \frac{120 + 75}{60 - 9}$$

$$= \frac{195}{51}$$

$$= 3.82\,A$$

for finding I_2

$$= \frac{\begin{bmatrix} 5 & 10 \\ -3 & 25 \end{bmatrix}}{\begin{bmatrix} 5 & -3 \\ -3 & 12 \end{bmatrix}}$$

$$= \frac{125 + 30}{51}$$

$$= \frac{155}{51}$$

$= 3.03A$ (current flow 4Ω)

current through 3Ω

$$= I_1 - I_2$$

$$= 3.82 - 3.03$$

$$= \cancel{0.520}\ 0.79\,A$$

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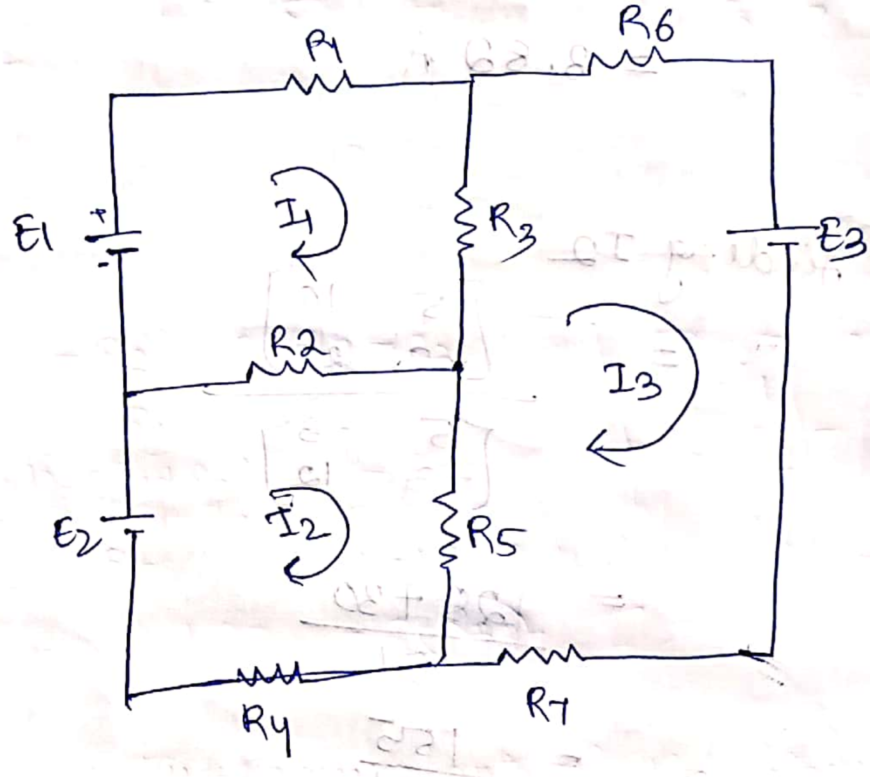
Mesh Analysis using Matrix form :-

2nd // $E_2 - R_2(I_2 - I_1) - R_5(I_2 - I_3) - R_4 I_2$



Appling KVL in first mesh (1) :-

$\cancel{+E_1 - I_1R_1 - I_1(R_3 - R_1)} - I_1R_2$

$$E_1 - I_1R_1 - R_3(I_1 - I_3) - R_2(I_1 - I_2) = 0$$

$$\Rightarrow E_1 - I_1R_1 - I_1R_3 + I_3R_3 - I_1R_2 + I_2R_2 = 0$$

$$\Rightarrow E_1 - I_1(R_1 + R_2 + R_3) + I_2R_2 + I_3R_3 = 0$$

$$\Rightarrow E_1 = I_1(R_1 + R_2 + R_3) - I_2R_2 - I_3R_3$$

$$\Rightarrow (R_1 + R_2 + R_3) I_1 - R_2 I_2 - R_3 I_3 = E_1 \quad -(1)$$

Mesh - 2

$$E_2 - (I_2 - I_1) R_2 - R_5 (I_2 - I_3) - R_4 I_2 = 0$$

$$\Rightarrow \cancel{E_2 - (I_2 - I_1) R_2 - R_5 (I_2 - I_3)}$$

$$\cancel{E_2 (I_2 - I_1)}$$

$$\Rightarrow E_2 - R_2 I_2 + R_2 I_1 - R_5 I_2 + R_5 I_3 - R_4 I_2 = 0$$

$$\Rightarrow E_2 - I_2 (R_2 + R_5 + R_4) - R_2 I_1 + R_5 I_3 = 0$$

$$\Rightarrow E_2 = I_2 (R_2 + R_5 + R_4) + R_2 I_1 - R_5 I_3$$

$$\Rightarrow R_2 I_1 - R_5 I_3 + I_2 (R_2 + R_5 + R_4) = E_2 \quad \text{(2)}$$

Mesh - 3

$$E - I_3 R_6 - R_3 (I_3 - I_1) - R_5 (I_3 - I_2) - I_3 R_7 = 0$$

$$\Rightarrow E - I_3 R_6 - R_3 I_3 + R_3 I_1 - R_5 I_3 + R_5 I_2 - I_3 R_7 = 0$$

$$\Rightarrow E - I_3 (R_6 + R_3 + R_5 + R_7) + R_3 I_1 + R_5 I_2 = 0$$

$$\Rightarrow I_3 (R_6 + R_3 + R_5 + R_7) - R_3 I_1 - R_5 I_2 = E \quad \text{(3)}$$

$$
\begin{matrix}
(R_1+R_2+R_3) & -R_2 & -R_3 \\
-R_2 & (R_2+R_4+R_5) & -R_5 \\
-R_3 & -R_5 & (R_3+R_5+R_6+R_7)
\end{matrix}
$$

$$
\begin{bmatrix}
\overset{R_{11}}{(R_1+R_2+R_3)} & -R_2 & -R_3 \\
-R_2 & \overset{R_{22}}{(R_2+R_4+R_5)} & -R_5 \\
-R_3 & -R_5 & \underset{R_{33}}{(R_3+R_5+R_6+R_7)}
\end{bmatrix}
\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}
=
\begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}
$$

This is the matrix equivalent of the above three equation

R_{11} = Self resistance of mesh 1

R_{22} = Self resistance of mesh 2

that is sum of all the resistances present in the mesh 2

R_{33} - Self resistance of mesh 3

that is the sum of all the resistanc present in mesh 3

$R_{12} = R_{21} = -$ (Sum of all the resistances common to mesh (1) and mesh (2).)

&

$R_{23} = R_{32} = -$ (Sum of all the resistances common to mesh (2) & (3))

$R_{13} = R_{31} = -$ (Sum of all the resistances common to mesh (3) & (1))

using the symbols the generalised form of the above matrix equivalent can be written as

$$\begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

Note:-

* All the self resistances will be always possitive.
* All the mutual resistances will be always negative.

Q.1. write the impedance matrix of the network shown in the figure and find the value of I_3

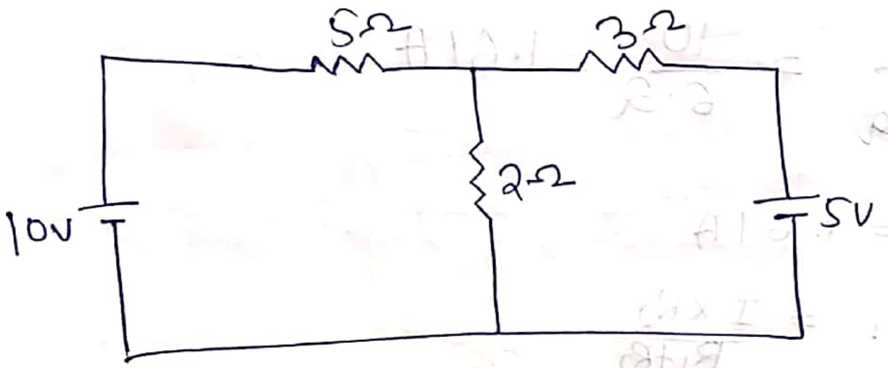
LAB

Superposition Theorem :→

In a linear bilateral containing more than one sources of energy the overal effect of ~~the~~ all the sources consider simultaneously each same as the algebric sum of individual effects, of each source considered one at a time and being independent of all other sources.

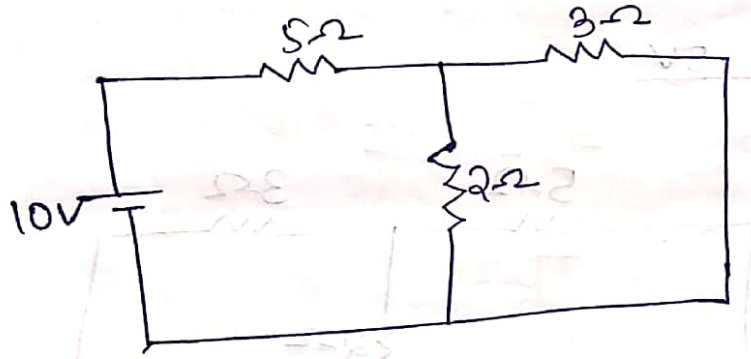
* In Superposition Theorem if there are more than one source consider one source at a time, other source may be short circuit or open circuited
* If it is a voltage source then it is short circuit. If it is a current source it is open circuit.
* Then find the current across the particular branch.
* Same process will continue when considering the other source.
* In the end considering both the sources find the current across the particular branch

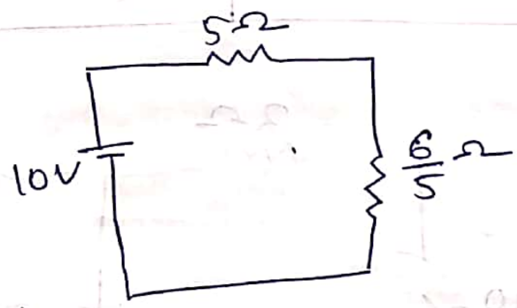
Q:- Find current across 2Ω

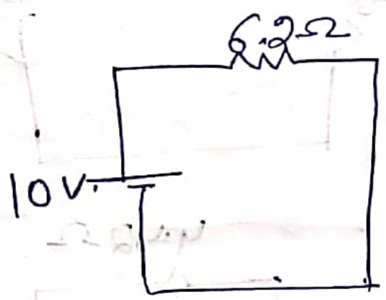


Step-1

considering 10 V







$V = 10V$

$R_{eq} = 6.2\Omega$

$$I = \frac{V}{R_{eq}} = \frac{10}{6.2} = 1.61A$$

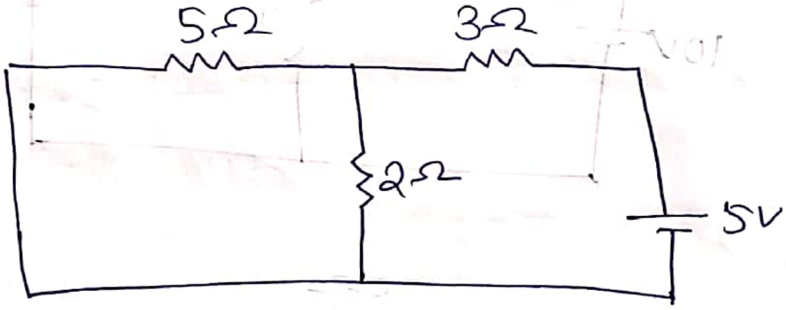
$I = 1.61A$

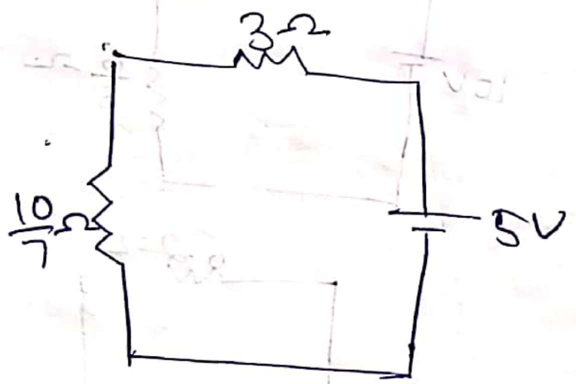
$$I_1 = \frac{I \times R_2}{R_1 + R_2}$$

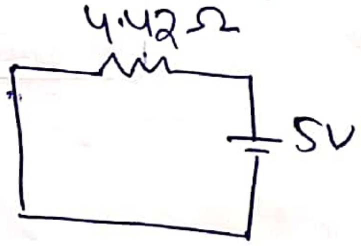
$$= \frac{1.61 \times 3}{2+3} = \frac{4.83}{5} = 0.966A$$

Step-2

Considering 5V







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$\Rightarrow$ $V = 5V$

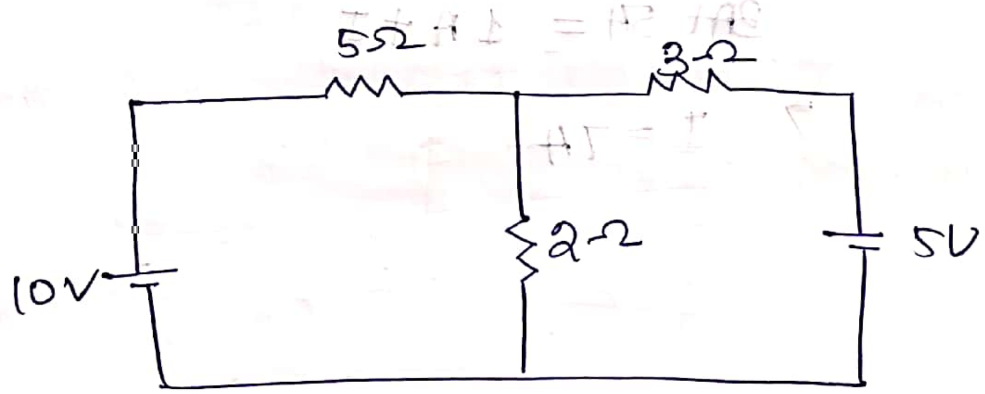
$R = 4.42\Omega$

$$I = \frac{V}{R} = \frac{5}{4.42}$$
$$= 1.131A.$$

$$I_2' = \frac{1.131 \times 5}{2+5}$$
$$= \frac{5.655}{7} = 0.807A$$

Step-3

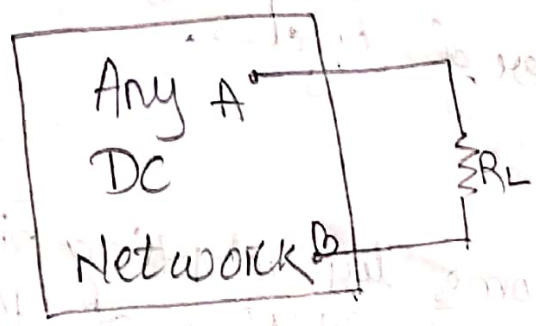
considering Both voltage source 10V & 5V



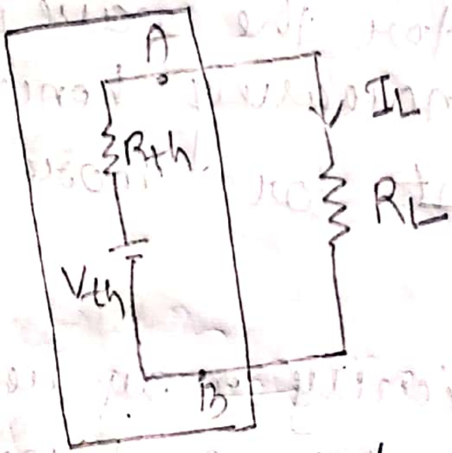
when I consider 10V the current across 2Ω resistance is downward, when I consider 5V voltage source the current across the 2Ω is also downward, so that the current across 2Ω will be.

$$I = 0.96 + 0.807$$
$$= 1.767.$$

THEVENIN'S THEOREM



A- Original network



B- Thevenin's equivalent circuit.

Def^n:- In Order to find the responds through any perticular element connected across a paire of terminals A & B of a linear active DC network the rest of the network may be replaced by a Thevenin's equivalent circuit containing a voltage source called Thevenin's voltage V_{th} and A series resistance called Thevenin's resistance R_{th}

For ~~the~~ it may be noted that V_{th} is the open circuit potential difference across A & B due to rest of the network in the absence of R_L (load resistance), and R_{th} is the equivalent resistance of rest of the network as viewed from terminals A & B in the absence of R_L with all the source made inactive

$$I_L = \frac{V_{th}}{R_{th} + R_L} \quad \ldots\ldots (1)$$

$$V_{AB} = I_L \times R_L \quad \ldots\ldots (2)$$

Step-1

Replace the current sources if any equivalent voltage sources. $V = SR$

Step-2

Identify a pair of terminals A & B across the desire element and mark it as R_L.

Step-3

Find the voltage across A & B in the absence of R_L and mark as V_{th}.

Step-4

Replace all voltage sources with circuit resistance by calculate the equivalent resistance from looking into the network from the open terminals A & B and mark this as R_{th}.

Step-5

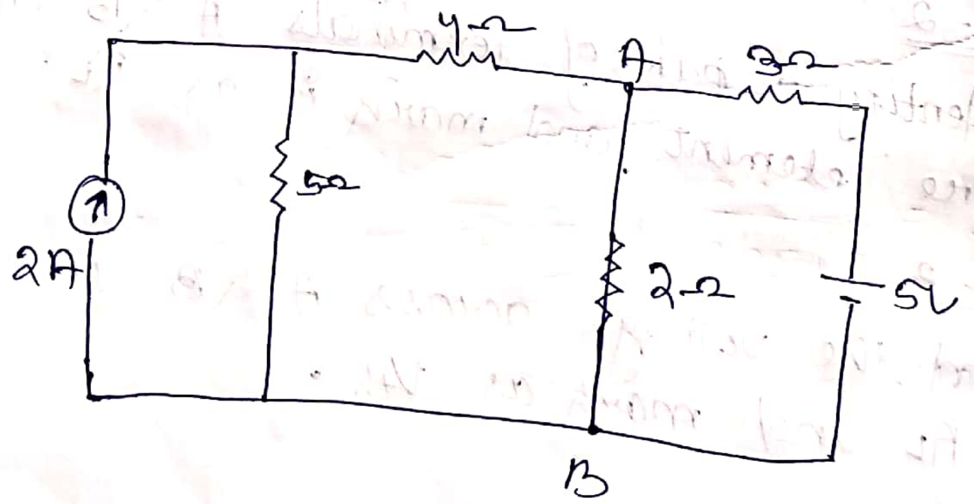
Draw the Thevenin's equivalent circuit as shown in the fig. B

Step-6

Solve load current & voltage as per the eqn. no (1) & (2)

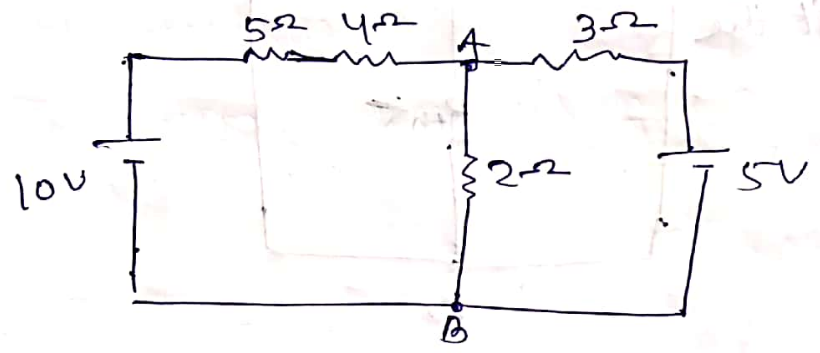
Q-1

Find the current flowing ~~through~~ in the 2Ω resistor of the circuit shown in the fig. below by appling Thevenin's Theorem.



Step-1

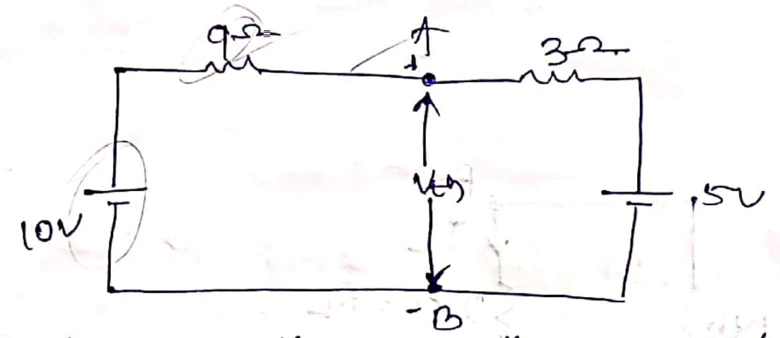
Replacing the current source as voltage source we got the circuit diagram as given below.



choice

Step-2

for finding V_{th}



1-ϕ = 230
3-ϕ - R Y b

Appling KVL on the circuit we get

$10 - 9I - 3I - 5 = 0$

~~10 - 9I - Vth = 0~~

$\Rightarrow 10 - 12I - 5 = 0$

~~-Vth + 5 - 3I~~ = 0

$\Rightarrow 5 = 12I$

$\Rightarrow I = \frac{5}{12} = 0.41A$

$V_{th} = 10 - 9 \times 0.41$

$= 10 - 3.69$

$= 6.31 V$

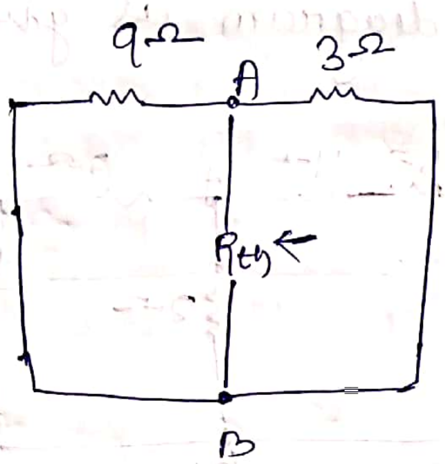
$5 + 3 \times 0.41$

3.12

Step-3

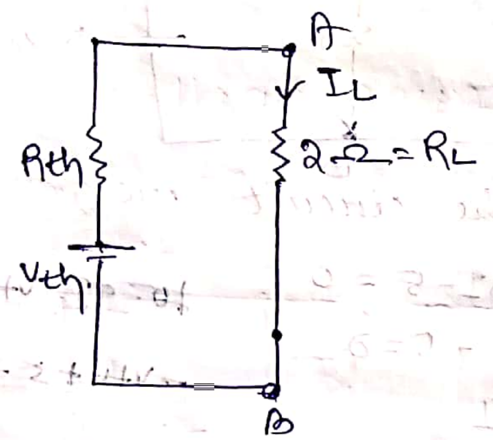
For finding R_{th}

For calculate R_{th}, circuit the voltages



$$R_{th} = \frac{9\times3}{9+3} = \frac{27}{12} = 2.25\,\Omega$$

Step-4

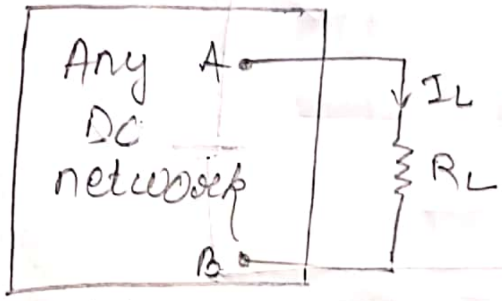


$$I_L = \frac{V_{th}}{R_{th}+R_L} = \frac{6.31}{2.25+2} = \frac{6.31}{4.25}$$

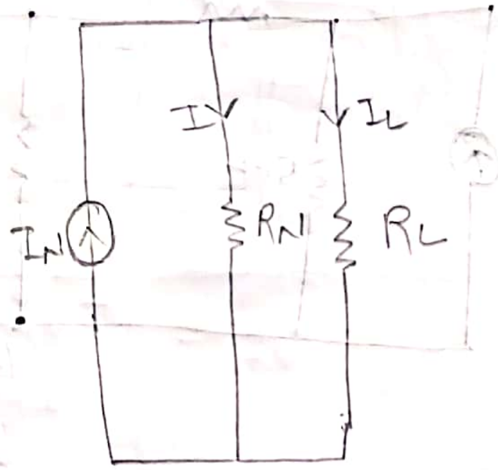
$$= 1.48A$$

NORTON'S THEOREM

It is the opposite of Thevenin's Theorem. Application of this theorem becomes easier if the network contains current source only



(a) original network



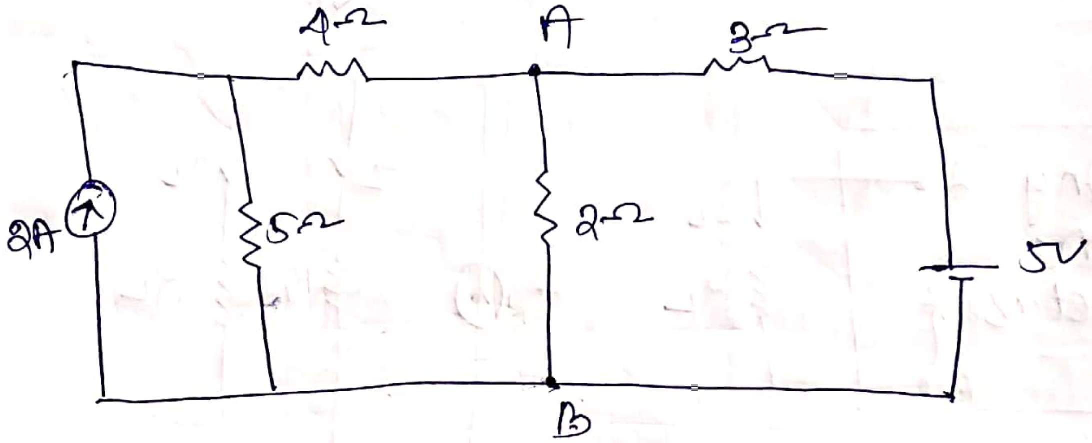
(b) Norton's equivalent circuit.

Defn :- In order to find the responds through any particular element connected across a pair of terminals A & B of a linear active DC network, the rest of the network may be replaced by a Norton's equivalent circuit. Containing a current source called Norton current (I_N) and parallel resistance called Norton's Resistance (R_N).

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

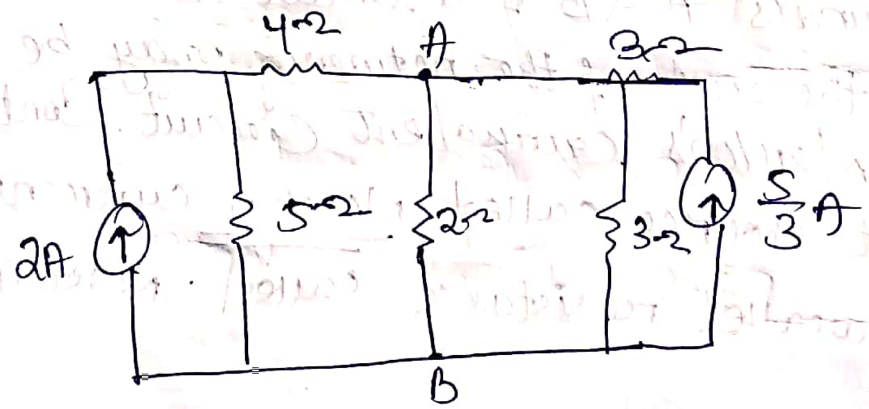
Q.1

Find the current flowing in the 2Ω Resistor of the circuit shown in the figure below by appling Norton's theorem.



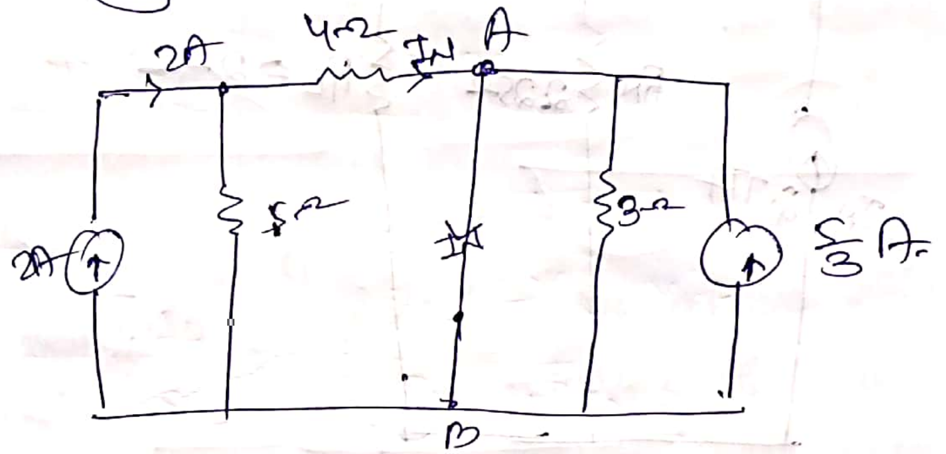
Step-1

Converting voltage source to current source



Step-2

For finding IN which is the circuit current that would flow through A & B. Due to the rest of the network with R_L Replaced by the short circuit. to find this we may redraw the network by replacing the 2Ω resistor by short circuit.



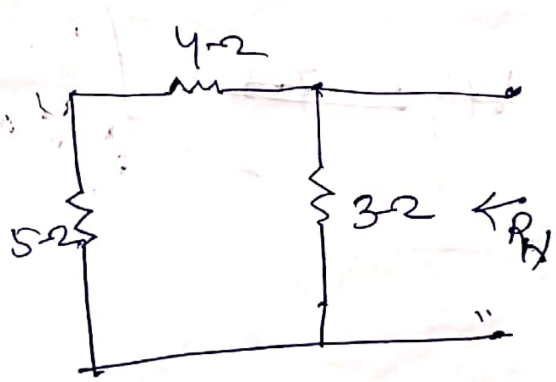
$$I_N = \left(\frac{2 \times 5}{5+4}\right) + \frac{5}{3}$$

$$= \frac{10}{9} + \frac{5}{3}$$

$$= \frac{10+15}{9} = \frac{25}{9} = 2.77 \text{ A}$$

Step-3

For Finding R_N which is the resistance of the network viewed from A & B with all the source inactive.

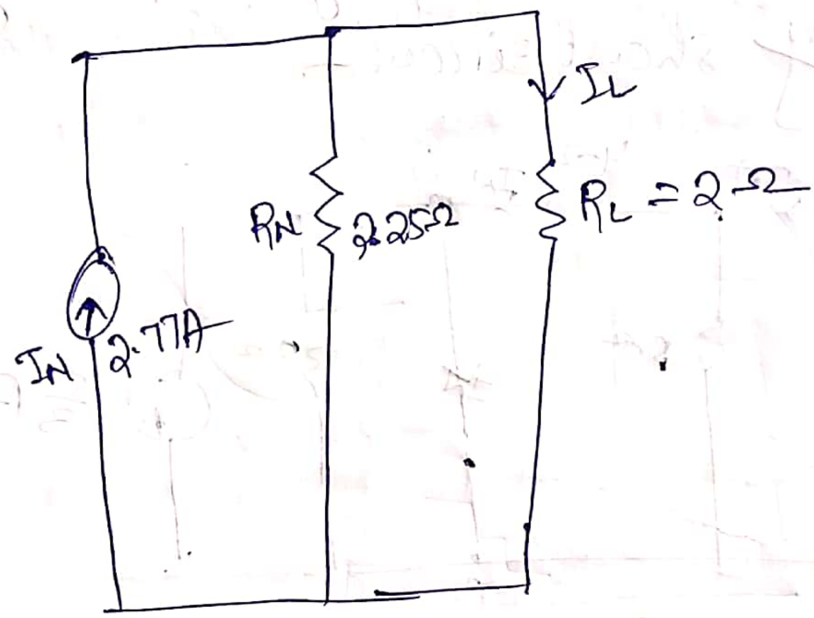


$$R_{eq} = \frac{9 \times 3}{9+3}$$

$$= \frac{27}{12}$$

$$= 2.25 Ω$$

Step-4



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

$$= \frac{2.77 \times 2.25}{2 + 2.25}$$

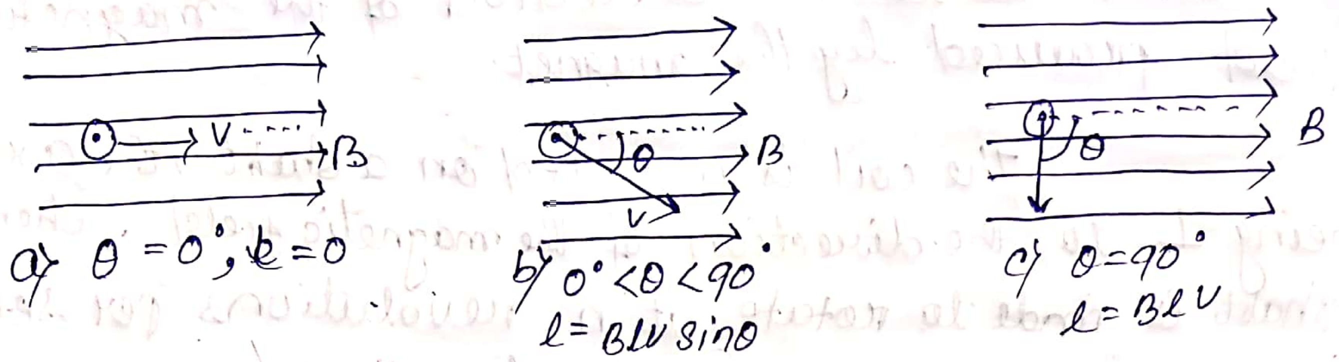
$$= 1.46\ A$$

Single Phase (1-ϕ) AC circuits

The basic object of this chapter is to familiarize with 1-ϕ AC generation and the basic nature of 1-ϕ emf.

1-ϕ emf generation:-

1-ϕ emf generation is based on the principle of dynamically induced or motional emf. According to this principal, a conductor of length 'l' while moving at a velocity 'v' making at an angle 'θ' to a steady magnetic filed of flux density 'B', becomes the seat of a dynamically induced emf 'e' as described ~~as the~~ in the figure below.



Dynamic induced emf in a conductor.

In the above figure the emf induced may have different values for different equations.

$$\boxed{e = BLV\sin\theta} \quad \text{------(1)}$$

This principle may be extended to obtain 1-φ emf in a coil as per the arrangement shown in the figure below.

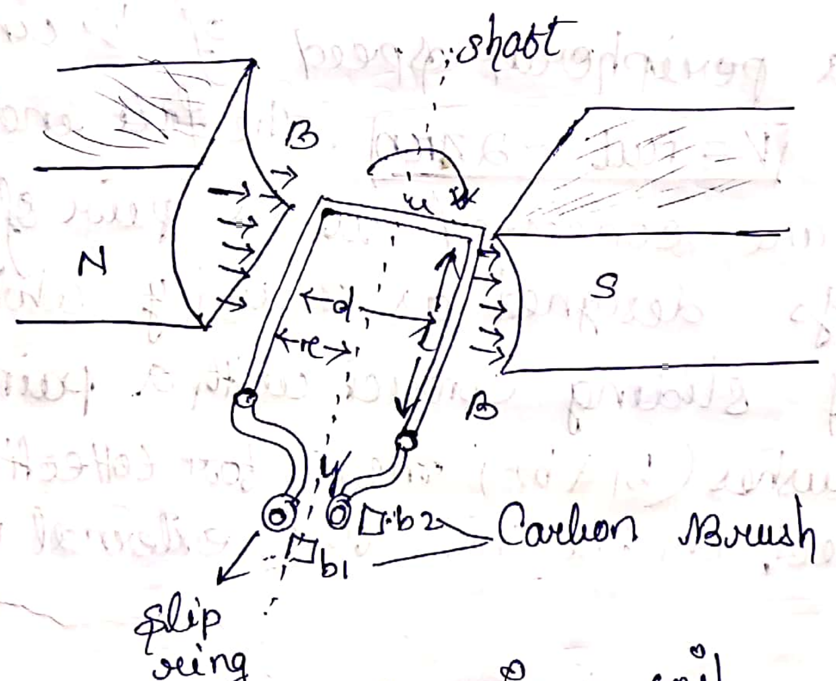


figure 1-φ emf generation in a coil.

The simplest practical case consist of a pair of magnetic poles designed as N (north pole) and S (south pole) in the form of a permanent magnet with a coil placed between, which is freely rotate about an axis $\perp$ to the direction of the magnetic field produced by the magnet.

The coil is mounted on a shaft, the axis being $\perp$ to the direction of the magnetic field. When the shaft is made to rotate at 'n' revolutions per second (rps), it produces an angular speed units (rad/sec) such as $\boxed{\omega = 2\pi n}$. The coil also assumes the same angular speed. The coil during its rotation describes a circle, The radius of which may be taken as 'r' units (m) such as $r = d/2$. As the coil rotates in the space, the conductors assume a peripheral speed of 'v' units (m/s) given by $\boxed{V = r\omega = 2\pi r n}$. The free ends of the coil coil are connected to a pair of isolated slip rings designed as x and y which form a kind of sliding contact with a pair of fixed carbon brushes (b_1 & b_2) meant for collection of the emf induced in the coil for external use.

Dt. 10.09.19

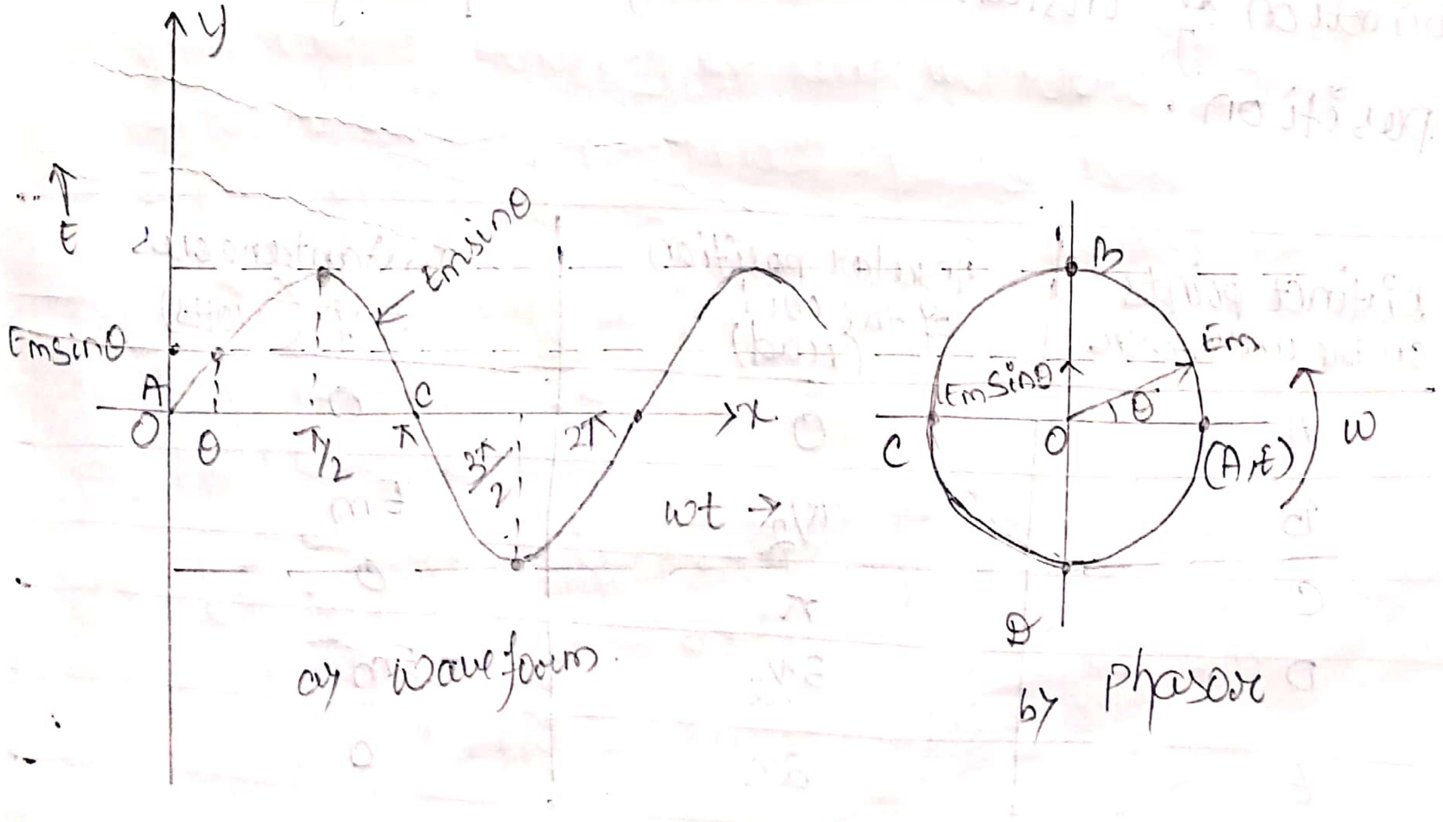
Sinusoidal wave from and phasor representation of EMF.

With the help of graphycal means it is possible to have a better feel of ~~vibrations~~ viriations of the single phase(1-ϕ)emf represented in the equation no-4 with respect to time and angular positions of the coil.

Two familiar technics used for this purposed are

1. Wave form representation
2. Phasor representation

1. Wave form Representation of EMF :-



In this technique the variation of E as obtained from equation no-4 are plotted as a function of 'θ' or ωt in a cartesian coordinate system. This gives the plot of fig. A which is the result of the step by step plotting of instantaneous emf 'E' taken along y-axis corresponding to respective values of θ or ωt taken along x-axis.

A few destinct points of this waveform are ~~highlighted~~ high lighted in the table given below along with the information about the angular position and instantaneous emf there of

* Table:-
Variation of instantaneous emf with angular position.

Distinct points on the wave form	Angular position of the coil (rad)	Instantaneous emf (volts)
A	0	0
B	$\pi/2$	Em
C	π	0
D	$3\pi/2$	-Em
E	2π	0

A complete revolution of the coil corresponds to one complete cycle or 2π radians or $360°$

In view of this the plotting of the above figure is limited to one full cycle only.

2. Phasor Representation of Emf

As the number of cycles increases the length of the plot under the wave form representation technique goes on increasing hence the technique may not be convenient for more number of cycles.
flexible.

This difficulty may be overcome by adopting phasor techniques. ~~thes~~ A phasor representation of the instantaneous emf is shown in the fig. b. in which the instantaneous variation of emf over a full cycle corresponds to one complete revolution of a phasor along a predefined circle.

Thus a rotating phasor is the key accept of this technique which is shown with the help of an arrow taking a perticular radial position at a perticular instant of time. the arrow has a fixed length equal to the magnitude of the pick emf E_m

The direction of rotation of phasor is shown by the arrow mark, corresponding to 'ω' which is in accordance with direction of rotation of coil.

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for a particular instant of time t the phasor gets positioned at the corresponding angular position indicated by $\theta = \omega t$.

The projection over to the y-axis drawn from the tip of the phasor at a particular position indicates the instantaneous value of the emf at that instant, thus satisfying equation (4) in every respe

The salient points (A, B, C, D, E) in the above figure have also been corresponding between the two forms of represent is that one complete cycle representation of the waveform in the fig (a) is equivalent to one complete revolution of the phasor in figure (b).

Note :

Phase and phase difference are two commonly uses terms associated with waveforms & phasor.

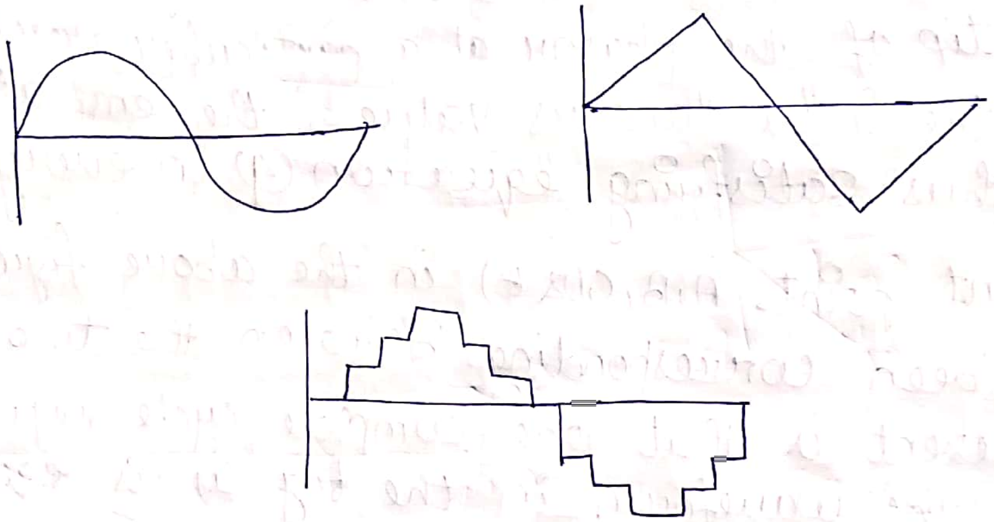
Phase of a phasor is defined as the instantaneous angular position of a waveform or phasor.

It is designed by the symbol θ or ωt

On the other hand phase difference is the angular difference between two waveforms or phasor as regards to their starting point. It is designed by the symbol ϕ.

Cycle

one complete set of +ve & -ve value of alternating quantity is called as cycle.



Time Period

The time taken by an alternating quantity to complete one cycle is called it's time period T.

Exp:- A 50 Hz alternating current has a time period of 1/50 second.

Frequency :-

The number of cycles/second is called the frequency of the alternating quantity.

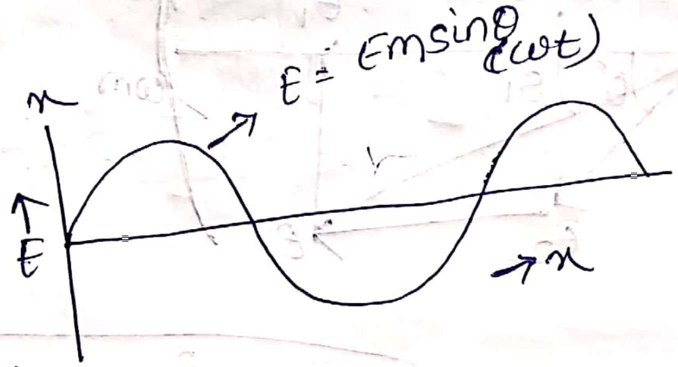
Amplitude

The maximum value, +ve or -ve of an alternating quantity is known as its amplitude

Q. A coil rotating at 1000 RPM in a uniform magnetic field includes a sinusoidal emf of pick value of 100V. If the time is recorded at $t=0$ corresponding to 0 instantaneous emf, how long would it take for the instantaneous emf to attend a value of 30V for the first ~~by~~ time.

E_m = pick value
$E = 30V$

Ans



$n = 1000 RPM$

$= \frac{1000}{60} = 16.66$ RPS

$Emf = 100 V$

$t = 0$

$E = E_m \sin$

$\omega = 2\pi n$

$= 2\pi \times 16.66$

$= 33.32\pi$

$= 33.32 \times 3.14$

$= 104.62$

$E = 30V$,

$E = E_m \sin\omega t$

$\Rightarrow 30 = 100 \sin\omega t$

$\Rightarrow \sin\omega t = \frac{30}{100}$

$\Rightarrow \omega t = \sin^{-1}\left(\frac{30}{100}\right)$

$= \cancel{17.45}\ 0.30$ Rad

$\omega t = 0.30$ Rad

$\Rightarrow t = \frac{0.30}{\omega} = \frac{0.30}{104.62} = 0.0028$ Sec.

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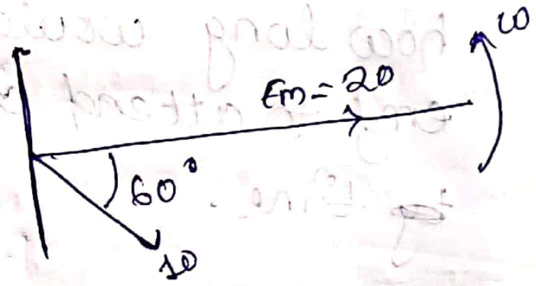
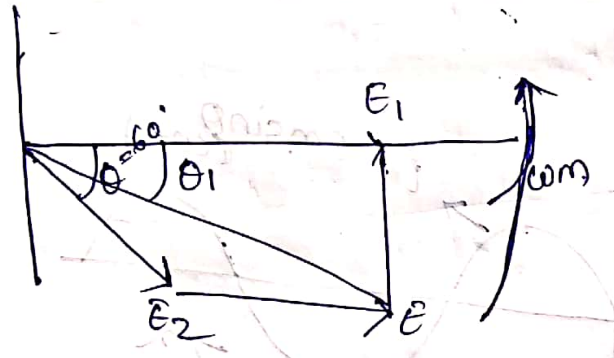
Q. Given the phasor representation for the sinusoidal emfs given by $e_1 = 20 \sin 314t$
$e_2 = 10 \sin (314t - 60)$

find the resultant of two phasors.





$$E_m = \sqrt{E_{m1}^2 + E_{m2}^2 + 2 E_{m1} E_{m2} \cos\theta}$$

$$= \sqrt{400 + 100 + 2 \cdot 20 \cdot 10 \times \cos 60°}$$

0.34.

$$E_m = 26.45V$$

$$\phi_1 = \tan^{-1}\left(\frac{E_{m2} \sin\theta}{E_{m1} + E_{m2}\cos\theta}\right)$$

$$= \tan^{-1}\left[\frac{10 \times \sin 60}{20 + 10 \cos 60}\right]$$

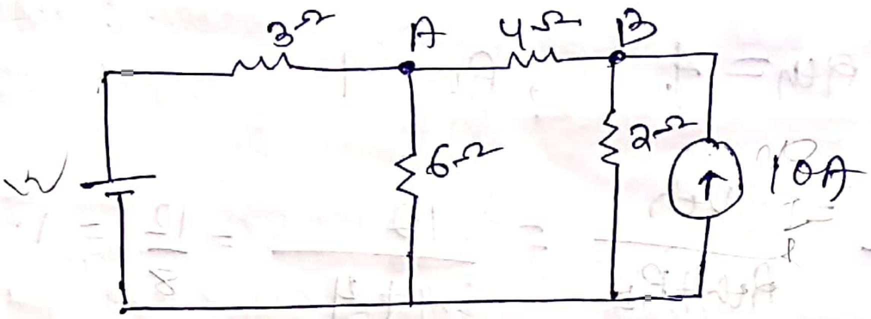
$$= \tan^{-1}\left[\frac{\cancel{10} \times \frac{\sqrt{3}}{2}}{20 + \cancel{10} \times \frac{1}{2}}\right]$$

$$= \tan^{-1} \frac{5\sqrt{3}}{25} = \tan^{-1} \frac{\sqrt{3}}{5}$$

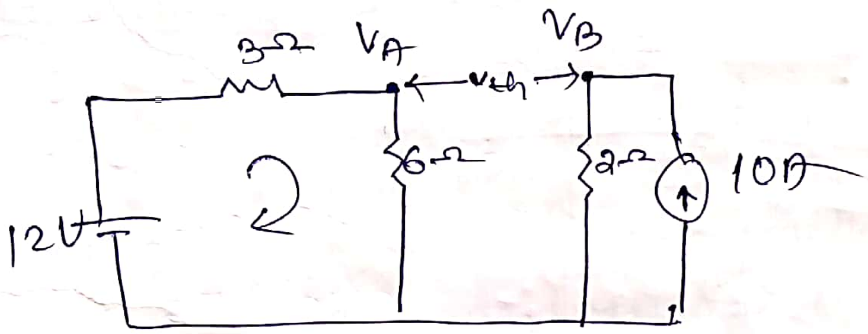
$$\cancel{= 0.327} = 19.1°$$

$$E = E_m \sin(\omega t - \theta)$$
$$= 26.45 . \sin(\omega t - 19.1^\circ)$$
$$= 26.45 \sin(314t - 19.1^\circ)$$

Q. using Thevinins Theorem calculate the current flowing through the 4Ω resistor



step-1



$$12 - 3I_p - 6I_p = 0$$
$$\Rightarrow I = 12/6 = 1.33A$$
$$V_A = 1.33 \times 6 = 7.98V$$
$$V_B = 10 \times 2 = 20V$$
$$V_{th} = 20 - 8 = 12V (V_{BA})$$

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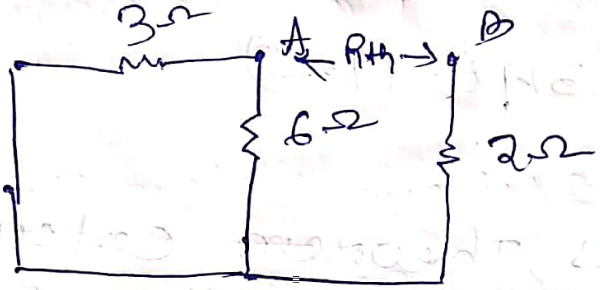
1st step

Rth



$$R_{th} = \frac{6\times3}{6+3}+2 = 4$$

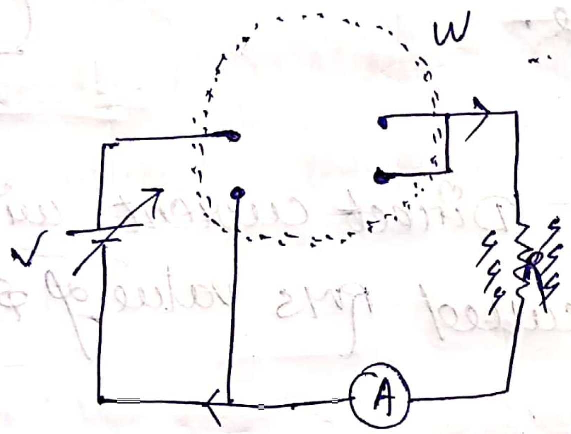
$R_{th} = 4$, $R_L = 4$

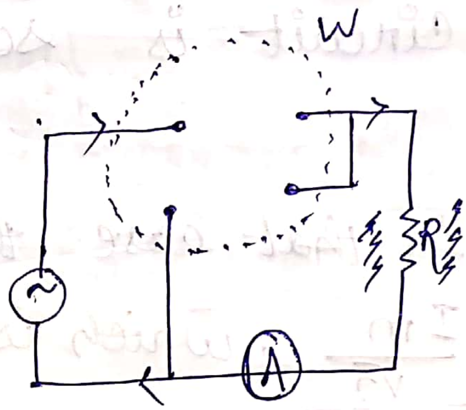
$$I_L = \frac{V_{th}}{R_{th}+R_L} = \frac{12}{4+4} = \frac{12}{8} = 1.5$$

Dt. 13.09.19

Root Means Squre Value : (RMS)

Defn: The RMS value of an AC is given by that DC current which, when flowing through a given circuit for a given time produces the same heat as produced by the Alternating current (AC) when flowing through the same circuit for the same time.





