BEE

Basic Electrical and electronics Engineering

Voltage:

The difference in potential energy of the charges is called potential difference. Potential difference in electrical terminology is known as voltage which is denoted by V or v. It is expressed as,

$$V = \frac{W}{Q} \text{ (or) } v = \frac{dw}{dq}$$

where dw represents a small change in energy and dq represents a small change in charge.

The energy is expressed in joules, charge in coulombs and the voltage in volts.

One volt is defined as the potential difference b/w two points when one joule of energy is used to move one coulomb of charge from one point to another.

Current:

In all semiconductors and conductive materials, free electrons are present. These electrons move at random in all directions. This movement of electrons from one end of the material to the other end is known as electric current denoted by I or i and is expressed as

$$I = \frac{Q}{t} \text{ (or) } i = \frac{dq}{dt}$$

where dq represents a small change in charge and dt represents a small change in time.

Current is defined as the rate of flow of electrons in a conductive (or) semiconductive material is called current in ampere (A).

Energy: (W)

Energy is defined as the capacity of a body for doing work. Energy may exist in many forms like mechanical, chemical.

Energy is measured in joules (J).

Power:

Power is defined as the rate of change of energy and is denoted by P or p

$$P = \frac{energy}{time} = \frac{w}{t} \text{ (or) } p = \frac{dw}{dt}$$

where dw represents a change of energy and dt represents a small change in time. It can also be written as

$$p = \frac{dw}{dt} = \frac{dw}{dq} \times \frac{dq}{dt}$$

$$= v \times i = vi \text{ watts} (w)$$

By defination one watt is the amount of power generated when one joule of energy is consumed in one second. Thus, the number of joules consumed in one second is always equal to the number of watts.

Ohm's Law:

Ohm's Law states that at constant temperature the current flowing through a conductor is directly proportional to the voltage applied across the terminals of the conductor. It can be written as

$$I \propto V$$

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

where 'R' is the resistance of the conductor.

What is the power in watts if energy equal to 50J is used in 2.5s?

$$P = \frac{energy}{time} = \frac{50}{2.5} = 20w$$

If 70J of energy is available for every 30C of charge, what is the voltage

$$V = \frac{W}{Q} = \frac{70}{30} = 2.33V$$

Five columbs of charge flow past a given point in a wire in 2s. What is the current.

$$I = \frac{Q}{t} = \frac{5}{2} = 2.5A$$

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→ Network:

The interconnection of different elements like resistors, voltage sourceses, inductors is called as an electric network.

→ Circuit:

simply an electric circuit consists of three parts (1) energy source, such as battery (or) generator (2) the load or sink, such as lamp or motor and (3) connecting wires. This arrangement represents a simple circuit.

Types of elements:

1. Active and passive elements
2. Unilateral and Bilateral elements
3. Linear and Non-Linear elements
4. Lumped and Distributed elements.

Active and passive elements:

Active: The elements which have the capability of delivering power to some external device are known as active elements.

Ex: Energy sources such as voltage source and current source.

Passive:

The elements that are only capable of receiving power are known as passive elements. some passive elements such as inductors and capacitors are capable of storing energy and delivering it to an external element later.

Bilateral and Unilateral elements.

Bilateral:

The elements in which the voltage-current relation is the same for current flowing in either direction are called as bilateral elements.

Ex: High conductivity materials like copper etc.

Unilateral:

The elements which have different relations between voltage and current for two possible directions of current are called unilateral elements.

Ex: Vacuum diodes, silicon diodes.

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Linear and Non-Linear Elements:

Linear:

An element in which the voltage-current characteristics form a straight line passing through the origin is called a linear element.

Ex: The current passing through a resistor is proportional to the voltage applied through it.

Non-Linear:

An element in which the voltage-current characteristics are not in the form of a straight line passing through the origin is called non-linear element.

Ex: Inductors, capicitors.

Lumped or Distributed elements:

Lumped:

The elements which are small in size and in which simultaneous actions take place for any cause at the same instant of time are called lumped elements.

Ex: Capacitors, resistors etc.

Distributed elements:

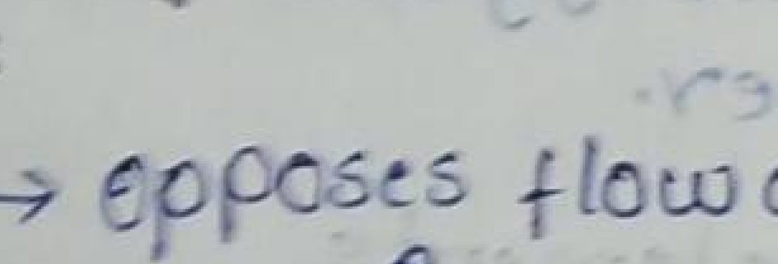
Those which are not electrically separable for analytical purposes.

Ex: A transmission (wires) line which has distributed resistance, inductance, and capacitance along its length may extend for hundreds of miles.

Basic circuit components (R, L, C)

1. Resistor (R):

Resistance → opposes flow of electrons

symbol: 

units: ohm

$V \propto I \Rightarrow \boxed{V = IR}$

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

$P = VI$
$= V \times \frac{V}{R} \Rightarrow \frac{V^2}{R}$ $\boxed{P = \frac{V^2}{R}}$

$P = VI$
$= IRI$
$\boxed{P = I^2R}$

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$P = \frac{dw}{dt}$

$dw = P.dt$

Integrating on b.s

$\int dw = \int P dt$