It is also known as the effective of virtual value of AC. The former term being used more extensibly for computing the RMS value of symmetrical sinusoidal AC. There are two methods for measuring RMS value

1) Mid-Ordinate Method.

2) Analitical method.

for symmetrical (+ve, 1/2 cycle = -ve, 1/2 cycle) but non-sinusoidal waves. ~~The~~

* The Mid-ordinate method would be found more convinient.

* A simple Experimental arrangement for measuring the equivalent DC value of a sinusoidal current is shown in the figure above.

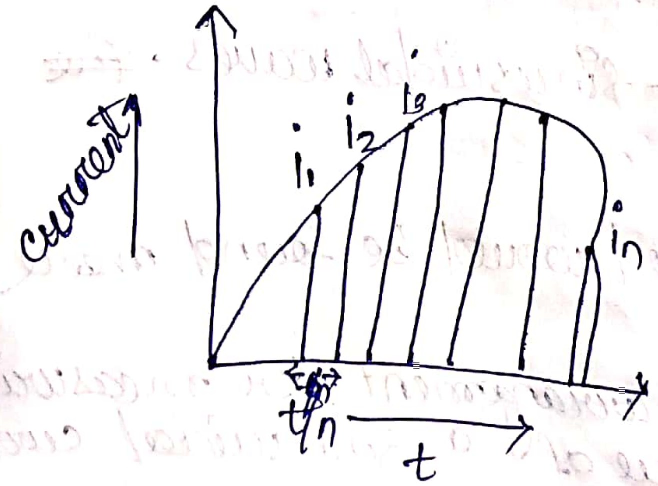
* The two circuits are similar Resistances but one is connected to a battery and other is connected To a sinusuidal generator.

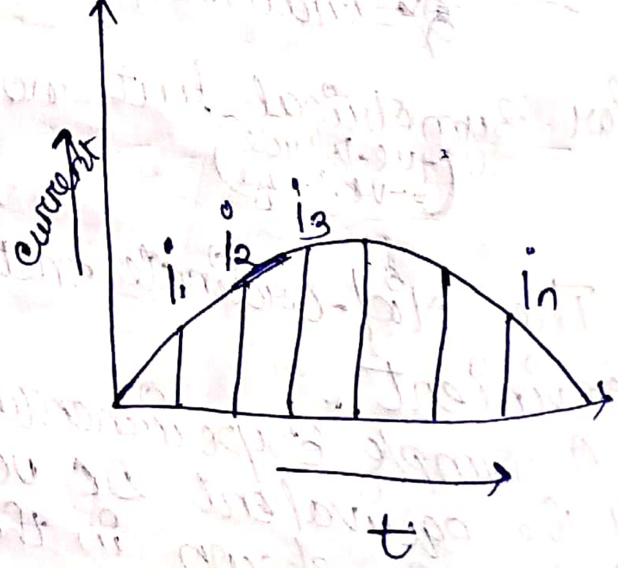
* Watt meters are used to measure the heat power in is circuit.

* The voltage applied to each circuit is so adjusted that heat power production of each circuit is same. $(P = VI)$

* In that case the Direct current will be $\frac{I_m}{\sqrt{2}}$, which is called RMS value of sinusuidal current

1) Mid-Ordinate Method :-





* The figure shows that the two half cycles for both symmetrical sinusoidal & non-sinusoidal Alternating currents

* Deviding time base 't' into n equal intervals of time is duration of $\frac{t}{n}$ seconds.

* Let the average values of instantaneous current during this intervals be respectively $I_1, I_2 \ldots I_n$.

suppose that is Alternating current is passed through the circuit of resistance $R\,\Omega$ then

Heat produced in the first interval $= 0.24 \times 10^{-3} I_1^2 R \frac{T}{n}$ kcal

Heat produced in the 2nd interval $= 0.24 \times 10^{-3} I_2^2 R \frac{T}{n}$ kcal

⋮

Heat produced in the nth interval $= 0.24 \times 10^{-3} I_n^2 R \frac{T}{n}$ kcal

Total heat produced in 't' seconds

$$= 0.24 \times 10^{-3} \times RT \left(\frac{I_1^2 + I_2^2 + \cdots I_n^2}{n} \right) \text{kcal}$$

Now suppose that a DC of value I produces the same heat through the same resistance during the same time 't' heat produced by it is equals to $0.24 \times 10^{-3} I^2 RT$ kcal.

By definition the two amounts of heat produced should be equal

$$0.24 \times 10^{-3} I^2 RT \text{ kcal} = 0.24 \times 10^{-3} RT \left(\frac{I_1^2 + I_2^2 + \cdots I_n^2}{n} \right)$$

$$\Rightarrow I^2 = \left(\frac{I_1^2 + I_2^2 + \cdots I_n^2}{n} \right)$$

$$\boxed{\Rightarrow I = \sqrt{\left(\frac{I_1^2 + I_2^2 + \cdots I_n^2}{n} \right)}}$$

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* Squre Root of the mean of the squres of the instantaneous currents.

Simillarly we have.

$$\boxed{V = \sqrt{\frac{V_1^2+V_2^2+\dots V_n^2}{n}}}$$

2) Analytical Method

The standard from a sinusoidal AC is equal to $I = I_m \sin \omega t$

$= I_m \sin \theta$

The mean of the squre of the instantaneous value of current over one complete cycle is-

$$\boxed{I = \int_0^{2\pi} \frac{I^2 d\theta}{2\pi - 0}}$$

The squre root is $\sqrt{\int_0^{2\pi} \frac{I^2 d\theta}{2\pi - 0}}$

hence the RMS value is $I = \left[\int_0^{2\pi} \frac{I_m^2 \sin^2\theta}{2\pi}\right]^{1/2}$

$$= I_m \left[\frac{1}{2\pi}\int_0^{2\pi}\left(\frac{1-\cos 2\theta}{2}\right) d\theta\right]^{1/2}$$

$$= I_m \left[\frac{1}{4\pi} \left\{ (\theta)_0^{2\pi} - \left(\frac{\sin 2\theta}{2} \right)_0^{2\pi} \right\} \right]^{1/2}$$

$$= I_m \left[\frac{1}{4\pi} \left\{ (2\pi - 0) - \tfrac{1}{2}(\sin \pi - \sin 0) \right\} \right]^{1/2}$$

$$= I_m \left[\frac{1}{4\pi} \times 2\pi \right]^{1/2}$$

$$= I_m \left[\tfrac{1}{2} \right]^{1/2} = \frac{I_m}{\sqrt{2}} = 0.707\, I_m$$

* RMS value of current equals = 0.707 × max. value of current

Note:-

In Electrical Engineering work unless indicated otherwise, the values of the given current & voltage are always the RMS value.

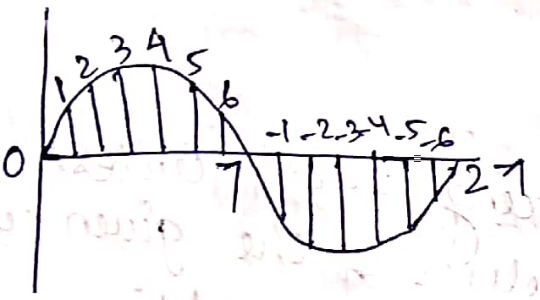
It should be noted that average heating effect produced during ~~half~~ one cycle is

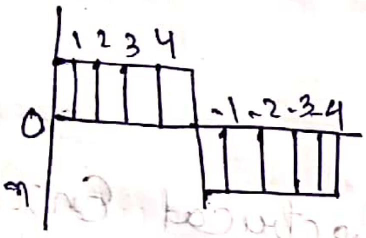
$$I^2 R = \left(\frac{I_m}{\sqrt{2}} \right)^2 R = \frac{I_m^2}{2} \times R$$

Average Value

The average value (I_A) of an AC is expressed by the steady state current which transpors across any circuit the same charge ~~in RMS.~~ As it transpors by that AC During the same time

In case of a symetrical AC (that is one whose two half cycles are exactly simillar wheather sinusuidal or non-sinusuidal), The average value over a complete cycle is Zero.





Hence in this case the average value is obtained by adding ~~or~~ of integrating the instantaneous values of current over one half cycle only

But incase of unsymetrical AC the average value must always be taken over the whole cycle.

Mid-ordinate Method :-

$$I_{avg} = \left(\frac{I_1 + I_2 + \cdots I_n}{n}\right)$$

Analytical method

The standard equation of an AC is

~~Iavo~~

$$I = I_m \sin\theta$$

$$\boxed{I_{avg} = \frac{\int_0^{\pi} I_m \sin\theta \, d\theta}{\pi - 0}}$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin\theta \, d\theta$$

$$= \frac{I_m}{\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_m}{\pi}\left[\cos\theta\right]_{\pi}^{0}$$

$$= \frac{I_m}{\pi}\left(\cos 0 - \cos\pi\right)$$

$$= \frac{I_m}{\pi}(1+1)$$

$$\boxed{I_{avg} = \frac{2I_m}{\pi}}$$

$$\boxed{I_{avg} = 0.637\, I_m}$$

Note:-

Rms value is always greater than the average value expect in the case of rectangular wave when both are equal.

Dt. 17.09.19

FORM FACTOR

Form factor is defined as the ratio of RMS value & average value for sinusoidal AC ~~com~~only.

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

$$= \frac{0.707\, I_m}{0.637\, I_m} = 1.11$$

$$\boxed{F.F = 1.11}$$

* Peak factor or crest factor or amplitude factor.

It is defined as the ratio between the maximum value & the Rms value.

$$\frac{I_m}{\frac{I_m}{\sqrt{2}}} = \sqrt{2} = 1.414$$

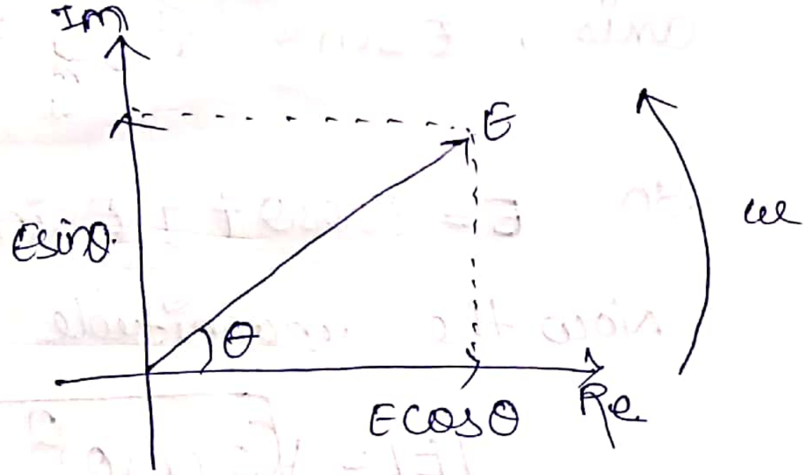
for AC sinusoidal wave only.

Complex voltages & Currents

The concept of phasor notation and complex algebra is quit essential to understand complex voltages & currents in AC circuits. The voltage and current phasors which exhibit variations in their magnitude & phase with respect to time are called complex voltage & current.

complex voltages & currents can be represented graphycally and mathematically for numerically application. Graphycall representation involves two popular schemes known as complex representation & polar representation.

1) a+ib (Rectangular)
2) b∠θ (polar)



According to the complex algebra to orthogonal phasors can be represented simultaneously in one complex term which gives the resulting action of the two individual phasors one of them is called the Real part and other is called Imaginary

In a cartesian coordinate system the x-axis is treated as real axis and y-axis is treated as Imaginary axis.

But in Electrical engineering Domain x-axis remaining the same as the real axis. Y-axis is treated as the imaginary axis which is shown in the above figure. Where the instantaneous phasor position of 'E' is characterised by two components "$E\cos\theta$" along Real axis, $E\sin\theta$ along imaginary axis.

So $E = E\cos\theta + j(E\sin\theta)$

Now the magnitude of E will be

$$|E| = \sqrt{(E\cos\theta)^2 + (E\sin\theta)^2}$$

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$$\theta = \tan^{-1}\left(\frac{E \sin\theta}{E \cos\theta}\right)$$

According to the complex algebra the value of 'J' operatore is numerically equivalent to

$$\boxed{J = \sqrt{-1}}$$

This is quit useful to simplefy the terms having higher powers of 'j' obtained from the multiplication of two or more complex quantities.

ADDITION OF TWO COMPLEX NO. BY 'J' OPERATOR.

$$(A + JB) + (C + JD)$$
$$= \boxed{(A + C) + J(B + D)}$$

SUBSTRACTION OF TWO COMPLEX NO. BY 'J' OPERATOR.

$$(A + JB) - (C + JD)$$
$$= \boxed{(A - C) + J(B - D)}$$

MULTIPLICATION OF TWO COMPLEX NO. BY 'J' OPERATOR

$$(A + JB)(C + JD)$$
$$= A(C + JD) + JB(C + JD)$$
$$= AC + AJD + CJB + J^2BD$$
$$= AC + JAD + JBC - BD$$
$$= \boxed{(AC - DB) + J(AD + BC)}$$

DIVISION OF TWO COMPLEX NO. BY 'J' OPERATOR.

$$\frac{A+JB}{C+JD}$$

$$= \frac{(A+JB)(C-JD)}{(C+JD)(C-JD)}$$

$$= \frac{AC-AJD+CJB-J^2BD}{C^2-(JD)^2}$$

$$= \frac{AC-AJD+CJB+BD}{C^2-(JD)^2}$$

$$= \frac{AC+BD+J(BC+AD)}{C^2+D^2}$$

$$= \boxed{\frac{(AC+BD)+J(BC-AD)}{C^2+D^2}}$$

$$= \boxed{\frac{AC+BD}{C^2+D^2}+J\frac{(BC-AD)}{C^2+D^2}}$$

Multiplication of two complex no. by polar operator.

$$(A\angle\alpha) \times (B\angle\beta)$$

$$= \boxed{(A \times B)\angle\alpha+\beta}$$

Division of two complex no. by polar operator.

$$\frac{A\angle\alpha}{B\angle\beta}$$

$$= \frac{A}{B}\angle\alpha-\beta$$

$10\angle0.64$

$5\angle0.92$

Q.1

Two complex quantities are Represented as $A = 8+J6$ and $B = 3+J4$ calculate their sum, difference, product & division.

Ans

$A = 8+J6$

$B = 3+J4$

Addition $A+B = (8+J6)+(3+J4)$

$= 11+10J$

difference $A-B = (8+J6)-(3+J4)$

$= 5-J2$

Product $AB = (8+j6)(3+j4)$

$= (24-24) + j(32+18)$

$= 0 + j50$

Division $A/B = \dfrac{8+j6}{3+j4}$

$= \dfrac{24+24}{9+16} + j\dfrac{18-32}{9+16}$

$= \dfrac{48}{9+16} + j\dfrac{-14}{25}$

$= \dfrac{48}{25} - j0.56$

$= 1.92 - j0.56$

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Dt. 19.09.19

AC Through Resistance & Inductance.

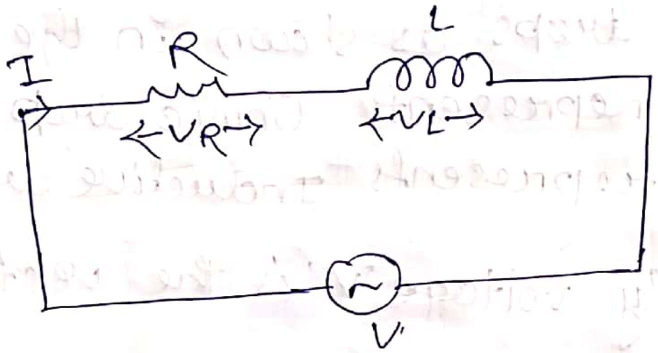
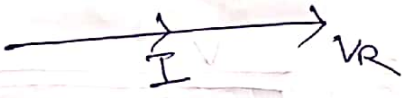


fig.(a)

let V is the RMS value of the applied voltage
I is the RMS value of the Resultant current

$V_R = IR$ = voltage drop across 'R' (In phase with I)

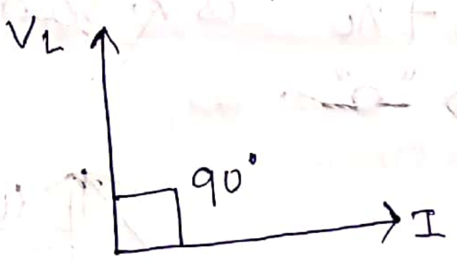


(both V & I in same phase)

$V_L = IX_L$ = voltage drop across the coil (ahead 90° to the current)

X_L = Inductive Reactants

$\boxed{\text{value} = 2\pi f L}$



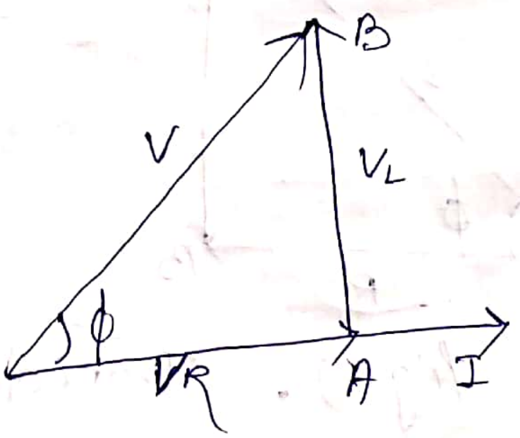


fig.(b)

These voltage drops as shown in the triangle OAB, $\vec{OA}$ represents Ohmic drop (resistive drop) (V_R) and $\vec{AB}$ represents Inductive drop (V_L).

The apply voltage 'V' is the vector sum of these two.

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

$$= \sqrt{(IR)^2 + (I X_L)^2}$$

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

$$\Rightarrow I = \frac{V}{\sqrt{(R^2 + X_L^2)}}$$

The quantity $\sqrt{R^2 + X_L^2}$ is known as impedance (Z) unit is also "Ω".

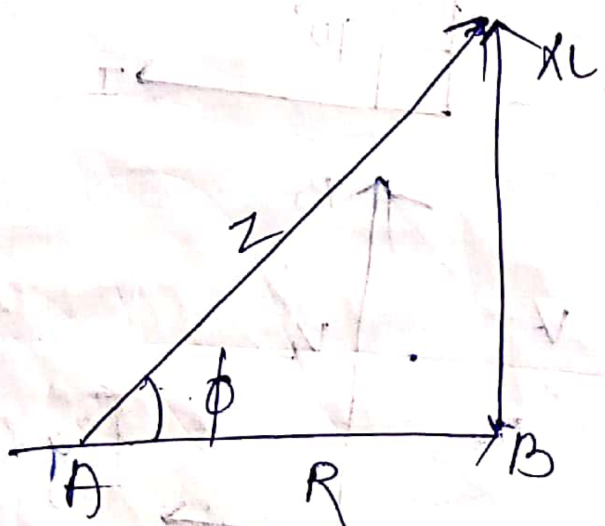


fig (c). Impedance Triangle

as seen in the impedance triangle ABC

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

$\Rightarrow$ (impedance)^2 = (Resistance)^2 + (Reactant)^2

from the figure (b). It is clear that the applied voltage 'V' leads the current 'I' by an angle ϕ. such that $\boxed{\tan\phi = \frac{V_L}{V_R}}$

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

$\boxed{\omega = 2\pi f}$

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

$$= \frac{2\pi f L}{R}$$

$$\boxed{\tan\phi = \frac{\omega L}{R}}$$

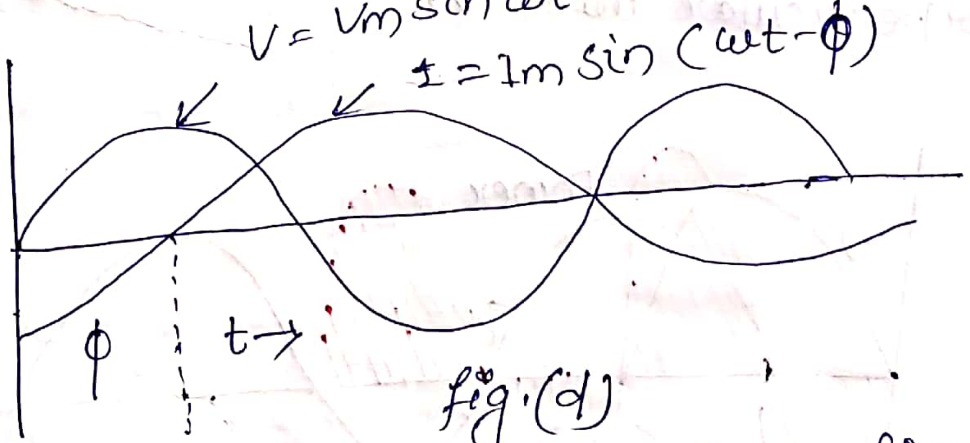


fig.(d)

Thus the same fact is also given in the figure (d)

In other words current 'I' lags behind the applied voltage by an angle ϕ, hence If applied voltage is given by $V = V_m \sin \omega t$ then the current equation is $I = I_m \sin(\omega t - \phi)$.

where $I_m = \frac{V_m}{Z}$

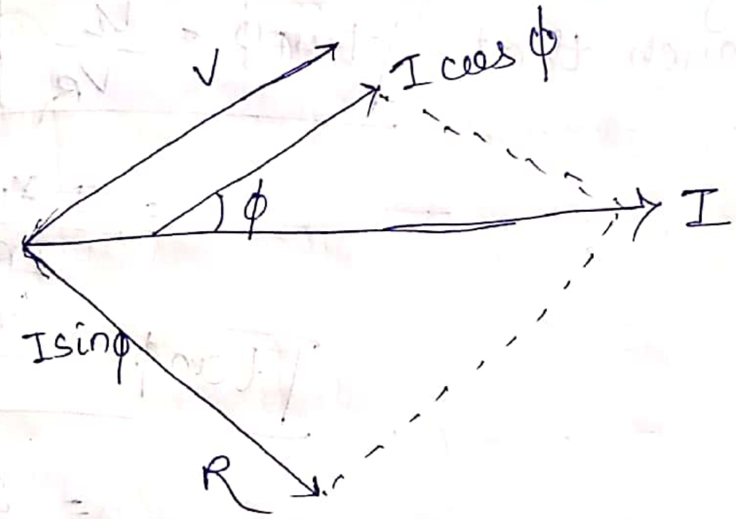
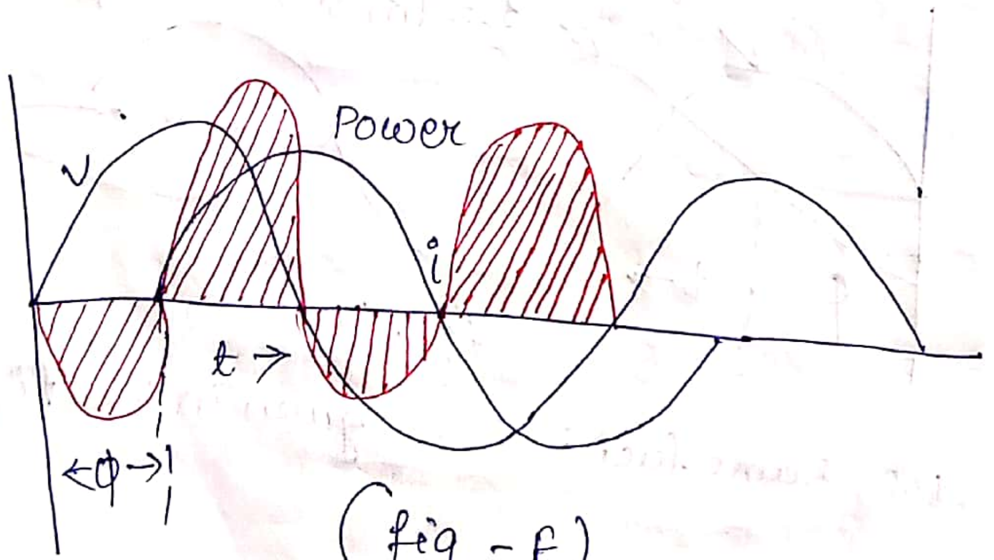


fig (e)

In the above figure I has been result into two mutually perpendicular components $I\cos\phi$ along the applied voltage V and $I\sin\phi$ is perpendicular with V.



(fig - F)

The mean power consume by the circuit is given by the product of V & and the component of the current 'I', which is phase in with 'V'. So $\boxed{P = VI\cos\phi}$ = (RMS voltage(V) × RMS current(I) × power factor)

Note:

* In an AC circuit the product of RMS voltage and RMS current gives volt ampere (VA) and not true power in ~~work~~ watt. ~~So true~~

* So true power $\boxed{W = VA \times \cos\phi}$

* It should be noted that power consumed is due to Ohmic Resistance only because pure inductance does not consume any power.

Now $P = VI\cos\phi$

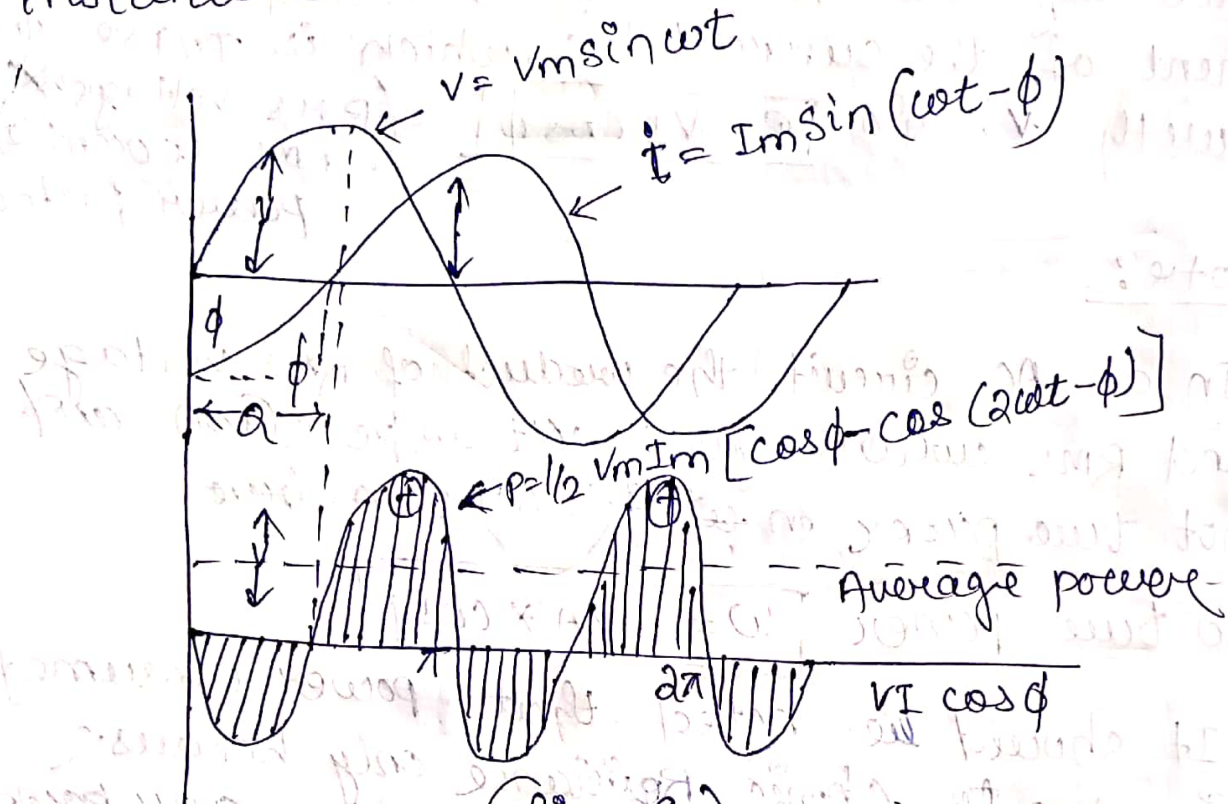
$= VI \times \frac{R}{Z}$ $\qquad V = IZ$

$= \frac{V}{Z}\, IR$

$= \frac{IZ}{Z}\, IR$

$\boxed{P = I^2R \text{ watt}}$

Let us calculate power in terms of instantaneous value.



(fig - g)

instantaneous power is $vi = V_m \sin \omega t \times I_m \sin(\omega t - \phi)$

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

$$= \frac{1}{2} V_m I_m \cdot 2 \sin \omega t \cdot \sin(\omega t - \phi)$$

$$= \frac{1}{2} V_m I_m - [\cos(\omega t + \omega t - \phi) - \cos(\omega t - \omega t + \phi)]$$

$$= \frac{1}{2} V_m I_m - [\cos(2\omega t - \phi) - \cos\phi]$$

$[\because \cos(A+B) - \cos(A-B)$

$= \cos A \cdot \cos B - \sin A \cdot \sin B - \{\cos A \cdot \cos B + \sin A \cdot \sin B\}$

$= \cos A \cdot \cos B - \sin A \cdot \sin B - \cos A \cdot \cos B - \sin A \cdot \sin B$

$= -2 \sin A \cdot \sin B]$

$$= \frac{1}{2} V_m I_m [\cos\phi - \cos(2\omega t - \phi)]$$

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Obviously this power consists of two parts.

i) a constant part $\frac{1}{2} V_m I_m \cos\phi$ which contributes to real power.

ii) a pulsating component $\frac{1}{2} V_m I_m \cos(2\omega t-\phi)$

which has a frequency twice that of the voltage & current. It does not contribute to actual power since it's average value over a complete cycle is zero.

Hence, average power consumed.

$$= \frac{1}{2} V_m I_m \cos\phi$$

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

$$= VI\cos\phi$$

where V & I represents the R.M.S. value.

Symbolic Notation

$$Z = R + JX_L$$

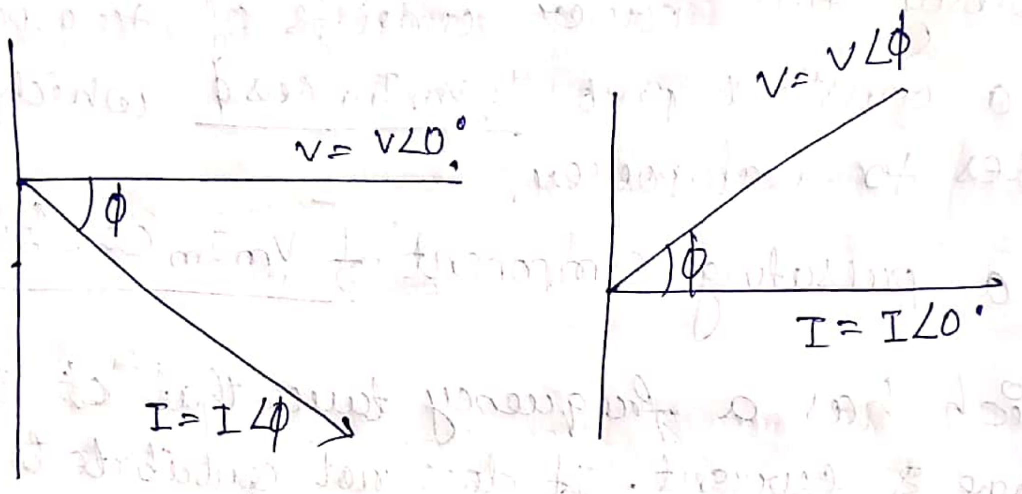
Impedance vector has numerical value of

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

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

Z may also be expressed in the polar form as $Z = Z\angle\phi^\circ$

(i)



Assuming $V = V\angle 0°$

$$I = \frac{V}{Z} = \frac{V\angle 0°}{Z\angle\phi°} = \frac{V}{Z}\angle -\phi°$$

It shows that current vector is lagging behind the voltage vector by $\phi°$. The numerical value of current is $\frac{V}{Z}$

(ii) However we assumed that

$I = I\angle 0$ then

$V = IZ = I\angle 0° \times Z\angle\phi°$

$V = IZ\angle\phi°$

It shows that voltage vector is ϕ ahead of current vector

Imp

Power factor

It may be defined as

(i) cosine of angle of lead or lag.

(ii) The Ratio $= R/Z = \frac{\text{Resistance}}{\text{Impedance}}$ (from fig-c)

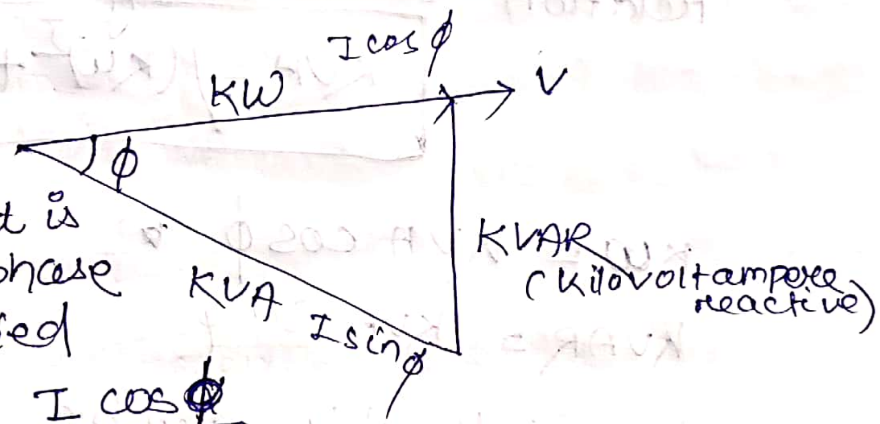
(iii) The ratio $\frac{\text{True power}}{\text{apparant power}}$

$$= \frac{\text{Watts}}{\text{volt amperes}}$$

$$= \frac{W}{VA}$$

Dt. 20.9.19

Active & Reactive components of circuit current I.



Active component is that which is in phase with the applied voltage 'v' is, I cos ϕ

It is also known as wattful component

Reactive component is that which is quadature with V, that is, I sin ϕ, It is also known as wattless component

It should be noted that product of volt & ampere in an AC circuit gives VA. Out of this the actual power is VA cos ϕ is equal to W and Reactive power is VA sin ϕ

Expressing the values in KVA we find that it has two rectangular component.

a) Active component which is obtained by multiplying KVA by $\underline{\cos\phi}$ and this gives the power in KW.

b) The reactive component known as reactive KVA and is obtained by multipling KVA by $\underline{\sin\phi}$, is written as KVAR. The following relation can be easily deduced ~~$KVA^2 = KW^2 + KVA$~~

$$\boxed{KVA = \sqrt{(KW)^2 + (KVAR)^2}}$$

$$KW = KVA \cos\phi$$

$$KVAR = KVA \sin\phi$$

The relationship can be easily understood by the refering the KVL triangle in the figure above.

where it should be noted that laging KVR has been taken as negative.

Exp

Suppose a circuit draws a current I ampere which is equal to 1000 A and a voltage of 20,000 V & has a power factor of 0.8, then, your input will be

$$P = VI$$

$$= 1000 \times \frac{20,000}{1000}$$

$$= 20,000 \text{ KVA}$$

$$p.f. = 0.8$$

$$\cos\phi = 0.8$$

$$\cos^2\phi + \sin^2\phi = 1$$

$$\Rightarrow \sin^2\phi = 1 - \cos^2\phi$$

$$\Rightarrow \sin\phi = \sqrt{1 - \cos^2\phi}$$

$$= \sqrt{1 - 0.8^2}$$

$$= 0.6$$

$$KW = 20,000 \times 0.8$$

$$= 16000$$

$$KVAR = 20,000 \times 0.6$$

$$= 12000$$

now

$$KVA = \sqrt{(KW)^2 + (KVAR)^2}$$

$$= \sqrt{(16000)^2 + (12000)^2}$$

$$= 20,000$$

Active, Reactive & aparent power

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

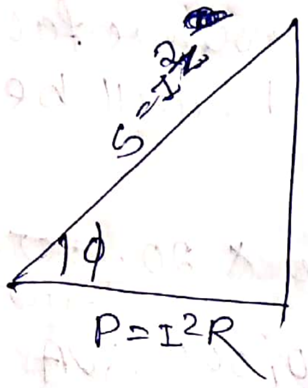


fig (a)

Let in a series arange circuit draw a current 'I' when an alternating voltage value 'V' is applied to it. Suppose that current lags behind the applied voltage by 'φ' then three powers drawn by the circuit as under

A. Apparant Power (S) :

It is given by the product of RMS value of the applied voltage and circuit current

So $S = VI$

$= (IZ) I$

$= I^2 Z$ (VA' unit.

in DC → $V = IR$
AC $V = IZ$

B. Active Power : (P or W) :

It is the power which is actually dispreiated in the circuit resistance so, $P = I^2R$

$= VI\cos\phi$ watt.

c- Reactive Power (Q).

It is the power developed in the inductive reactants of this circuit $Q = I^2X_L$

$= I^2 Z \times \sin\phi$

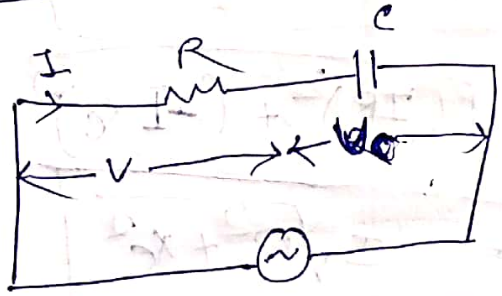
$= I^2 Z \sin\phi$

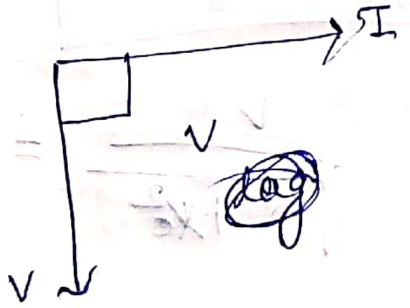
so $I^2 Z \sin\phi$ we also called $VI\sin\phi$ KVAR

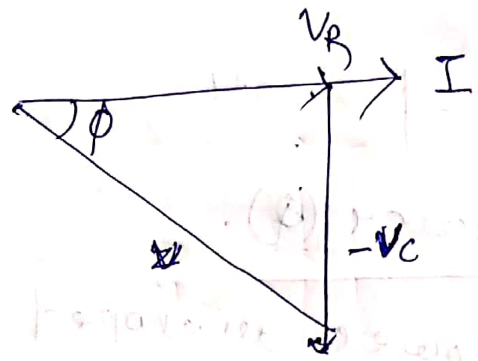
These three powers as shown in the power triangle fig (a), where $S^2 = P^2 + Q^2$

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

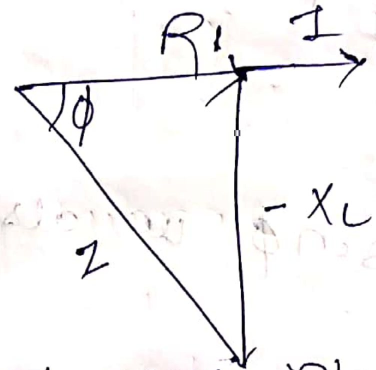
AC through Resistance & capacitance







(voltage triangle)



(Impedance triangle)

Here $V_R = IR$, drop across 'R' is phase with 'I'.

$V_C = I X_L$, drop across the capacitor, laging I by 90° ~~as cap~~

As capacitive reactants X_C is taken negative V_C is shown along negative direction of y-axis.

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

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

$$\boxed{V = I\sqrt{R^2 + X_C^2}}$$

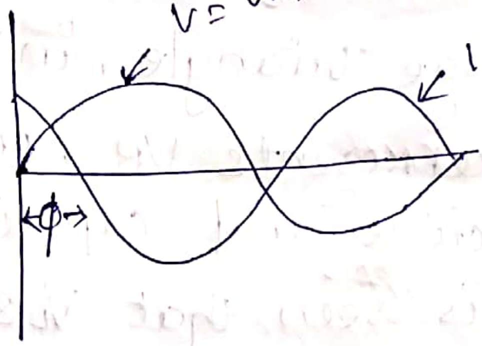
$$I = \frac{V}{\sqrt{R^2 + X_C^2}} = \frac{V}{Z}$$

$$\boxed{\begin{aligned} X_L &= 2\pi f L \\ X_C &= \frac{1}{2\pi f C} \end{aligned}}$$

$X_L = 2\pi f L$ — Inductive Reactance

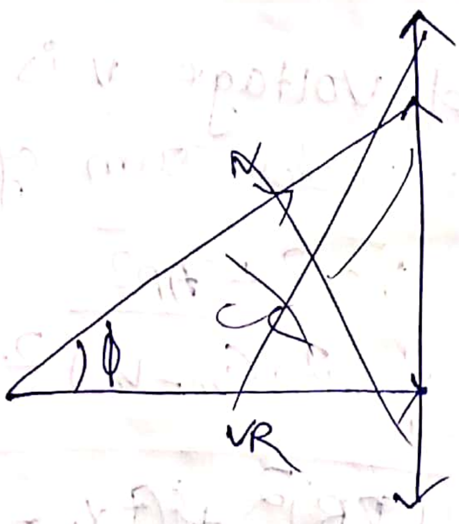
$X_C = \frac{1}{2\pi f C}$ — Capacitive Reactance

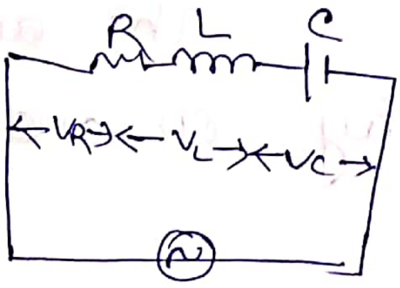
From fig. voltage triangle it found that I leads 'v' by an angle ϕ, such that $\boxed{\tan\phi = \frac{-X_C}{R}}$

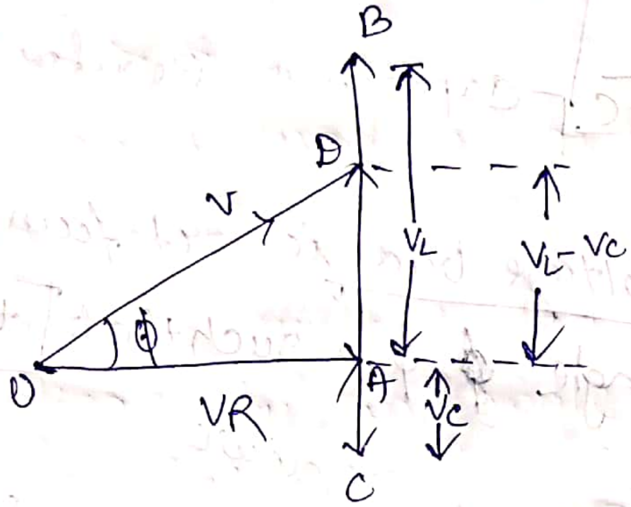


I dia source power factor source conversion.

Resistance, Inductance & capacitance in series (RLC series circuit)







In the voltage triangle, in the above figure 'OA' represents VR, AB & AC represents the inductive and capacitive drops Respectively. It is seen that V_L & V_C are 180° out of phase with each other i.e. they are in direct opposition to each other.

Substracting BD = AC from AB, we get net Reactive drop $AD = I(X_L - X_C)$.

The applied voltage V is represented by OD and the vector sum of OA & AD

$$OD = \sqrt{OA^2 + AD^2}$$

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

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

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

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

$$\Rightarrow I = \frac{V}{\sqrt{R^2 + X^2}} = \frac{V}{Z}$$

The term $\sqrt{R^2 + (X_L - X_C)^2}$ is known as the impedance of the circuit.

$$(\text{Impedance})^2 = (\text{Resistance})^2 + (\text{net Reactive})^2$$

$$\Rightarrow Z^2 = R^2 + (X_L - X_C)^2$$

$$\Rightarrow Z^2 = R^2 + X^2$$

where X is the net Reactance

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

$$\text{Power factor} = \cos\phi = \frac{R}{Z}$$

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

$$= \frac{R}{\sqrt{R^2 + X^2}}$$

Hence in the RLC circuit

$V = V_m \sin\omega t$

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

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The (+ve) sign is used when current leads

i.e. $X_C > X_L$.

The -ve sign is used when current lags

i.e. $X_L > X_C$

In general the current lag or lead, the supplied voltage by an angle ϕ

such that $\tan\phi = \frac{X}{R}$.

24.09.2019

Parallel RMS circuit :-

Solving parallel circuit:

When impedance are joined in parallel there are three methods are available.

a) Vector or phasor method

b) Admitance method.

c) Vector algebra.

a) Vector or phasor method:

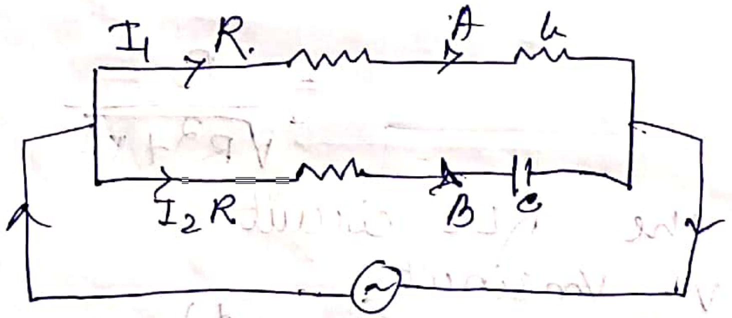
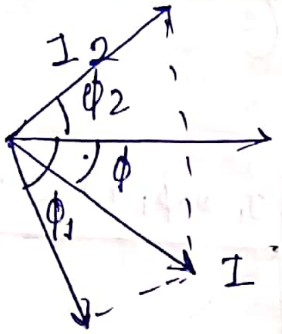


fig (a)



(b)

for branch A $Z_1 = \sqrt{R_1^2 + X_L^2}$

$I_1 = \frac{V_1}{Z_1}$

$\cos\phi = \frac{R_1}{Z_1}$

$$\boxed{\phi = \cos^{-1}\left(\frac{R_1}{Z_1}\right)}$$

Here current I_1 lags behind the applied voltage by an angle ϕ_1 which is shown in the fig (b)

→ for branch B $Z_2 = \sqrt{R_2^2 + X_C^2}$

$I_2 = \frac{V_1}{Z_2}$

$\cos\phi_2 = \frac{R_2}{Z_2}$

$\Rightarrow \phi_2 = \cos^{-1}\frac{R_2}{Z_2}$

Here current I_2 leads the velocity V by an angle ϕ_2 which is shown in the fig (b)

b) <u>Resultant current:-</u>

The resultant current 'I' is the vector sum of the branch I_1 and I_2 and can be found by using parallelo gram law of vectors.

part '2' is prefered as it is quick and convenient.

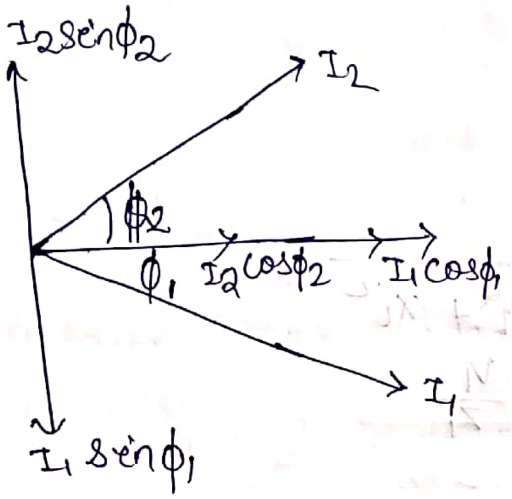


fig (a)

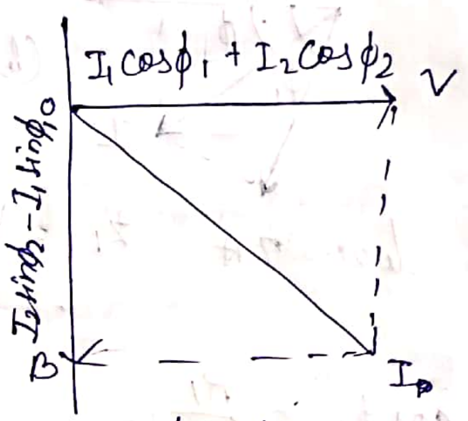


fig (b).

from fig (a) some of the active component of I_1 and I_2 is equal to $I_1\cos\phi_1 + I_2\cos\phi_2$.

Some of the reactive component of I_1 and I_2 is equal to $I_2\sin\phi_2 - I_1\sin\phi_1$.

If 'I' is the resultant current and ϕ, its phase then its active and reactive component must be equal to these x and y component respectively as shown in the fig (b).

$$\boxed{I\cos\phi = I_1\cos\phi_1 + I_2\cos\phi_2}$$ active component

$$\boxed{I\sin\phi = I_2\sin\phi_2 - I_1\sin\phi_1}$$ Reactive component

Now resultant current $I = \sqrt{(I_1\cos\phi_1 + I_2\cos\phi_2)^2 + (I_2\sin\phi_2 - I_1\sin\phi_1)^2}$

Then $\sin\phi = \dfrac{I_2 \sin\phi_2 - I_1 \sin\phi_1}{I_1 \cos\phi_1 + I_2 \cos\phi_2}$

If tan ϕ is positive then current leads if -ve then current lags to the applied voltage (V)

power factor for the whole circuit given by

$$\boxed{\cos\phi = \frac{I_1 \cos\phi_1 + I_2 \cos\phi_2}{I}}$$

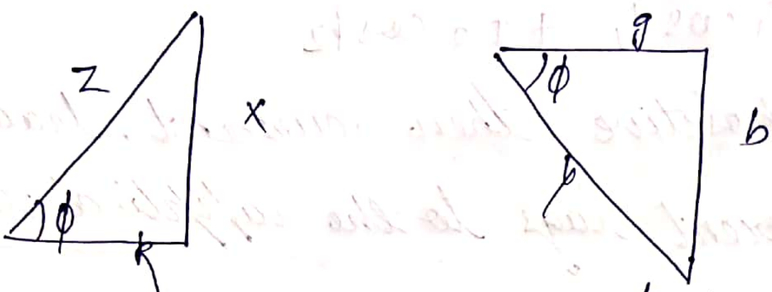
Admitance Method: (Y)

admitance of a circuit is defined as the resiprocal of its impedance $\boxed{Y = \frac{1}{Z}}$

it is also called $\boxed{Y = \frac{I}{V}}$

or $Y = \dfrac{\text{RMS current}}{\text{RMS Voltage}}$

* It's unit is siemens. (ohm) circuit has two component as impendance 'z' or a which is shown in the figure 'A' below X & R similarly admitance (Y) has also ~~too~~ two Components which is the figure shown in the below.



g is your conductance , b is your susceptance

conductance $\boxed{'g' = Y\cos\phi}$

$$\boxed{\cos\phi = \frac{g}{Y}}$$

In place $Y = \frac{1}{Z} \times \frac{R}{Z}$

$$\boxed{\Rightarrow Y = \frac{R}{Z^2}}$$

$$\boxed{g = \frac{R}{R^2+x^2}}$$

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

$$\Rightarrow Z^2 = R^2+x^2$$

Similarly $b = Y\sin\phi$

$\sin\phi = b/Y$

$$\Rightarrow b = \frac{1}{Z} \times \frac{x}{Z}$$

$$\boxed{\Rightarrow b = \frac{x}{Z^2}}$$

$$\boxed{b = \frac{x}{R^2+x^2}}$$

the admitance $Y = \sqrt{g^2+b^2}$

* The unit of g, b, y are Simens.

we will regarded the capasetive subtance as positive and Enductive subtances as -ve.

- The End -

Module-2

Dt. 17.10.19

3-ϕ Ac circuits :

3-ϕ System :

The measure component of A. ~~three~~ 3-ϕ Ac system are 3-ϕ Ac sources and 3-ϕ load device. A 3-ϕ A source may be thought of as a combination of three ~~ϕ~~ 1-ϕ Ac sources of same magnitude and frequency having mutual phase difference of 120° electrical degrees from each other.

when in electrical Engineering we often encounter the term electrical degree when rotating machine are consult.

The Relation between ~~&~~ mechanical degree & electrical degree is that

(*) $\boxed{\text{One mechanical degree} = \frac{P}{2} \text{ electrical degree}}$

where P is the number of magnetic poles present in the rotating machine.

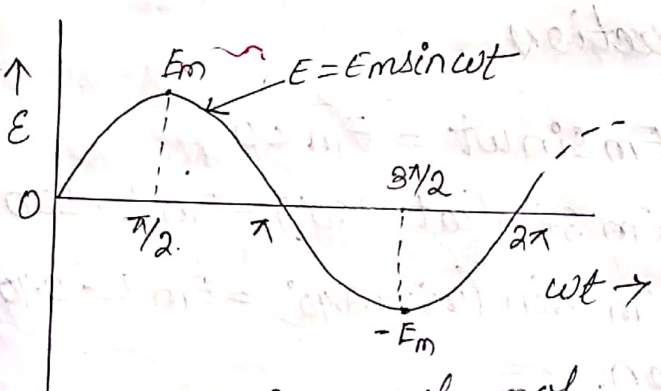
Difference Between ~~ϕ-1~~ 1-ϕ AC system & ~~ϕ-3~~ 3-ϕ AC system :→

1-ϕ AC system.	3-ϕ AC system
• It is not show balanced, And efficient comparision to 3-ϕ AC system.	• Three phase systems are more balanced, efficient and robust in comparision to 1-ϕ system.
• 1-ϕ systems operate at one voltage level that is called phase voltage	• 3-ϕ system having star connection possesses two operating voltage levels called line voltage & phase voltage.
• The output and efficiency of a 1-ϕ machine is less than that of a ~~single phase~~ 3-ϕ machine for a given size of frame	• The output and efficiency of a 3-ϕ machine is greater than that of single phase machine for a given size of frame.
• 1-ϕ AC motors produce pulsating ~~term~~ torque	• 3-ϕ AC motors can produce uniform ~~term~~ torque

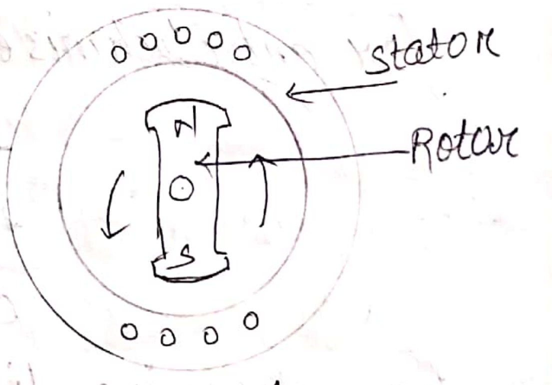
3-ϕ Emf Generation:

* A device used for generation of 3-ϕ emf is called a <u>3-ϕ AC Generator</u> or simply it is called <u>alternator.</u>

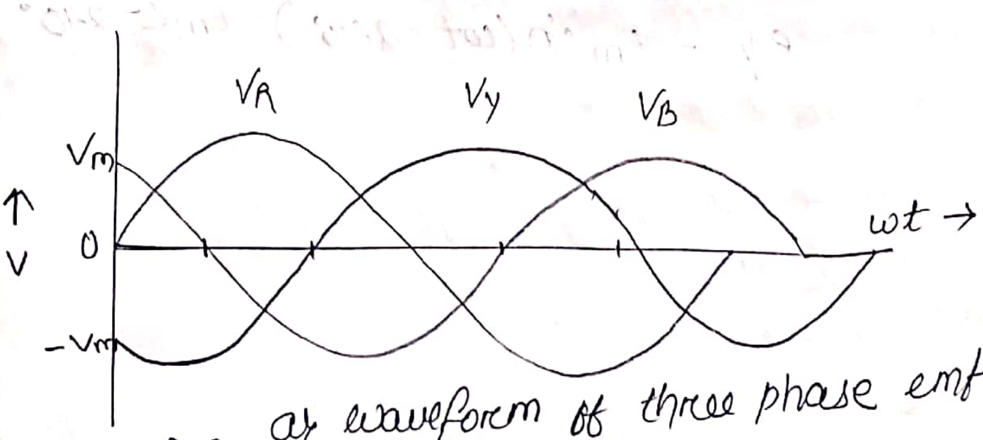
The principle of 3-ϕ emf generation is simillar to 1-ϕ emf generation which we have already discussed. However there exist some constructional differences before proceeding, let us first focus our attention to the requirement of each case which is indicated in the figure below.



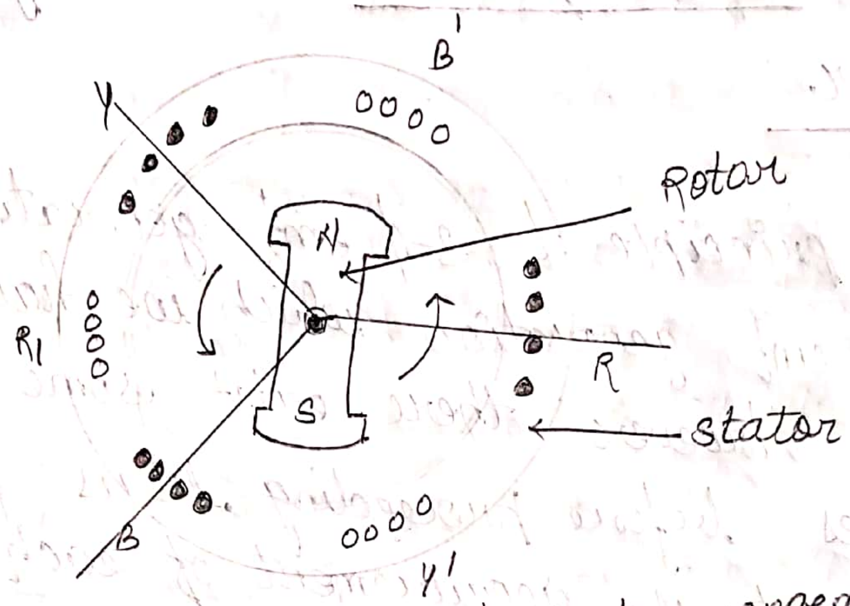
5.1 (a) waveform of single ~~three~~ phase emf



(b) Physical arrangement



5.2 a) waveform of three phase emf



(b) Physical arrangement.

a) waveform

for anticlockwise direction

$$e_R = E_m \sin \omega t = E_m \angle 0^\circ$$
$$e_Y = E_m \sin(\omega t - 120^\circ) = E_m \angle -120^\circ$$
$$e_B = E_m \sin(\omega t - 240^\circ) = E_m \angle -240^\circ$$

for clockwise direction.

$$e_R = E_m \sin \omega t = E_m \angle 0^\circ$$
$$e_B = E_m \sin(\omega t - 120^\circ) = E_m \angle -120^\circ$$
$$e_Y = E_m \sin(\omega t - 240^\circ) = E_m \angle -240^\circ$$

A device used for generation of 3-ϕ emf generation is called a 3-ϕ Ac generator or simply an alternator. The principle of 3-ϕ emf generation is simillar to that of single phase emf generation, which is already explained. However there exist some constructional difference. Before proceeding any ~~before~~ further, let us first focus our attention on the requirement for each case and indicated to the figure.

fig 5.1 (a) illustrates a sinusoid that represents the instantaneous emf induced in one coil due to rotary motion of a magnetic field as per arrangements shown in figure 5.1 (b) on the other hand fig 5.2 (a) illustrates three sinusoids having a mutual phase shift of 120 degrees between one another, thus representing the 3-ϕ instantaneous emf that may be induced in three separate coils (R, Y, and B) having cyclic arrangement along the periphery of a circle subject to the rotary motion of a magnetic field as shown in figure 5.2 (b).

In a practical 3-ϕ alternator, the external frame supports the three phase balanced winding that forms the armature, since the armature remains stationary, It is referred as stator. The three phase of stator winding are designated by simbols $R-R'$, $Y-Y'$, $B-B'$, which have a mutual spacing of 120 degrees between each other as shown in fig 5.2 (b).

On the other hand, the field system is mounted over a shaft with a provision of rotation, hence called the rotor. The field constitutes a pair of magnetic poles designated by symbols N & S, which provide the necessary magnetic flux. when the shaft is driven by a prime mover, a relative motion between the armature and the field is developed that produces the time rate of change of magnetic flux linkage in the armature conductors and hence emf gets induced in them. The nature of emf induced in the three phases of stator assumes sinusoidal waveform having same magnitude and frequency but displaced from each other by 120 electrical degrees. The re fare three individual phases of the stator can not attain peak emf value simultaneously. The sequence in which the three individual phase emf attains there +ve peak is refered as phase sequence

In the rotor of fig 5.2(b) assumes rotation in the cantaclock wise direction, then the order in which the emfs of respective phases attain there peak values represented by R-Y-B sequence or +ve sequence. If Em happens to be the peak value of the emf induced per phase, then the instantaneous emf of respective phases for R-Y-B sequence may be represented by Eqn (5.1)

$e_R = E_m \sin \omega t = E_m \angle 0°$

$e_Y = E_m \sin(\omega t - 120) = E_m \angle -120°$

$e_B = E_m \sin(\omega t - 240) = E_m \angle -240$

for clockwise

$e_R = E_m \sin \omega t = E_m \angle 0°$

$e_B = E_m \sin(\omega t - 120) = E_m \angle -120°$

$e_Y = E_m \sin(\omega t - 240) = E_m \angle -240°$

There exists a simple relationship between the
speed of revolution of the rotor in revolutions per minute
marked as N, existing number of poles in the field
system marked as P, and the generation frequency of
the induced emf marked as f. It may be clearly
noted that the frequency of the emf remains same
for all the three phases. Assuming that if a rotor
having P number of poles revolves at N revolution
per minute, the frequency f of the induced emf
per phase may be calculated in a simple manner

f (usually expressed in cycle per sec)

$$= \frac{P}{2} \times \frac{N}{60}$$

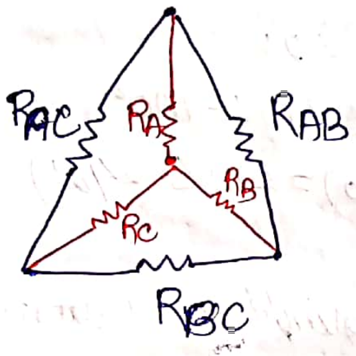
$$= \frac{PN}{120}$$

So $f = \frac{PN}{120}$ Hz, where P - poles

N = Synchronous speed

f = frequency

Delta to star conversion

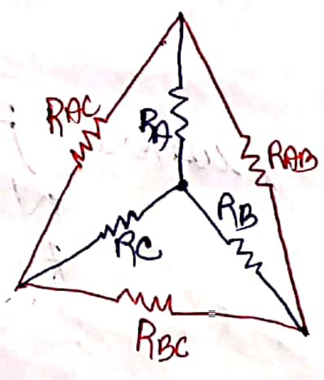


$$R_A = \frac{R_{AB} * R_{AC}}{R_{AB} + R_{BC} + R_{CA}}$$

$$R_B = \frac{R_{AB} \times R_{BC}}{R_{AB} + R_{BC} + R_{AC}}$$

$$R_C = \frac{R_{AC} \times R_{BC}}{R_{AB} + R_{BC} + R_{AC}}$$

Star to delta conversion

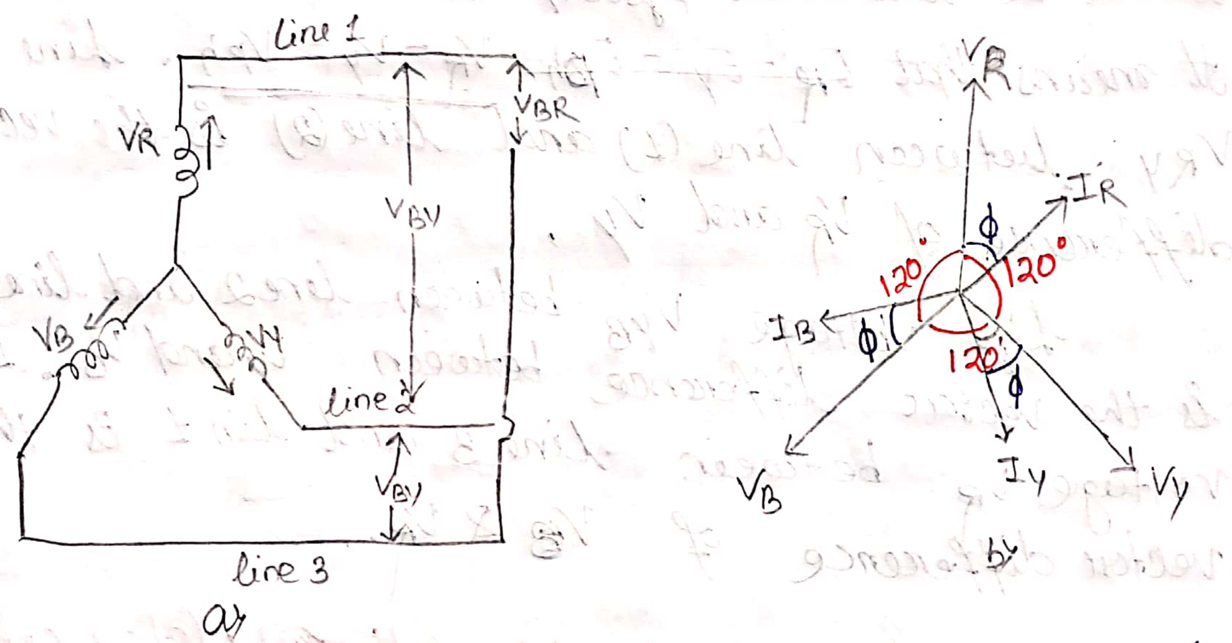


$$R_{AB} = R_A + R_B + \frac{R_A R_B}{R_C} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_C}$$

$$R_{BC} = R_B + R_C + \frac{R_B \cdot R_C}{R_A} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_A}$$

$$R_{CA} = R_C + R_A + \frac{R_C \cdot R_A}{R_B} = \frac{R_A R_B + R_B R_C + R_C R_A}{R_B}$$

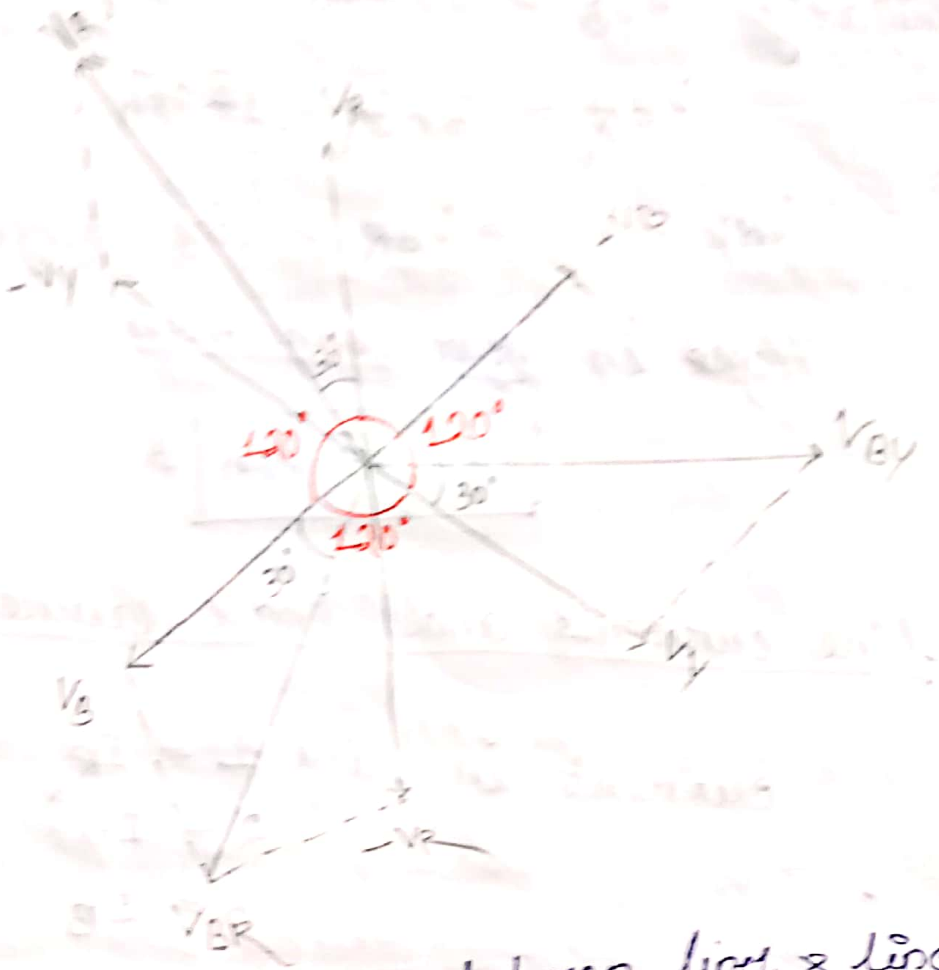
Voltage & current Relation in Star Connection :-



The voltage induce in each winding is called phase voltage. And current in each winding is like wise known as phase current. However the voltage available between the pair of terminals is called line voltage (V_L). and current flowing in each line is called line current (I_L). In fig(a) there is a inter connection, there are two phase windings between each pair of terminals but since their simillar ends have joined together they are in opposition. Oviously the instantaneous value of potential differerence between any two terminals is the arithmatic difference of the two phase emfs concerned. However the RMS value of this potential difference is given by the vector difference of the two phase emfs. The vector diagram for phase voltages and current in a star connection each shown in the above figure (b). where a balanced system hasbeen assumed. It means that ~~$E_R = E_Y = E_{ph}$~~ $V_R = V_Y = V_{ph}$. Line voltage V_{RY} between line (1) and line (2) is the vector difference of V_R and V_Y,

Line voltage V_{YB} between line 2 and line 3 is the vector difference between V_Y and V_B. Line voltage V_R between line 3 and lin 1 is the vector difference of V_B & V_R.

Line Voltages & phase voltages: (Star connection)



The potential difference between line 1 & line 2 is $V_{RY} = V_R - V_Y$, hence V_{RY} is found by compounding V_R and V_Y reversed and its value is given by the diagonal of the parallelogram which is shown in the above figure. Obviously the angle between V_R and V_Y reversed each 60°. hence if $V_R = V_Y = V_B$, V_{ph} the phase emf.

then $V_{RY} = V_R - V_Y$

$$= 2 V_{ph} \times \cos\left(\frac{60°}{2}\right)$$

$$= 2 V_{ph} \cos 30°$$

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

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

Similarly $V_{YB} = V_Y - V_B = \sqrt{3} V_{ph}$

$V_{BR} = V_B - V_R = \sqrt{3} V_{ph}$

$V_{RY} = V_{YB} = V_{BR}$ = line voltage say V_L

Hence in star connection -

$\boxed{V_L = \sqrt{3} V_{ph}}$ Ø.

b) Line currents and phase currents :- Ø

current in line 1 = I_R

2 = I_Y

3 = I_B

$I_R = I_Y = I_B$ = say, I_{ph} = phase current

$\boxed{\text{Line current} = I_L = I_{ph}}$ (Star connection)

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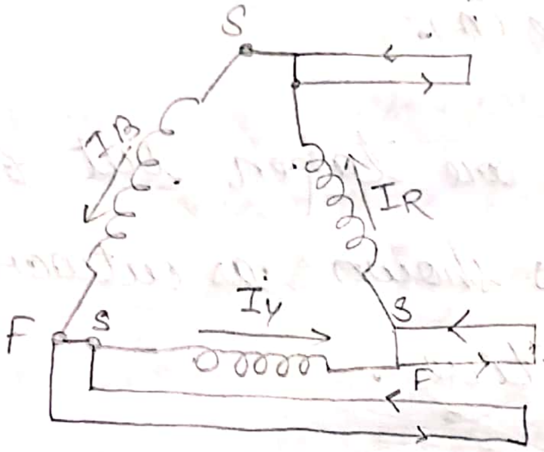
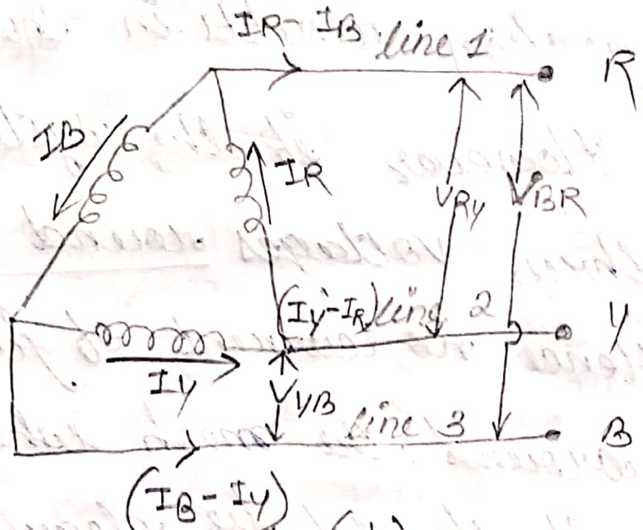
Delta connection of Mesh connection:



(a)



(b)

In this form of inter connection the dissimillar ends of three phase winding are join together that is the "starting" end of one phase is joined to the "finshing" end of the other phase and show on. which is shown in the fig (a).

In other words the three windings are joined in series to from a closed mesh which is shown in the figure (B).

Three leads are taken out from the three junctions as shown as outward direction are taken as positive.

It might look as if the ~~φ~~ this short interconnection results in short circuit the three windings. However if the system is balanced then sum of three voltages round the ~~fosed~~ closed mesh is zero. Hence no current of fundamental frequency can flow around the mesh when the terminals are open. It should be clearly understood that at any instant the EMF. in 1-φ is equal and opposite to the resultant of those in the other two phases.

This type of connection is also refered as ~~D.~~ 3-φ, three wire system.

Line Voltages & Phase Voltages:

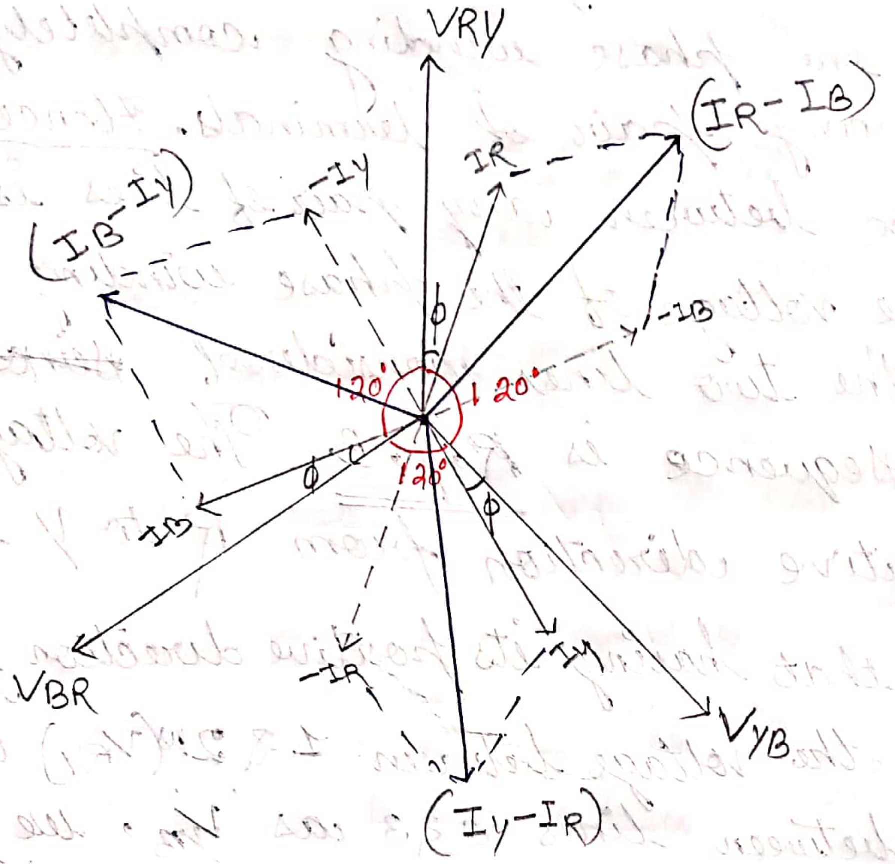
It is seen from the figure (b) that there is only one phase winding completely included between any pair of terminals. Hence Δ-connection the voltage between any pair of lines is equal to the phase voltage of the phase winding connected between the two lines considered ~~since~~ since phase sequence is R, Y, B. The voltage having its positive direction from R to Y leads by 120° on that having its positive direction from Y-B. calling the voltage between 1 & 2 (V_{RY}) and that ~~having~~ between lines 2 & 3 as 'V_{YB}', we find that 'V_{RY}' lead 'V_{YB}' by 120°. Similarly 'V_{YB}' leads V_{BR} by 120° as shown in the figure. Let,

$V_{RY} = V_{YB} = V_{BR} =$ the line voltage V_L. Then it is seen that $\boxed{V_L = V_{ph}}$

Now we will

Line currents & phase currents:

P. T. O.



current in line 1 that is $I_1 = I_R - I_B$

current in line 2 $\quad I_2 = I_Y - I_R$

" $\quad I_3 = I_B - I_Y$

current in line no 1 is found by compounding I_R and I_B reversed and its value is given by the diagonal of parallelogram which is shown in the phasor diagram. The angle between I_R & I_B reversed $(-I_B)$ is 60°. If $I_R = I_Y$ is the phase current I_{ph} (say) then current in the line no-1.

$$I_1 = 2I_{ph} \times \cos\left(\frac{60}{2}\right) = 2 \times I_{ph} \times \frac{\sqrt{3}}{2}$$

$$= \sqrt{3} I_{ph}$$

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$$\boxed{I_1 = \sqrt{3} I_{ph}}$$

current in line no 2 is

$$I_2 = I_Y - I_R$$

$$\boxed{I_2 = \sqrt{3} I_{ph}}$$

In line no 3. $I_3 = I_B - I_Y$

$$\boxed{I_3 = \sqrt{3} I_{ph}}$$

Since all the line currents equal in magnitude that is $I_1 = I_2 = I_3 = I_L$. i.e. $\boxed{I_L = \sqrt{3} I_{ph}}$

Power:

power per phase $= V_{ph} \times I_{ph} \cos\phi$

Total power $= 3 \times V_{ph} I_{ph} \cos\phi$

However $V_{ph} = V_L$ and $I_{ph} = \sqrt{3} I_{ph}$

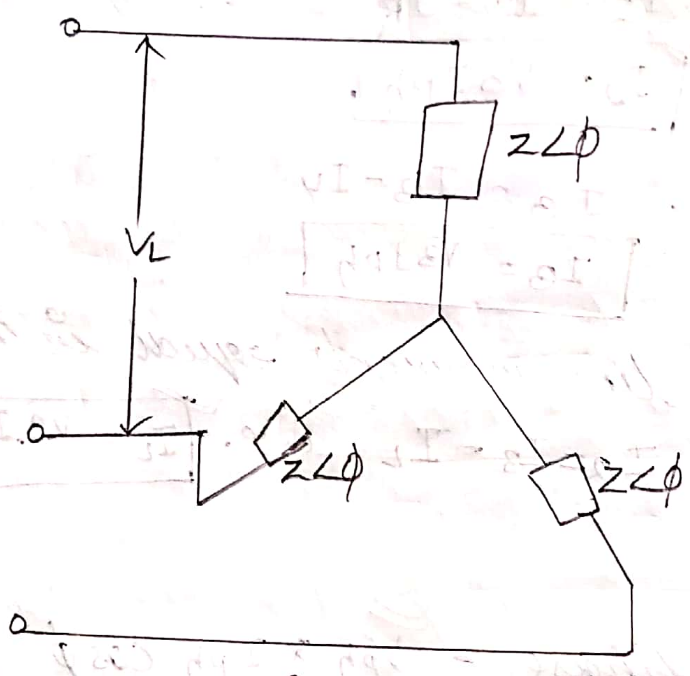
$$\Rightarrow I_{ph} = \frac{I_L}{\sqrt{3}}$$

Hence in terms of line values the above expression for power becomes $P = 3 \times V_L \times \frac{I_L}{\sqrt{3}} \cos\phi$

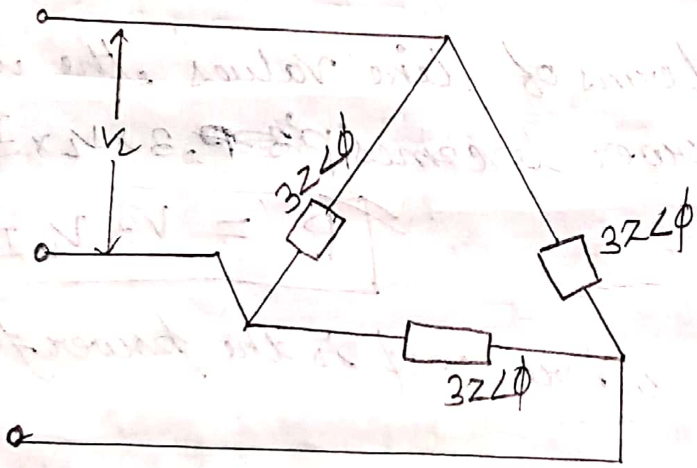
$$\boxed{P = \sqrt{3} V_L I_L \cos\phi}$$

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

Balance Y/Δ and Δ/Y conversion:



(a)



(b)

In few view of the above relationship between the line and phase current and voltages, Any balanced star connection system may be complete displaced by an equivalent Δ connected system. for an Exmp. A three phase Y connected system having voltage of V_L and line current I_L may be replaced by a Δ connected system in which phase voltage is V_L and phase current is $\frac{I_L}{\sqrt{3}}$.

Similarly a balanced Y connected load having equal branch impedance each of $\underline{Z\angle\phi}$ may be replaced by an equivalent Δ connected load whose each phase impedance each $\underline{3Z\angle\phi}$ which is shown in the above figure.

For a balanced Y connected load

Let V_L = line voltage, I_L = line current and Z_Y = Impedance per phase

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

$$\cancel{I_{ph} = \frac{I_L}{\sqrt{3}}} \quad I_{ph} = I_L$$

$$\text{so} \quad \boxed{Z_Y = \frac{V_L}{\sqrt{3}\, I_L}}$$

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Now in the equivalent Δ-system the line voltages and currents must have the same values as in the Y-connected system. Hence we must have

$$V_{ph} = V_L$$

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

So $Z_\Delta = \frac{V_{ph}}{I_{ph}} = \frac{V_L \sqrt{3}}{I_L}$

$$\boxed{Z_\Delta = \frac{V_L \sqrt{3}}{I_L}}$$

$$\boxed{Z_\Delta = 3 Z_Y}$$

$\Rightarrow$ ~~$Z_\Delta = 3Z_Y$~~

$$\boxed{Z_\Delta = 3Z_\lambda \text{ or}}$$

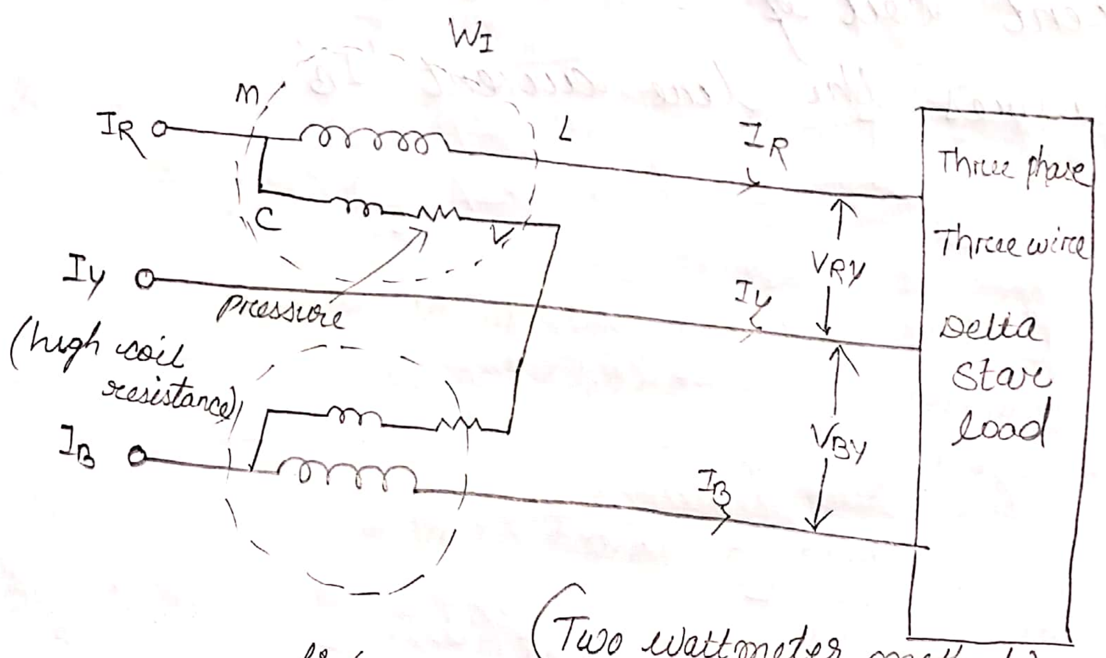
$$\boxed{Z_\lambda = \frac{Z_\Delta}{3}}$$

power measurement in three phase circuit:

Following method are available for measuring power in a 3-ϕ load

a) Three wattmeter method.
b) Two wattmeter method.
c) One wattmeter method.

b) Two wattmeter method:



fig(a) (Two wattmeter method)

→ This mathod is the most ebbective method of all mathods.

→ The cercuit diagram bore this shceme far clearly shown in the above figure. In which one phase is common to both pressure coil and current coil are connected in series with the remaining two phases.

→ As shown in the above figure, pressure coil of the first wattmeter ('w1') measures the line voltage 'V_{RY}' and the pressure coil of the 2nd wattmeter (w_2) majors the line voltage 'V_{YB}'.

→ Similarly current coil of the first wattmeter W_1 measures the line current 'I_R' and the current coil of the second wattmeter 'W_2' measures the line current 'I_B'.

In the figure (a) and (b) power measured by the 1st wattmeter (W_1) may be given in the form.

$$\boxed{W_1 = V_{RY} \times I_R \cos\alpha}$$

$$\boxed{W_1 = V_L I_L \cos(30+\phi)} \quad \text{---(i)}$$

$W_2 = V_{By} + I_B \times \cos\beta$

$$\boxed{W_2 = V_L \times I_L \times \cos(30-\phi)} \quad \text{- - - (ii)}$$

Now sum of the two readings can be found by adding the eqn (i) and (ii)

$$W_1 + W_2 = V_L I_L[\cos(30+\phi) + \cos(30-\phi)]$$

$$= V_L I_L (\cos 30 \cdot \cos\phi - \sin 30 \cdot \sin\phi + \cos 30 \cdot \cos\phi + \sin 30 \cdot \sin\phi]$$

$$= V_L I_L [2\cos 30 \cdot \cos\phi]$$

$$= V_L I_L 2 \times \frac{\sqrt{3}}{2} \cos\phi$$

$$\boxed{W_1 + W_2 = \sqrt{3} V_L I_L \cos\phi}$$

$$\boxed{W_{total} = \sqrt{3} V_L I_L \cos\phi} \quad \text{- - - - - (iii)}$$

To calculate the power factor of the circuit with the help of the reading.

$[W_1 - W_2]$

$$W_1 - W_2 = V_L I_L[\cos(30-\phi) - \cos(30+\phi)]$$

$$= V_L I_L[\cos 30 \cdot \cos\phi + \sin 30 \cdot \sin\phi - \cos 30 \cdot \cos\phi + \sin 30 \cdot \sin\phi]$$

$$= V_L I_L[\sin 30 \cdot \sin\phi + \sin 30 \cdot \sin\phi]$$

$$= V_L I_L \times 2 \times \frac{1}{2} \times \sin\phi$$

$$\boxed{W_1 - W_2 = V_L I_L \sin\phi} \quad \text{- - - (iv)}$$

ratio of equation (4) & (3)

$$\frac{|W_1 - W_2|}{|W_1 + W_2|} = \frac{V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi} = \frac{1}{\sqrt{3}}\tan\phi$$

$$\boxed{\Rightarrow \phi = \tan^{-1}\sqrt{3}\,\frac{|W_1 - W_2|}{|W_1 + W_2|}} \quad -(vi)$$

for power factor $= \cos\phi$

$$= \cos . \tan^{-1}\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$$

Sometimes two readings are equal i.e.

$$W_1 = W_2$$

$$\Rightarrow \cos\phi = \cos . \tan^{-1}\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$$

$$\Rightarrow \cos\phi = \cos\tan^{-1}\sqrt{3}\left(\frac{W_2 - W_2}{W_1 + W_2}\right)$$

$$\Rightarrow \cos\phi = \cos\tan^{-1}\sqrt{3} \times 0$$

$$\Rightarrow \cos\phi = \cos 0$$

$$\Rightarrow \boxed{\cos\phi = 1} \quad (\because 1 \text{ unity factor})$$

unity power factor.

Power mangement in 3-ϕ circuits:

following methods are available for measuring power in a 3-ϕ load.

a) Three wattmeter method
b) Two wattmeter method
c) One wattmeter method

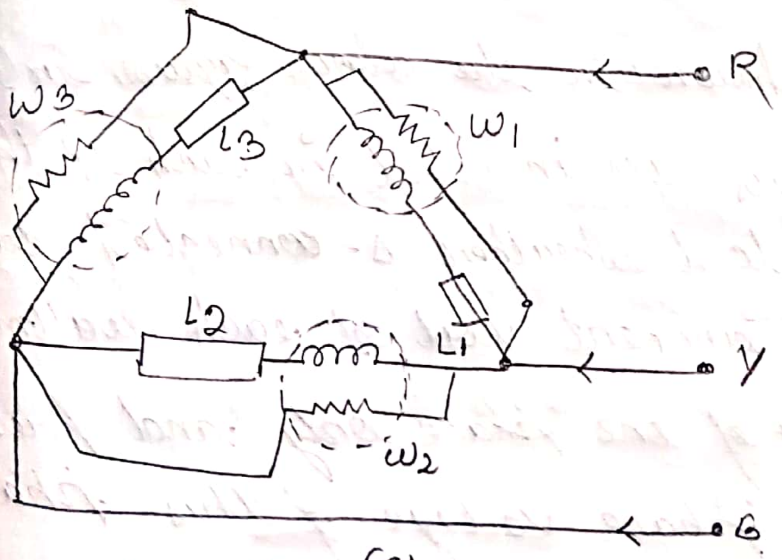
Three wattmeter method:

In this method, three wattmeters are inserted one in each phase and the algebric sum of their readings gives the total power consumed by the 3-ϕ load.

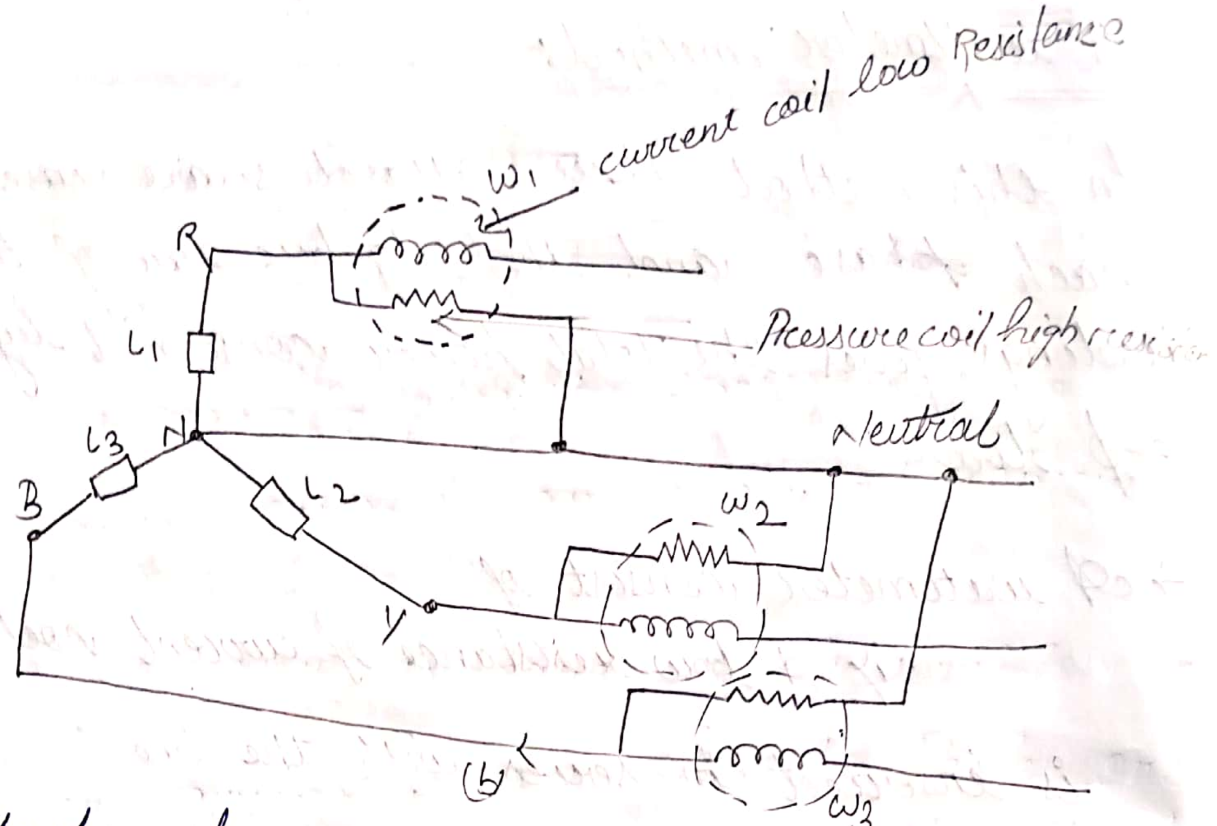
→ A wattmeter consist of

i) A low resistance of current coil which is inserted in series with the line the current

ii) High resistance pressure coil which is connected across the two points whose potential difference is to be measured.



(a)



A wattmeter shows a reading proportional to the product of the current through its current coil the potential difference across its potential or pressure coil and cosine of the angle between this voltage and current.

As shown in the above figure in this method 3 wattmeters are inserted in each of the three phase of the load wheather Δ-Connected or λ-connected. The current coil of each wattmeter carries the current of one phase only and pressure coil measures the phase voltage of this phase. Hence each wattmeter measures the power in a single phase. The algebric sum of the readings of three wattmeter must give the total power in the load.

tance

high resistance

The difficulty of this method is that under ordinary conditions It is not generally feasible to break into the phases of a Δ- connected load not is it always possible, in the case of a Y- connected load, to get at the neutral point which is required for connections as shown in the figure.

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Magnetic Circuit

M:3

Module : 3

Magneto Motive force (MMF):

It drives or trends to drive flux (ϕ) through a magnetic circuit corresponds to electro motive force (EMF) in an electrical circuit.

MMF is equal to the workdone in jouls in carring a unit magnetic pole once through the entire magnetic circuit. It is measured in ampere terms (AT) (NI) in fact as potential difference between any two points is measured by the workdone in carring a unit charge from one point to another. Similarly MMF between two points is measured by the workdone in jouls in carring a unit magnetic pole from one point to another.

Ampere Terms (AT):

It is the unit of magnetomotive force (MMF) and is given by the product of number of terms of magnetic circuits and the current in amperes.

in those Turns.

$$\boxed{MMF = NI}$$

Reluctance :

It is the name given to that property of the material which opposes the creation of magnetic flux through in it. In fact it measures the opposition offered to the passage of magnetic flux through a material and is analogs to Resistance in an electrical circuit. It's unit is

AT/web

$$Reluctance = \frac{L}{\mu A} = \frac{L}{\mu_0 \mu_r A}$$

$$\boxed{Resistance = R = \frac{\rho l}{A}}$$

$$R = \frac{l}{\sigma A}$$

In other words the Reluctance of a magnetic circuit is the number of Ampere Turns required per web. of magnetic flux in the circuit, since

$1\ AT/web. = \frac{1}{henery}$

the unit of Reluctance is Reciprocal of henery.

Magnetic flux(ϕ) $\propto$ MMF,

$$\Rightarrow \phi = K\,MMF$$

where K is a constant of proportionality and is defined as the reciprocal of Reluctance. Thus we may written as –

$\phi = \frac{1}{R} MMR$

$\Rightarrow \boxed{R(\text{Reluctance}) = \frac{MMF}{\phi}}$

$\boxed{R = \frac{NI}{BA}}$ $\left(\because \begin{array}{l} MMF = NI \\ \phi = BA \end{array}\right)$

$\Rightarrow R = \frac{NI}{\mu HA}$

$\Rightarrow R = \frac{NI}{\mu\left(\frac{NI}{l}\right)A}$ $\left(\because H = \frac{NI}{l}\right)$

$\Rightarrow \boxed{R = \frac{l}{\mu A}}$

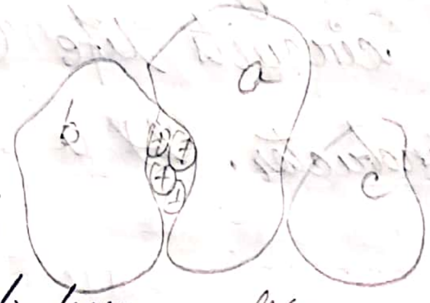
Note:

The quantity used in electromagnetism have some simillarities with the quantities with the electricity. The analogy between two shads is represented below

Electric quantity	magnetic quantity
1) EMF (volt)	1) MMF (AT)
2) current (A)	2) flux (web.)
3) Resistance (Ω)	4) Reluctance (AT/web)
4) current density (A/m²)	5) flux density (wb/m²)

Amper's Work Law or Amper's circuit Law:

The law states that the MMF around a closed path is equal to the current enclosed by the path



fig(a)

mathematically $\oint \vec{H}.\vec{ds} = I$ ampers

where $\vec{H}$ is the vector represented

Magnetic field in dot product with vector $\vec{ds}$ of the enclosing path 's' around current I ampere and that is why line integral ($\oint$) of dot product $\vec{H}.\vec{ds}$ is taken.

Work law is very comprehensive and is applicable to all magnetic field whatever the shape of enclosing path

Ex: 'a' and 'b' in the above figure. Since path 'c' does not enclose the conductor, the mmf around it is zero.

The above work law is used for obtaining the value of the magnetomotive force around simple idealized circuits like (a) along straight current carrying conductor. (b) a long solenoid.

Magneto Motive force Around a long straight conductor:

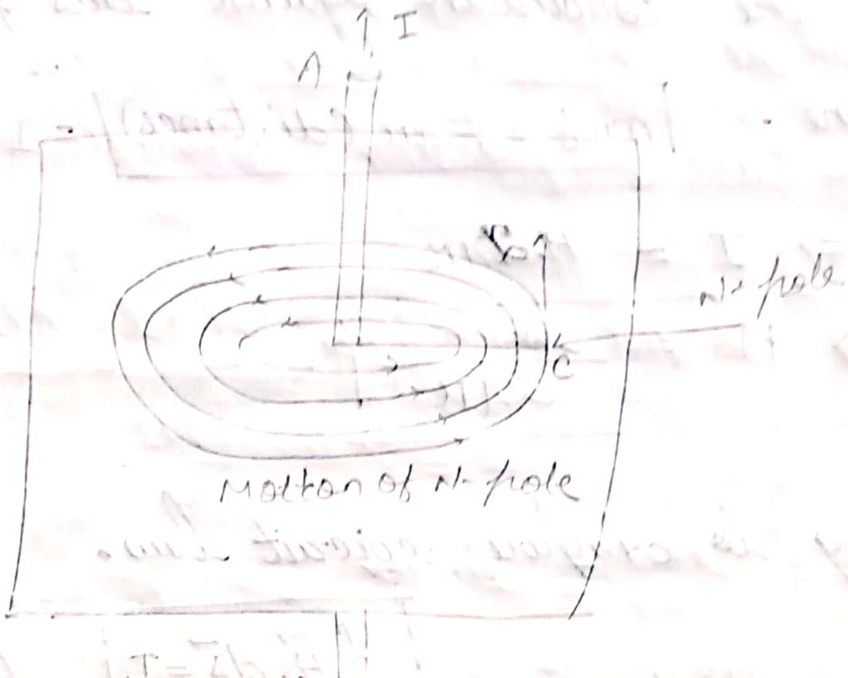
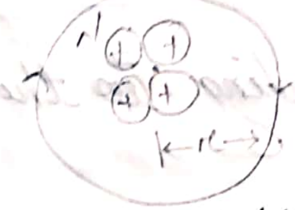


fig.(a)



fig(b)

In the fig(a) a straight conductor which is assumed to extend to infinite in either direction let it carry a current 'I' ampere upwards the magnetic field consist of circular lines of force having there plane perpendicular to the conductor. and there centers at the center of the conductor.

Suppose that field strength at point 'C' distance a 'r' meter from the center of the conductor is 'H' then it means that if a unit N-pole is placed at direction of this force would be tangental to the circular line of force passing through c, If this N-pole is moved once ~~surro~~ round the conductor against this force then the workdone. $\boxed{mmf = F \times r \text{ (distance)}} = I$

$$\Rightarrow I = H.2\pi r$$

$$\boxed{\Rightarrow H = \frac{I}{2\pi r}} \quad \text{- - - - (1)}$$

According to Ampere circuit law,

$$\boxed{\oint \vec{H}.d\vec{s} = I} \quad \text{(unit = joul/C}\ldots$$

According to the fig(b).

If there are N number of conductors then $\boxed{H = \frac{NI}{2\pi r}}$ (unit of $NI = A/m$)

$$\boxed{B = \mu_0 . \frac{NI}{2\pi r} = \mu_0 \mu_r \frac{NI}{2\pi r}} \quad \boxed{\mu = \mu_0 \mu_r}$$

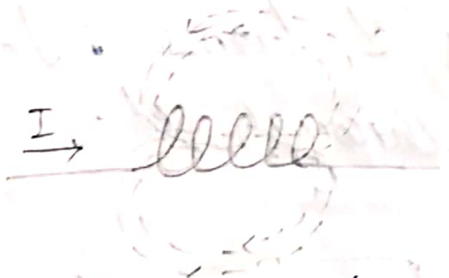
$\cancel{B = \mu}$

In Air $B = \mu_0 \frac{NI}{2\pi r}$

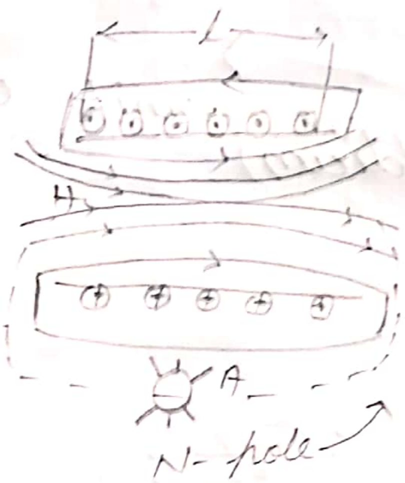
In meddium $B = \mu_0 \mu_r \frac{NI}{2\pi r}$

$\frac{web}{m^2} = \frac{Ts}{a} = \text{Tetsa}$ which is the unit of B

Magnetic field strength in a long solenoid:



Magnetic field around a coil carrying electric current



Let the magnetic field strength along the axes of solenoid be H. Let us assume that

1. The value of H remains constant throughout the length 'l' of the solenoid.

2. The volume of 'H' outside the solenoide is negligible.

H is the force acts on the N-pole only over the length 'l' then the workdone in one round is =

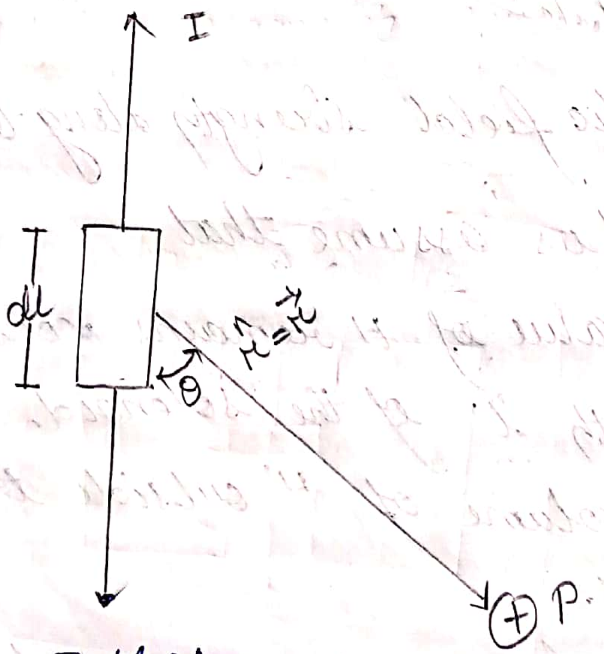
$$\boxed{\underbrace{H \times l}_{\text{Joul}} = I \text{ Amp.}}$$

The ampere terms lived with this path are
NI, where N = Number of terms ; I = is the
current passing through it.

According to the work law $\boxed{H \times l = NI}$
$$\Rightarrow H = \frac{NI}{l}$$

Also $B = \dfrac{\mu NI}{l}$ in Air
$B = \dfrac{\mu_0 \mu_r NI}{l}$ in meddium } unit web/m^2

Biot-Savart Law:



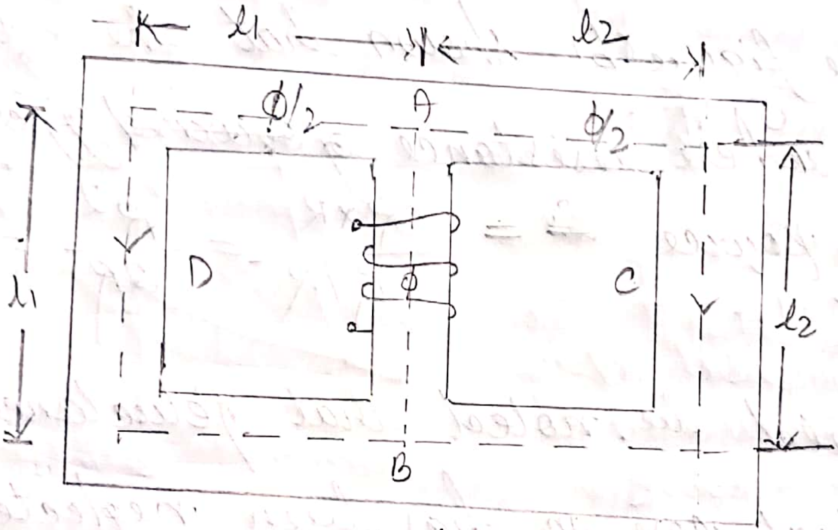
$$dH = \frac{I dl \sin\theta}{4\pi r^2} \ A/m$$

or, $d\vec{H} = (I d\vec{l} \times \vec{r}) / 4\pi r^2$ in vector form
The direction of $d\vec{H}$ is perpendicular
to the plane containing both $d\vec{l}$ and $\vec{r}$ i.e.

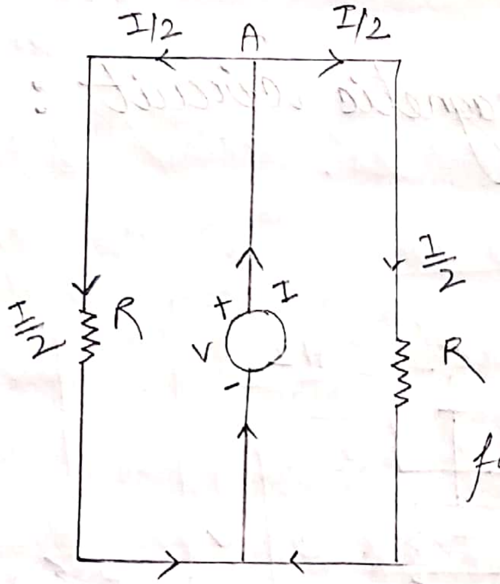
entering, or $dB_0 = \frac{\mu I dl}{4\pi r^2} \sin\theta$ wb/m²

* and $\vec{dB_0} = \frac{\mu \vec{I}\, \vec{dl} \times \hat{r}}{4\pi r^2}$ in vector form

parallel Magnetic circuit :



fig(a)



fig(b)

In fig(a) a parallel magnetic circuit is shown which consists of two parallel magnetic path ACB, ADB acted upon the same mmf each magnetic path has an average length of $2\times(l_1+l_2)$. The flux produced by the coil wound on the central ~~code~~ core is devided equally at the point

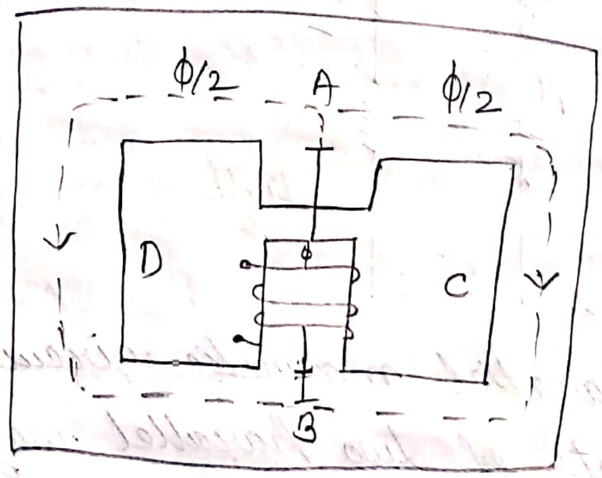
A. between the two outer parallel paths.

The reluctance offered by the two parallel path is equal to the half of reluctance of each path.

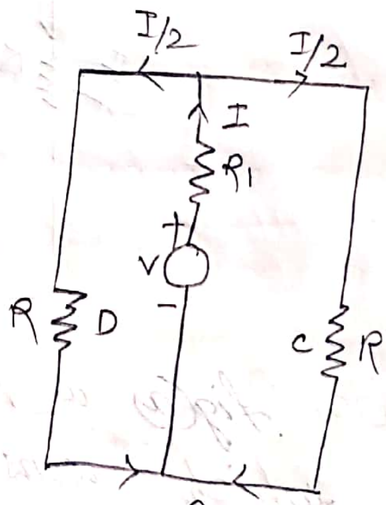
In the figure (b) shown that the equivalent circuit where resistance ~~of covered~~ offered to the voltage source ~~is~~ = $\frac{R \times R}{R+R} = \frac{R^2}{2R} = \frac{R}{2}$

It should be noted that Reluctance offered by the central core AB has been neglected AB in the above treatment

Series parallel magnetic circuit :



(a)



(b)

In the fig(a) it shows that two parallel magnetic circuit ACB and ACD connected across the common magnetic path AB, which contains an air gap of length ~~is~~ lg as usual the flux ϕ is the common core is devided equally at the point A between the two parallel path which has equal reluctance.

The reluctance of the path AB consists of

i) Aire gap reluctance
ii) The reluctance of the central core which comparetively negligible hence the Reluctance of the central core AB equals only the air gap reluctance across which are connected to equal parallel Reluctances.

Hence the MMF Required for this circuit would be the sum of

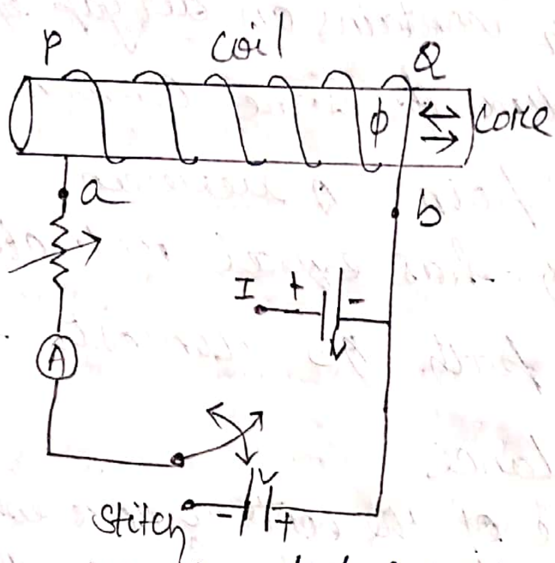
i) That required for the air gap
ii) That required for either of the two path (not for both)

The equivalent electrical circuit which is shown in the figure (b) where the total resistance offered to the voltage source.

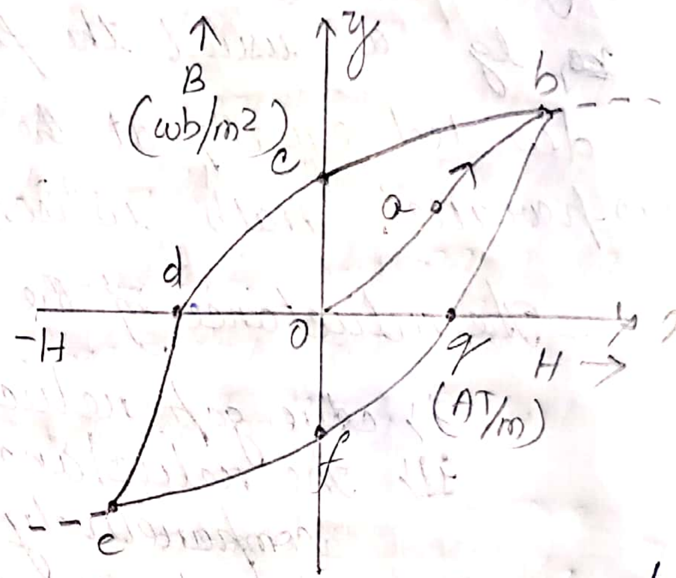
$$R_1 + \frac{R \times R}{R+R}$$

$$= R_1 + \frac{R^2}{2R} = R_1 + \frac{R}{2}$$

B-H curve for magnetic Materials:



Experimental set-up for determination of B-H curve



B.H. curve and B.H. loop

A graphical representation of the variation in 'B' as a result of variation in H in a sample of magnetic material is called B.H. curve or simply a magnetisation curve the arrangement of experimental determination of B.H. curve for a given specimen of a magnetic material is shown in the fig. (a). It consist of a specimen of magnetic material marked as P & Q. A piece of conducting wire with enamel covering is wound over the specimen which forms the coil two batteries a rheostat and one ammeter are connected to the closed loop wire as shown in the figure there may be two cases to examine the forward variation and reversal of magnetisation H as discussed below.

case-1

when the key is moved the position 'one' a current I flows in the conductor from a to b. which in terms sets of magnetic flux ϕ in the specimen. The cores of magnetic flux is straigh but outside the specimen it is curved let the magnetic flux in this case be directed from left to right which corresponds to the forward direction and magnetisation in the core of the specimen.

case-2

when the key is moved to the position (2), a current I flow in the conductor from end b to end a, which in turns saids of magnetic flux ϕ in the specimen. Inside the specimen the cores of magnetic flux is straight but outside the specimen it is curved let the magnetic flux in this case be directed from right to left which corresponds to reversal of magnetisation in the core of the specimen.

The objective of this experiment is to vary the applied mmf per unit length (H) from zero to a sufficiently large value for each of the two cases described above and observe the corresponding variation in flux density (B). This is achieved by varying the current in the circuit with the help of the rheostat present in the circuit. For each variation of the current in both directions (i.e. forward flow and backward flow) corresponding values of H and B are recorded and ploted in the graph to obtain the B-H curve as shown in curve fig.

Initially B remains directly proportional to H for which the graph gives a linear characteristic as illustrated by the portion oa. with increasing H, The cores get saturated and and does not permit a proportionate increase in B. Thus the graph becomes flat for increasing H. This has been shown by the region ab of the graph. In the next step. the current is reduced from the existing value to zero value and the curve is traced along bc. Then the current is reserved by changing over the switch from position 1 position to 2 and reversal of mmf takes place. As the current increase in the reverse direction. the mmf increases in the reverse direction too and the graph is retraced along cd

In the next step the mmf is increased in the negative direction until saturation is observed at point e. Then the current is reduced from the existing value to zero value and the curve is traced along ef. Then the current is again reversed by changing over the switch from position 2 to 1 and by repeating the process. we may close the graph at point 'b' by traversing through point 'g'.

The closed loop characteristic of B versus H so obtained by the process of repeating the forward application and reversal of 'H' in the specimen is called B-H loop or hysteris loop some salient points on the B-H loop are explained below. (b, c, d, e, f and g)

Saturation :

Point b and e represents two extreame condition of magnetization, called saturation condition of the magnetic material, during forward and reversal condition of magnetization respectively, for each of these points B has a limiting value which speaks of the maximum flux density that can be produced in a magnetic material for any increasing order of H.

Retentive capacity:

At locations c and f on the B-H curve, B indicates a non zero value (denoted by oc or of) even though H indicates a zero value. It means that B and H do not go step in step rather B exhibit a lagging effect with respect to H that is why the core retains some flux density of magnetism although mmf has been completely withdrawn. The amount of magnetism held by the core at these points is also referred as residual magnetism which is solely due to retentive capacity of the material.

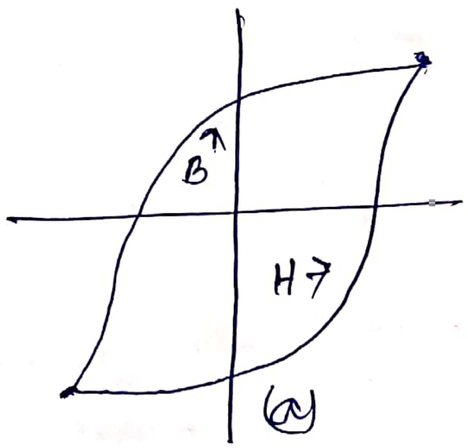
Coercivity: At the location d and g on B-H curve B indicates a zero value even through H indicate a non zero value. It means that B and H do not go step in step; rather B exhibit a lagging effect with respect to H. The amount of H required to reduce the residual magnetism to zero is called ~~core~~ coercive force.

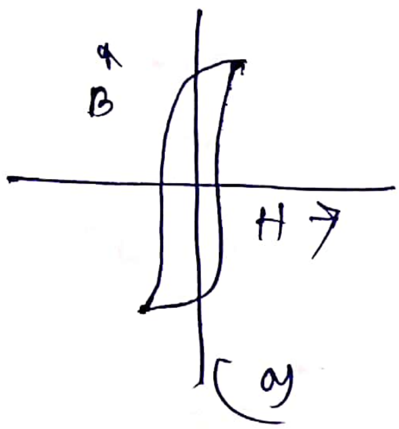
Hysteresis Loss:

The effect due to which the magnetism established in a magnetic materials lags behind the magnetization during cyclic application of forward and reverse magnetic fields to the sample of the magnetic material is called hysteresis.
Hysteresys is mainly due to inertial effect that is the inability of the magnetic dipoles present in the speciment to follow up, the desired orientation as demanded by the quick reversal of the impressed cyclic magnetic field. In this process some energy gets dissipited to overcome and opposition raised by the ~~NSH~~

Hysteresis. This loss of energy is termed as hysteresis loss. Letter the energy loss due to hysterisis is dessipated as heat energy. It is numerically equal to the area bounded within the hysterisis loop.

one major drawback of hysterisis loss is the temperature rise in the ~~star~~ core due to heat ~~engine~~ energy, which is highly undersible as it abbect the performance and operation of equipment. Thus it is always preberable to select magnetic materials with narrow hysterisis loop so as to reduce the hysteresis loos. This materials are designed separately and are manufactured with care. Some typical names of magnetic materials having narrow hysteresis loop are: a) silicon steel b) cold-rolled grain-oriented steel c) hot rolled grain oriented steel. A comparision of the Hysteresis loop for the two cases of ordinary steell and silicon steel is shown.





There are various factor that effect the hysteresis loss in a magnetic material. Steinmetz developed a generalized expression for hysteresis loss as given below in Eq.

$$W_h = K_h f (B_m)^k$$

where W_h = Hysteresis loss per unit volume in W/m^2

K_h = Hysteresis coefficient.

f = cyclic frequency of magnetization. (Hz)

B_m = maximum flux density (Wb/m^2)

K = Steinmetz coefficient (varies between 1.5 to 2.5).

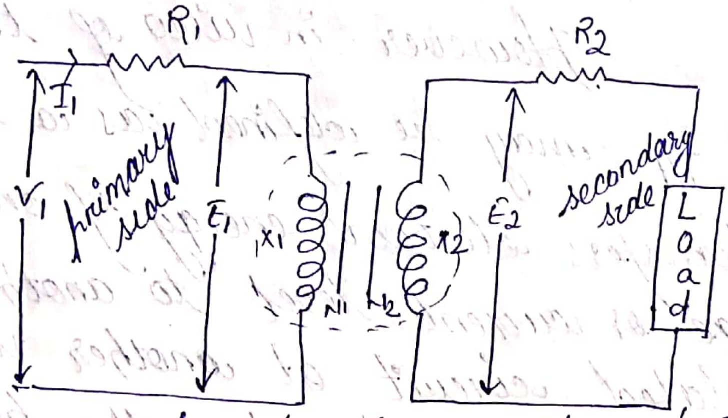
Transfermer

Module : 4

Module : 4

Single phase transfermer (1-ϕ):

It is a static device used to transferme ac electrical energy at constant frequency.



circuit diagram of 1-ϕ transfermer

The main aim of this chapter is to famillrize to the reader with the utility of the transfermers in practical ac circuit a transfermer plays an important roll in the present day power systems in transmitting at distributing electric power at various levels of voltage. for this reseaon transfer may be classified as

1. 1-ϕ and 3-ϕ transfermer (T/F)
2. step up and step down T/F
3. core type and shell type
4. power T/F, distribution T/F, instrument T/F, auto T/F.

In the construction view of a transefer. It may be defined as a static device of two windings (primary and secondary) who is are electrically isollated from each other but magnetically coupled by a common magnetic flux.

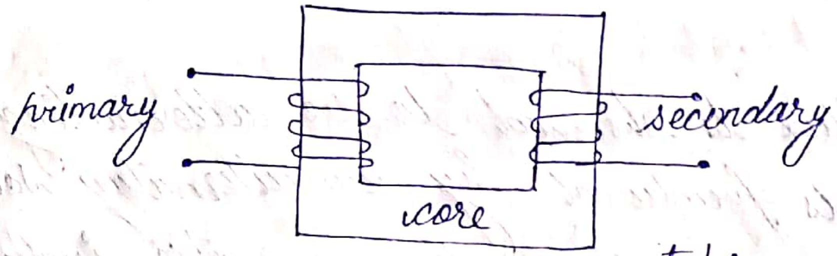
However in view of this operation 1-ϕ T/F may be defined as a static device, transfers electrical energy of one circuit of one voltage or current level to another electrically isolated circuit at another voltage or current level without changing the power and frequency.

construction:

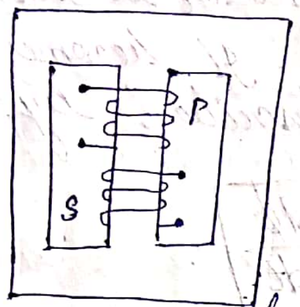
The main parts of a 1-ϕ T/F

1. A setup two isolated winding.
2. A common magnetic core.

Depending on the winding arrangement over the core 1-ϕ transfer may be classified as core type and shell type. In the core type transformer the windings surround the core in a shell type T/F, the core surrounds the winding the ckt diagram is shown in the below figure.

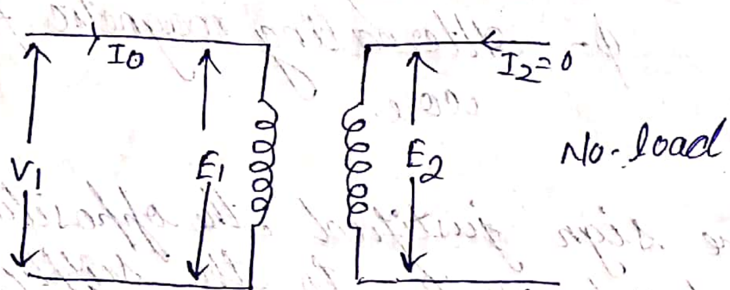


a) core type



b) shell type

operation :



operation of a transforms is based on the principle of Faraday's law of electromagnetic induction. which includes shelf induction and mutual induction. Let us first imagine that an alternating voltage of rms value V_1 and frequency 'f' is fed to the primary winding of a 1-ø T/F while the secondary winding is opened due to the action of AC voltage primary winding draws a current which refers to no load primary current Io.

This current sets up a magnetic flux ϕ in the magnetic core who is in term links both the windings.

This flux is observed to be alternating in nature as it is produced by an alternating source. According to the principle of electromagnetic induction when a coil or a conductor is link with an alternating magnetic flux. It becomes the seat of an induced emf described by.

$$\boxed{E = -N\frac{d\phi}{dt}} \quad ------ (1)$$

where E = induced emf in the coil.
N = Number of terns in the coil.
ϕ = Alternating magnetic flux in the core.

The -ve sign justified the opposition offered by the induced emf to the supply voltage that is satisfying Lenz's law, which states that the effect opposes the cause that produced it.

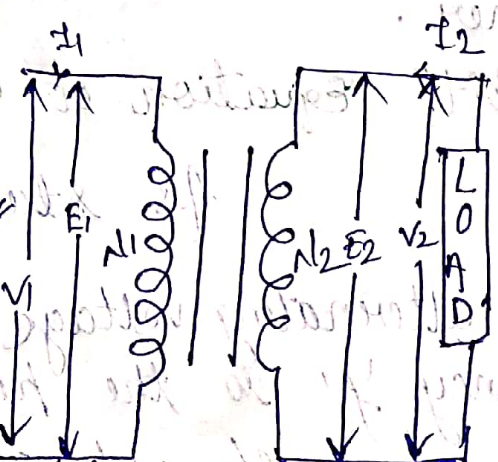
Since both windings are linked by a common alternative flux separate emf get induced in each winding. The emf is induced in the primary winding may be designated by E_1 which as the result of self induction i.e. (flux of a coil links the coil it self and induced in the secondary winding may be designated by E_2 which is the result of mutual induction (i.e. flux of a coil links another coil and induces a emf in the other coil) with the help of eq. we may now write the expression for E_1 and E_2 separately.

$$E_1 = -N_1 \frac{d\phi}{dt} \quad \text{---(2)}$$

$$E_2 = -N_2 \frac{d\phi}{dt} \quad \text{---(3)}$$

where N_1 and N_2 representing no. of turns in the primary and secondary winding respectively. As long as secondary winding remains open the terminal voltage remains equals to the emf induced in the secondary (i.e. during the noload condition - $V_2 = E_2$). The operation described is called no load operation of a single phase transformer.

operation of a 1-ϕ transformer with load:



In order to explain the load operation of a single phase transformer, let us connect to a load to the secondary terminal of the transformer as shown in the above fig. Due to this load a secondary current I_2 starts following in the closed loop of the secondary winding. This current produces another alternative flux (ϕ') whose direction of flow in the core is found to ~~be~~ opposite ~~it~~ to the earlyer flux (ϕ) present in the same core. Hence the net flux in the core reduces from ϕ_2 to ϕ_1 is equal to $(\phi-\phi')$. As the flux reduces in strength the emf induced in two windings reduces in magnitude too.

A reduction in the magnitude of E_1 may be view as ~~weaking~~ weakening of the opposition offers to the supply voltage V_1, and as a result the new current in the primary increases from I_0 to I_1, so finally it may be conclude-d that although those the winding are electri-cally isolated, a change in load current I_2 the secondary winding reflected the corresponding change on the primary curr-ent I_1. This part of the opperation as known as on load opperation of a 1-ϕ transfor-mer.

EMF Equation of a 1-ϕ transformer:

As stated in the previous section the alternating voltage of RMS value V_1 and fre-quency 'f' to the primary winding makes a current flow of I_0 in the same winding.

which in term develops a magnetic flux 'ϕ' in the core assuming that the supply is sinusoidal, the flux should also be sinosuidal in nature which be mathematically expressed as: $\phi = \phi_m \sin \omega t$ ---- (4)

It is also mentioned earlyer that due to the rate of change of flux linkage with the winding to separate emf get induced in respective winding as indicated in the eq^n (2) & eq^n(3) respectively. These eq^n become the starting point for obtaining the required EMf eq^n of a 1-ϕ transformer so eq^n(2) & eq^n (3) are explained in the following manner to get the final emf eq^n.

$$E_1 = -N_1 \frac{d\phi}{dt}$$

$$= -N_1 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$= -N_1 \phi_m \omega \cos \omega t$$

$$= -N_1 2\pi f \phi_m [-\sin(\omega t - \pi/2)]$$

$$\Rightarrow E_1 = N_1 2\pi f \phi_m \sin(\omega t - \pi/2)$$

$$\Rightarrow E_1 = E_{m1} \sin(\omega t - \pi/2) \quad \text{---} (5)$$

$$\text{so} \quad E_{m1} = 2N_1 \pi f \phi_m \quad \text{---} (6)$$

$$E_2 = -N_2 \frac{d\phi}{dt} = -N_2 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$= -N_2 \phi_m \omega \cos \omega t$$

$$= -N_2 \phi_m 2\pi f (\cos \omega t)$$

$$= -N_2 2\pi f \phi_m [-\sin(\omega t - \pi/2)]$$

$$= -N_2 2\pi f \phi_m \sin(\omega t - \pi/2)$$

$$E_2 = E_{m2} \sin(\omega t - \pi/2) \text{ --- } (7)$$

so $$\boxed{E_{m2} = 2N_2 \pi f \phi_m} \text{ --- } (8)$$

eqn. (6) & eqn (8) represents the peak value corresponding to the instantaneous emf given by eqn (5) & (7) respectively. Therefore from their respectively peak values.

$$E_{m1} = 2\pi N_1 f \phi_m$$

$$E_{1rms} = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi N_1 f \phi_m}{\sqrt{2}} = \sqrt{2}\pi N_1 f \phi_m$$

$$\boxed{E_{RMS} = 4.42 N_1 f \phi_m} \text{ --- } (9)$$

$$E_{m2} = 2\pi N_2 f \phi_m$$

$$E_{2RMS} = \frac{E_{m2}}{\sqrt{2}} = \frac{2\pi N_2 f \phi_m}{\sqrt{2}}$$

$$= \sqrt{2}\pi N_2 f \phi_m \text{ --- }$$

$$\boxed{E_{2rms} = 4.4 N_2 f \phi_m} \text{ --- } (10)$$

Eqn (9) represents the primary side emf eqn for a single phase transformer. Eqn (10) represents the secondary side emf eqn for a 1-ϕ transformer.

In this two eqn it is important to note that emf induced in ~~the~~ a particular winding of a transformer as a function of supply frequency.

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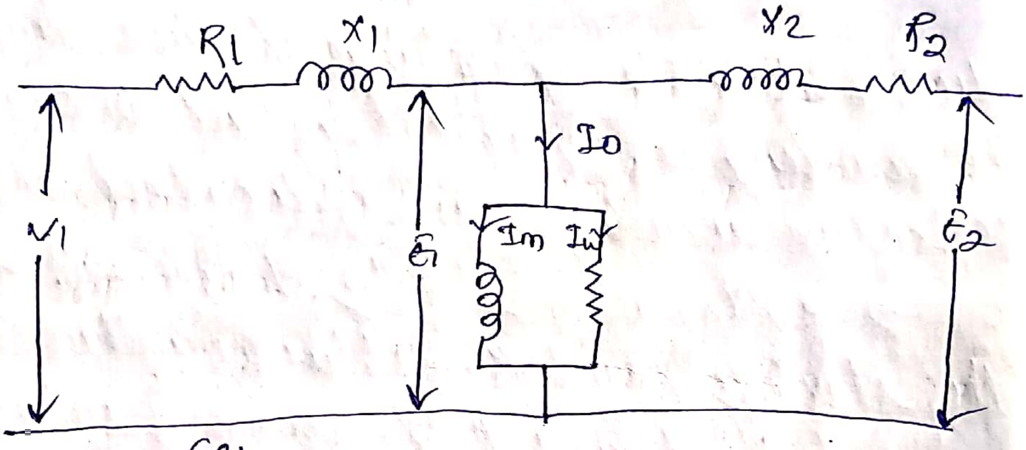
Transformer phasor diagram :

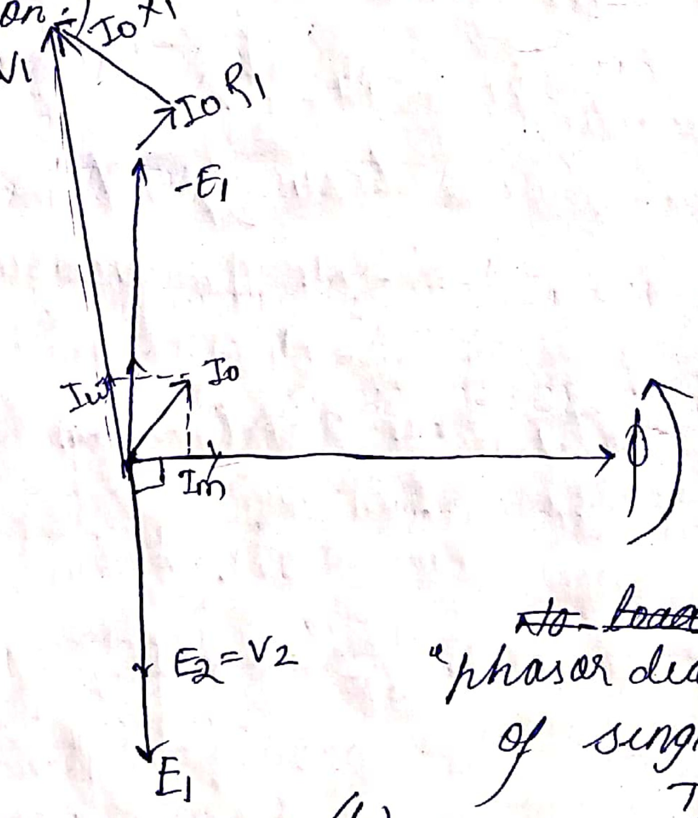
1. Noload phasor diagram
2. Unload phasor diagram

No load phasor diagram :



(a)

(circuit diagram of transformer under no-load condition)



~~No load~~ No-load "phasor diagram" of single phase T/F."

(b)

In order to draw the no-load phasor diagram we start with flux phasor as the reference phasor, and plot it along the +ve x-axis of the coordinate system which is shown in the fig(a).

As already indicated in the equation,

$$E_1 = E_m \left[\sin\left(\omega t - \frac{\pi}{2}\right)\right] \quad \text{---} (9)$$

$$\phi = \phi_m \sin \omega t \quad \text{---} (10)$$

A sinusoidal flux induces EMFs in the primary and secondary windings, which are also sinusoidal in nature and maintain a phase lag of $\frac{\pi}{2}$ radians. Hence the two emf phasors may be plotted in the same phasor diagram along the negative y-axis thus satisfying the phase lag of $\pi/2$ radians between the flux (ϕ) and emfs (E_1 and E_2), since in no-load condition there is no current flow in the secondary side so, $I_2 = 0$. The secondary emf and secondary terminal voltage become equal which is shown in figure 'b' that is $\boxed{V_2 = E_2}$

The primary current I_0 may be divided into two orthogonal components that is I_m & I_w. I_m represents magnetising component of I_0 which is the source for the common flux(ϕ)

Hence ϕ and I_m remains in the same phase in other hand I_w represents the iron loss component of I_0.

Such that $I_w \perp I_L$, ~~and~~ In order to locate primary side supply voltage V_1, let us draw the induced emf E_1 in the opposite direction.

Then by adding the no-load voltage draw phasor along with the EMF phasor E_1, we may find V_1 the mathematically expression for V_1.

$$\boxed{V_1 = E_1 + I_0 (R_1 + jX_1)} \quad \text{---} (11)$$

$$= E_1 + I_0 R_1 + I_0 jX_1$$

The angle between V_1 and I_0 is no load power factor angle ϕ_0 whose power factor is $\cos\phi_0$. mathematically we may find some more relations from the No-load phasor diagram as given below.

Iron loss at no load

$$\boxed{P_i = V_1 \times I_0 \cos\phi_0} \quad \text{---} (12)$$

Loss component of No-load current

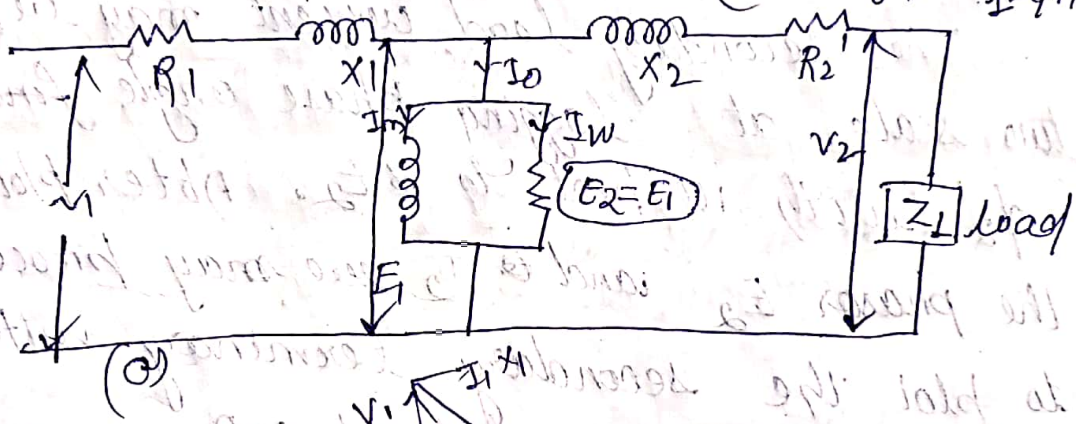
⇒ $I_w = I_0 \cos\phi_0$ --- (13)

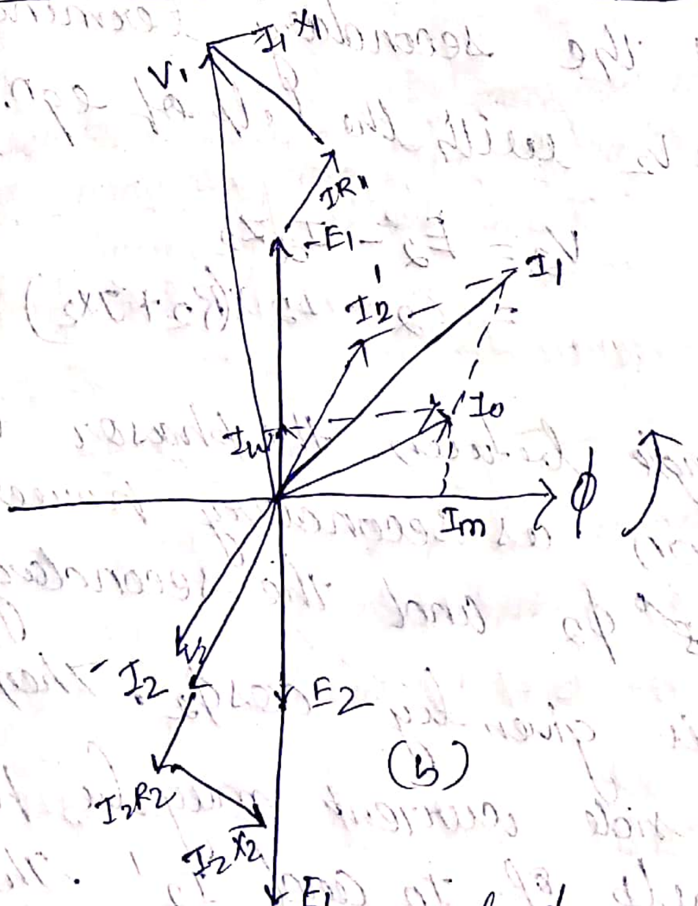
magnetising component of No-load component

⇒ $I_m = I_m \sin\phi_0$ ---- (14)

On-load phasor diagram :

(circuit diagram of onload 1-φ T/F)





(phasor diagram of onload 1-φ T/F)

Some portion of No-load phasor diagram remains unchanges inth an load phasor diagram. The phasor which remain same in both the cases are the flux(ϕ) and the EMF's E_1 and E_2 which are ploted in the figure a and fig 'b.'

The secondary load current may be ploted two scale at lagging phase angle find ϕ_2' with respect to E_2. After ploting the phasor E_2 and I_2 we may proceeds to plot the secondary terminary voltage phasor V_2 with the help of eqn.

$$V_2 = E_2 - I_2 Z_2$$
$$= E_2 - I_2 \times (R_2 + jX_2) \quad \text{---(15)}$$

The angle between the phasor V_2 and I_2 is known as secondary power factor angle ϕ_2 and the secondary power factor is given by $\cos\phi_2$. Then the primary side current may be ploted with the help of I_0 and I_2'. The No-load current I_0 is ploted in the same way by taking the resultant of I_m and I_w. However plotting of I_2' requires some understanding. I_2' represents the primary current which neutralize the demagnetizing effect of I_2.

Such that the relationship is given by

$$\frac{I_2'}{I_2} = K$$

$$\Rightarrow I_2' = K I_2 \quad \text{--- (16)}$$

Since I_2' and I_2 opposes each other by the principle, I_2' is to be plotted to scale on the opposite direction of I_2

Then the resultant of I_0 and I_2' may be ploted with the help of parallelogram law of phasor addition. for obtaining primary current I_1 and satisfying the equation.

$$I_1 = I_0 + I_2' \quad \text{--- (17)}$$

In order to plot the primary voltage phasor V_1 the primary emf phasor E_1 may have to extended backward and then the primary winding voltage drop may be added with it because the expression for V_1 is the phasor some of.

$$V_1 = E_1 + I_1 Z_1 \quad \text{--- } \cancel{18}$$

$$= E_1 + I_1 (R_1 + JX_1) \quad \text{--- (18)}$$

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finally the angle between the phasor V_1 & I_1 is known as primary power factor angle ϕ_1, and the primary powerfactor is given by $\cos\phi_1$.

Q. The primary side of a transformer is connected to 230V, 50Hz supplied. if the no-load power consumption is 80watt, what would be the magnetising current and loss current assume that no-load power factor is 0.8 lagging.

Ans:

$$I_m = I_0 \sin\phi_0$$

$$I_w = I_0 \cos\phi_0$$

given that $\cos\phi_0 = 0.8$

$$P = V I_0 \cos\phi_0$$

$$\Rightarrow 80 = 230 \times I_0 \times 0.8$$

$$\Rightarrow 80 = 184\, I_0$$

$$\Rightarrow \frac{80}{184} = I_0 \Rightarrow I_0 = 0.434\,A$$

$$I_m = I_0 \sin\phi_0$$

$\Rightarrow I_m = 0.434 \times \cancel{0.02} \sqrt{1 - 0.64}$
(magnetising current) $= 0.434 \times 0.6 = 0.2604 A$

$I_w = 0.434 \times 0.8$
$= 0.3472 A$

<u>Voltage and current transfermation Ratio:</u>

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{I_1}{I_2} = K.$$

It is clear that the volts per terms is exactly same for both the primary and secondary windings i.e, in any T/F secondary and primary induced emf are related to each other by the ~~number of~~ Ratio of number of secondary and primary terms.

K is a constant called voltage transfer motion Ratio of terms ratio.

for step up transferm $V_2 > V_1$ In this case voltage transformation Ratio 'K' will be greater than 1 $(K > 1)$

four step down T/F, "$V_2 < V_1$"
In this case $K < 1$

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In an ideal T/F the losses are negligible (iron loss & copper loss) .. volt ampere input to the primary and volt ampere output from secondary can be approximately equal to

$$\boxed{\text{Input} - \text{losses} = \text{output}}$$

when we considering ideal gas

$$\boxed{\text{output VA} = \text{Input VA}}$$

$$\Rightarrow V_2 I_2 = V_1 I_1$$

$$\boxed{\Rightarrow \frac{V_2}{V_1} = \frac{I_1}{I_2} = K}$$

$$\Rightarrow \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Dt. 15. 11.19

DC Machine:

DC machine is of two types
1) DC generator
2) DC Motor

DC Generator:

It converts mechanical Energy into Electrical energy.

DC generator is of two types

1. Separately excited DC generator
2. Self excited DC generator.

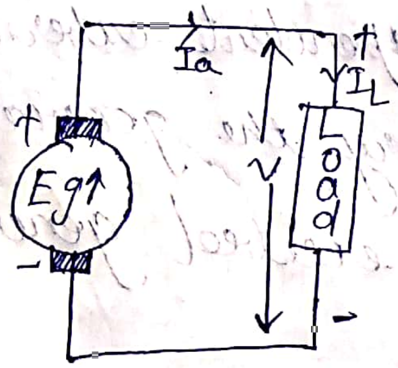
Self excited, also three types

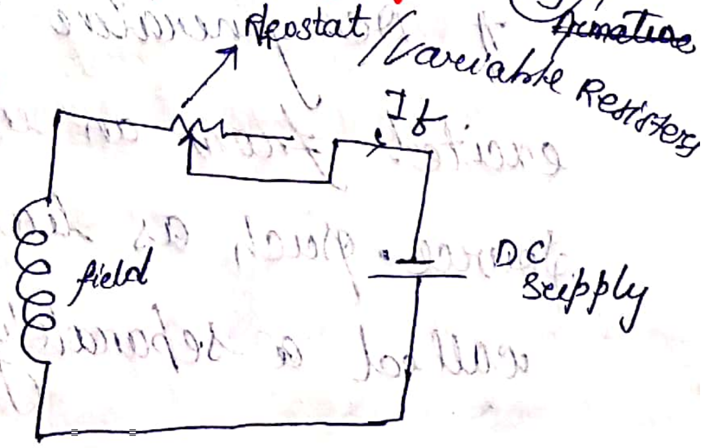
1. Series wound DC generator
2. ~~Shaund~~ Shunt (Parallel) wound DC generator,
3. Compound wound DC generator.

Compound would also two types,

1. Short shaund
2. Long shound

Separatedly excited DC generator:





Eg - Generated EMF

1.44B

$I_a = I_L = I$

$E_g - IR_a - V = 0$

$\Rightarrow E_g - IR_a = V$

$$\boxed{\Rightarrow V = E_g - I_a R_a}$$

'E_g' is the generated EMF

'R_a' is armature Resistance

'I_a' is the armature current

V is the terminal voltage.

Power Develop: (P_g)

$P_g = E_g \times I$

power deliverd to external load

$P_L = V \times I$

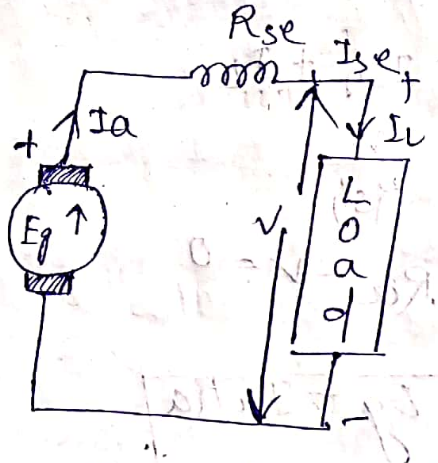
A DC generator whose field winding is excited from an independent external or source, such as battery, the generator is called a separately excited generator

Self excited DC-generator:

A DC gerator whose field winding is excited by the current supply or by the generator it self is called a self excited generator.

In such machines the field coils are inter connected with the armature winding, the field coils may be connected either in series with the armature, or partly in series or partly in parallel with the armature.

Series wound Generatar:



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

$$E_g - I_a R_a - I_a R_{se} - V = 0$$

$$\Rightarrow E_g - I_a (R_a + R_{se}) - V = 0$$

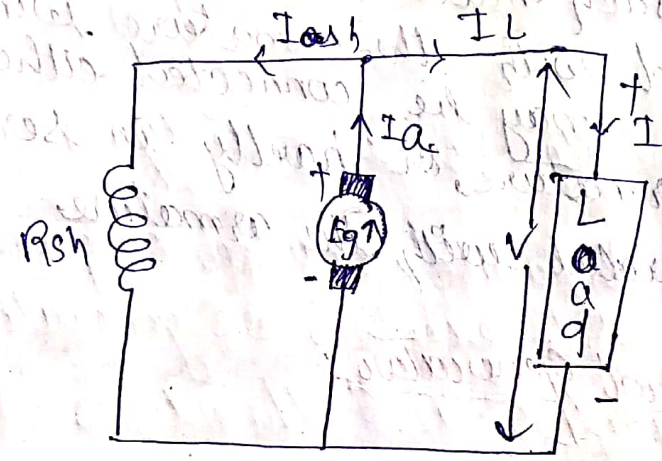
$$\boxed{\Rightarrow V = E_g - I_a (R_a + R_{se})}$$

* The Resistance (R_{se}) of Series field winding ~~are~~ ~~Rse~~ very low which is equal to 0.5 Ω

Power develop $P_g = E_g \times I$

power delivered = $P_L = V \times I$

~~Shaund~~ shunt wound DC generator:



$I_a = I_{sh} + I_L$

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

$E_g - I_a R_a - V = 0$

$$\boxed{\Rightarrow V = E_g - I_a R_a}$$

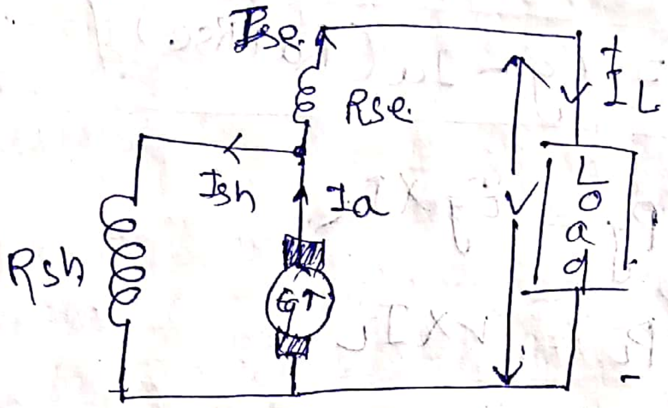
Power developed $P_g = E_g \times I_a$

Power delivered $\Rightarrow P_L = V \times I_L$

* The resistance of ~~shaund~~ shunt field winding R_{sh} naturally very high, which is equal to 100Ω

compound wound generator:

1. short shunt



$$I_{se} = I_L$$

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

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

$$E_g - I_aR_a - I_{se}R_{se} - V = 0$$

$$\boxed{\Rightarrow E_g - I_aR_a - I_{se}R_{se} = V}$$

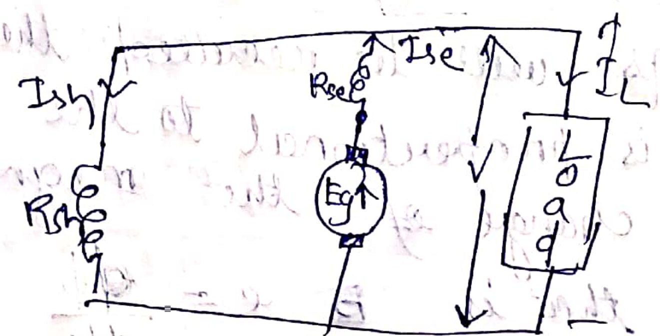
Power developed $P_g = E_g \times I_a$.

Power delivered $P_L = V \times I_L$

2. Long shunt:

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

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



$$E_g - I_a R_a - I_a R_{se} - V = 0$$

$$\Rightarrow V = E_g - I_a R_a - I_a R_{se}$$

$$\boxed{\Rightarrow V = E_g - I_a(R_a + R_{se})}$$

$$P_g = E_g \times I_a$$

$$P_L = V \times I_L$$

~~Resistance~~

Emf. Eqn of DC Generator:

Let ϕ be the flux perpose in webers

Z = the total number of Armature conductors or coil sides on the armature

P = no. of poles.

A = number of parallal paths in the armature

N = Rotational speed of the armature in RPM

(measuring speed Taconmeter)

As will be recalled the induced emf is proportional to the time rate of change of the magnetic flux.

that is, $e = \frac{d\phi}{dt}$

~~usena~~

during one revolution of armature in a pre pole generator is armature conductor gets the magnetic flux p-times so flux cut by one conductor in one revolution is equals to '$\text{P}\phi$' weber.

since the number of revolution made by the armature per minute is N so no. of revolutions made per second is $\frac{N}{60}$ and therefore flux cut by each conductor per second = flux cut by one conductor per revolution into no. of revolution of armature per second.

$$N = P\phi \times \frac{N}{60} \text{ wb}$$

The average EMF induced in one conductor will be $e = P\phi \times \frac{N}{60}$

The number of conductors in series between a +ve brush and -ve brush is $= \frac{\text{the no. of conductors}}{\text{No. of parallel paths}}$ ~~devided~~

i.e. No. of Armature conductors per parallel path is

$$= \frac{Z}{A}$$

The total emf generated between the terminals E = (Average emf induce in a one conductor) X (No. of conductors in each circuit or parallel path)

$$= \left(P\phi \times \frac{N}{60}\right) \times \frac{Z}{A}$$

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

for ~~wave~~ winding = No. of parallel path A = 2

Lap winding = No. of parallel paths A = P

Q. A 6 pole lap wound armature has 840 conductors and flux per pole is 0.018 wb. calculate the generated EMF when the machine is running at 600 RPM.

Ans: Give data

$\phi = 0.018$ wb.

$Z = 840$

$N = 600$ RPM

~~A=6~~ E = 6

$$E = \frac{P\phi NZ}{60 \times A}$$

$$\Rightarrow 6 = \frac{T \times 0.018 \times 600 \times 840}{60 \times 2}$$

$$\Rightarrow \frac{6 \times 60 \times 2}{0.018 \times 600 \times 840} = T$$

$$\Rightarrow 0.08 = T$$

Q. calculate the voltage Induced in the armature winding of a 4 pole wave wound DC machine having 728 conductors and running at 1800 RPM. The flux per pole is 35 m web?

$E = 4$

$N = 1800$ RPM

$\phi = 35 \times 10^{-3}$

$Z = 728$

$$E = \frac{T \phi N Z}{60 A}$$

$$\Rightarrow 4 = \frac{T \times 35 \times 10^{-3} \times 1800 \times 728}{60 \times 2}$$

$$\Rightarrow \frac{4 \times 60 \times 2}{35 \times 10^{-3} \times 1800 \times 728} = T$$

$$\Rightarrow \frac{4800}{458.640} =$$

DC Motor:

It converts Electrical Engergy to mechanical energy.

Working principle of DC motor:

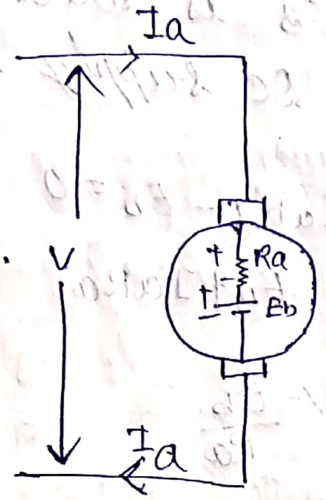
The principle upon which a DC motor works is very simple if a current carreying conductor is placed in a magnetic field, mechanical force is experienced on the conductor. The direction of which is given by Fleming's Lebt hand rule (also called motor rule) and hence the conductor moves in the direction of force. The magnitude of mechanical force experienced of the conductor is given by $\boxed{F' = B I_c l_c}$

'B' is the field strength (wb/m^2 or T)

'I_c' is the current flowing through the current (Ampere)

'l_c' is the length of conductor (m)

Importants of back Emf : E_B



Applying KVL

$$V = I_a R_a + E_b$$

when the motor armature continues to rotate due to motor action the armature conductors cut the magnetic flux and therefore EMFs are induced them the direction of this induced emf known as back emf, each such that it opposes the applied voltage.

Since the back emf is induced due to the generator action, the magnitude of heat is, therefore given by the same expression as that for the generated emf in a generator

$$\cancel{E_b = I_a R_a + E_b}$$

$$E_b = \frac{P\phi NZ}{60A}$$

The armature circuit is equivalent to a source emf, E_B is series ~~meet~~ with a resistance R_a across a DC supply main voltage 'V'.

$$V - I_a R_a - E_b = 0$$

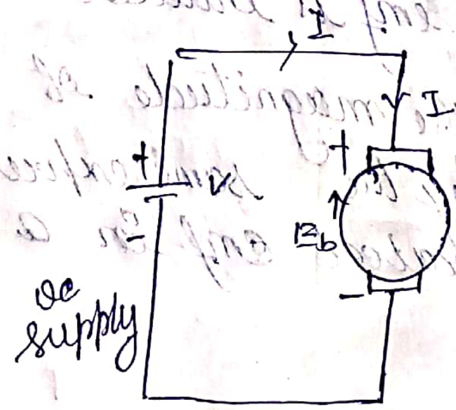
$$\Rightarrow V = E_B + I_a R_a$$

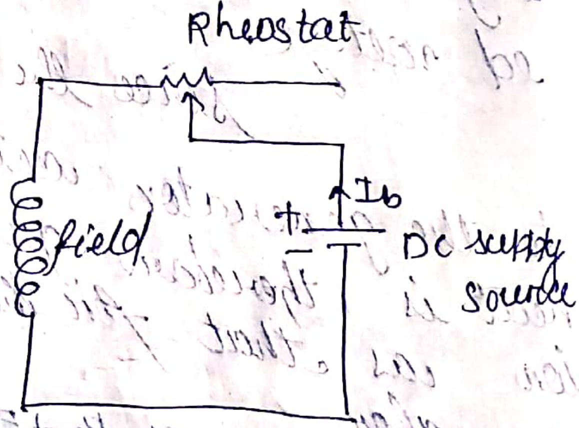
$$I_a = \frac{V - E_b}{R_a}$$

Types of DC motor:

1) separately excited DC motor.
2) Shelf excited DC motor.

Separately excited DC Motor:





$V - I_aR_a - E_b = 0$

$\Rightarrow V = I_aR_a + E_b$

power drawn from supply mains:

$P = VI$

mechanical power developed

P_m = Power input to the armature − power loss to armature

$= VI - I^2R_a$

$= I(V - IR_a)$

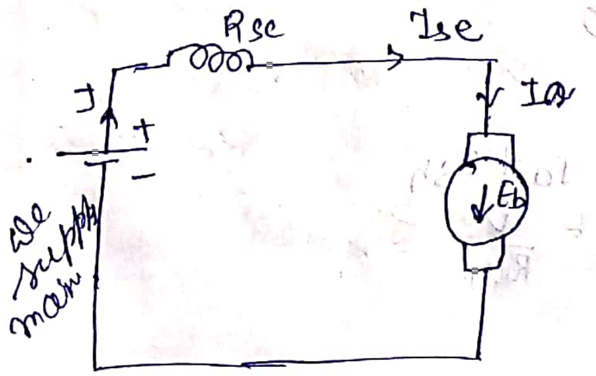
$= I E_b$

REMEMBER

$$\boxed{P_m = E_bI_a}$$

Shelf Excited DC Motor:

Series wound DC motor:



$I = I_a$

$V - I_aR_{se} - I_aR_a - E_b = 0$

$\Rightarrow V = I_aR_{se} + I_aR_a + E_b$

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

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

power drawn from the supply mains $= VI_a$

mechanical power developed P_m.

$\rightarrow$ Power input − losses in armature field

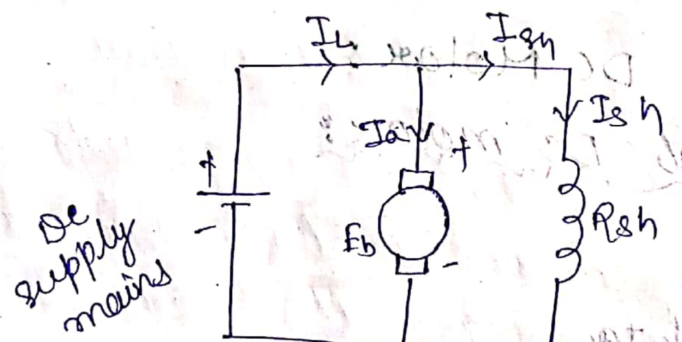
$\Rightarrow VI_a - I_a^2(R_a + R_{se})$

$\Rightarrow I_a(V - I_a(R_a + R_{se}))$

$\Rightarrow I_a E_b$

$\Rightarrow E_b I_a$

shunt wound DC Motor:



$I_L = I_a + I_{sh}$

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

$V - I_a R_a - E_b = 0$

$\Rightarrow V = E_b + I_a R_a$

$P = VI_L$

mechanical power developed =
: power input - losses in armature and field

~~$= VI_a - I_a^2(R_a + R_{se})$~~

$= VI_L - VI_{sh} - I_a^2 R_a$

$= V(I_L - I_{sh}) - I_a^2 R_a$

$= VI_a - I_a^2 R_a$

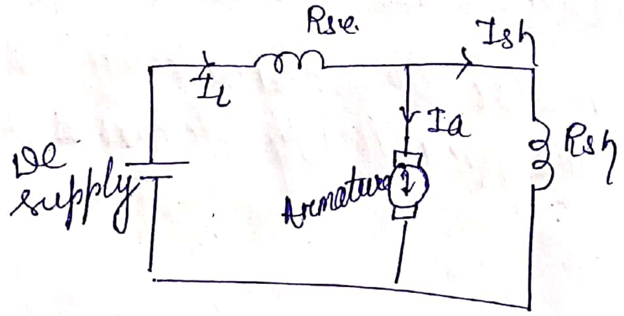
$= I_a(V - I_a R_a)$

$= I_a E_b$

compound wound DC motor:

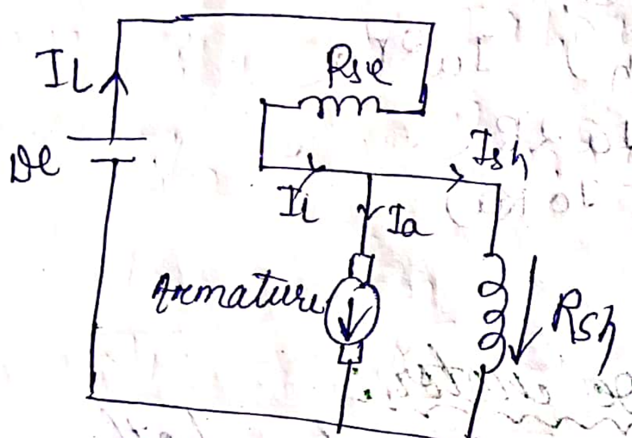
A compound dc motor has both and series field coils. compound wound motors are of two types namely cumulative compound wound and differential compound wound motors.

cumulative compound wound motor:



cumulative compound motor is one in which the field windings are connected in such a way that direction of flow current of flow is same in both of the field windings.

Differential compound wound motor:



In this motor in which the field windings are connected in such a way that the direction of flow of current is opposite to each other in the two field winding

Speed Equation

From the emf equation of DC motor we got that
$$E_b = \frac{P\phi N Z}{60A} \quad \text{---(1)}$$

From the KVL we got the eqn,

$$V - I_aR_a - E_b = 0$$
$$\Rightarrow E_b = V - I_aR_a \quad \text{---(2)}$$

Now comparing eqn no.(1) & eq(2)...

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

$$\Rightarrow N = \frac{(V - I_aR_a)\,60A}{P\phi Z}$$

$$\Rightarrow N = K\frac{(V - IR_a)}{\phi}$$

($\because$ since Z, A, P are constant for a perticular machine)

$$\Rightarrow N = K_1 \frac{E_b}{\phi}$$

$$\Rightarrow N = K\frac{E_b}{\phi}$$ ($\because$ where K is a constant)

~~In a DC~~

for a DC motor if initial values of speed armature current back emf or flux per pole are N_1, I_{a1}, E_{b1} and ϕ_1 respectively and corresponding final values are N_2, I_{a2}, E_{b2} and ϕ_2 respectively.

Then $N_1 \propto \frac{E_{b1}}{\phi_1}$

$N_2 \propto \frac{E_{b2}}{\phi_2}$

where $E_{b1} = V - I_{a1}R_a$

$E_{b2} = V - I_{a2}R_a$

$$\Rightarrow \frac{N_2}{N_1} = \frac{\frac{E_{b2}}{\phi_2}}{\frac{E_{b1}}{\phi_1}} = \frac{E_{b2}}{\phi_2} \times \frac{\phi_1}{E_{b1}}$$

$$= \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

REMEMBER

$$\boxed{\Rightarrow \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}}$$

for DC shunt motor or separatedly excited DC motor flux practically remains constant

$\phi_2 = \phi_1$.

$$, \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

REMEMBER

$$\boxed{\frac{N_2}{N_1} = \frac{V - I_{a2}R_a}{V - I_{a1}R_a}}$$

In the above expression since the applied voltage V is constant and the voltage drop in the armature ($I_a R_a$) is negligible in comparision to the supply voltage V.

IMP: pt!
Speed of a DC motor remains almost constant.

for a DC series motor, prior to saturation $\phi \propto I_a$

$$\Rightarrow \frac{\phi_1}{\phi_2} = \frac{\phi_{a1}}{\phi_{a2}}$$

REMEMBER

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}}$$

FOR DC series motor after saturation:

flux is independent of armature current I_a so $N \propto E_b$

$$\Rightarrow \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

Armature Torque Equation:

$\omega = \frac{2\pi n}{60}$

Let 'Te' Electromagnetic torque developed in Nm by the motor running at N RPS, so power develop equals to workdone per second = $T_e \omega$ ---- (1)

Electrical equivalent of mechanical power develop by the armature $= E_b I_a$ ---- (2)

comparing eqn (1) & (2)

$$T_e \omega = E_b I_a$$

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

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

$$= \frac{E_b I_a \times 30}{3.14 \times N}$$

$$\boxed{T_e = 9.55 \frac{E_b I_a}{N}} \quad \text{--- (3)}$$

Now substituting the value of $E_b = \frac{P\phi NZ}{60A}$

$$T_e = \frac{9.55 \times \frac{P\phi NZ}{60A} \times I_a}{N}$$

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

Induction Motor:

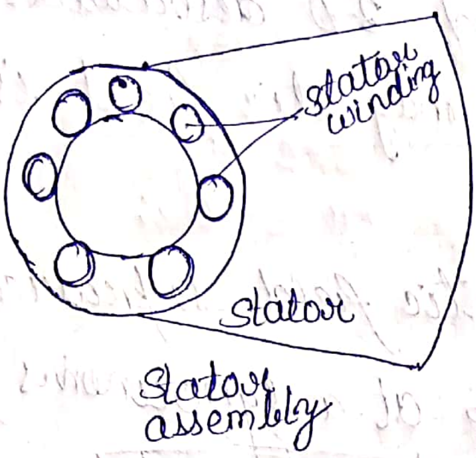
Introduction to three phase induction motors, Three phase induction motors from the major section calmost more than 90% of industrial drives because of its inharant advantages. In the family of AC motors three phase induction motors as self static cand they also have the simplest construction cas ca Result it requires very less maintenance cand keeps calmost trouble with service. It has calso higher efficiency compaired to DC and synchronoms motors and operates at ca regionable good power factor.

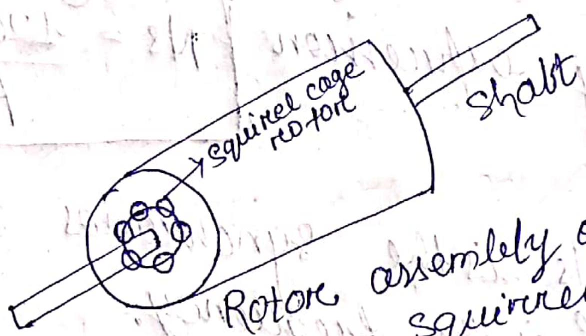
Induction motor have ca rotating path called roter and ca stationary part called stater the stater consist of ca cylindrical frame called Yoke. The yoke is used cas ca support for the stater core. The stater core is slotted hallo cylindinder that houses ca three phase balanced star connected windings with provision to feed ca balance three phase Ac supplied to the stater winding in the hollow space the stator core the rotor assembly is carefully mounted with the help of an axial-shaft and ball bearing arrangement. The shaft along with the rotor assemble is three two rotad by maintaining a uniform air gap through out.

Depending upon the type of winding used in the rotor three phase induction motors may be classified as

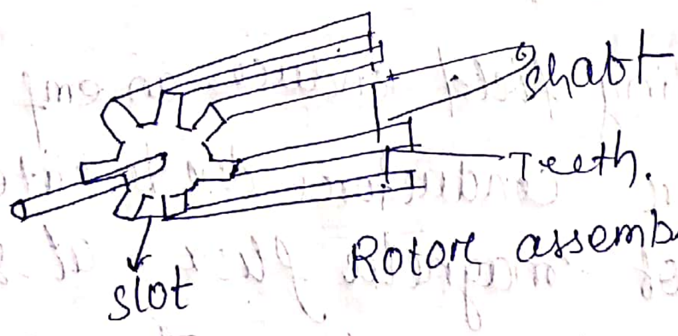
1. Squirrel cage induction motor.
2. Wound rotor or slip ring induction motor.

A squirell cage rotor has short circuited conductors round the perifori of the rotor which resemble a squirrel cage on the other hand a wound rotor has a balanced three phase winding simillar to stator winding.





Rotor assembly of squirrel-cage induction motor



Rotor assembly of wound-rotor induction motor.

The principle operation of 3-ϕ induction motor:

when a balanced 3-ϕ supply is given to a balanced 3-ϕ distributed windings a rotating magnetic field is developed.

The magnetic field so produced revolves in the air gap at a syncronoms field given by expression $\boxed{N_s = \frac{120f}{P} \text{rpm}}$

N_s is the synchronos speed

f is the frequency.

P is the number of poles in the stator winding.

The rotating field enduces an emf in the rotor conductors due to rate of change of magnetic flux. at stands steel position of the rotor maximum emf is enduced as rate of change of flux linkage is a function of the relative motion between the rotating field and the rotor conductors.

Relative speed or slip speed = $(N_S - N_R)$ RPM

N_R = Rotor speed

concept of slip:

slip indicates the relative speed of a motor with respect to the synchronous speed of rotating magnetic field of the stator Express in % or per unit ratio of N_S

Slip is designed by a symbol 's' and it has no unit.

$$s = \frac{N_S - N_R}{N_S} \text{ in PU}$$

$$\% \text{ of } s = \frac{N_S - N_R}{N_S} \times 100$$

slip at stand steel (constant)

when the motor remains in stand steel condition it has a skill rotore

hence $N_R = 0$

$s = 1$ PU

Slip & Synchronos speed:

when the motor approaches the synchronous speed the rotor speed becomes equal to the synchronous speed so $N_R = N_S$

$S = 0$ pu

or $S = 0\%$

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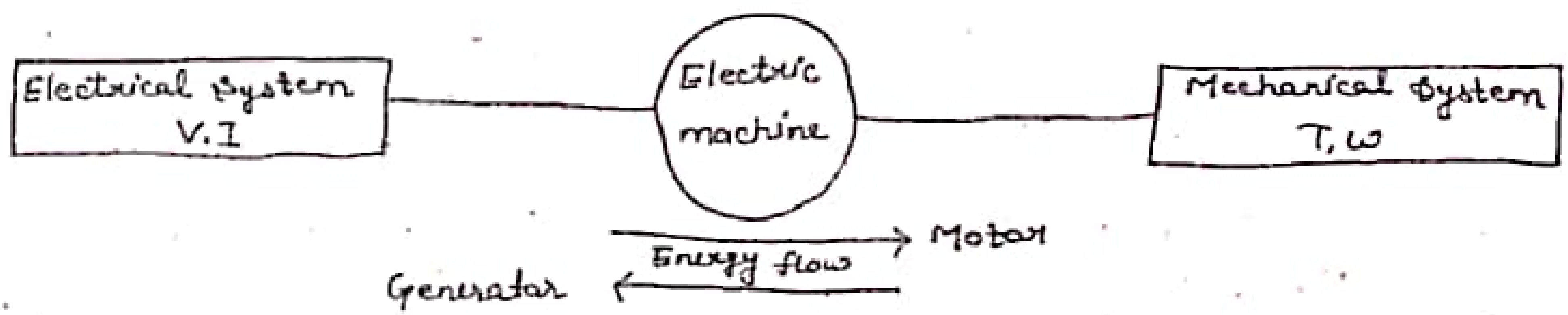
D.C. MACHINES

Quest: Explain the principle of Electromechanical Energy Conversion?

Ans: According the principle of conservation of energy, the energy can neither be created nor be destroyed but it can be transformed from one form to another. We daily use many devices that convert one form of energy into another form. For example, a heater converts electrical energy into heat energy while an electric bulb converts electrical Energy into light energy.

The conversion of electrical energy into mechanical energy or vice-versa is known as Electromechanical Energy Conversion.



Quest: What is D.C Machine? Explain the construction of D.C. Machine.

Ans: An electrical machine which convert mechanical Energy into Electrical Energy is called as Electrical generator.
While an electrical machine which convert electrical Energy into mechanical Energy is called as Electric motor.
Such electrical machines may be related to an Electrical Energy of an alternating type called a.c machines or may be related to an Electrical Energy of direct type called d.c machine.

"The first electromagnetic machine to be developed were d.c machine. D.C machine works on the principal of Faradays Law".

<u>Construction of D.C Machine</u>: The construction of d.c machine basically remain same whether it is a generator or a motor. Any d.c generator can be run as a d.c motor and vice-versa.

All d.c. machine have four principle components as shown in the block diagram.

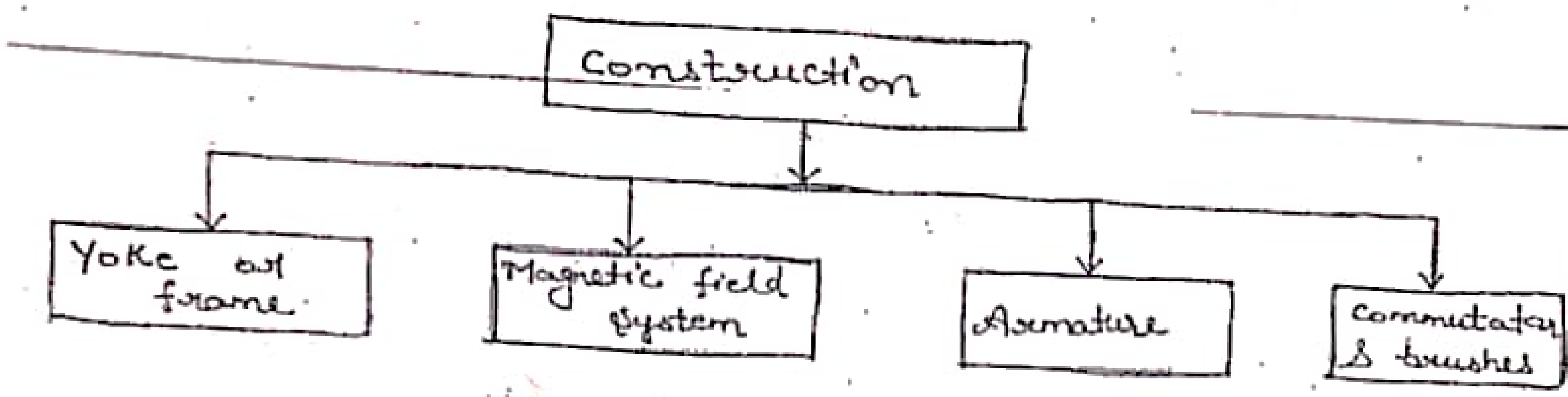
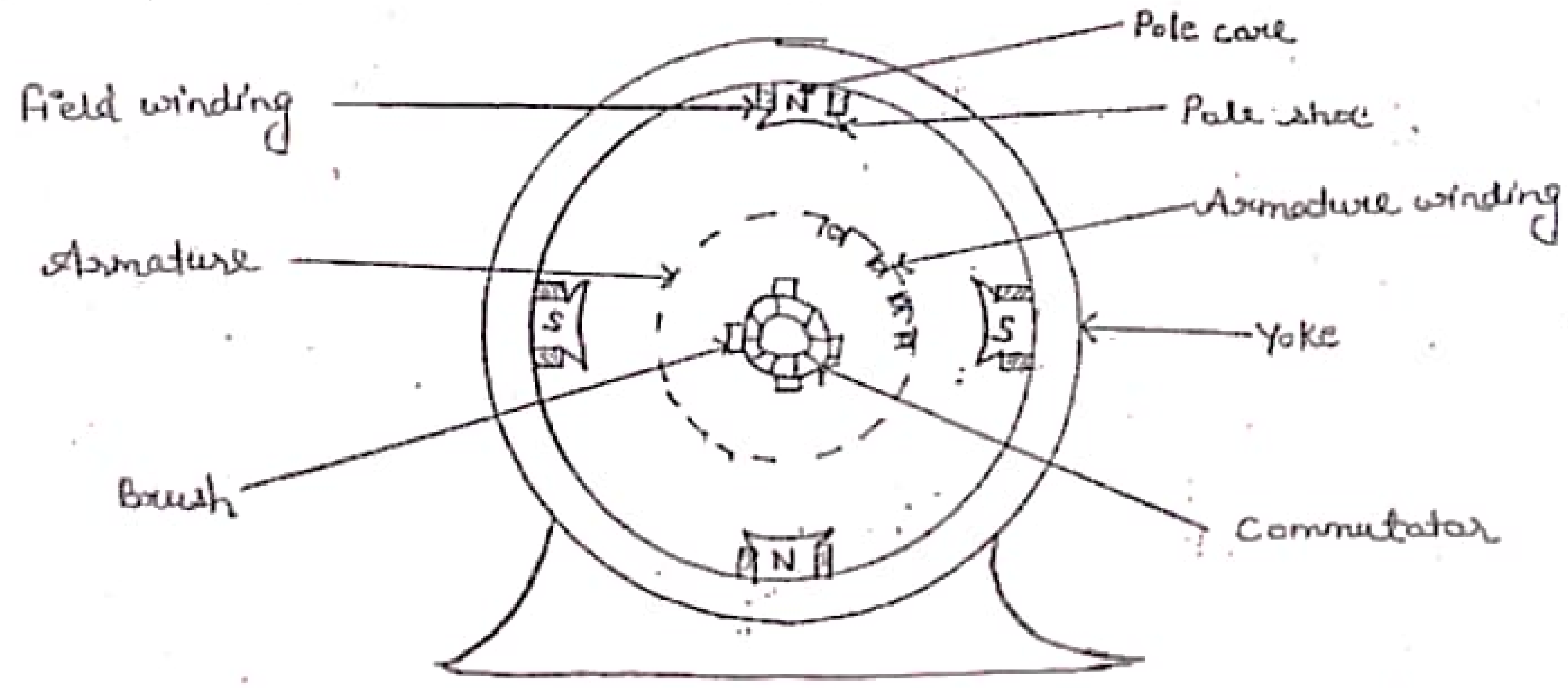


fig: Block diagram.

1) <u>Yoke or frame</u>: It is the outer cover of the d.c machine in which main poles are fixed. The insulating material get protected from harmful atmospheric element like moisture and dust.

a) It provides mechanical support to the inner parts of the machine.

b) It provide a low reluctance path for the flux.



2) <u>Magnetic Field System</u>: The magnetic field system is the stationary part of the machine. It produces the main magnetic flux in which the armature rotate.

The pole shoe serves two purposes:-

a) It support the field coil.

b) It increases the cross section area of the magnetic circuit.

3) <u>Armature</u>: The rotating part of d.c machine is called armature. The purpose of armature is to rotate the conductor in the uniform magnetic field. The armature core has slots on its outer surface. The conductor are placed on slots and known as Armature winding.

a) LAP winding, $A=P$, where $A=$ No. of parallel path.

b) Wave winding, $A=2$, $P=$ No. of poles.

1) LAP winding is employed for high current and low voltage rating machine.

2) Wave winding is employed for low current and high voltage rating machine.

4) <u>Commutator & Brushes</u>: The basic nature of emf induced in the armature conductor is alternating. A commutator is a mechanical rectifier which converts the alternating voltage into direct voltage. Brushes are stationary and resting on the surface of the commutator. The current is collected from the armature winding by means of two or more carbon brushes.

Ques: Derive E.M.F. equation of D.C Generator.

Ans: We shall now derive an expression for the emf generated in a d.c. generator.

Let,

$\phi =$ Magnetic flux/ pole in weber

$P =$ No. of poles

$N =$ Speed of armature in r.p.m.

$Z =$ Total number of armature conductor

$A =$ No. of parallel paths in which Z number of conductor are divided

$E_g =$ Emf of generator $=$ emf / parallel path.

Now emf gets induced in the conductor according to Faradays Law of electromagnetic induction, e = Rate of cutting the flux

Magnetic flux cut by one conductor in one revolution of the armature is
$d\phi = P\phi$ webers.

Time taken to complete one revolution is $dt = 60/N$ second.

$\therefore$ emf ~~generated / conductor~~ $= \frac{d\phi}{dt} = \frac{P\phi}{\frac{60}{N}} = \frac{P\phi N}{60}$ = volts.

Emf of generator, E_g = emf per parallel path.

= (emf/conductor) X no of conductor in series per parallel path.

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

V. Imp $\boxed{E_g = \frac{P\phi ZN}{60A}}$

LAP winding, $A = P, E_g = \frac{\phi NZ}{60}$

Wave winding, $A = 2, E_g = \frac{\phi PNZ}{120}$

Ques: Explain the types of D.C. Generator.

Ans: D.C. generator is classified into two categories as -

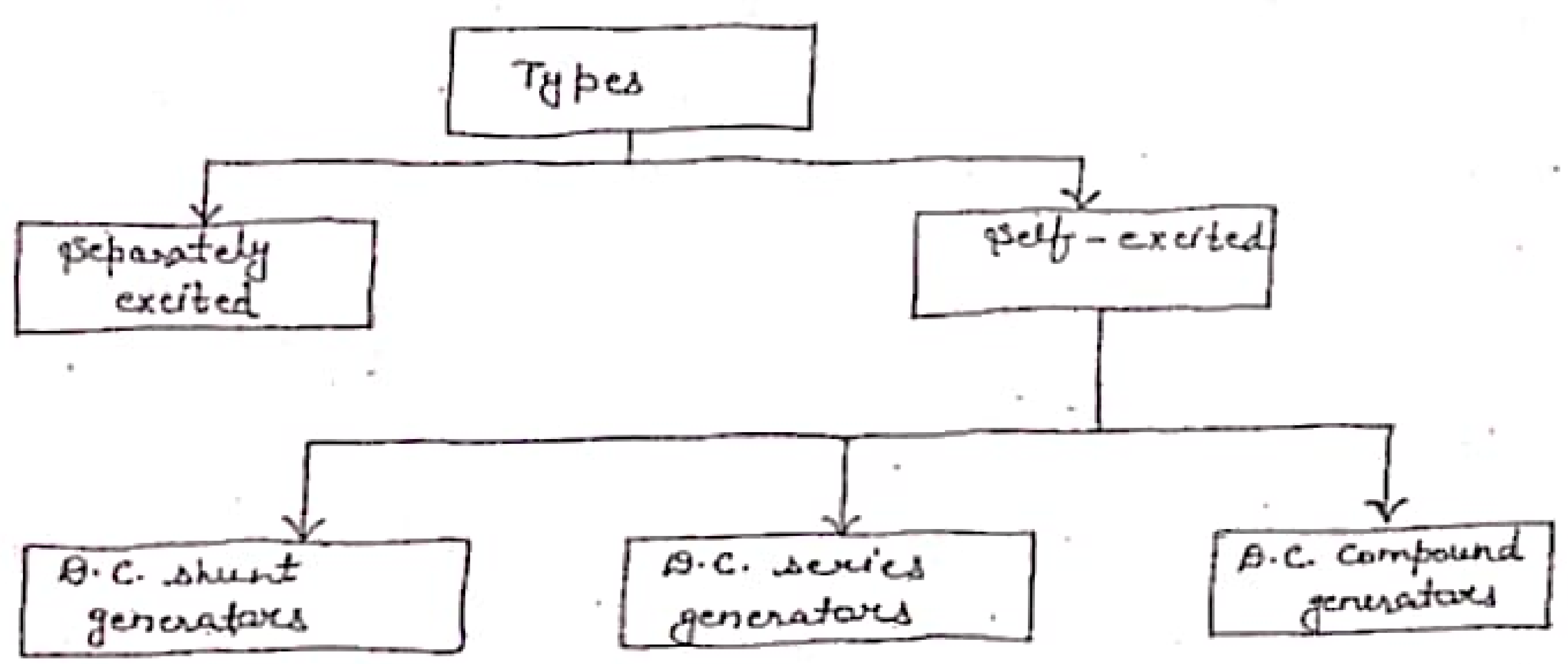


fig: Block diagram.

1. Separately Excited D.C. Generator:

The separately excited d.c. generator are rarely used in practice because they need an additional d.c. source.

A d.c. generator whose field winding is excited from an independent external d.c. source is called separately excited d.c. generator.

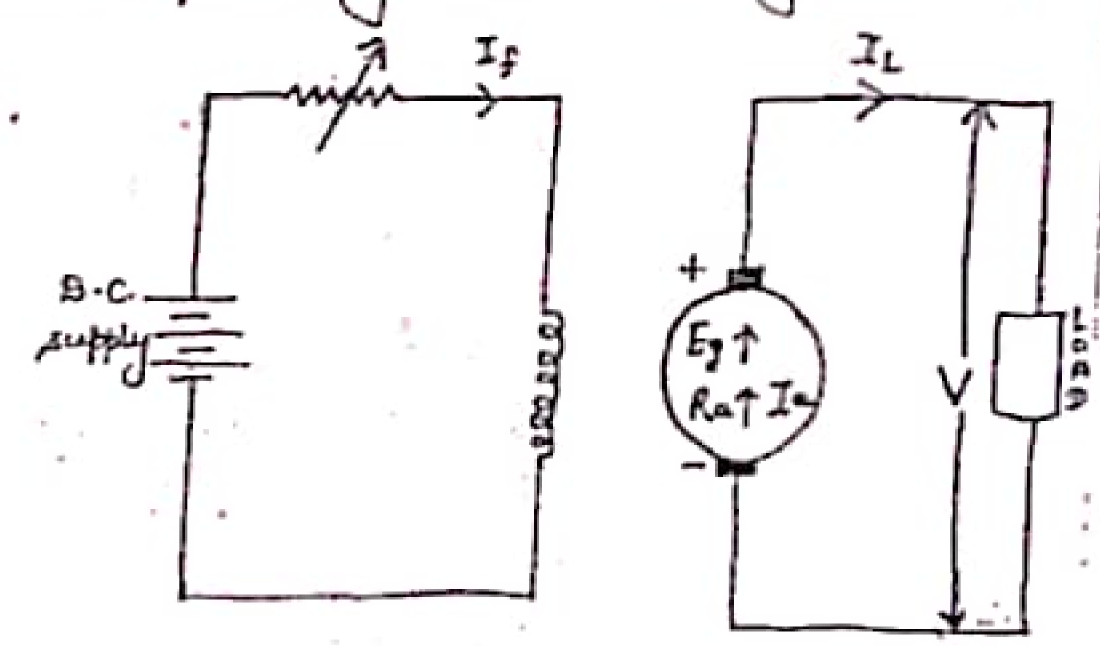
current, voltage and power relation.

a) Armature current, $I_a = I_L$

b) Terminal voltage,
$V = E_g - I_a R_a$ − brush drop.

c) Electric power developed $= E_g I_a$

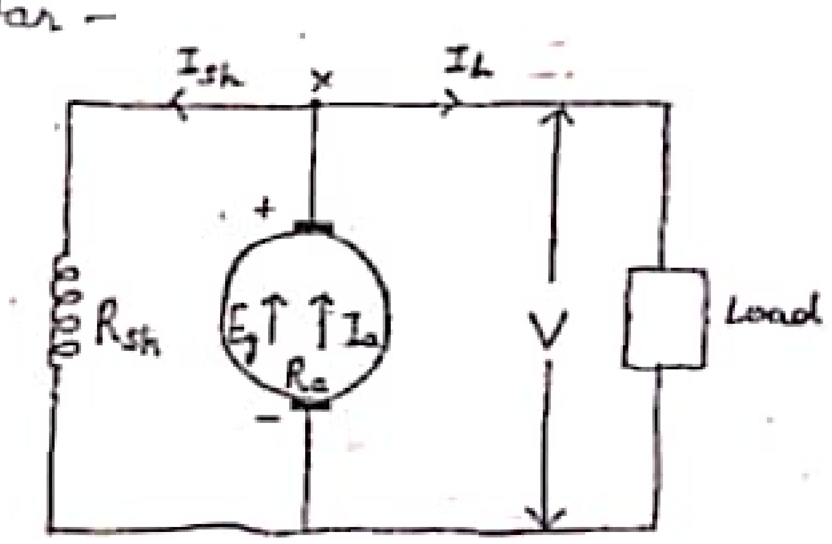
d) Power delivered to load $= V I_a$



2. Self Excited D.C. Generator:

The field winding are excited by the current produced by the generator itself. The field winding of self excited d.c. generator is not excited by any external energy source.

(i) D.C. Shunt Generator:- In d.c. shunt generator, the field winding is connected in parallel with the armature winding. The connection of d.c. shunt generator -



Current, voltage and power relation.

a) Armature current, $I_a = I_L + I_{sh}$ (using KCL at point x)

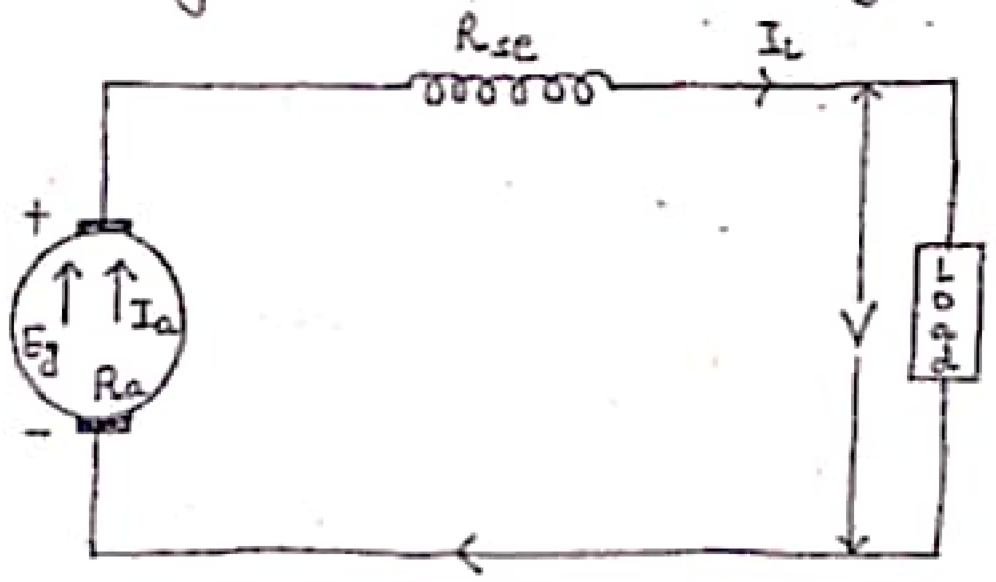
b) Shunt field current, $I_{sh} = V/R_{sh}$ (using KVL)

c) Terminal voltage, $V = E_g - I_a R_a$ − brush drop if exist.

d) Power developed in Armature = $E_g I_a$

e) Power delivered to load $= VI_L$

(ii) <u>D.C. Series Generator</u> :- In series generator, the field winding is connected in series with armature winding ~~so that whole armature~~ current flows through the field winding as well as load.



current, voltage and power relation.

(a) Armature current, $I_a = I_{se} = I_L = I$ (say)

(b) Terminal voltage, $V = E_g - I(R_a + R_{se})$

(c) Power developed in armature $= E_g I_a$

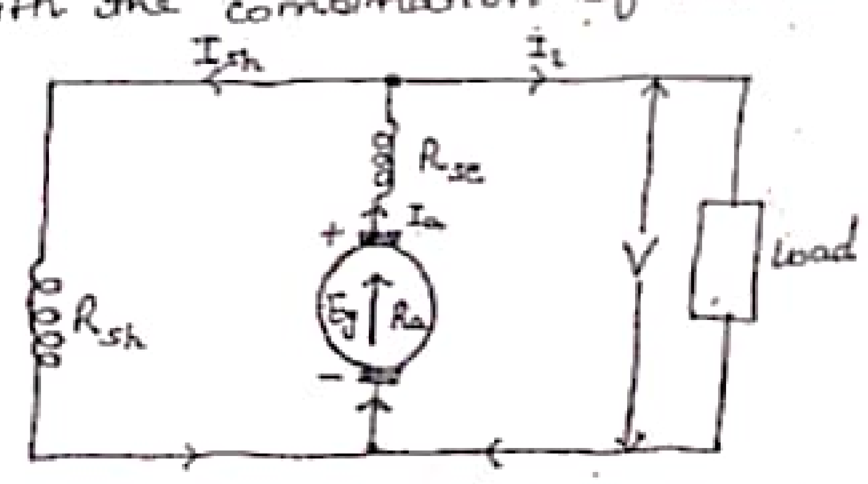
(d) Power delivered to load $= VI_a$ or VI_L $\quad [\because I_a = I_L]$

(iii) <u>D.C. Compound Generator</u> :- In d.c. compound generator, the part of field winding is connected in parallel with armature and in series with the armature.

(a) Long shunt compound Generator

(b) Short shunt compound Generator.

(a) <u>Long Shunt Compound Generator</u>: The shunt field winding is connected in parallel with the combination of both armature and series field winding.



current, Voltage and Power relation.

a) Series field current $I_{se} = I_a = I_L + I_{sh}$; Shunt field current $I_{sh} = V/R_{sh}$

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

c) Power developed in armature $= E_g I_a$

d) Power delivered to load $= VI_L$

(b) <u>Short Shunt Compound Generator</u>: In this generator, the shunt field winding is connected in parallel with the armature only.

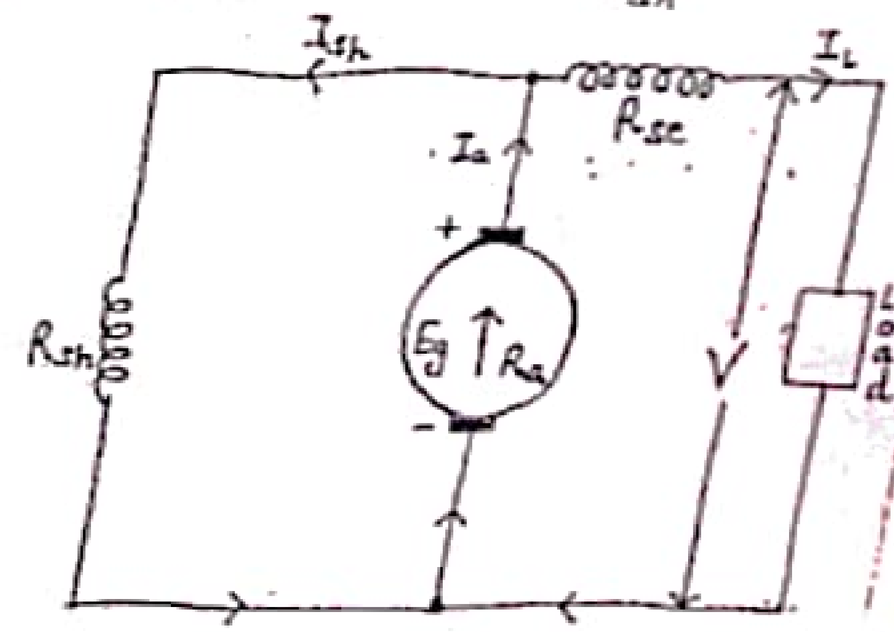
current, voltage and power relation.

a) Series field current, $I_{se} = I_L$; shunt field current, $I_{sh} = \dfrac{V + I_{se}R_{se}}{R_{sh}}$

b) Terminal voltage, $V = E_g - I_a R_a - I_{se} R_{se}$

c) Power developed in armature $= E_g I_a$

d) Power delivered to load $= VI_L$



Solved Examples on d.c Generator

Ques: An 8 pole d.c. Generator running at 1200 rpm and with a flux of 25 mWb/pole generates 440V. Calculate no. of conductors.

Sol: Given,

No. of poles, $P = 8$

Speed, $N = 1200$ rpm

flux, $\phi = 25\,mWb = 0.025\,Wb$

Generated emf, $E_g = 440\,V$

Step 1: When armature is LAP ~~wound~~ wound then no. of parallel paths, $A = P = 8$

we know that, $\quad E_g = \dfrac{NP\phi Z}{60A}$

$\therefore$ no of conductor required, $Z = \dfrac{E_g \times 60 \times A}{\phi N P}$

$$= \frac{440 \times 60 \times 8}{0.025 \times 1200 \times 8} = 880$$

so, $\boxed{Z = 880 \text{ conductors.}}$

Step 2: When armature is wave wound then
No. of parallel paths, $A = 2$

$\therefore$ No of conductor required, $Z = \dfrac{E_g \times 60 \times A}{\phi N P}$

$$= \frac{440 \times 60 \times 2}{0.025 \times 1200 \times 8} = 220$$

so, $\boxed{Z = 220 \text{ conductor.}}$

Ques: A 4 pole LAP wound armature has 144 slots with two coils sides per slot, each coil having two turns. If the flux per pole is 20 mWb and armature rotates at 720 rpm. What is the induced voltage?

Sol: Given,
Number of poles, $P = 4$
Flux per pole, $\phi = 20 \text{ mWb} = 20 \times 10^{-3}$ wb
Number of parallel path, $A = 4$ [$\because$ LAP wound $A = P = 4$]
Speed, $N = 720$ rpm

Step 1: The total no of conductor (Z) is given by
Z = No. of slots × no. of coil side per slot × no. of turns in each coil
$= 144 \times 2 \times 2 = 576.$

$\boxed{Z = 576.}$

Step 2: Here induced emf means generated emf, so it is given by

$$E = \frac{NP\phi Z}{60A} = \frac{720 \times 4 \times 20 \times 10^{-3} \times 576}{60 \times 4} = 138.24$$

$\boxed{E = 138.24 \text{ Volts}}$

Ques: A D.C. Generator has an armature emf of 100 V when the useful flux per pole is 20 mWb and the speed is 800 rpm. Calculate the generated emf
(i) With the same flux and a speed of 1000 rpm.
(ii) With a flux per pole of 24 mWb and a speed of 900 rpm.

Sol: Given,
$E_{g1} = 100V$
$\phi = 20 \text{ mWb}$,
$N_1 = 800$ rpm

Step 1: In first case, E_{g2} is calculated as: $E_g \propto \phi N$
We know that $N_2 = 1000$ r.p.m in first case so,

$\therefore \dfrac{E_{g1}}{E_{g2}} = \dfrac{\phi_1}{\phi_2} \times \dfrac{N_1}{N_2}$ but $\phi_1 = \phi_2$

$\therefore \dfrac{100}{E_{g2}} = \dfrac{800}{1000}$

$\therefore \boxed{E_{g2} = 125 \text{ V}}$

Step 2: In second case, E_{g2} is calculated as:
$\phi_2 = 24 \text{ mWb}$, $N_2 = 900$ rpm (given)

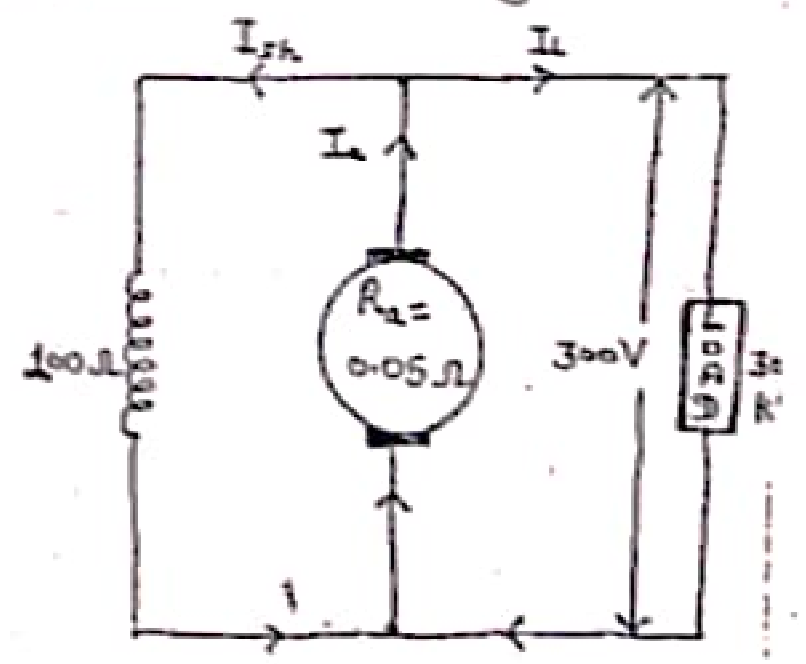
$$\frac{100}{E_{g2}} = \frac{20 \times 10^{-3}}{24 \times 10^{-3}} \times \frac{800}{900}$$

$\therefore \boxed{E_{g2} = 135 \text{ V}}$

V.V. Imp

Ques: A 30 kW, 300 V dc shunt generator has armature and field resistance 0.05 Ω and 100 Ω respectively. Calculate the total power developed by the armature when it delivers full load output.

Sol: Given,
$P = 30 \text{ kW} = 30 \times 10^3$ W
$V = 300$ volt
Armature resistance $R_a = 0.05\Omega$
Field resistance $R_{sh} = 100\Omega$



Step 1: We know that, $P = V I_L$

or $$I_L = \frac{P}{V}$$

$$\therefore \quad I_L = \frac{30\times10^3}{300} = 100\,A$$

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

$$\therefore \quad I_{sh} = \frac{300}{100} = 3\,A$$

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

$= 100 + 3$

$I_a = 103\,A$

Step 2: The emf generated is given by

$$E_g = V + I_a R_a$$

$$E_g = 300 + 103\times0.05$$

$$E_g = 305.15V$$

Step 3: The power developed by armature is given by

Power developed by armature $= E_g I_a$

$= 305.15\times103$

$= 31.43\times10^3\,W$

$= 31.43\,kW.$

Ques: What will be change in emf induced in flux is reduced by 20% and the speed is increased by 20% in case of a d.c. generator.

Sol: Step 1: We know that, for a d.c. generator,

$$E_g \propto N\phi$$

Step 2: If speed is increased by 20% then

$$N_2 = N_1 + 20\%\text{ of } N_1$$

$$\therefore \quad N_2 = N_1 + 0.2N_1$$

$$\boxed{N_2 = 1.2N_1}$$

Step 3: If flux is reduced by 20% then

$$\phi_2 = \phi_1 - 20\%\text{ of }\phi_1$$

$$\phi_2 = \phi_1 - 0.2\phi$$

$$\boxed{\phi_2 = 0.8\phi_1}$$

Step 4: The ratio of E_{g1} and E_{g2} find out by

$$\frac{E_{g1}}{E_{g2}} = \frac{N_1}{N_2}\times\frac{\phi_1}{\phi_2} = \frac{1}{1.2}\times\frac{1}{0.8} = 1.041$$

$$\therefore \quad E_{g2} = 0.96\,E_{g1}$$

So the emf will change to 96% of the original value.

D.C. MOTOR

Ques: Explain the principle of operation of a d.c. motor?

Ans: " When a current carrying conductor is placed in a magnetic field; it experiences a mechanical force and hence the conductor moves in the direction of force."

As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductors acts as a twisting or turning force on the armature which is called a torque.

The direction of the force is given by Fleming's left hand rule. The magnitude of force is given by the relation.

$$\boxed{F = BIL \text{ newton}}$$

Where,

B = flux density in wb/m^2

I = current flowing through the conductor in ampere.

L = Length of the conductor in meter.

Ques: Explain the back emf in D.C. Motor?

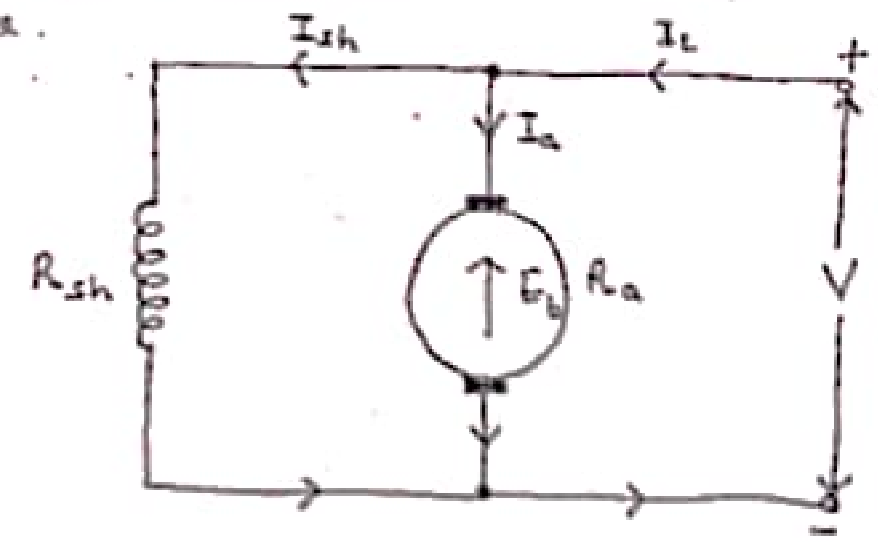
Ans: When the motor armature rotates, its conductor cut the magnetic flux. Therefore the emf is induced in them. In case of motor, the emf of rotation is known as Back emf or Counter emf. According to Lenz law, the back emf opposes the applied voltage.

$$\boxed{E_b = \frac{NP\phi Z}{60A}}$$

This emf always opposes the supply voltage, hence it is called back emf.

Ques: Write down the voltage equation of D.C. Motor.

Ans: Let in d.c. motor as shown in figure.



V = applied voltage

E_b = back emf

I_a = Armature current

R_a = Armature resistance.

$$I_a = \frac{V - E_b}{R_a}$$

or $\quad V = E_b + I_a R_a$

This is known as voltage equation or fundamental equation of d.c. motor.

Ques: Write down the power equation of D.C. Motor.

Ans: The voltage equation of a d.c. motor is given by:

$$V = E_b + I_a R_a$$

Multiplying both sides of above equation by I_a we get

$$\boxed{VI_a = E_b I_a + I_a^2 R_a}$$

This equation is called power equation of a d.c motor.

VI_a = Electric power supplied to armature (Armature input)

$E_b I_a$ = Power developed (Mechanical power) by armature (Armature output).

$I_a^2 R_a$ = Electric power wasted in armature (armature copper loss).

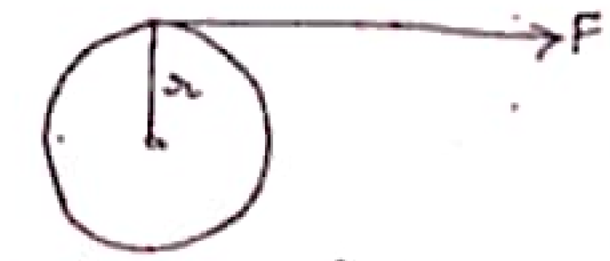
Thus from the armature input, a small portion is wasted as $I_a^2 R_a$ loss and the remaining portion $E_b I_a$ is converted into mechanical power within the armature.

Ques: Derive the Torque equation of D.C. Motor.

Ans: It is measured by the product of the force (F) and the radius (r) at which this force acts i.e;

$$\boxed{T = F \times r}$$

Let the armature is rotating at a speed of N rpm as shown in figure.



The angular speed of the armature is:

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

So, workdone in one revolution is:

W = F X distance travelled in one revolution

$W = F \times 2\pi r$

and, P = power developed = $\frac{\text{workdone}}{\text{time}}$

$$\frac{F \times 2\pi r}{\text{time for 1 rev.}} = \frac{F \times 2\pi r}{\frac{60}{N}} = (F \times r) \times \left(\frac{2\pi N}{60}\right)$$

$$\therefore \quad \boxed{P = T \times \omega \text{ watts}}$$

where,

T = torque in N-m

ω = angular speed in rad/sec.

Power in Armature = Armature torque X ω

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

but E_b in a motor is given by,

$$E_b = \frac{NP\phi Z}{60A}$$

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

$$\therefore \quad T_a = \frac{1}{2\pi} \phi I_a \times \frac{PZ}{A}$$

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

Since Z, P and A are fixed for a given machine.

$$\therefore \quad \boxed{T_a \propto \phi I_a}$$

Hence torque in a d.c. motor is directly proportional to flux per pole and armature current.

1. For a shunt motor, flux ϕ is practically constant :

$$\boxed{T_a \propto I_a}$$

2. For a series motor, flux ϕ is directly proportional to armature current.

$$\boxed{T_a \propto I_a^2}$$

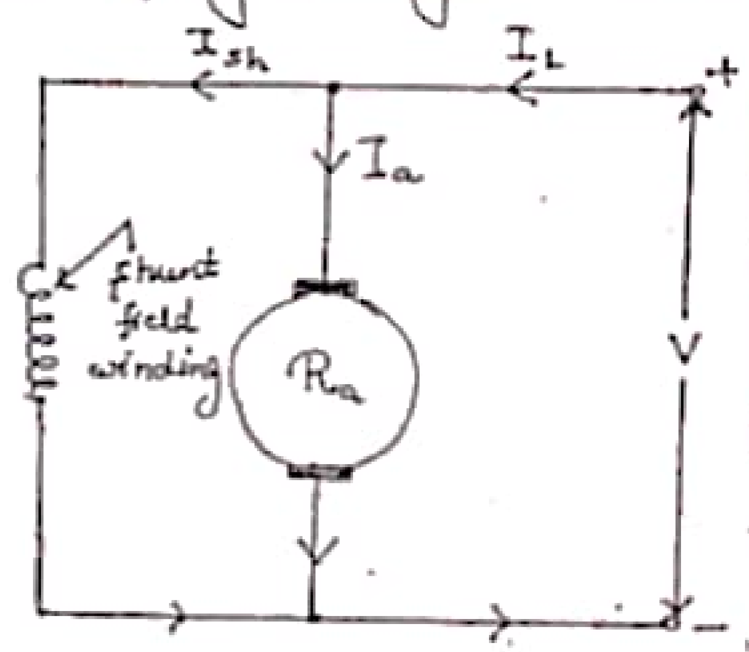
Ques: What is the types of D.C. Motor?

Ans: The different types of D.C. motors are :

1) D.C. shunt Motor
2) D.C. Series Motor
3) D.C. compound Motor.

1) D.C. Shunt Motor :

In this type, the field winding is connected across the armature winding and the combination is connected across the supply voltage as shown in the figure.



Current, Voltage and Power Relation

(a) $I_L = I_a + I_{sh}$

(b) $I_{sh} = \frac{V}{R_{sh}}$

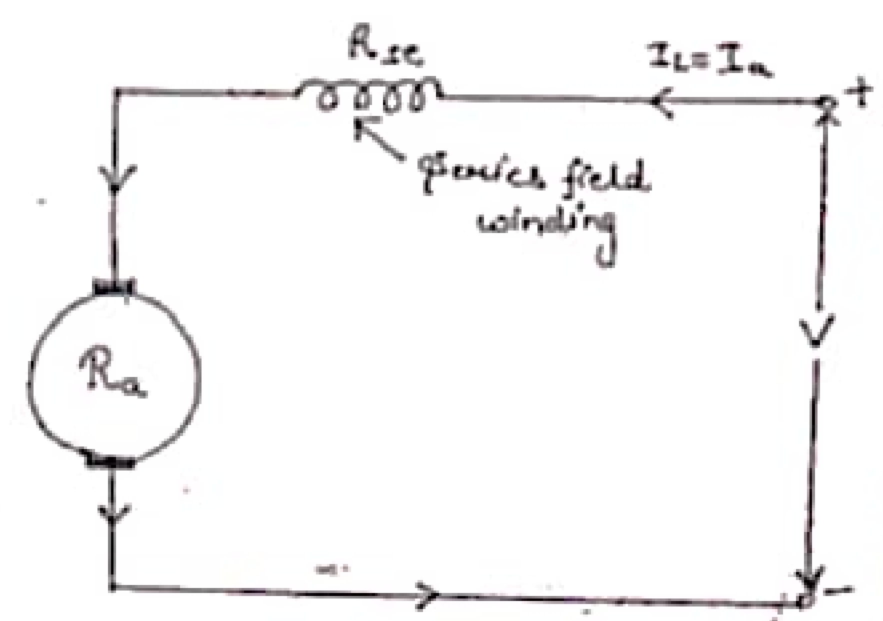
(c) Back emf , $E_b = V - I_a R_a$

(d) Power drawn from supply $= VI_L$

(e) Mechanical power developed $= E_b I_a$

2) D.C. Series Motor :

In this type of motor, the field winding is connected in series with the armature as shown in the figure.



Current. Voltage and Power Relation.

(a) $I_a = I_L = I_{se}$

(b) $E_b = V - I(R_a + R_{se})$

(c) Power drawn from supply $= VI_L$

(d) Mechanical power developed $= E_b I_a$

3) D.C. Compound Motor : The D.C. compound ... field winding connected in series and part of the field winding is in parallel with armature.

Ques: Explain Torque and speed equation of D.C. Motor.

Ans: We know that,

$$T \propto \phi I_a . \quad \text{from torque equation.}$$

Now flux ϕ is produced by the field winding and is proportional to the current passing through the field winding.

$$\phi \propto I_{field}$$

For a d.c. series motor, I_{se} is same as I_a. Hence flux ϕ is proportional to the armature current I_a

$$T \propto I_a \phi \propto I_a^2 \quad \text{(for series motor)}$$

For a d.c. shunt motor, I_{sh} is constant as long as supply voltage is constant. Hence flux ϕ is also constant.

$$T \propto I_a \quad \text{(for shunt motors)}$$

Similarly as $E_b = \frac{NP\phi Z}{60A}$, we can write the speed equation.

$$E_b \propto \phi N$$

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

Therefore, in a d.c. motor, speed N is directly proportional to back emf E_b and inversely proportional to flux per pole ϕ.

But $\quad V = E_b + I_a R_a$

$\therefore \quad E_b = V - I_a R_a$

$\therefore$ Speed equation becomes,

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

So for shunt motor as flux ϕ is constant.

$$\therefore \quad N \propto V - I_a R_a$$

While for series motor, flux ϕ is proportional to I_a

$$\boxed{N \propto \frac{V - I_a R_a - I_a R_{se}}{I_a}}$$

Ques: Draw the characteristics of D.C. Motor.

Ans: There are three types of characteristics of d.c. motor.

1) <u>Torque and Armature current characteristic (T_a/I_a)</u>:
It is the curve between armature torque T_a and armature current I_a of a d.c. motor. It is also known as electrical characteristic of the motor.

2) <u>Speed and armature current characteristics (N/I_a)</u>:
It is the curve between speed N and armature current I_a of a d.c. motor.

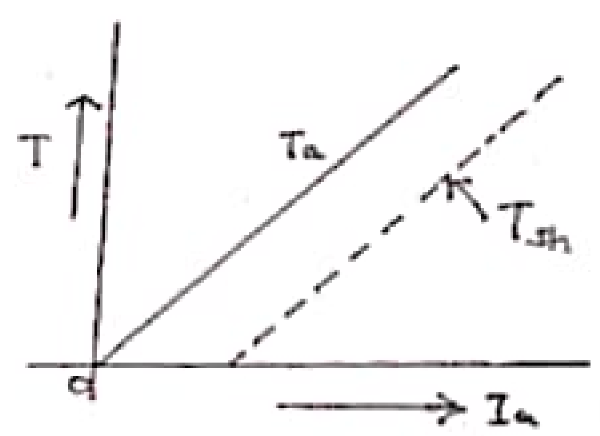
3) <u>Speed and torque characteristics (N/T_a)</u>:
It is the curve between speed N and armature torque T_a of a d.c. motor. It is also known as Mechanical Characteristic.

<u>Characteristics Of D.C. Shunt Motor</u> :-

1) Torque-Armature current characteristic: We know that in a d.c. motor. $T_a \propto \phi I_a$

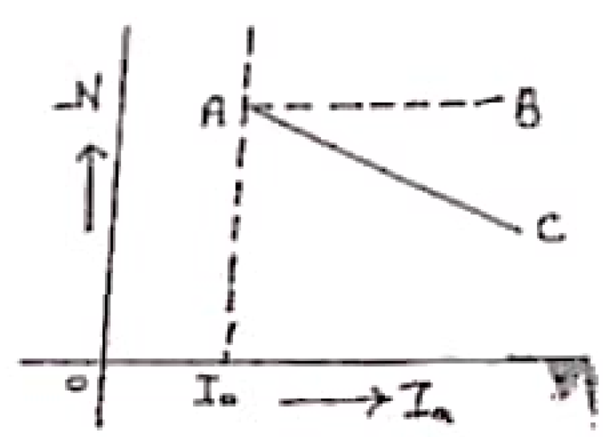
Since the motor is operating from a constant supply voltage, flux ϕ is constant

$\therefore \quad T_a \propto I_a$

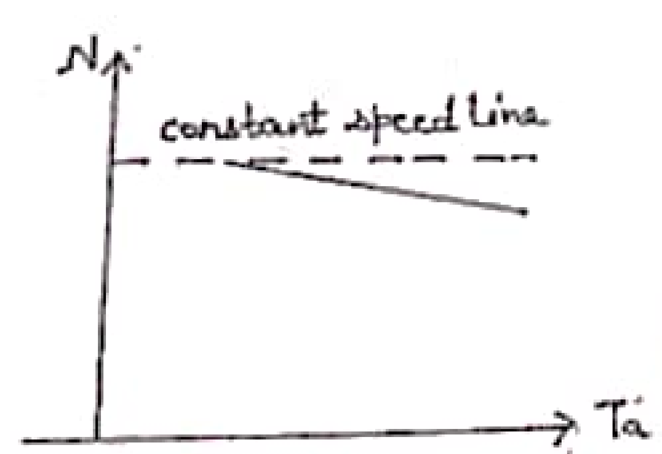


2) Speed-Armature current characteristic: The speed N of a motor is given by $N \propto \frac{E_b}{\phi}$

The flux ϕ and back ~~emf~~ emf in shunt motor are almost constant under normal condition.



3) Speed Torque characteristic:
These characteristic can be derived from the above two characteristics. This curve is similar to speed-armature current characteristics as torque is proportional to the armature current.

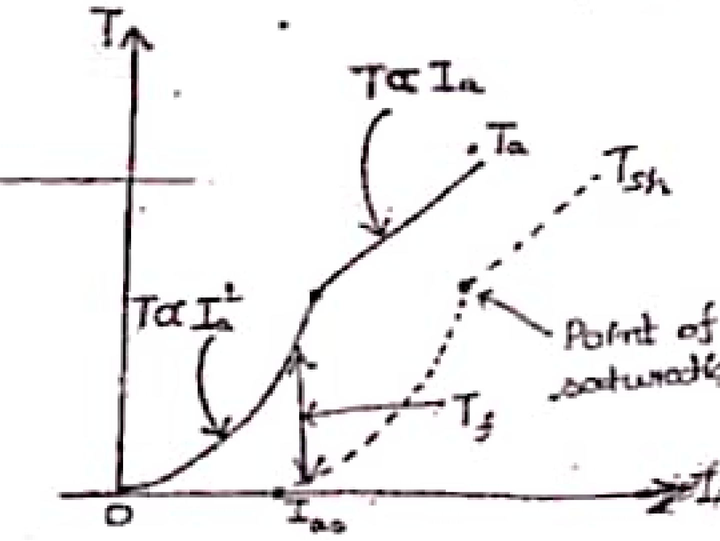


<u>Characteristics Of D.C. Series Motor</u> :

1) Torque-Armature current characteristic:
Flux produced is proportional to the armature current.

$\therefore \quad \phi \propto I_a$

Hence $T_a \propto \phi I_a \propto I_a^2$

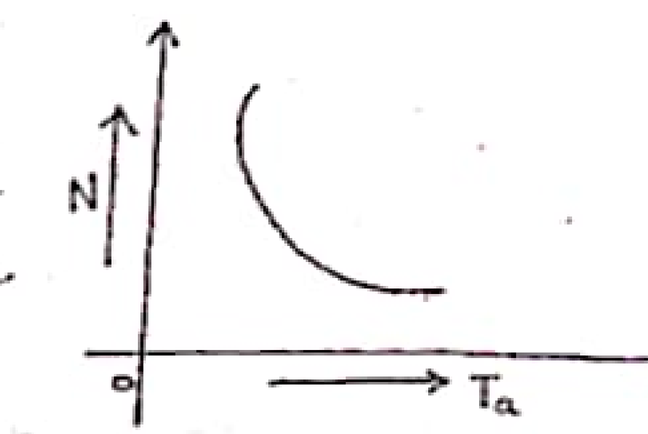


2) Speed and armature current characteristics: The speed N of series motor is given by $N \propto \frac{E_b}{\phi}$ where $E_b = V - I_a(R_a + R_{se})$

or $N \propto \frac{V - I_a(R_a + R_{se})}{\phi}$

when armature current is low then the voltage drop $I_a(R_a + R_{se})$ is very small or almost negligible. The speed of a d.c. motor is

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



We know that in a d.c. motor, $\phi \propto I_a$. Hence equation (1) is now becomes

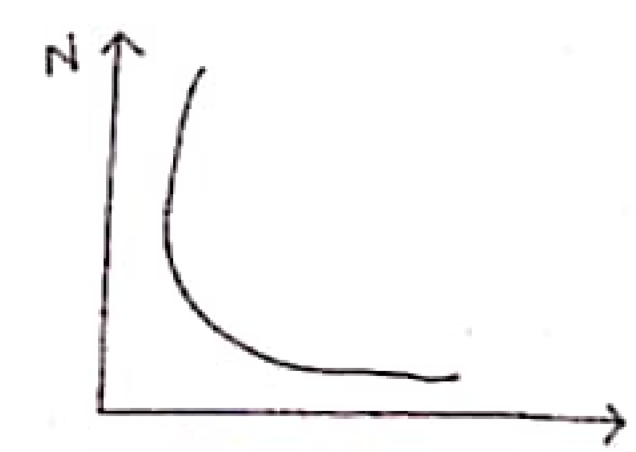
$N \propto \frac{1}{I_a}$

3) Speed-torque characteristics: In case of series motors,

$T \propto I_a^2$ and $N \propto \frac{1}{I_a}$

Hence we can write,

$N \propto \frac{1}{\sqrt{T}}$



Ques: Why series motor is never started on No Load?

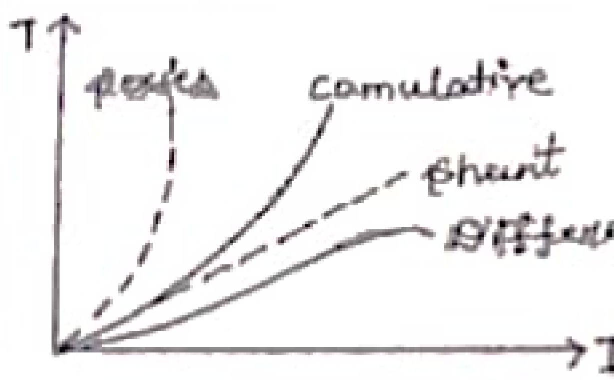
Ans: In case of a d.c. series motor, $\phi \propto I_a$ and no load as I_a is small hence flux produced is also very small. According to speed equations,

$N \propto \frac{1}{\phi}$ as E_b is almost constant.

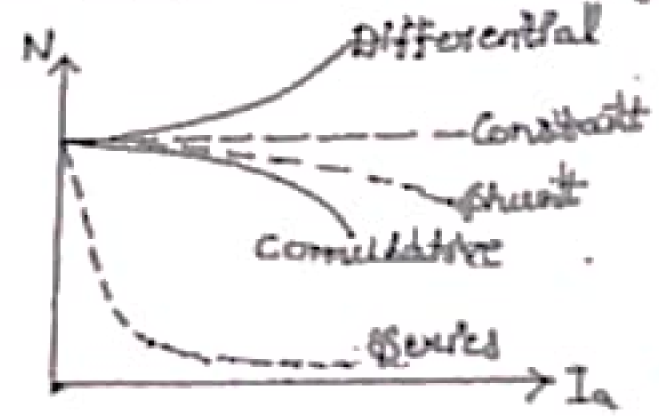
So on very light load or no-load as flux is very small, the motor tries to run at dangerously high speed which may damage the motor mechanically. This is the reason why series motor should never be started on light or no load.

Ques: Write down the characteristics of D.C Compound Motor.

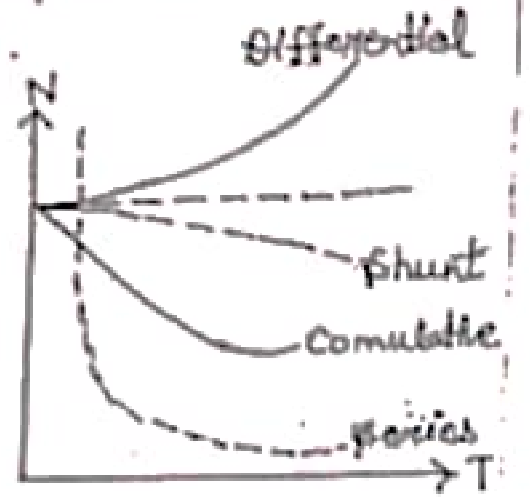
Ans: The various characteristics of both the types of compound motors cumulative and the differential are shown in the figure.



(a) T Vs I_a



(b) N Vs I_a



(c) N Vs T

Ques: Explain the Application of D.C Motors

Ans:

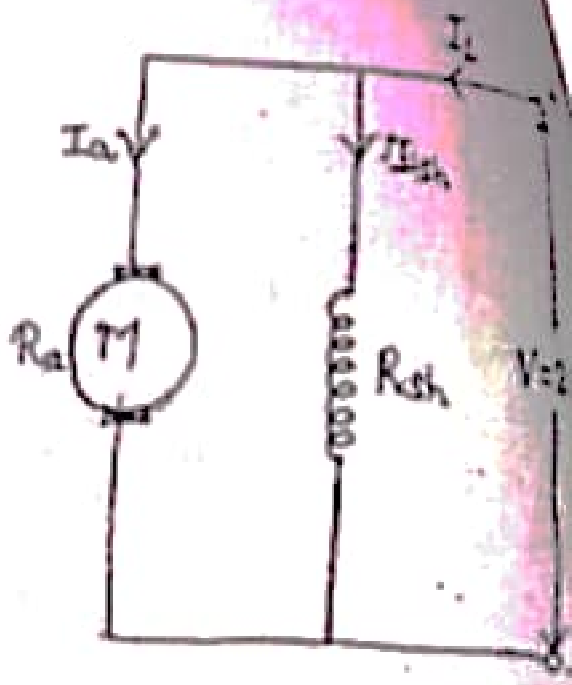
Type of motor	Characteristics	Applications.
Shunt	Speed is fairly constant and medium starting torque.	1. Blowers and fans 2. Centrifugal and reciprocating pumps 3. Lathe machines 4. Machine tool 5. Milling machine 6. Drilling machine.
Series	High starting torque. No load condition is dangerous. Variable speed.	1. Cranes 2. Hoists, Elevators 3. Trolleys 4. Conveyors 5. Electric locomotives.
Cumulative compound	High starting torque. No load condition is allowed	1. Rolling mills 2. Punches 3. Shears 4. Heavy planers 5. Elevators
Differential compound	Speed increases as load increases.	No suitable for any practical application

Ques:- A 250 V, d.c. shunt motor takes a line current of 20 A. Resistance of shunt field winding is 200 Ω and resistance of the armature is ... Find the armature current and the back e.m.f.

Sol:- Given,

Voltage, $V = 250V$, $I_L = 20A$, $R_a = 0.3\Omega$, $R_{sh} = 200\Omega$, $I_L = I_a + I_{sh}$

Step 1: Calculate the Armature current (I_a)



$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{200} = 1.25 \text{ A}$$

$$I_a = I_L - I_{sh}$$
$$= 20 - 1.25$$
$$I_a = 18.75 \text{ A}$$

Step 2: Now we can calculate the back emf (E_b)

$$E_b = V - I_a R_a$$
$$= 250 - 18.75 \times 0.3$$
$$E_b = 244.375 \text{ V}$$

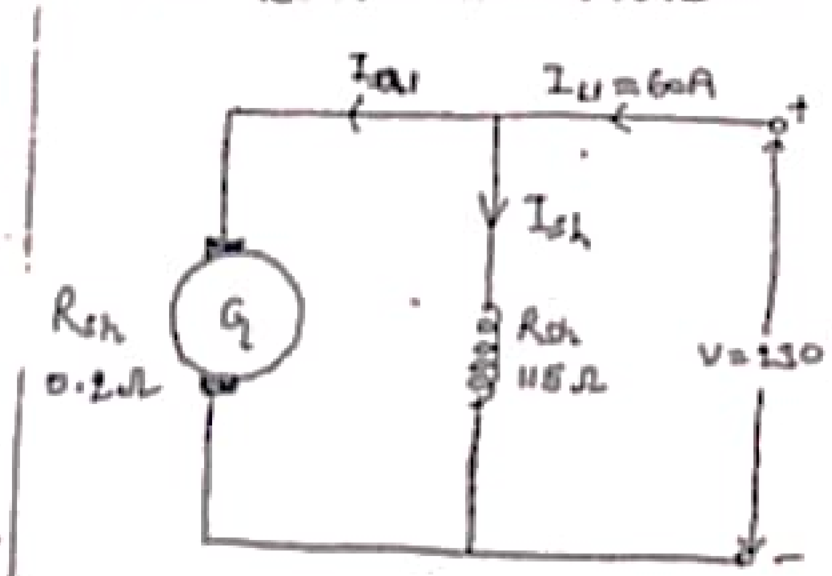
So, Back emf(E_b) = 244.375 V and Armature current = 18.75 A

Ques:- A D.C. shunt motor runs at 600 r.p.m. taking 60 A from a 230 V supply. Armature resistance is 0.2 ohm and field resistance is 115 ohms. Find the speed when the current through the armature is 30 A.

Sol :- Given,

$N_1 = 600$ rpm, $I_L = 60A$, $V = 230$ Volts, $R_{sh} = 115\Omega$, $N_1 = 600$ rpm, $I_{a2} = 30$

Step 1: Draw the circuit diagram



$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{115} = 2A$

$I_{a1} = 60 - 2 = 58$ A

$E_{b1} = V - I_{a1}R_{a1}$ R_{sh}

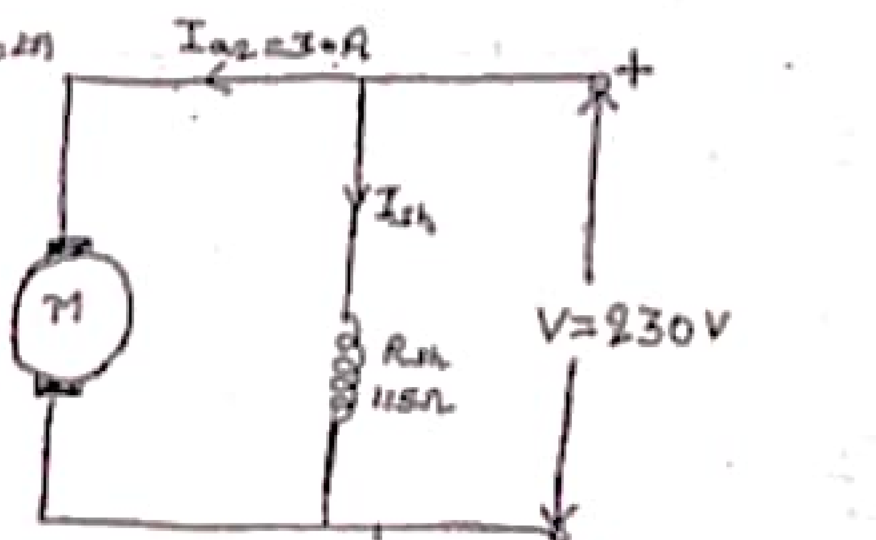
$= 230 - 58 \times 0.2\Omega$

$E_{b1} = 218.4$ V

$E_{b2} = V - I_{a2} R_a$

$= 230 - 30 \times 0.2$

$= 224$ V



$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \Rightarrow N_2 = 615.38$ rpm

Ques: A 6-pole lap wound shunt motor has 500 conductors in the armature. The resistance of armature path is $0.05\,\Omega$. The resistance of shunt field is $25\,\Omega$. Find the speed of the motor when it takes $120\,A$ from d.c. ~~motor~~ mains of $100\,V$ supply. Flux per pole is 2×10^{-2} Wb.

Sol: Given,

$P = A = 6,\ Z = 500,\ R_a = 0.05\,\Omega,\ R_{sh} = 25\,\Omega,\ V = 100\,V,\ I_L = 120\,A,\ \phi = 2\times10^{-2}\,Wb.$

Step 1: For finding back emf E_b, first we find I_{sh} and I_a

$$I_{sh} = \frac{V}{R_{sh}} = \frac{100}{25} = 4A$$

$$I_a = I_L - I_{sh} = 120 - 4 = 116\,A. \qquad [\because I_L = I_{sh} + I_a]$$

Step 2: The back emf is given by.

$$E_b = V - I_aR_a = 100 - 116\times0.05 = 94.2\,V$$

Step 3: We know that,

$$E_b = \frac{NP\phi Z}{60A}$$

$$N = \frac{E_b \times 60A}{P\phi Z} = \frac{94.2\times60\times6}{6\times2\times10^{-2}\times500} = 565\ rpm$$

$$\therefore \boxed{N = 565\ rpm.}$$

INDUCTION MOTORS

Ques: Explain the construction of a three phase induction motor?

Ans: A three phase induction motor consist of two main parts as shown in the block diagram.

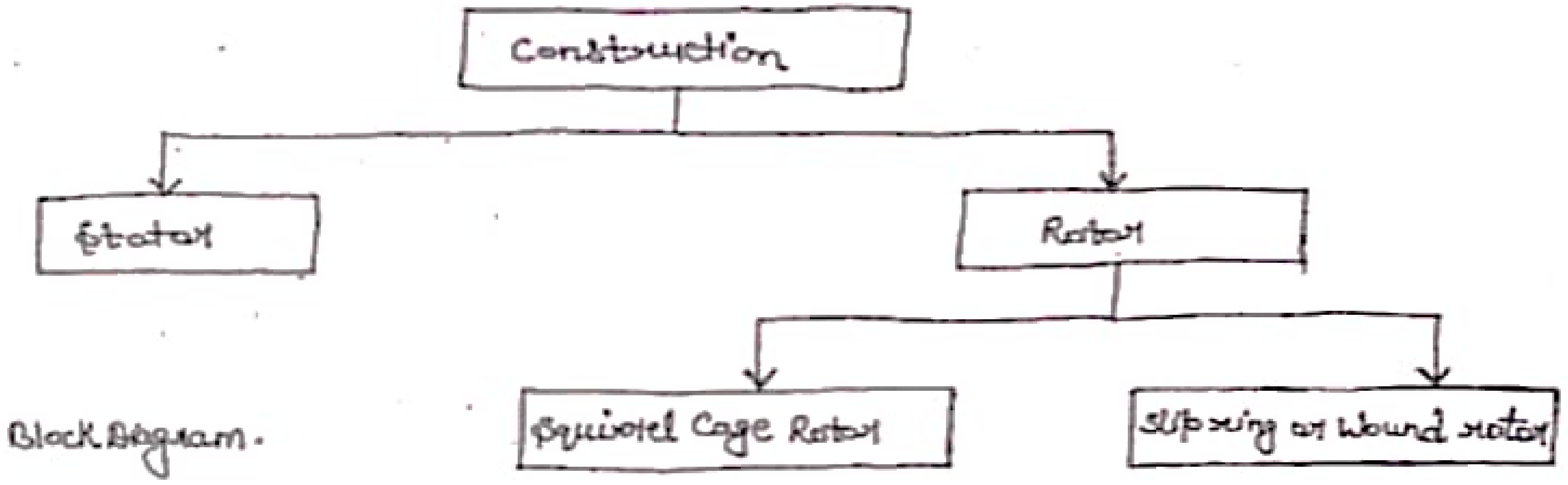
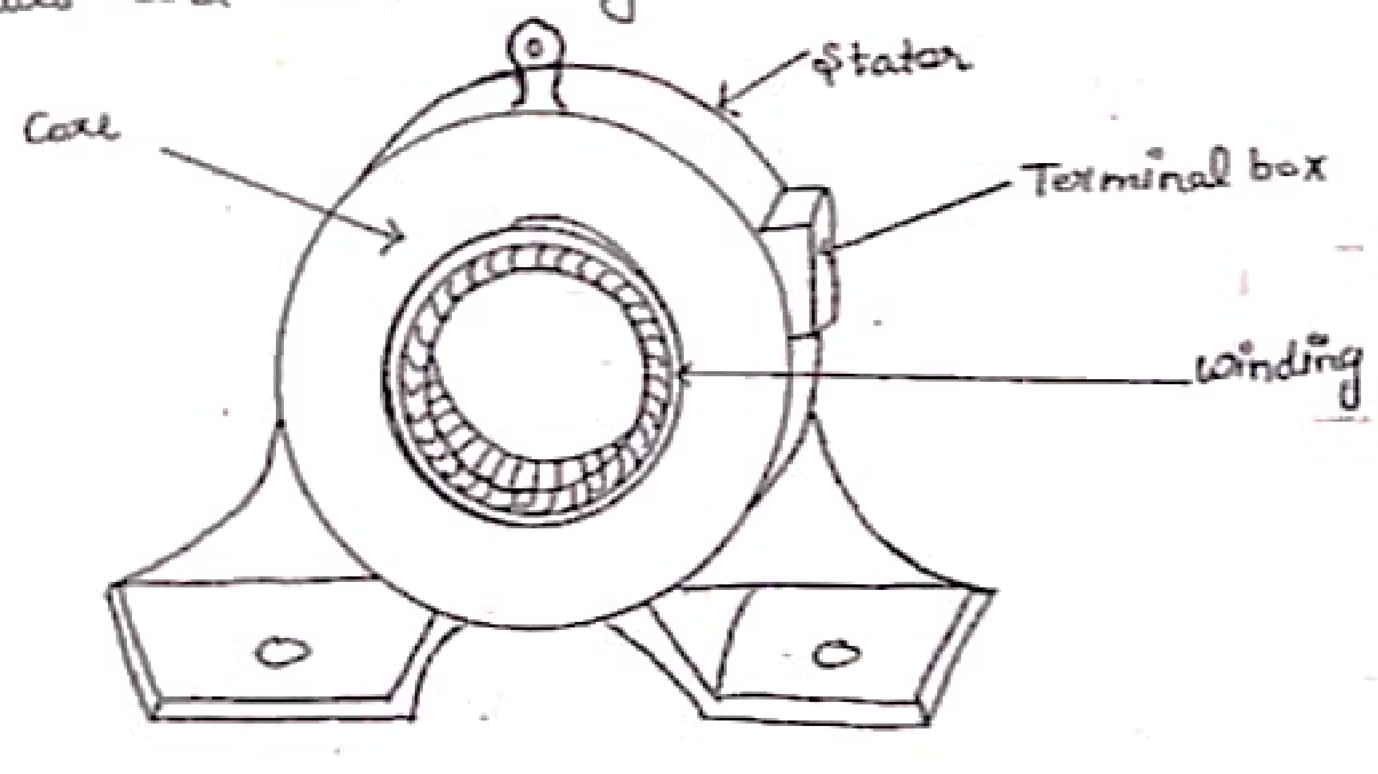


fig: Block Diagram.

1) Stator: Stator is the stationary part of the motor. It consist of a steel frame which enclose a hollow, cylindrical core made up of thin laminations of silicon steel to reduce eddy current and hysteresis losses. The insulated conductors are placed in the stator slots and are suitably connected to three phase a.c. supply.



2) Rotor: Rotor is the rotating part of the motor. The rotor, mounted on a shaft, is hollow laminated core having slots on its outer periphery. There are two types of rotors used in 3-phase induction motor.

a) Squirrel cage Rotor

b) Slip Ring or Wound Rotor.

(a) Squirrel Cage Rotor: The motor whose rotor is squirrel cage type is known as squirrel cage induction motor. Most of the motors have squirrel cage rotor because of simple and rugged construction. Winding, copper or Aluminium bar is placed in each slot.

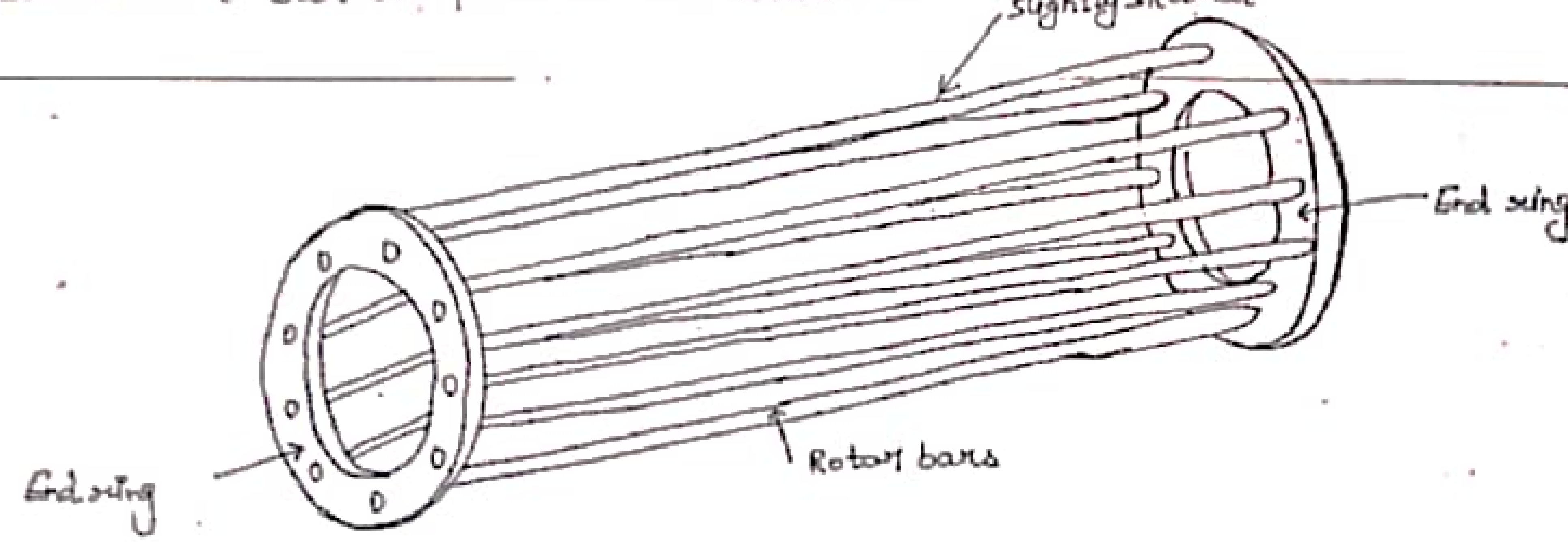


fig: Squirrel Cage Rotor.

(ii) The rotor slots are usually not parallel to the shaft but are inclined at some angle, known as skewing. The skewing of the rotor has some advantages like:

(i) It reduces the magnetic humming noise while ~~operating~~ operation.
(ii) To obtain more uniform torque
(iii) It reduces the magnetic locking tendency of the rotor.

(b) Slip ring or Wound rotor: The motor employing this type of motor are known as slip ring Induction motor.

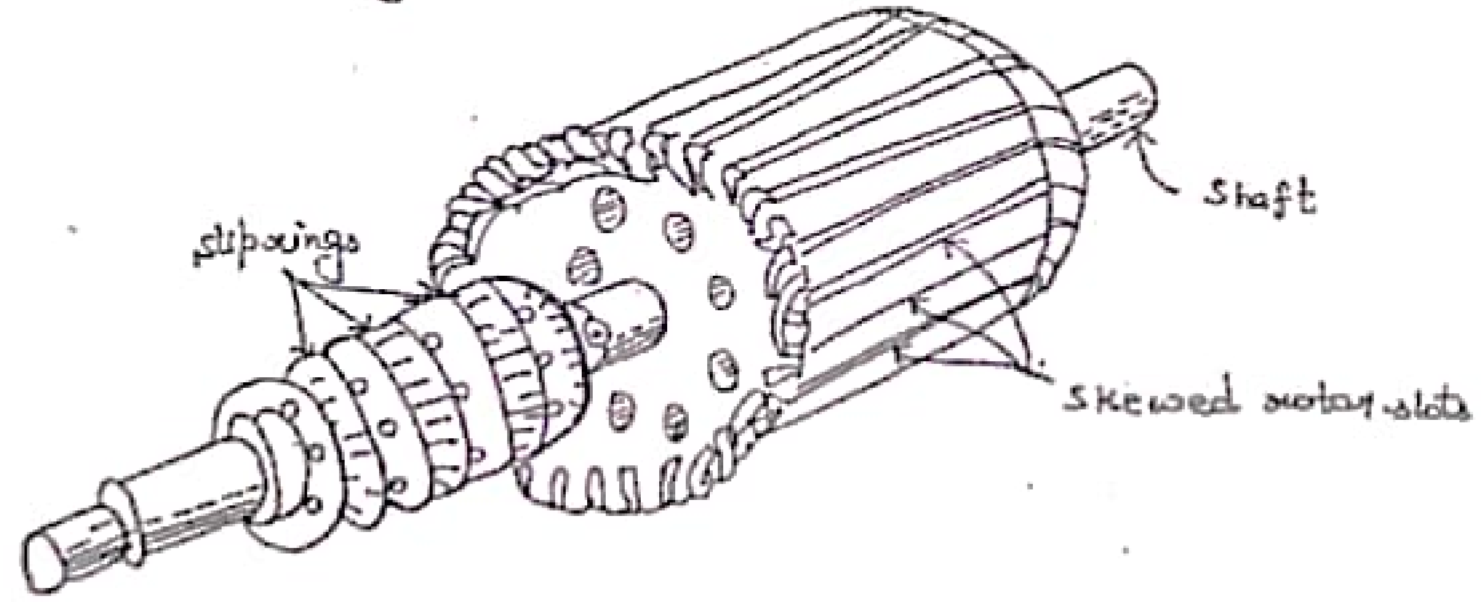


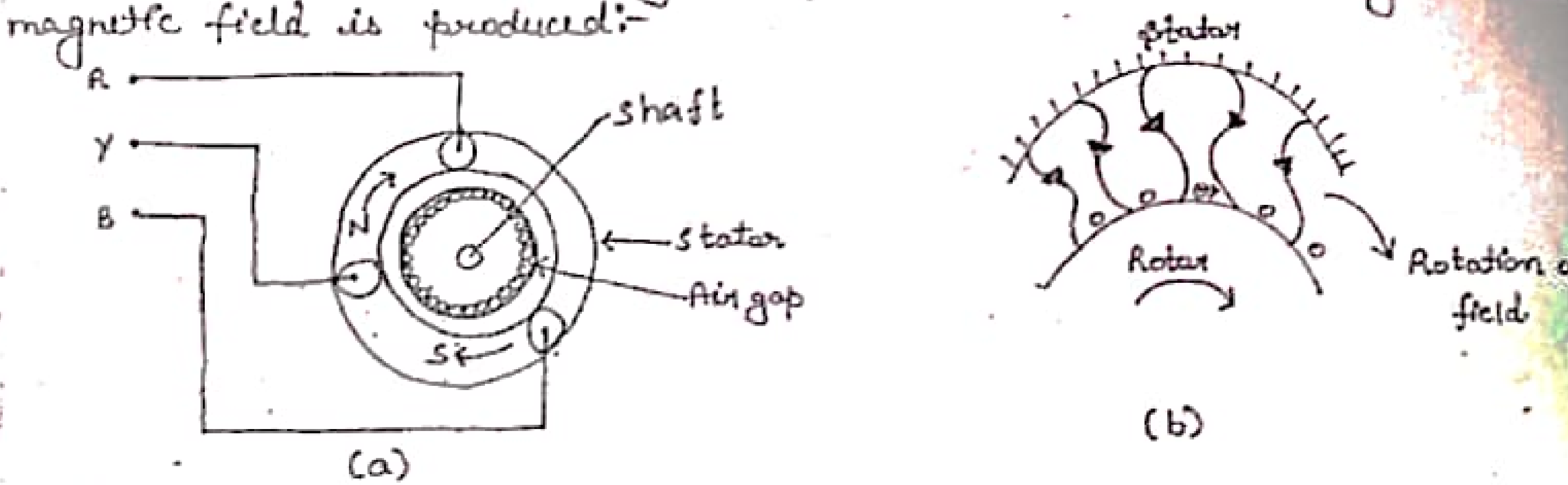
fig: Wound rotor.

The motor having this type of rotor are rarely used. This type of motor are used where high starting torque is required. In this type of rotor, it is possible to add any external resistance to achieve the high starting torque.

Ques: Write down the principle of Operation of three phase induction motor.

Ans: A three phase induction motor works on the principle of Electromagnetic induction. The principle of operation can be understood by the following steps.

Step I: When a 3-phase supply is given to the stator winding, a rotating magnetic field is produced:-



Step II: The rotating magnetic field passes through the air gap of and cuts the rotor conductor then an emf is induced in rotor conductor according to Faradays law of electromagnetic induction.

Step (III): This induced emf produces a current in the rotor conductor as rotor conductor are short circuited. This current interacts with rotating magnetic field to developed torque and hence rotor start rotating.

Ques: What is SLIP?

Ans: "The difference between the synchronous speed and the actual rotor speed is called slip". It is denoted by 's'. This is also called absolute slip or fractional slip.

$$s = N_s - N_r$$

where, N_s = Synchronous speed
N_r = Rotor speed.

The percentage slip is expressed as:

$$\% s = \frac{N_s - N_r}{N_s} \times 100$$

$$s = \frac{N_s - N_r}{N_s}$$

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

Case 1 : If rotor is stationary then $N=0$ and $s=1$.

Case 2 : $N_r = N_s$ then $s=0$.

So, the value of slip varies from $s=0$ to $s=1$

Ques : Explain the effect of slip on Rotor Parameters?

Ans : The effect of slip on the following Rotor Parameters..

1. Rotor frequency
2. Rotor impedance
3. Rotor current
4. Rotor power factor.

1. Effect on Rotor frequency :

In case of induction motor, the speed of rotating magnetic field is given by

$$N_s = \frac{120f}{P} \quad \text{or} \quad f = \frac{PN_s}{120} \quad --(i)$$

$$f_r = \frac{P(N_s-N)}{120} \quad ----(ii)$$

Dividing eq^n (ii) by (i), we get

$$\frac{f_r}{f} = \frac{N_s-N}{N_s} \qquad \left(s = \frac{N_s-N}{N_s}\right)$$

$$\frac{f_r}{f} = s$$

$$\boxed{f_r = sf}$$

At standstill Condition :

The impedence per phase, $Z_2 = \sqrt{R_2^2+X_2^2}$

Rotor current per phase, $I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{R_2^2+X_2^2}}$

Rotor power factor, $\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2+X_2^2}}$

Rotor at slip s :

Impedance per phase, $Z_2' = \sqrt{R_2^2+(sX_2)^2}$

Rotor current per phase, $I_2' = \frac{E_2'}{Z_2'} = \frac{sE_2}{\sqrt{R_2^2+(sX_2)^2}}$

Rotor power factor, $\cos\phi_2' = \frac{R_2}{Z_2'} = \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}}$

Ques : Explain torque equation of a 3-phase induction motor?

Ans : There are following three factors :

a) Rotor emf b) Rotor current c) Power factor of the rotor circuit

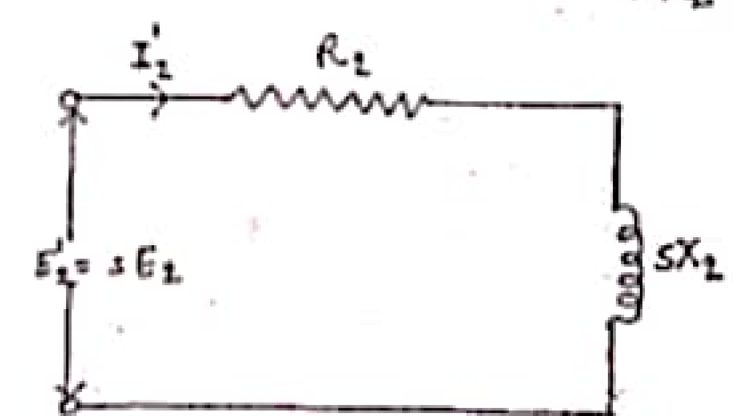
Rotor emf / phase, $E_2' = sE_2$

Rotor reactance/phase, $X_2' = sX_2$

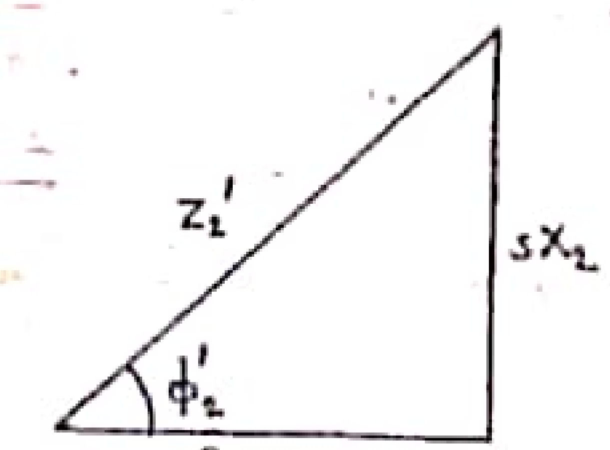
Rotor impedance/ phase $Z_2' = \sqrt{R_2^2+(sX_2)^2}$

Rotor current/ phase $I_2' = \frac{E_2'}{Z_2'} = \frac{sE_2}{\sqrt{R_2^2+(sX_2)^2}}$

Rotor p.f., $\cos\phi_2' = \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}}$



(a)



R_2 (b)

$\therefore$ Running torque, $T_r \propto E_2' I_2' \cos\phi_2' \quad \because E_2 \propto \phi$

$$\propto \phi I_2' \cos\phi_2'$$

$$\propto \phi \times \frac{sE_2}{\sqrt{R_2^2+(sX_2)^2}} \times \frac{R_2}{\sqrt{R_2^2+(sX_2)^2}}$$

$$\propto \frac{\phi s E_2 R_2}{R_2^2+(sX_2)^2} \quad \because E_2 \propto \phi$$

$$= \frac{K\phi s E_2 R_2}{R_2^2+(sX_2)^2}$$

$$= \frac{K_1 s E_2^2 R_2}{R_2^2 + (sX_2)^2} \qquad (\because E_2 \propto \phi)$$

If the stator supply voltage V is constant, then stator flux and hence ~~E_2 will be constant~~

$$\therefore \quad T_r = \frac{K_2 s R_2}{R_2^2 + (sX_2)^2}$$ where K_2 is another constant.

Condition for maximum torque

$$T_r = \frac{K_2 s R_2}{R_2^2 + s^2 X_2^2}$$

$$\frac{dT_r}{ds} = \frac{K_2[R_2(R_2^2 + s^2X_2^2) - 2sX_2^2(sR_2)]}{(R_2^2 + s^2X_2^2)^2} = 0$$

or $(R_2^2 + s^2X_2^2) - 2s^2X_2^2 = 0$

or $R_2^2 = s^2 X_2^2$

or $R_2 = sX_2$

Thus for maximum torque (T_m) under running conditions:

Rotor resistance/phase = Fractional slip × standstill rotor reactance/phase

Now, $T_r \propto \frac{sR_2}{R_2^2 + s^2X_2^2}$

Putting $R_2 = sX_2$, the maximum torque is given by:

$$T_m \propto \frac{1}{2X_2}$$

slip corresponding to maximum torque, $s = \frac{R_2}{X_2}$

Ques: Write down the characteristic of Torque slip?

Ans: The curve obtained by plotting torque against slip from $s=1$ (at start) to $s=0$ (at synchronous speed) is called torque slip characteristics of 3-phase induction motor.

We know that torque is given by

$$T_r = \frac{sR_2}{R_2^2 + (sX_2)^2}$$

a) Low slip region:-

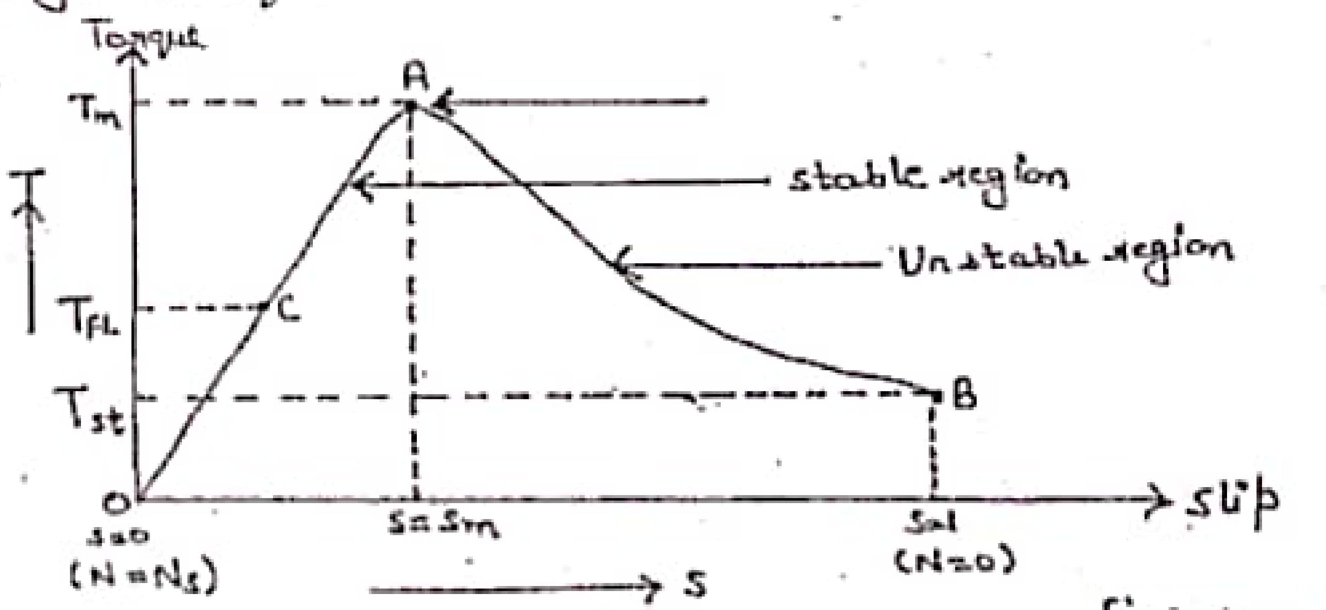
The torque-slip characteristic curve starts from origin shown in figure. When the value of $s=0$, then $T=0$.

b) Medium slip region:- ($s=0$ to $s=s_m$): At normal working condition, value of slip is small, so term $(sX_2)^2$ is also small and hence negligible.

$$T \propto \frac{s}{R_2} \qquad (R_2 \text{ is constant})$$

$$T \propto s$$

So, the torque slip curve is straight line. This is known as stable region of motor.



OA = Stable region
AB = Unstable region
Point A = Maximum torque
Point B = Starting torque
Point C = Full load torque.

fig: Torque-slip characteristics.

c) High slip region ($s_m < s < 1$):

$$T \propto \frac{sR_2}{(sX_2)^2}$$

$$T \propto \frac{1}{s}$$

High slip region torque is inversely proportional to the slip.

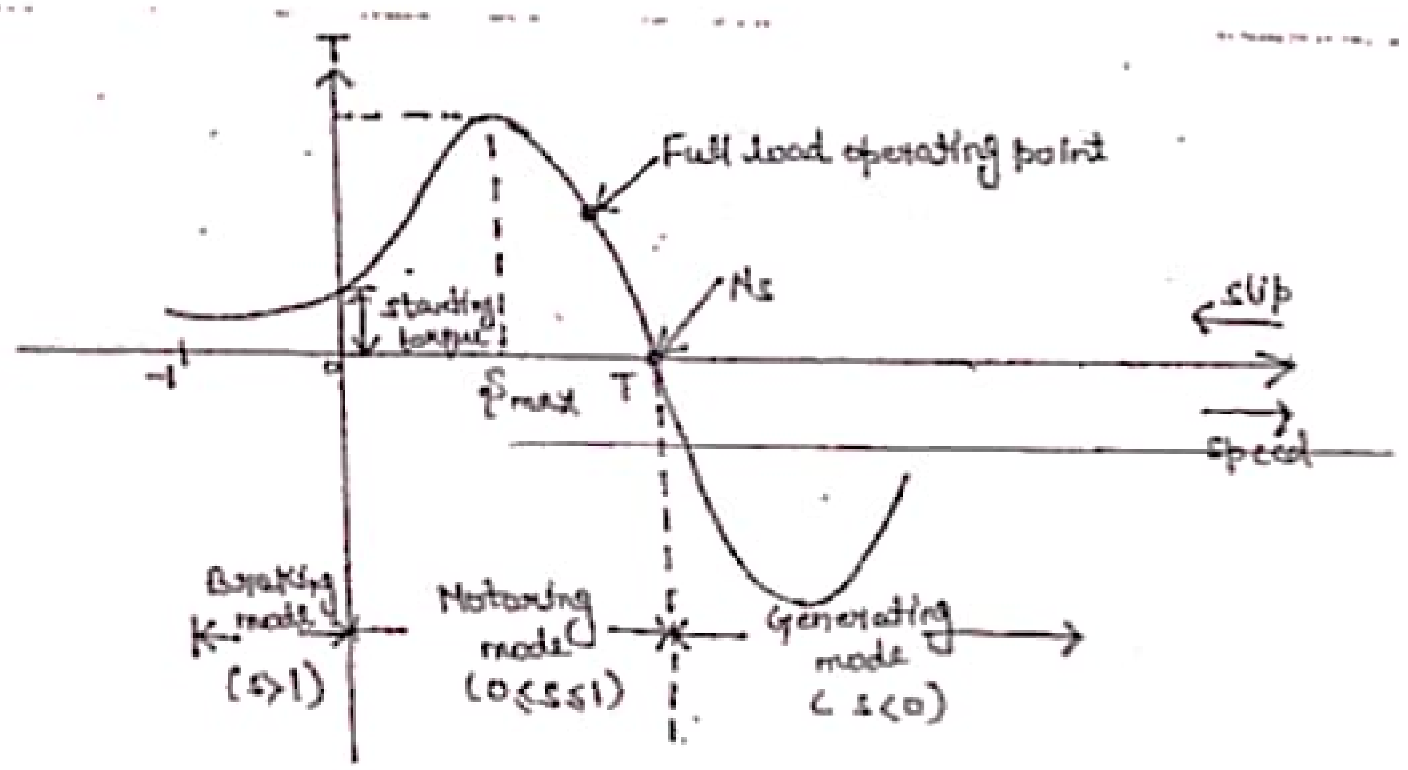
Ques: Explain the Torque-speed curve of Induction Motor?

Ans: They have three operating modes or region:

1) Motoring Mode: $0 \leq s \leq 1$, slip is positive

2) Generating Mode: $s < 0$, slip is negative

3) Braking Mode: $s > 1$



Ques: Write down the Applications of 3-phase induction motor?

Ans: (a) Squirrel Cage Motor

Squirrel cage motor are constant speed motor. So these motor are preferred for the following applications:

(i) fans and blowers
(ii) lathe machine
(iii) printing machine
(iv) grinders
(v) drilling machine
(vi) Water pumps
(vii) textile mills.

(b) Slip Ring Motor:

(i) Cranes
(ii) Lift
(iii) Elevators
(iv) Hoist
(v) compressor
(vi) Large pumps
(viii) cement mill and Rolling mill.

Ques: Comparison of Squirrel cage & slip Ring Induction Motor.

Ans:

S.No	Squirrel Cage Induction Motor	Slip Ring Induction Motor.
1.	Higher frequency	Lower efficiency
2.	Lower starting torque	High starting torque
3.	Low cost and low maintenance	High cost & high maintenance
4.	Simple in construction	complicated in construction.
5.	Slip rings and brushes as absent	slip rings brushes are present to add external
6.	Lower losses	Higher losses
7.	No speed control	Speed control can be done.

Solved Examples

Exam: A 50 Hz 4-pole, 3-phase induction motor has a rotor current of frequency 2 Hz. Determine (i) Slip (ii) Speed of the motor.

Sol: Given, $f = 50\text{Hz}$ $P=4$, $f' = 2$ Hz

Step I) The rotor frequency is given by

$$f' = sf \quad \text{or} \quad s = \frac{f'}{f} = \frac{2}{50} = 0.04 \text{ or } 4\%$$

$\therefore$ $\boxed{s = 4\%}$

Step II) We know that synchronous speed is given by.

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}.$$

Now, $s = \frac{N_s - N_r}{N_s}$

$$0.04 = \frac{1500 - N_r}{1500} = 1440 \text{ rpm}.$$

$\therefore$ $\boxed{N_r = 1400 \text{ rpm}}$

Ques: A 3-φ, 6-pole, 50 Hz induction motor has a slip of 1% at no-load and 3% at full load. Find.

(i) Synchronous speed (ii) No-load speed (iii) Full-load speed (iv) Frequency of rotor current at stand still (v) Frequency of rotor current at full-load.

Sol: Given,

$P = 6$, $f = 50$Hz, No-load slip. $S_{nl} = 1\% = 0.01$

full load slip. $S_{fl} = 3\% = 0.03$

Synchronous speed of motor

$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$ rpm $\therefore \boxed{N_s = 1000 \text{ r.p.m}}$

Step (II): No-load speed

$N_{nl} = N_s(1 - S_{nl}) = 1000(1 - 0.01) = 990$ rpm $\therefore \boxed{N_{nl} = 990 \text{ rpm}}$

Step (III): Full load speed:

$N_{fl} = (1 - S_{fl}) = 1000(1 - 0.03) = 970$ rpm $\therefore \boxed{N_{fl} = 970 \text{ r.p.m}}$

Step (IV): Frequency of rotor current at stand still

$S \cdot f = 1 \times 50 = 50$ Hz [$\because s = 1$ at standstill]

Step (V): Frequency of rotor current at full load.

$f_r = s_{fl} \times f = 0.03 \times 50 = 1.5$ Hz $\therefore \boxed{f_r = 1.5 \text{ Hz}}$.

Exam: A 3-phase induction motor is wound for 4 poles and is supplied from 50 Hz system. Calculate -
(i) N_s, (ii) Rotor speed when slip is 4% (iii) Rotor frequency when rotor runs at 600 rpm:

Sol: Given,

$P = 4$, $s = 4\%$ i.e; 0.04, $f = 50$ Hz

Step I) The synchronous speed is given by

$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ rpm.

Step II) The rotor speed when slip is 4% is calculate as

$N_r = N_s(1 - s) = 1500(1 - 0.04) = 1440$ r.p.m.

Step III) The rotor speed when rotor runs at 600 rpm

$N_1 = 600$ r.p.m

$s_1 = \frac{N_s - N_1}{N_s} \times 100 = \frac{1500 - 600}{1500} \times 100 = 60\%$

$f_r = s_1 f = 0.6 \times 50 = 30$ Hz

Examp: A 5 h.p., 230V, 50 Hz induction motor has a rated full load speed of 950 rpm. The induced voltage per phase of rotor at standstill is 100V. ~~Calculate~~
(i) No. of poles and % full load slip
(ii) Rotor induced voltage and its frequency at full load.

Sol: Given,

$V_L = 230$V, $f = 50$ Hz, $N_r = 950$ rpm, $E_2 = 100$ V

Step I) The practical value of full load slip is above 4 to 6%. Hence the nearest synchronous speed to $N_r = 950$ rpm. is $N_s = 1000$ r.p.m.

But $N_s = \frac{120f}{P}$ i.e. $1000 = \frac{120 \times 50}{P}$

$\therefore$ $P = 6$ (no. of poles)

$\% s = \frac{N_s - N_r}{N_s} \times 100 = \frac{1000 - 950}{1000} \times 100 = 5\%$ (slip).

Step II) The rotor induced voltage & its frequency at full load is

$E_{2r} = sE_2 = 0.05 \times 100 = 5$V

$f_r = sf = 0.05 \times 50 = 2.5$ Hz

Exam: A 4-pole, 3-phase, 50 Hz, star connected induction motor has a full load slip of 4%. Calculate full load speed of the motor.

Sol: Given, $P = 4$, $f = 50$ Hz, $S_{fl} = 4\%$

Step I) The synchronous speed is given by

$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ rpm.

Step II) The full load speed is

$S_{fl} = \frac{N_s - N_{fl}}{N_s}$

$\therefore$ $0.04 = \frac{1500 - N_{fl}}{1500}$

$\therefore$ $\boxed{N_{fl} = 1440 \text{ rpm}}$

Ques: Why single phase induction motor is not self starting?

Ans: When a single phase supply is connected to the stator winding a pulsating or Alternating magnetic field is produced. This pulsating field builds up in one direction, fall to zero and then build up in the opposite direction. This condition the resultant torque is zero and pulsating magnetic field can not produce rotation in rotor. Therefore, a single phase induction motor is not a self-starting motor.

Why single phase induction motor are not self starting with the help of a theory called Double Revolving field Theory.

Double Revolving field Theory:

According to double revolving field theory consider the two components of the stator flux, each having magnitude half to of maximum magnitude of stator flux i.e. $(\phi_{1m}/2)$.

Let ϕ_f is forward component rotating in anticlockwise direction which ϕ_b is the backward component rotating in clockwise direction.

The resultant $\phi_R = 0$. This is nothing but the instantaneous value of stator flux at start. After $90°$, the two components are rotated in such a way that both are pointing in the same direction. $\phi_R = (\phi_{1m}/2) + (\phi_{1m}/2) = \phi_{1m}$.

At start these two torques are equal in magnitude but opposite in direction. Each torque tries to rotates the rotor in its own direction. Thus net torque experienced by rotor is zero at start hence the single phase induction motor are not self starting.

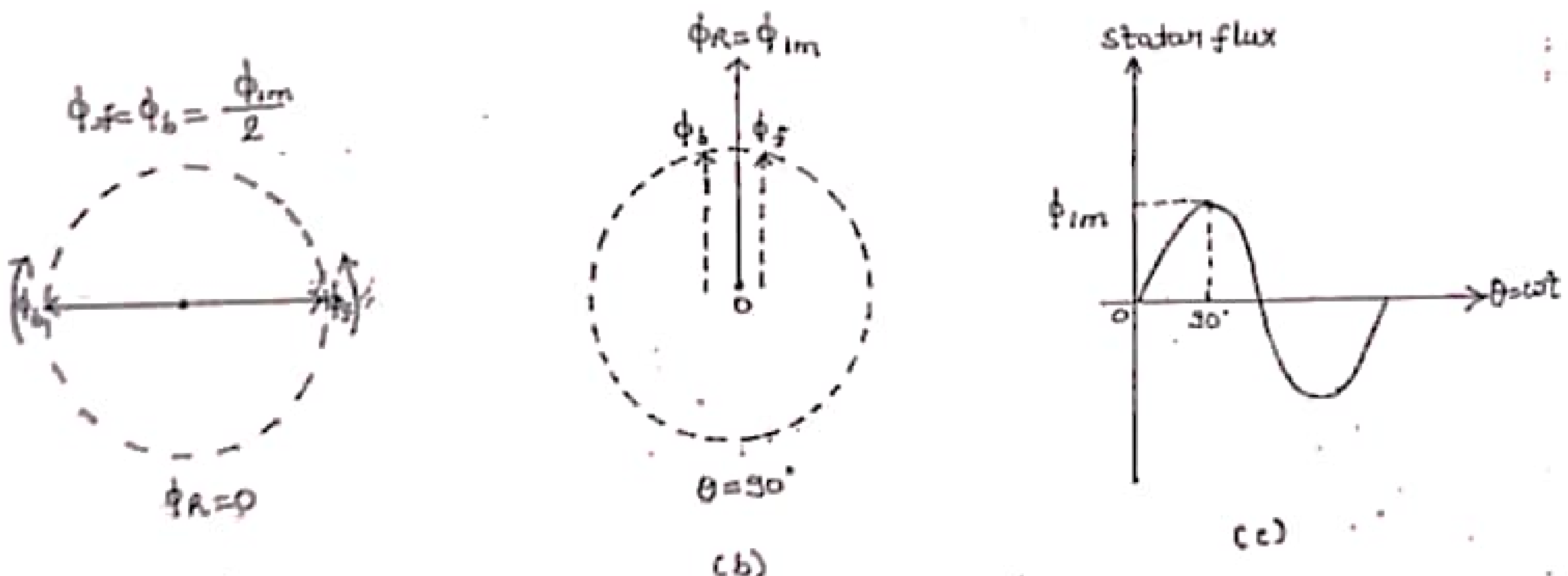
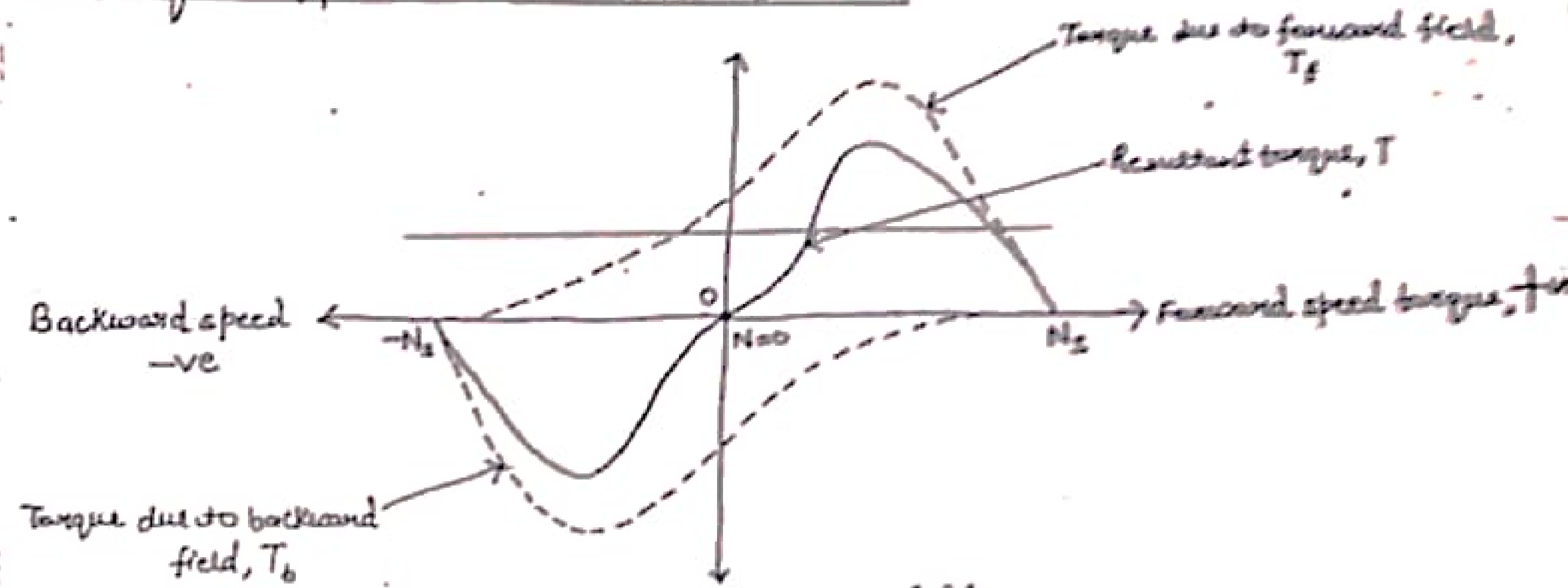


Fig: Stator flux and its two components.

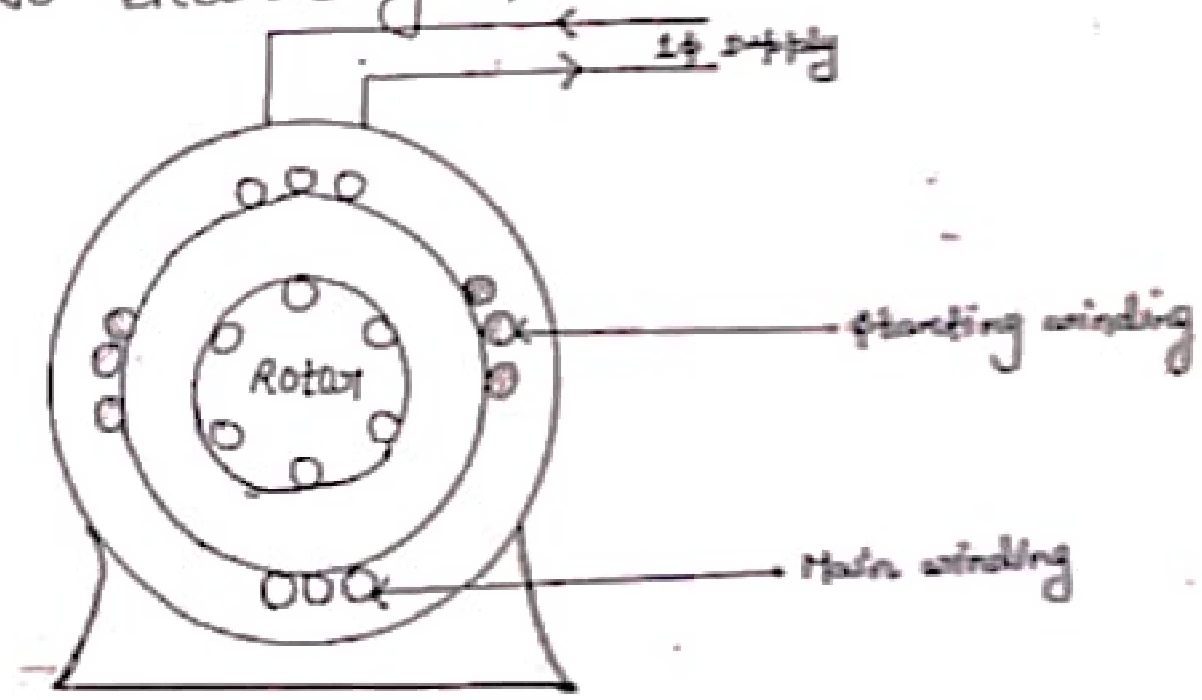
Torque-Speed Characteristics —



Torque speed characteristics

Ques: How do make single phase induction motor self starting?

Ans: The single phase induction motor is not self-starting. To make a single phase induction motor self starting, we should produce a Rotating Magnetic field in stator. The auxiliary winding is connected across the supply voltage and $90°$ electrically apart with main winding.

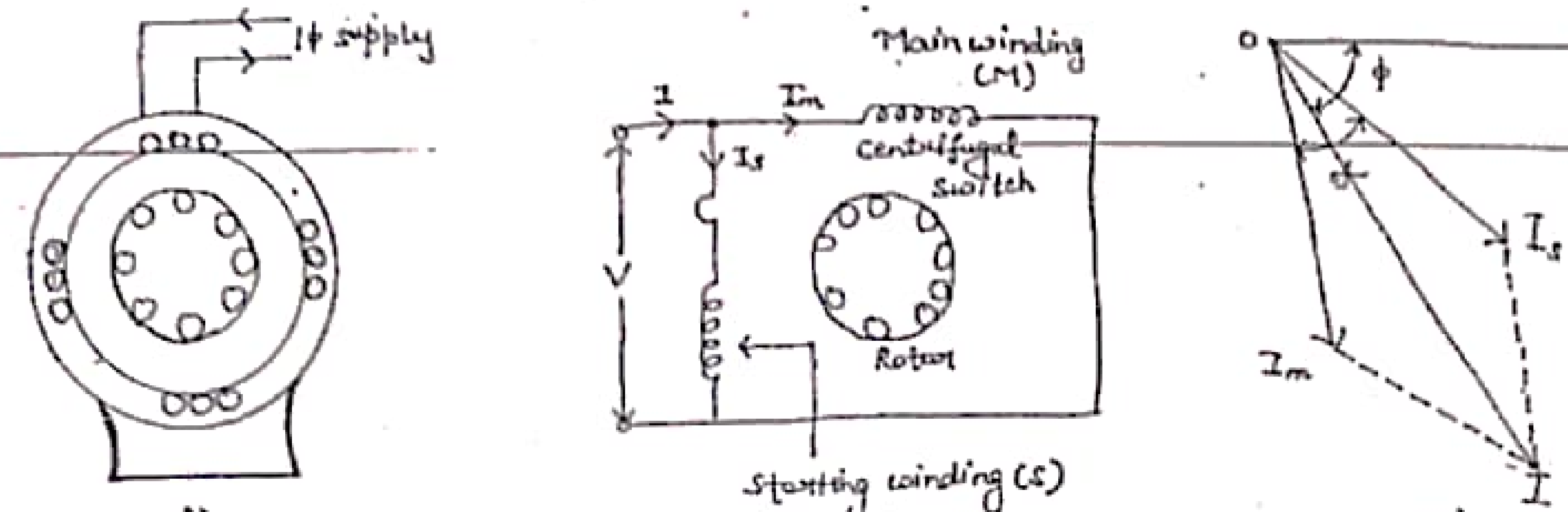


Single phase induction motors are usually classified according to the auxiliary means used to start the motor. They are classified as follows:

(1) Split phase motor (Resistance start motor)
(2) Capacitor – start motor
(3) Capacitor start, capacitor run motor.
(4) Shadded pole motor.

(1) Split Phase Induction Motor: Split phase induction motor is also called resistance start motor.

The main field winding and the starting winding are displaced 90° in space like the winding in a two phase induction motor.



(i) (ii) (iii)

Operation:

i) When the two stator windings are energised from a single phase supply, the main winding carries current Im while the starting winding carries current Is.

ii) Im and Is have a reasonable phase difference angle α (25° to 30°) between them.

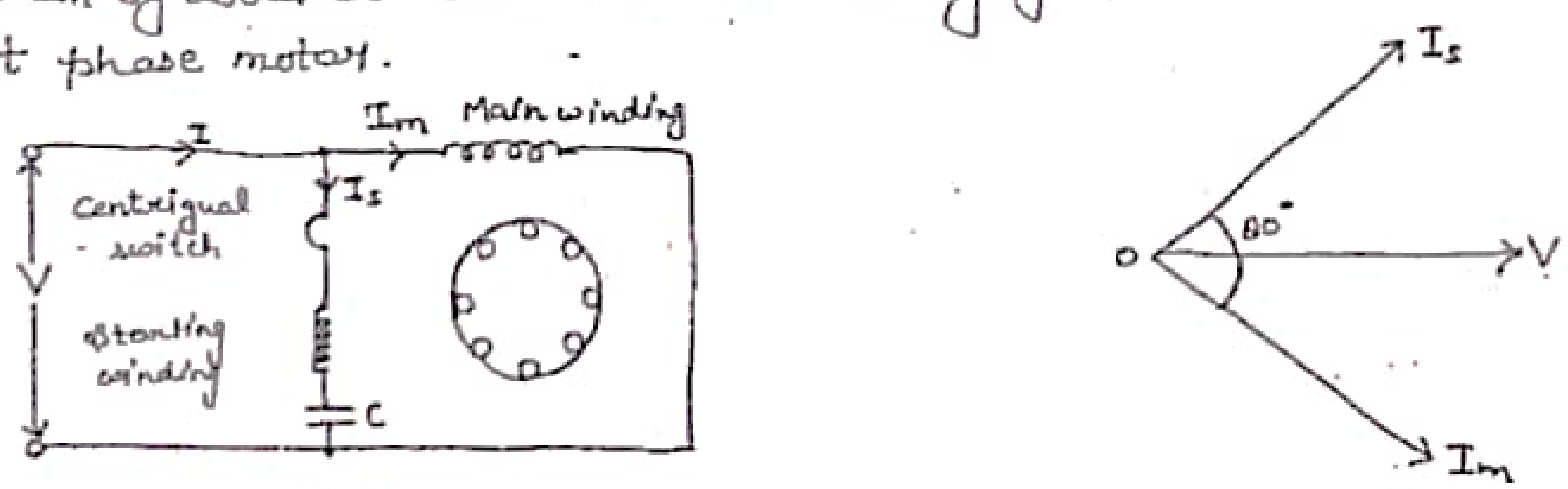
Application:

* Split phase motors are cheap and they are most suitable for easily started loads where frequency of starting is limited.

The common application are -

- fans and blowers
- washing machine & refrigerator.
- Food processing machine, Grinders
- Wood working tools.

(2) Capacitor start Motor: The value of capacitor is so chosen that Is lead Im by about 80° which is considerably greater than 25° found in split phase motor.



(i) (ii)

Application:

* Capacitor start motor are used for load of higher inertia where frequently start are required.

These motors are most suitable for:-

a) Pumps

b) Compressor

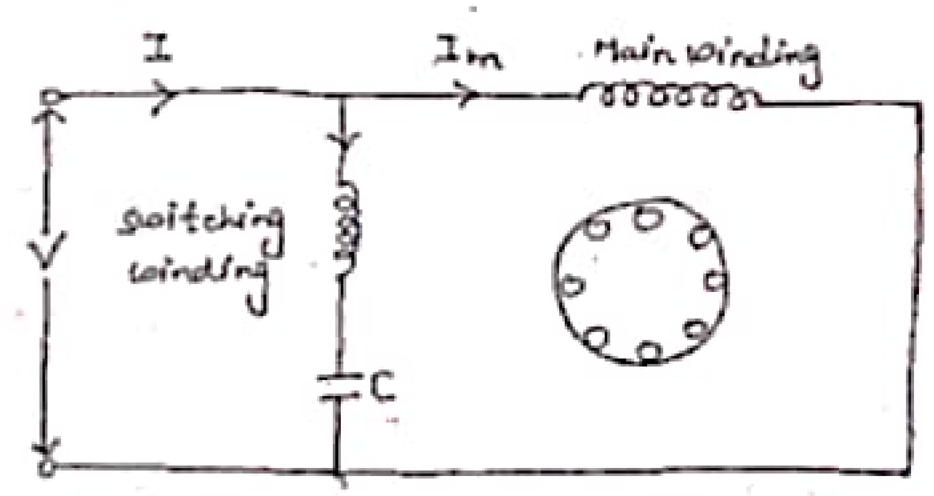
c) Air conditioners

d) conveyors.

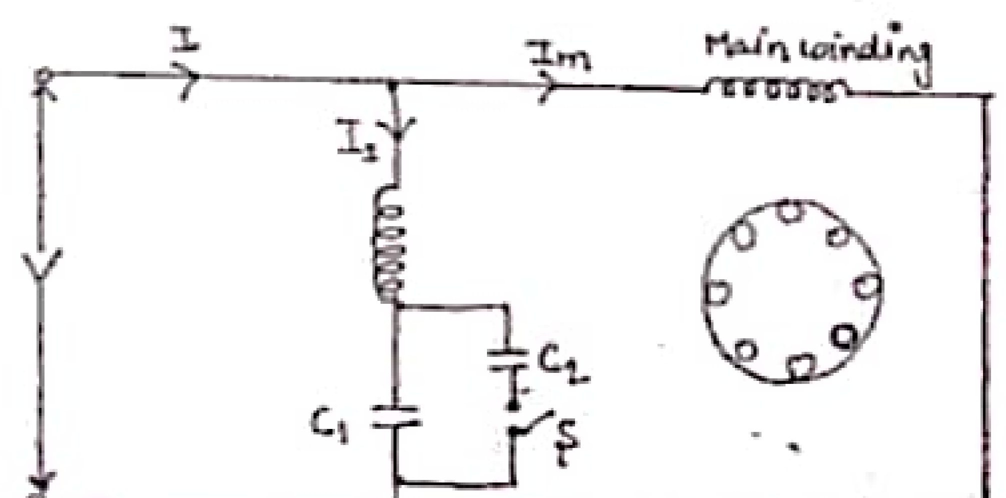
(3) Capacitor start Capacitor Run Motor:

Two designs are generally used - as -

(i) A single capacitor C is used for both starting and running. The design eliminated the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.



(ii) Two capacitors C1 and C2 are used in the starting winding. The smaller capacitor C1 required for optimum running conditions is permanently connected in series with the starting winding.



Application:

a) Hospitals (b) Air compressor (c) Refrigeration (d) Other places where silence is important.

(4) Shaded Pole Motor: A shaded pole motor consist of a stator and a cage type rotor. The stator is made up of salient poles.

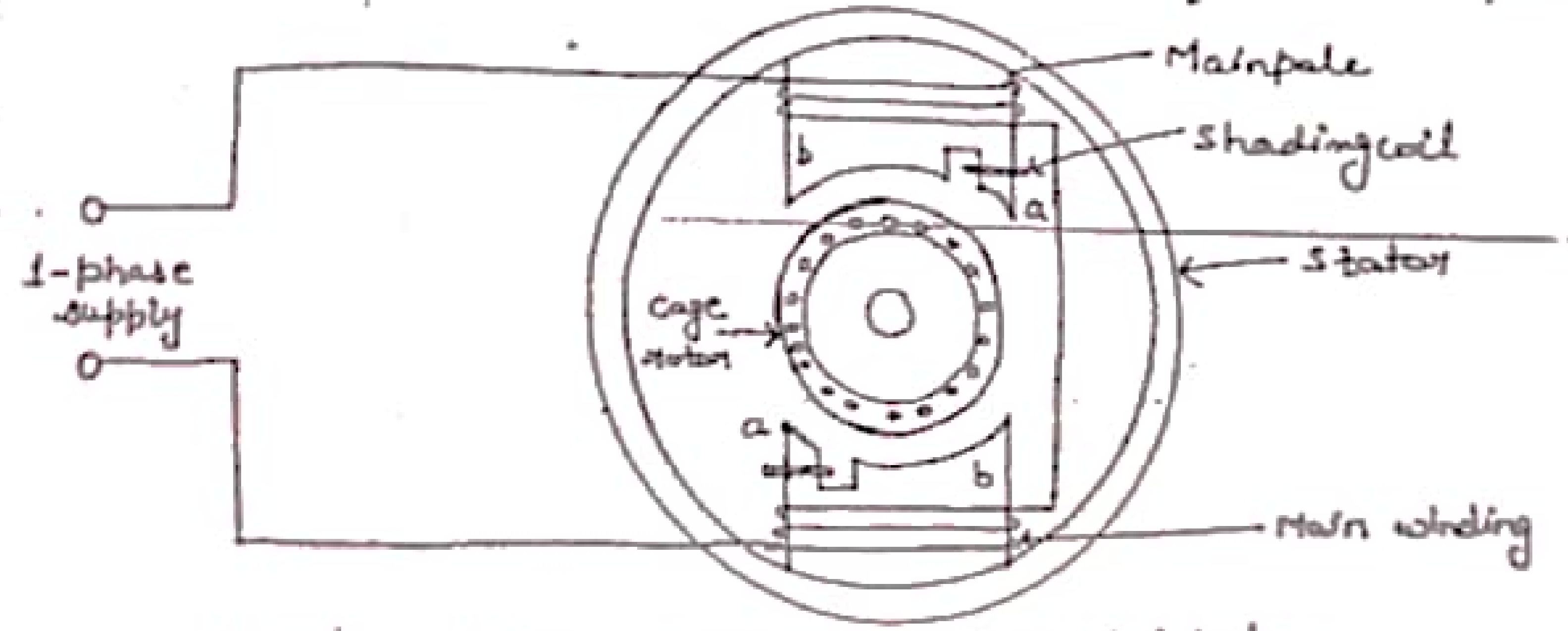


fig: shaded-pole motor with two started poles.

When the a.c. supply is connected to the main winding the alternatic flux is set up in the core. This alternating flux induces the current in a shading coil which opposes the core flux due to Lenz law. The flux in the shaded portion of the pole lags the flux in the unshaped portion of it.

Application:

Because of low starting torque, the shaded pole motor is generally used for:

(a) Small fans , (b) Toys , (c) Hair dryers & Electric clocks.

THREE PHASE SYNCHRONOUS MACHINES

Ques: Write down the important feature of Synchronous Machine.

Ans: 1) It is always better to protect high voltage winding from centrifugal forces caused due to the rotation. So higher voltage armature is generally keep stationary.

2) It is easier to collect large currents at very high voltages from a stationary members.

3) The problem of sparking at the slip rings can be avoided by keeping field rotating and armature stationary.

4) Rotating field make overall construction very simple.

5) The Ventillation arrangement for high voltage side can be improved if it is kept stationary.

Ques: Explain the construction of Alternator or Generator?

Ans: There are two main parts namely:

(1) Stator (2) Rotor

1) Stator: The stator is the stationary part of the machine. It carries the armature winding in which the voltage is generated. The output of the machine is taken from the stator.

2) Rotor: The rotor is the rotating part of the machine. The rotor produces the main field flux. Rotor construction is of two types:

a) Salient (projecting) pole type b) Non-salient (cylindrical) pole type.

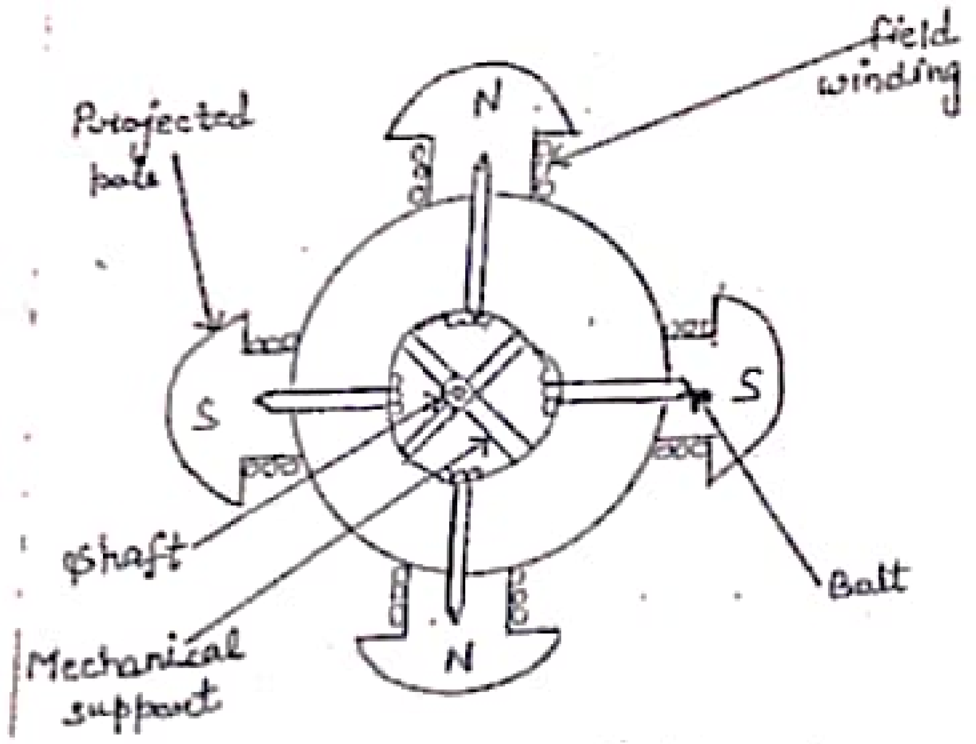
a) Salient (projecting) pole type: The terms salient means projecting or protruding. The poles are built up of thick steel laminations. The features of salient pole type rotor is:

(i) It is used in low and Medium speed (125–500 rpm) alternator.
(ii) These rotor have large diameters and small axial length.
(iii) The prime movers used to drive such rotor are generally water turbine

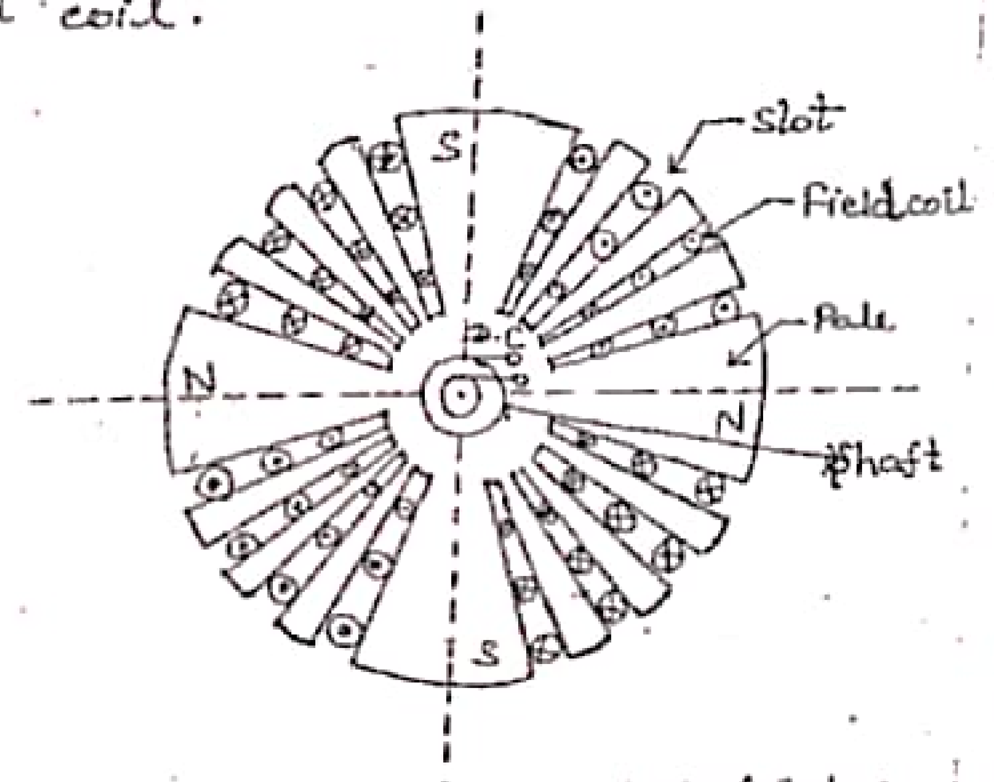
and I.C. engines.

(iv) Salient pole alternator driven by water turbine are called Hydro alternator or hydrogenerators.

(b) Non-salient type Rotor: ~~It is also~~ called smooth cylindrical type rotor. The rotor consist of smooth solid steel cylinder, having number of slots to ~~~~ accommodate the field coil.



fig(a): Salient Pole Type Rotor



fig(b): Smooth Cylindrical Rotor.

Features of non salient pole type rotor are-

(i) It is used in high speed (750-3000 rpm) alternators.

(ii) These rotors have small diameter and large axial length.

(iii) Prime movers used to drive such type of rotors are generally steam turbine.

(iv) Such high speed alternators are called turbo alternators.

Ques: Explain the principle of operation of Alternator.

Ans: The alternator works on the principle of Electromagnetic induction. When a rotor is ~~rotated by~~ rotated by means of prime mover, the armature conductors cuts the magnetic flux, therefore an emf is induced in the armature conductors, due to electromagnetic induction. The direction of induced emf can be found by Flemings Right hand rule and frequency is given by:

$$f = \frac{NP}{120}$$

where, N = Speed of rotor in rpm

P = Number of poles.

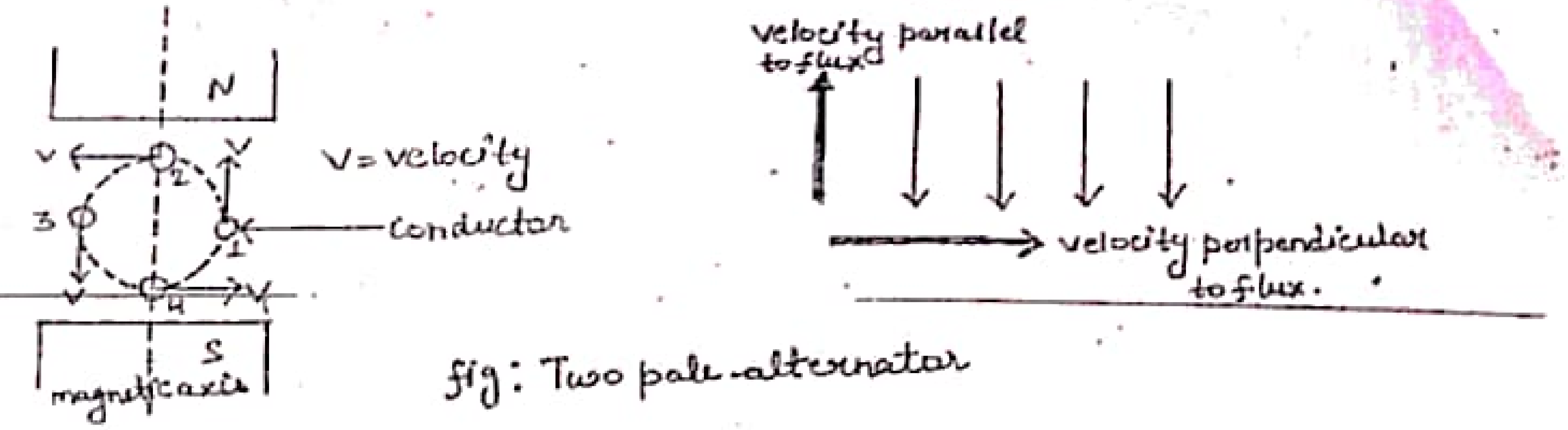


fig: Two pole alternator

Step 1): Let conductor starts rotating from position 1. The entire velocity components is parallel to the flux lines. Hence there is no cutting of flux lines. Hence there is no cutting of flux line line by the conductor. So $\frac{d\phi}{dt}$ at this instant is zero and hence induced emf in the conductor is zero

Step 2) Position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that emf gets induced in the conductor.

Step 3) At position 2, the entire velocity component is perpendicular to the flux lines. Hence there exists maximum cutting of the flux lines. The induced emf in the conductor is at its maximum.

Step 4) As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced emf in the conductor is zero.

Step 5) As the conductor moves from position 3 towards 4, the velocity component perpendicular to the flux lines against starts increasing. At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines.

Step 6) From position 4 to 1, induced emf decreases and finally at position 1, again becomes zero,

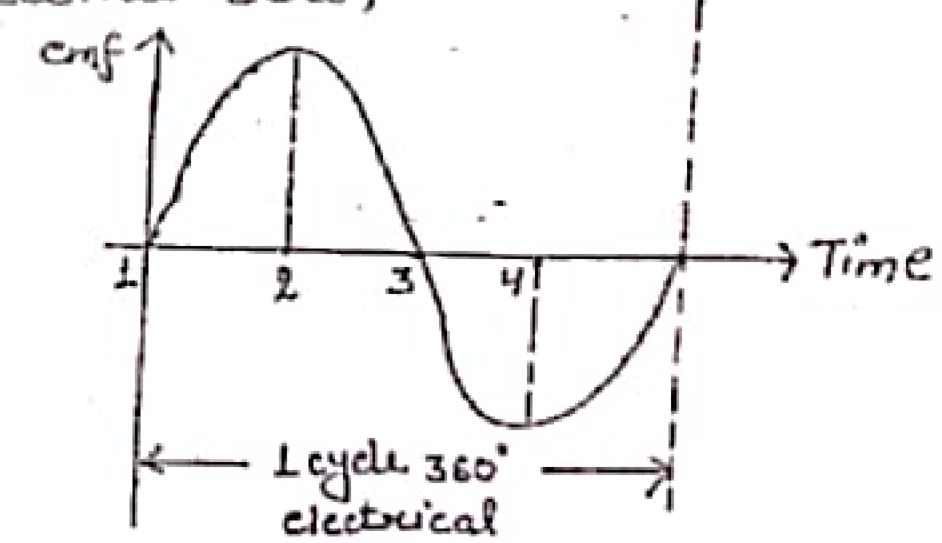
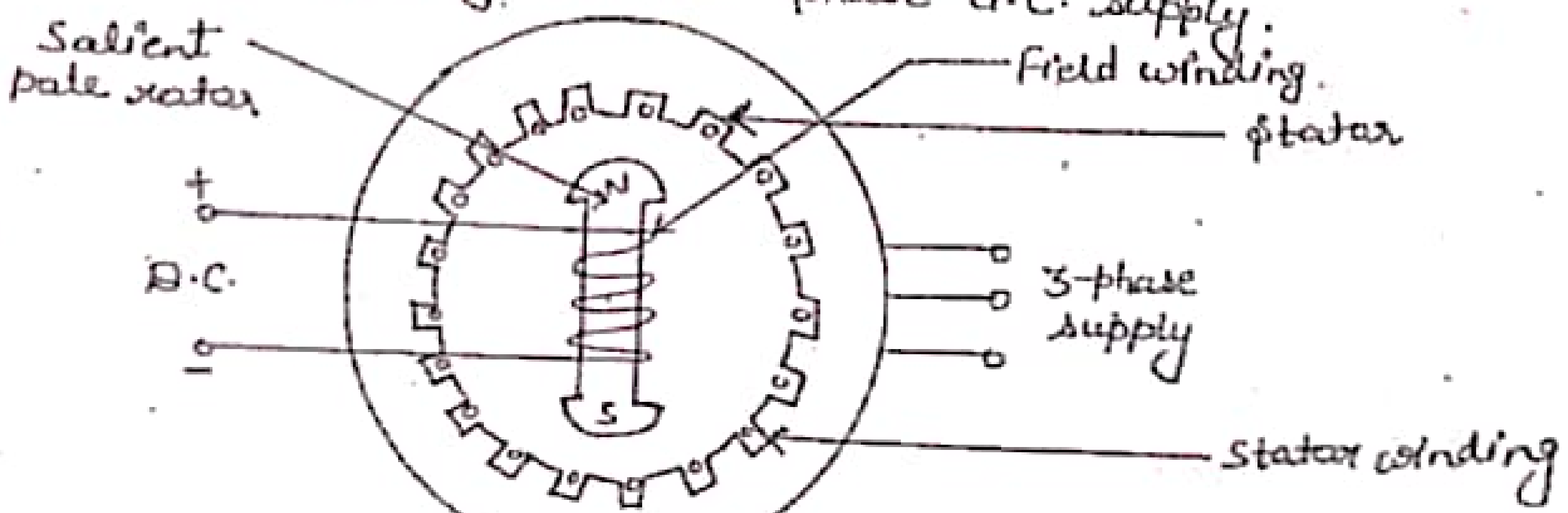


fig: Alternating nature of the induced emf.

Ques: Explain the principle of Synchronous Motor.

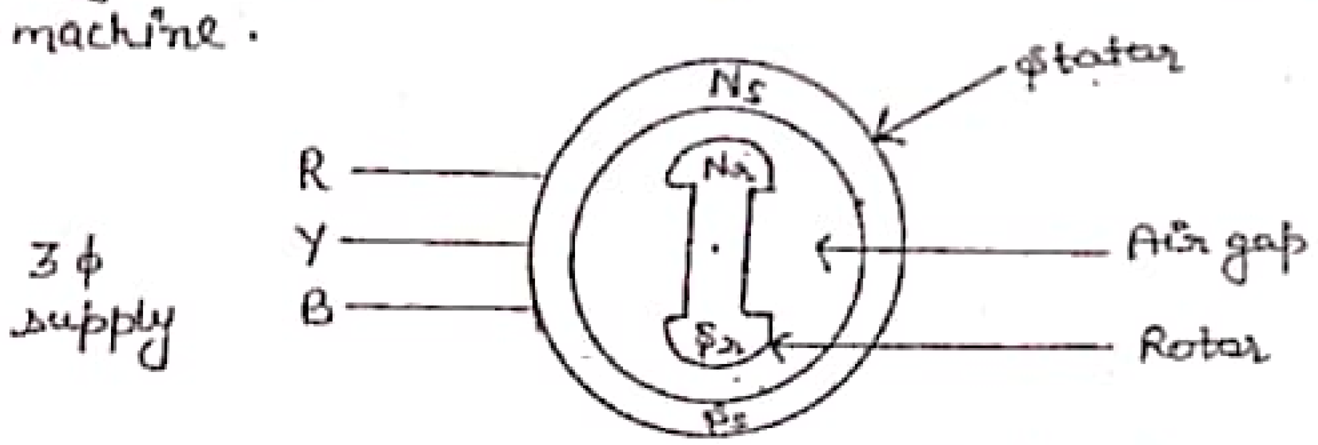
Ans: Stator: Stator is the stationary part of the machine. The three phase armature winding is placed in the slots of stator core and is wound for the same numbers of poles as the rotor as shown in the figure. The stator is excited by a three phase a.c. supply.



Rotor: The rotor of synchronous motor can be of the salient pole or cylindrical pole (non salient) type construction. The field winding is placed on the Rotor. The field winding is excited by a separate d.c. supply.

Ques: Why synchronous motor is not self starting?

Ans: Synchronous motor works on the principle of Magnetic Locking. The operating principle can be explained with the help of 2-pole synchronous ~~motor~~. machine.



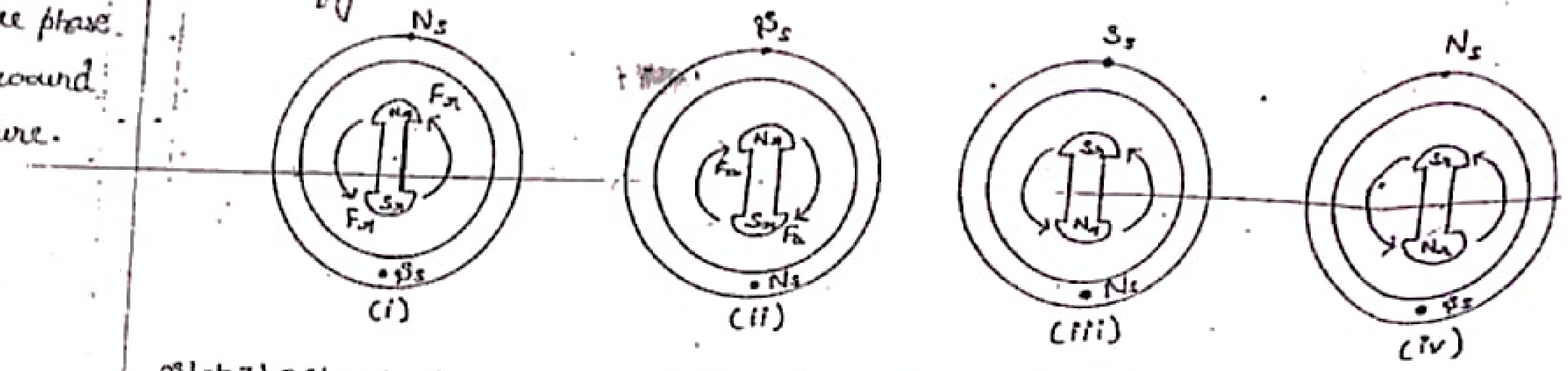
$N_s, S_s \rightarrow$ Stator north and South pole

$N_r, S_r \rightarrow$ Rotor north and South pole

Step I) When a three phase supply is given to the stator winding, a Rotating magnetic field is produced in stator.

Step II) The stator poles N_s and S_s rotate with synchronous speed. Stator pole N_s coincides with N_r and S_s coincides with S_r i.e., like poles of stator and rotor coincide with each other. As we know, like poles experiences a repulsive force.

Assume that the rotor tends to rotate in anticlockwise direction as shown in the figure.



Step 3) After half cycle or half period, stator poles interchange their position. Unlike poles coinciding each other and rotor experiences the attractive force F_a and tends to rotate in clockwise direction. The rotation of stator poles the rotor tends to drive in clockwise and anticlockwise direction in every half cycle. As a result, the average torque on rotor is zero. Hence 3-phase synchronous motor is not a self starting motor.

Step 4) The stator and rotor unlike poles will face each other, then due to strong force of attraction, magnetic locking is established, the rotor and stator poles continue to occupy the same relative position.

Step 5) Rotor continuously experiences a unidirection torque in the direction of the rotating magnetic field. Hence 3-phase synchronous motor must run at synchronous speed.

Method of starting a synchronous Motor–

1. Using small Induction motor.
2. Using small d.c. machine.
3. Using damper winding.

Ques: Explain V-curves and Inverted V-curves.

Ans: "The curve plotted between field current (I_f) and armature current (I_a) is called V-curves". Figure (a) shows a typical V-curve at no-load, half-load and full load.

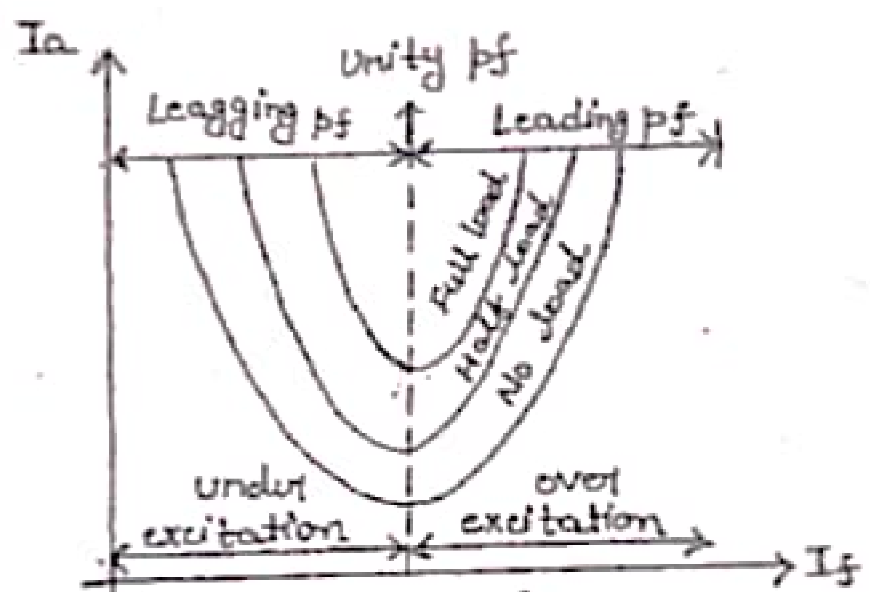
Effects are observed–

1) When the motor is under excited, the armature current and power factor is lagging. In this case, the motor behaves like an inductive load.

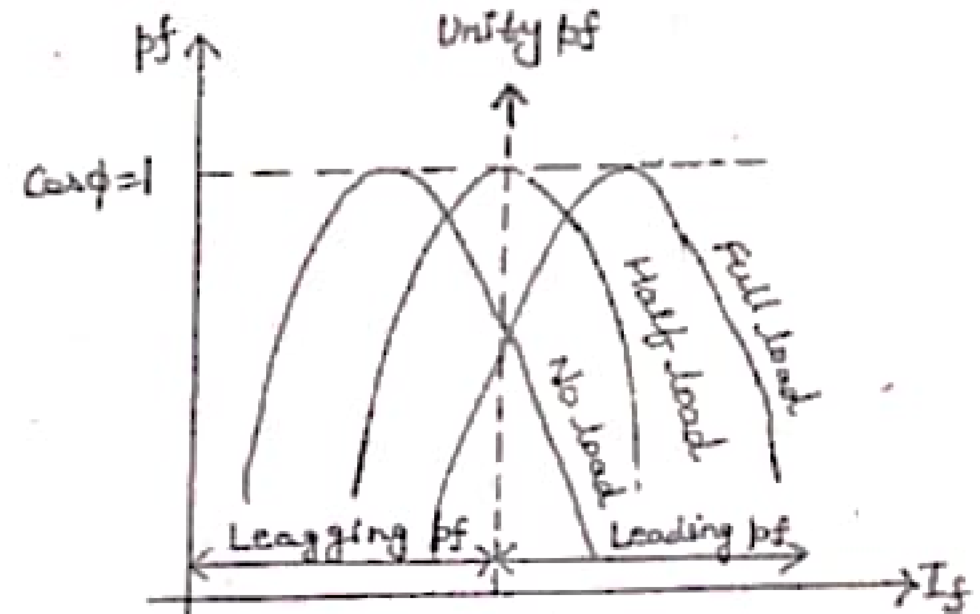
2) When the motor is normally excited, the power factor is unity. The armature current is minimum and is in phase with the terminal voltage.

3) When the motor is over-excited, the power factor is leading. In this case, the motor behaves like a capacitive load.

Curves obtained by plotting power factor against field current (I_f) at various load condition are called Inverted V-curves of synchronous motor. These curves are shown in the figure (b).



(a)



(b)

Ques: Write down the application of three phase synchronous motor.

Ans: Synchronous motors were mainly used in constant speed applications.

- Over excited synchronous motor can be used to improve the power factor.
- Synchronous motors are used to improve the voltage regulation of transmission lines.
- Synchronous motor only runs at synchronous speed, therefore it is used in textile, paper mill etc.
- Due to constant speed characteristics, it is used in:

a) Machine tools
b) Motor-generator set
c) Synchronous clocks.
d) Timing devices
e) Fans and blowers
f) Cement industries

Ques: Disadvantages of Synchronous Motor :-

Ans: a) It is not self starting

b) Its cost is higher as comparision to other motors.

c) It needs frequent maintenance.

d) Excitation ...

e) Auxiliary device or additional winding is necessary to make it self starting.

f) The construction of synchronous motor is more complicated than 3-phase Induction motor.

Ques: Comparision of Synchronous and Induction Motor.

Ans:

S.No	Particular	Synchronous Motor	Induction Motor
1.	Speed	Remains constant (i.e., N_s) from no-load to full-load.	Decreases with load.
2.	Power factor	Can be made to operate from Lagging to leading power factor	operates at lagging power factor.
3.	Excitation	Requires d.c. excitation at the rotor.	No excitation for the rotor.
4.	Economy	Economical for speeds below 300 r.p.m.	Economical for speeds above r.p.m.
5.	Self-starting	It is not a self starting motor. Auxiliary means have to be provided for starting.	Self-starting.
6.	Construction	Complicated	Simple.
7.	Starting torque	More	Less
8.	Cost and Maintenance	Motor is costly and required frequent maintenance.	Motor is cheap specially cage motors are maintenance free.
9.	Speed control	Speed control is not possible	Speed control is possible but difficult.

UNIT – 5th

(ELECTRICAL INSTALLATIONS)

Q.1 Write the short notes on;

(i) Service Mains OR Service line

(ii) Various types of cables used for Internal wiring

(iii) fuse units

(iv) MCB

(v) MCCB

(vi) ELCB

Ans :→ (i) Service Mains OR Service line :→ The overhead line or cable connecting the suppliers distributing line to the consumer is called service mains OR service line.

Service line are two type

(i) over head service line

(ii) Under ground service line.

(ii) Various type of cables used for Internal wiring :→

According to type of Insulation the cable are

(1) VIR (Vulcanized Indian Rubber) → conduct wiring

(2) TRS (Tough Rubber sheathed) → Moisture (220 – 400)V
OR
CTS (cab tyre sheathed)

(3) Lead sheathed cable → open area

(4) PVC (Poly vinyl chloride) → Temperature (250 – 400)V, (650 – 1000)V

(5) weather proof cable → A/c to weather

(6) Flexible cords & cable → Instruments

(7) XLPE cable - similar to PVC cable → Similar to PVC Cables

(8) Multi strand cable → Multi cables

(iii) fuse units :→ A fuse unit consists of the metal fuse element link, a set of contract b/w fixed and support body and Isolate them.

The various type of fuse unit are:

(1) Round type fuse unit
(2) kit-kat type fuse unit
(3) Cartridge type fuse unit
(4) HRC (High rupturing capacity) fuse unit
(5) Semi-Conductor fuse unit

(iv) MCB (miniature circuit Breaker) :→ MCB is mainly used for low Energy requirement. It is used 100A Current upto 160 A.

Ex Home wiring
Small electronic circuit

(v) MCCB (molded case circuit Breaker) :→ MCCB is mainly used for high energy requirement. It is used for 1000A Current upto 2500 A current.

Ex Indusdrial or Commercial
Electrical motor operator

(vi) ELCB (Earth-Leakage circuit Brecker) :→ It is a device that Provide Protection against earth leakage.
There are two type.

(1) Current operate type
(2) voltage operate type

Q.X2 write the short Note: on the following:

(1) Types of Batteries
(2) characteristics of Lead acid Accumulator
(3) Nickel metal hybride cells
(4) Power factor Correction (Improvement)

$\boxed{\text{Size} \propto I}$ $\boxed{\text{Material} \propto V}$

Ans:→ (1) Types of Batteries :→ There are two type of Batteries

(1) Primary Battery
(2) secondary Battery
1. Lead Acid Automotive Batteries
2. Nickel Iron (Edison) Batteries
3. Nickel cadmium Accumulators
4. Nickel metal Hybride cells.

(2) characteristics of Lead Acid Accumulator :→ There are three Improtant characteristics of Lead Acid Accumulator

(1) Voltage (2) capacity (Back up) (3) efficiency

(i) voltage :→ Average emf. of cell is approximate to E.m.f is increase specific Gravity increase

(ii) Capacity (Back up) :→ The ability of an Accumulator to last and Provide current is called rated output is also called Back up (capacity)

(iii) efficiency (η_{AH}) :→ It is the ratio of Ampere hours of discharge to Ampere hours of charge.

$$\% \eta_{AH} = \frac{\text{Ah of discharge}}{\text{Ah of charge}} \times 100$$

$$\% \eta_{AH} = \frac{I_d \times T_d}{I_c \times T_c} \times 100$$

(3)

(3) Nickel Metal hybride cell :→ Nickel metal hybride cell are small package high power cells. Its construction same as present nickel cadmium cells.

Charging of cells:

$$Alloy + H_2O + e^- \rightarrow Alloy(H) + OH^-$$

Discharging of cells:

$$Alloy(H) + OH^- \rightarrow Alloy + H_2O + e^-$$

(4) Power factor correction (Improvement) :→ Power factor Improvement either passive and active circuit. It is used of Top switch family of three PWM (Pulse width modulation). Power factor correction using 17 component output power 150 watt.

Q X3 What is MCCB and How does it differ from MCB? Explain its operating mechanism.

Ans: MCCB stands for molded case circuit breaker. MCCB has higher capacity then MCB. MCB is mainly used for low energy requirement just like house wiring or small electronic circuit. But MCCB is used for high energy requirement. It is used for Industrial and electrical motor. operator etc.

Operating mechanism of MCCB :→ MCCB is based on the principle of all type of thermal magnetic circuit breaker. "Whenever a fault occurs, the high current induces a magnetic field inside the breaker this magnetic induction trips a contract and current is Interrupted. MCCB have internal Arc dissipation measure to facilitate Interruption."

Q X4. Describe the various types of wire or cables usually used in Internal wiring of Building.

Ans Types of wire and cables :→ The internal wiring of building may be divided into different.

(1) Conductor
(2) Number of core used
(3) voltage grading
(4) types of Insulation used

(1) Conductor →
- 1. Copper conductor cable
- 2. Aluminium conductor cable

(2) Number of core used →
- 1. Single core cable
- 2. twin core cable
- 3. three core cable
- 4. ECC (Earth continuity conductor)
- 5. Double core cable

(3) Voltage grading →
- 1. 250/440 volts cable
- 2. 650/1100 volts cable.

(4) type of Insulation used →
- 1. VIR (Vulcanized Indian Rubber)
- 2. TRS (Tough Rubber sheathed) or CTS (cab tyre sheathed)
- 3. Lead sheathed cable
- 4. PVC (Poly vinyl chloride)
- 5. Weather proof cable.
- 6. Flexible cords & cable.
- 7. XLPE cable
- 8. Multi strand cable

Q×5 Draw the wiring diagram, schematic diagram, single line diagram, one light, one ceiling fan with Regulator and 5A 3 pin plug point each controlled by Individual switches.

Ans :

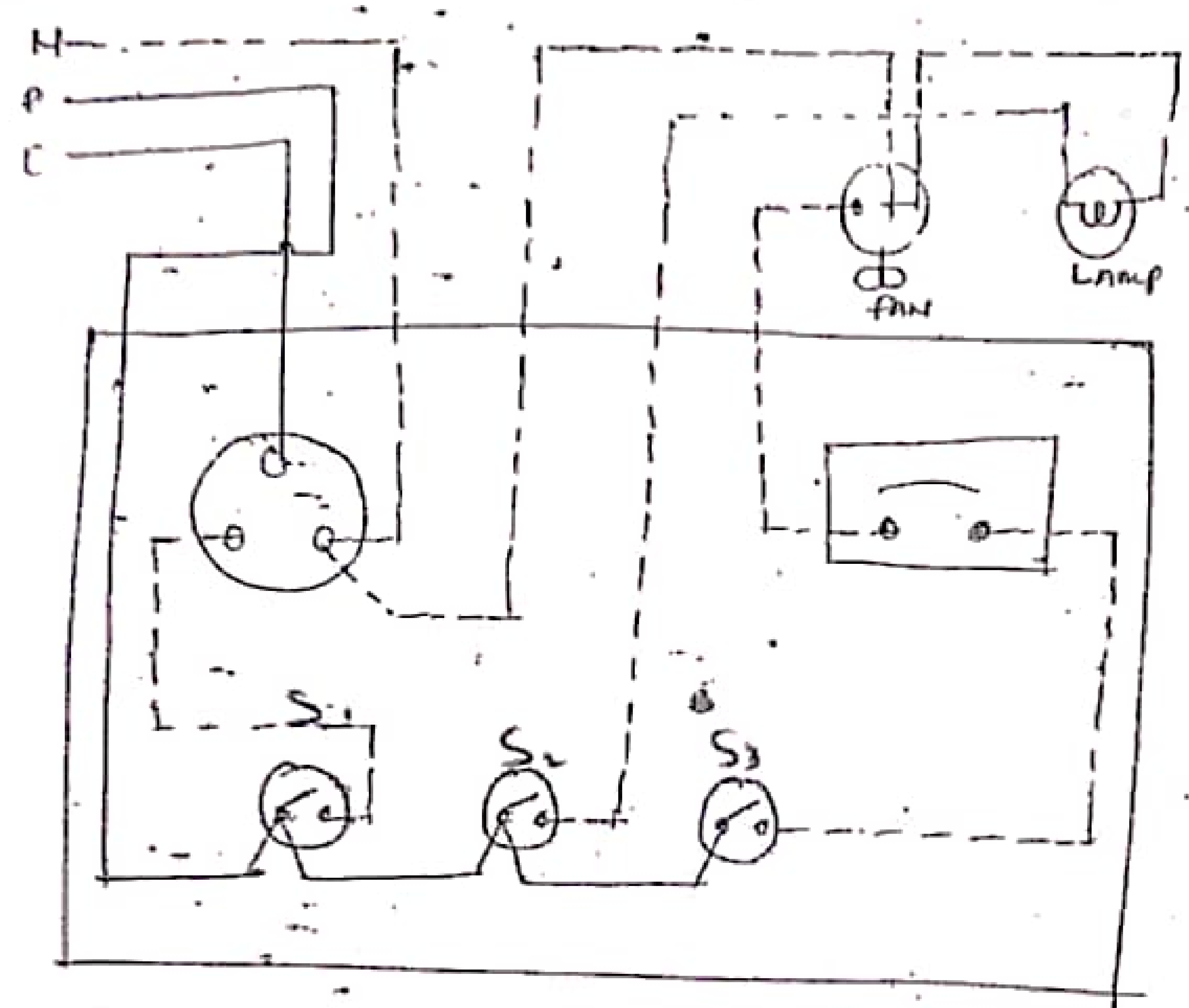


Fig. One Lamp, one fan & one Socket outlet controlled by Individual Switches.

Q×6 What is Switch fuse Unit? Describe any switch fuse unit with neat Diagram.

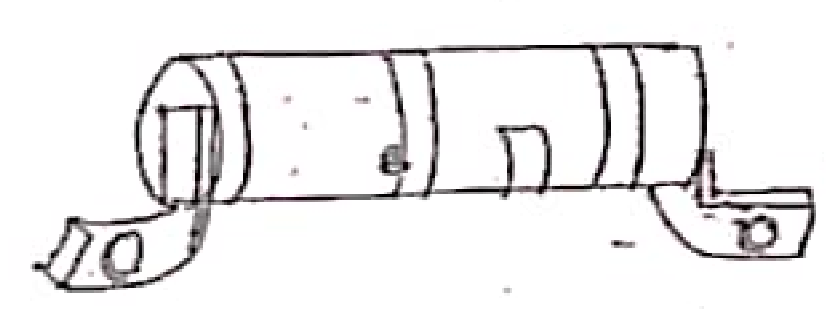
Ans : fuse Unit :→ A fuse unit consist of the metal fuse element link, a set of contact b/w fixed and support body and Isolate them.

The various type of fuse Unit are
(1) Round type fuse unit
(2) kit-kat type fuse unit
(3) Cartridge type fuse unit
(4) HRC (High rupturing capacity) fuse unit
(5) Semi conductor fuse unit.

(1) Round type fuse unit :→ This type of fuse ... of Porcelain or Bakelite box and two separated terminal for holding the fuse wire b/w them. This type of fuse is not in common use Because :... some disadvantage.

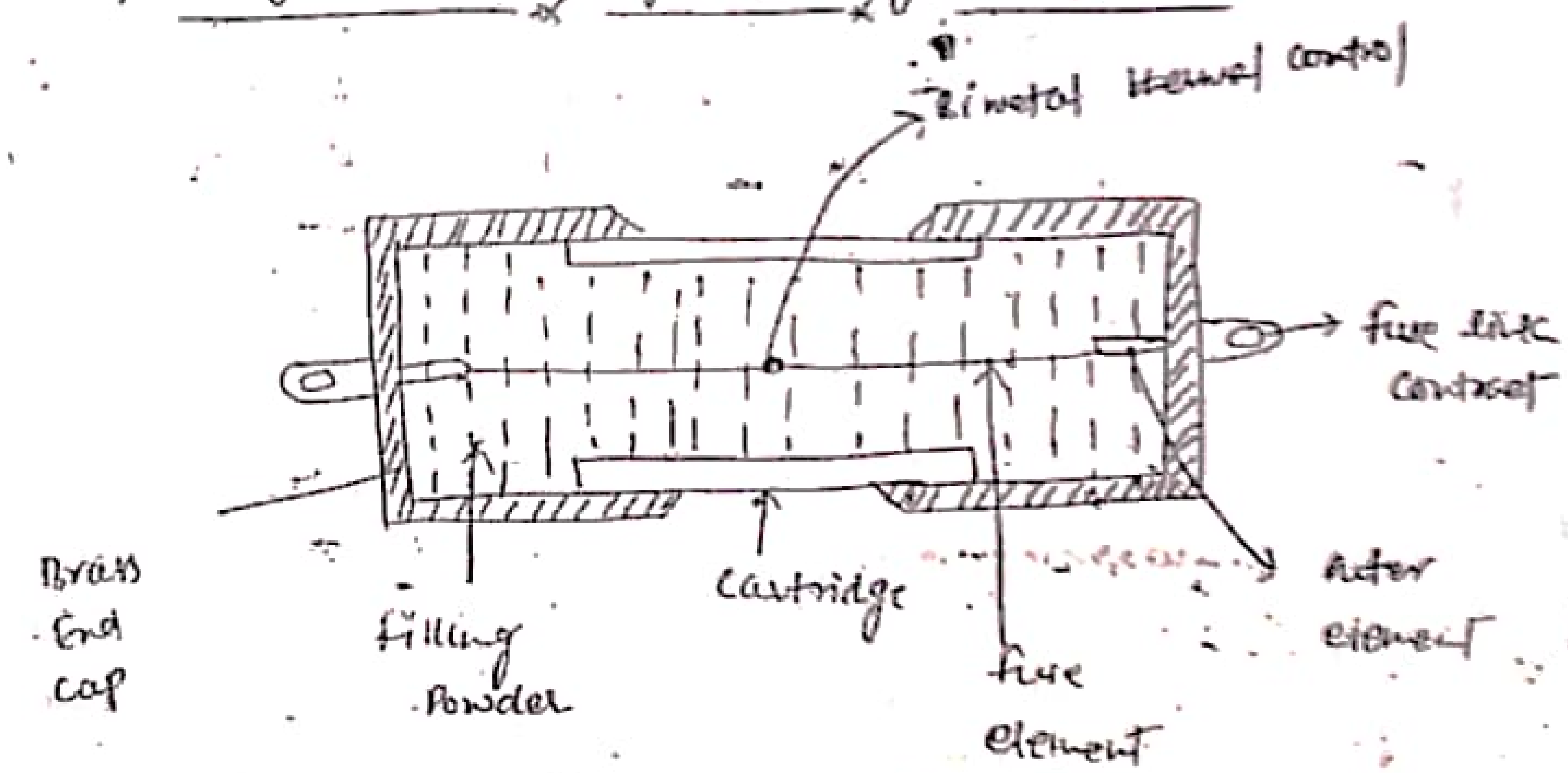
(i) one of terminal always energised for replacement of fuse either the worker will touch line wire and open the main switch.

(2) Cartridge type Fuse :→ It essentially consists of an Insulating container of ... or tube shape & sealed with Metallic cap known as Cartridge fuse.



There are various type of material used as filler like sand, calcium carbonate, Quartz etc. This type of fuse is available upto 660 V & 800A current.

(3) High Rupturing Capacity (HRC) fuse :→



"A very heavy Generating capacities of the modern Power Station, heavy current flow into the fault & fuse clearing the fault would be required. HRC fuse common used. It is capacity 500 MVA upto 66 KV & above.

The most advantage are -

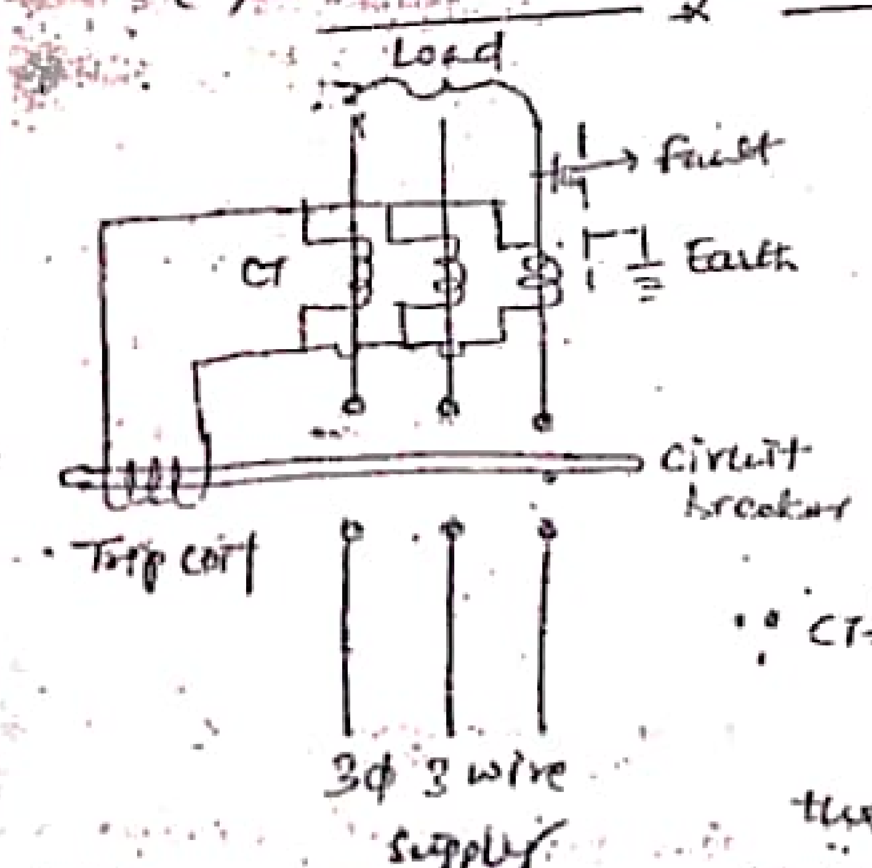
(i) No maintenance is required
(ii) The operation is quick & sure.
(iii) They are cheaper as other types of circuit
(iv) It is used clearing high as well as low current.

Q.7 What is ELCB? Draw their circuit diagram and Explain their working.

Ans: Earth-Leakage circuit Breaker (ELCB) :→ It is a device that provide protection against earth leakage. There are two type ELCB.

(1) Current operated type ELCB
(2) voltage operated type ELCB

(1) Current operated type ELCB :→ Current operated earth leakage circuit breaker is used when the product of the operating current in Ampere and the earth loop impedance in ohm does not exceed 40Ω. There CB is used



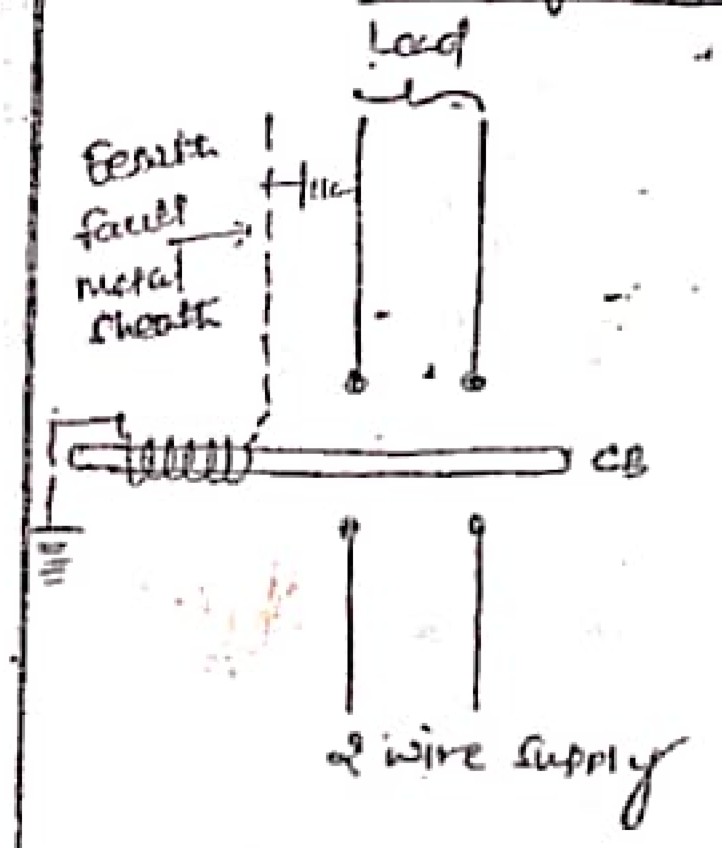
∵ CT = Current transformer

In Normal condition when there is no earth leakage the Algebraic sum of all the current in three coil & CT is zero. and no current flow through the trip coil.

In case any earth leakage the current are unbalanced an trip coil is energized and thus trip the circuit Breaker.

(2) Voltage operated type ELCB :→ Voltage operated earth leakage CB is suitable for use when the earth loop impedance exceed the value to the fuse or excess current in the CB.

When the voltage b/w the ECC (earth continuity conductor) and earth electrode rise to a sufficient value. the trip coil carry the current and trip to the CB.



Q.8 What is MCB (miniature circuit Breaker)? Explain its function and working with neat diagram.

Ans:- Miniature Circuit Breaker (MCB) :→ It is a device that provide protection to the wiring against over current and short circuit fault.

Working :→ "A short circuit the increase current energized the solenoid, operating the plunger to strike the trip and released of the latch mechanism."

Miniature Circuit Breaker (MCB) are available current rating 0.5, 1, 2, 2.5, 3, 4, 5, 6, 7.5, 10, 16, 20, 25, 32, 35, 40, 63, 100, 125, 160A

The voltage rating 240/415V upto 220V DC.

Application :→ It is used to protection equipment AC, computer & Refrigerator etc.

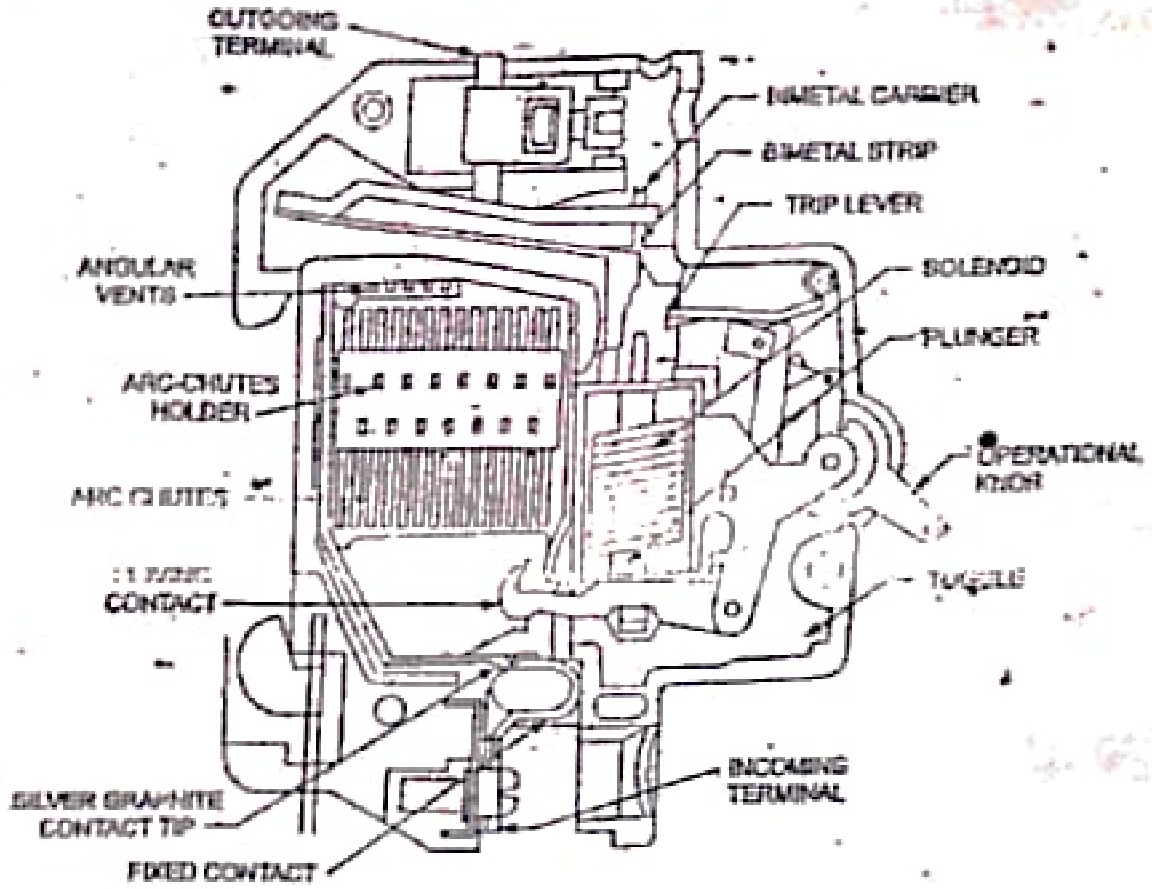


Fig.(1) *Miniature Circuit Breaker (Courtesy Havells)*

Qx9 : What is Earthing? Explain the Purpose of Earthing.

Ans : Earthing :→ The Earthing of electrical Equipment taking the equipment to zero potential & Avoid the Shock to the operator under fault condition.

Purpose of Earthing :→ The Earthing is Provided

(1) To avoid electric shock to the human being.
(2) To avoid Risk of fire due to earth leakage current.
(3) To protect all the m/c.
(4) To main line voltage constant.

Qx10 : Explain Advantage of Earthing & Grounded Neutral supply.

Ans : The following advantage are :

(1) It is very easy for Earth fault protection.
(2) Spikes include the lighting & switching in voltage.
(3) Let stresses on Insulation, If there is Earth fault else where.

Qx11 : Explain the Necessity of Earthing?

Ans : Necessity of Earthing :→ The resistance b/w the windings and the frame is say (R_i) called Insulation resistance and (R_{body}) be the resistance of a Person who happens to touch the machine.

$$I_{body} = \frac{V}{R_i + R_{body} + R_E}$$

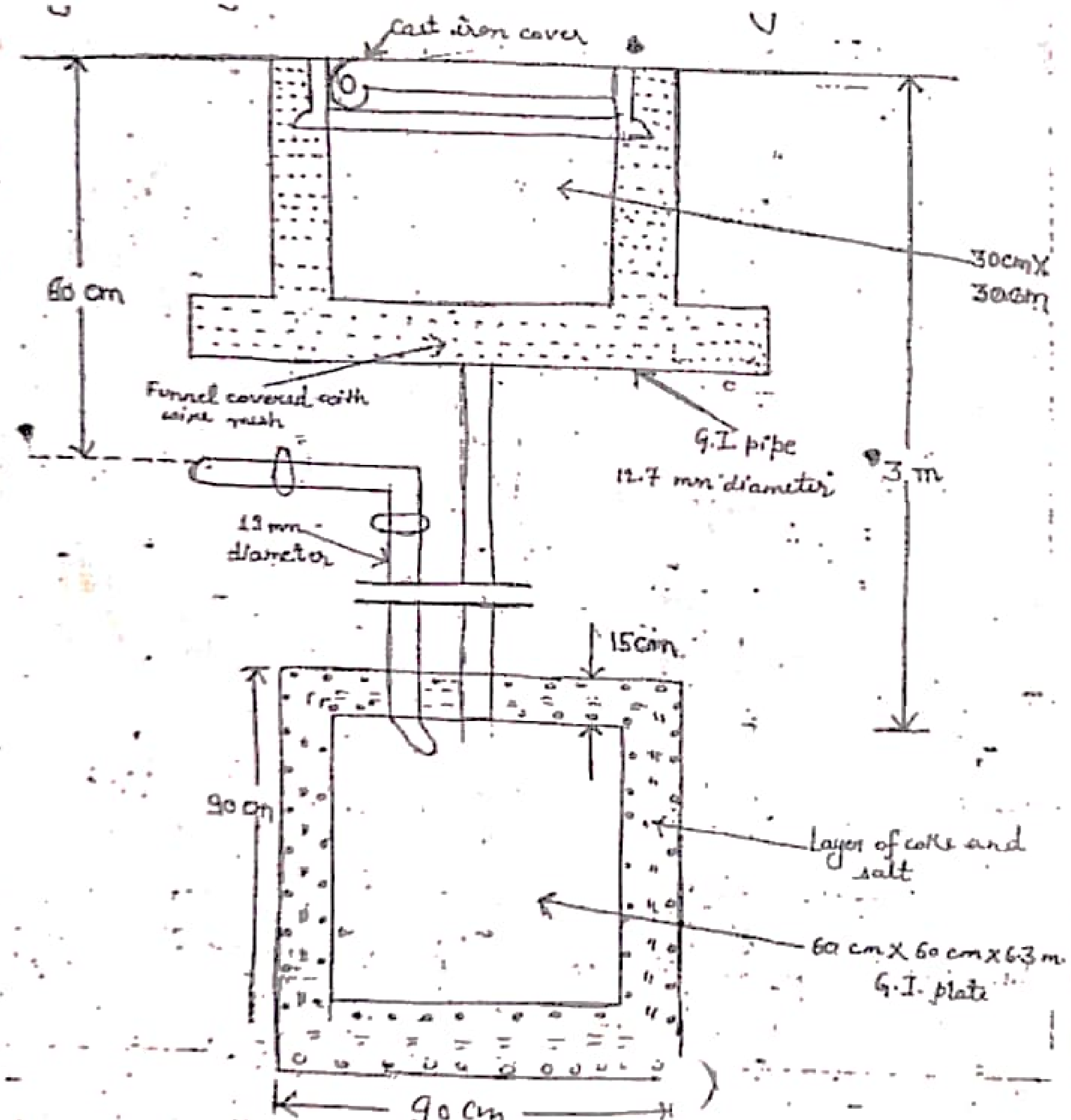
Qx12 : Explain various method of Earthing and Explain Plate & Pipe Earthing. Discuss the Merits & Demerits.

Ans : The various method of Earthing are :

(1) Plate Earthing.
(2) Pipe Earthing
(3) Earthing through water main
(4) Horizontal Strip Earthing.
(5) Rod Earthing.

(1) Plate Earthing :→ The copper plate size is 60 cm × 60 cm × 3.18 mm while G.I plate size is not less than 60 cm × 60 cm × 6.3 mm. the G.I plate are commonly used now-a-day the plate is embeded 3 meter (10 feets) into grounded.

The Earth wire is drawn through G.I pipe of 19 mm diameter about 60 cm below the ground. The Earthing efficiency increase with increase the plate area and depth of embedding. If the Resistivity of the soil is high.



(2) Pipe Earthing : In this method of Earthing a G.I pipe of 38 mm diameter and 2.75 meter (7 feet) length is embedded vertically into the ground. This pipe act as an Earth electrode. The depth depends on the condition of the soil.

The pit area around the pipe is filled with salt and coal mixture for improving the condition of the soil and earthing efficiency.

According to the Indian standard, the pipe should be placed at a depth of 4.75 m.

Advantage :→ The advantage of the pipe earthing over the plate earthing. The Earth lead used must be G.I wire of sufficient cross-sectional area to carry fault current safely. It should not be less than of copper conductor of 12.97 mm² cross sectional area.

Disadvantage :→ Pipe earthing is that the embedded pipe length has to be increased sufficiently in case the soil specific Resistivity is high order. The increase the excavation work and hence increased cost. In ordinary soil condition the range of the earth resistance should be 2 to 5 ohm.

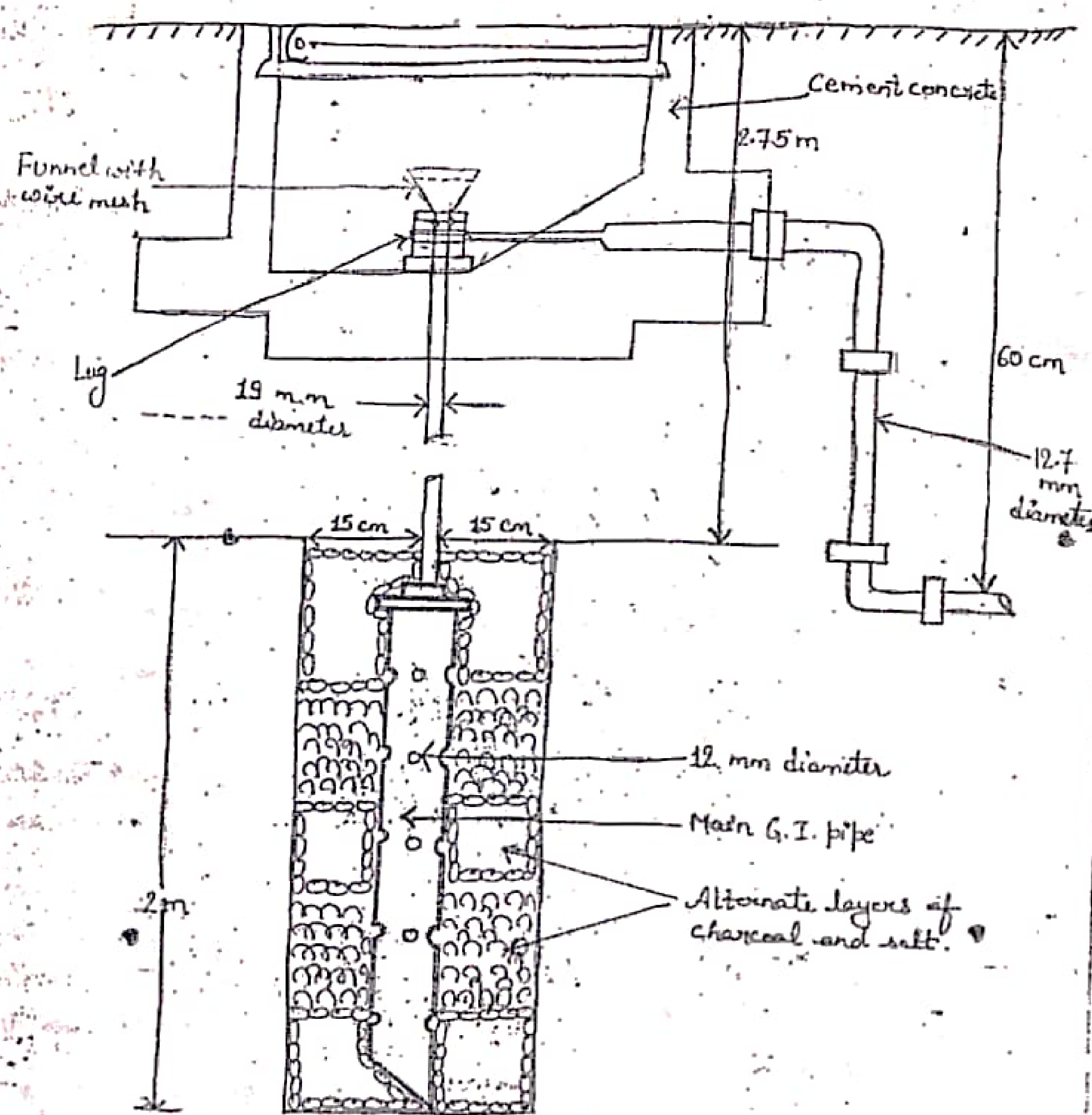


fig: Pipe earthing.

Qx: A battery has taken a charging current of 5.2 A for 24 hours at a voltage of 2.25 V, while discharging it gave a current of 4.5 A for 24 Hours at an Average voltage of 1.05 V. Calculate the quantity efficiency and the energy efficiency of the Battery.

Ans:

Charging Current $I_c = 5.2\ A$

Charging mean voltage $V_C = 2.25\ V$

Charging Period $T_c = 24$ Hours

Discharging Current $I_d = 4.5\ A$

Discharging Mean voltage $V_d = 1.05\ V$

Discharging Period $T_d = 24$ Hours

Quantity efficiency % $\eta_{AH} = \frac{I_d T_d}{I_c T_c} \times 100$

$= \frac{4.5 \times 24}{5.2 \times 24} \times 100$

$= 86.54\ \%$ Ans

Energy efficiency $\eta_{WH} = \frac{I_d T_d}{I_c T_c} \times \frac{V_d}{V_c} \times 100$

$= \frac{4.5 \times 24}{5.2 \times 24} \times \frac{1.05}{2.25} \times 100$

$= 71.15\ \%$ Ans

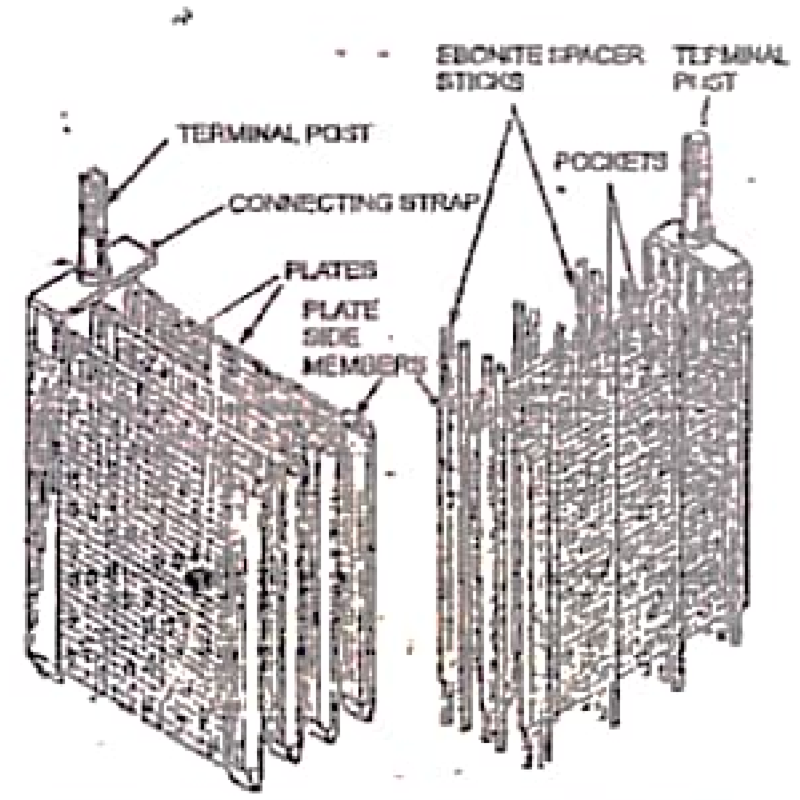
Qx: Give the construction, characteristics, Advantage, Disadvantage & Application of
(i) Nickel-Iron (Edison) Batteries (ii) Lead Acid
(iii) Nickel - Cadmium cell

Ans:(i) Nickel - Iron (Edison) Batteries :→

Active Material :→ The +ve plate consist of $Ni(OH)_2$ or (NiO_2) about 17% of Graphite is added to increase the conductivity and about 2% added Barium hydrooxide.

The -ve plate consist of FeO & $Fe(OH)_2$ and small amount of Nickel Sulphate and ferrous sulphide about 20% of KOH & more added (NiO_2)

Construction :→ The vessel containing the electrolyte & electrode is made of Nickel plate with welded Lid the -ve plate is one more than +ve plate. plate same polarity with their pocket fitted.



(a) Positive Plate Group (b) Negative Plate Group

Fig. Nickel - Iron (Edison) Batteries.

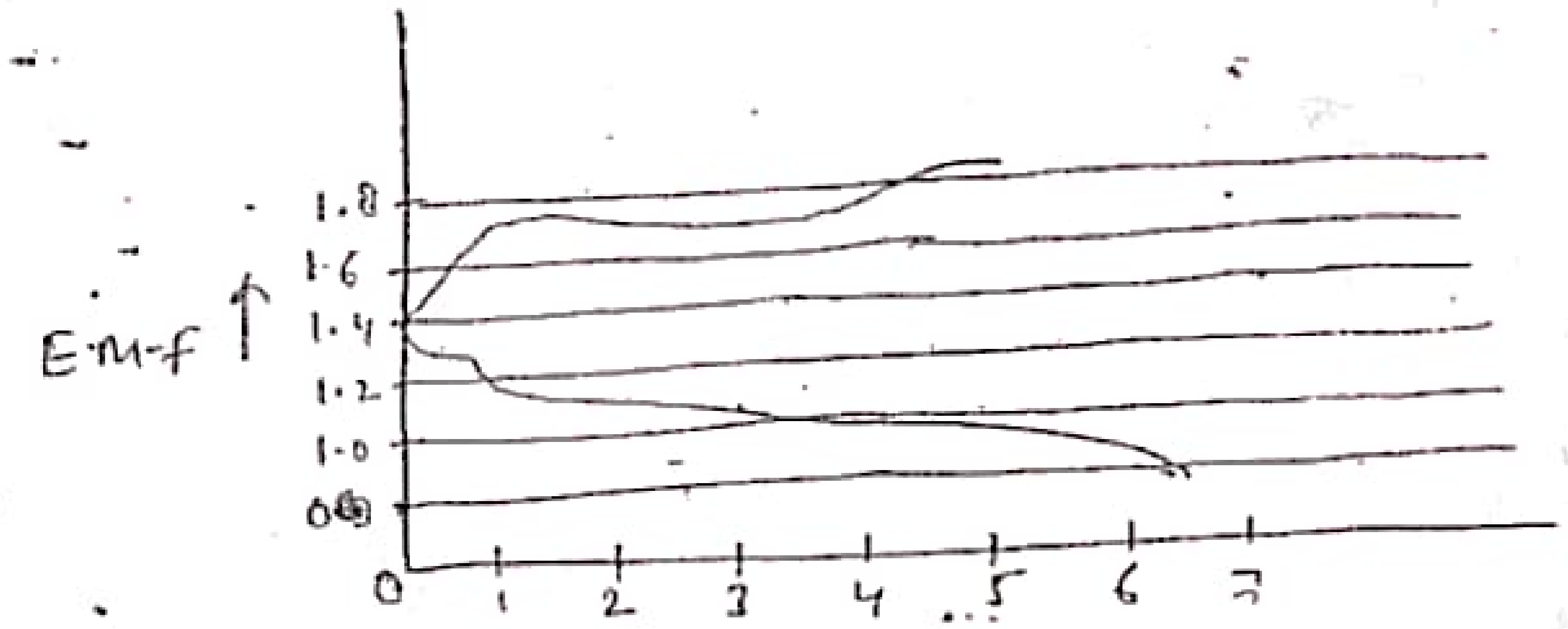
Operation :→

Charging Condition.

$$2\,Ni(OH)_3 + 2KOH + Fe \rightleftharpoons 2\,Ni(OH)_2 + 2KOH + Fe(OH)_2 +$$

(+ve plate) (-ve plate) (+ve plate) (-ve plate) Electrical Energy

Electrical characteristics :→



charge & Discharge Hour →

Advantage :→

(1) They have a long service life.
(2) They have rugged construction
(3) they need little maintenance.

Disadvantage :→

(1) High Initial cost
(2) High Internal resistance
(3) Lower E.M.F
(4) Low operating efficiency

Application :→

(1) Industrial trucks
(2) Mine locomotive
(3) Railways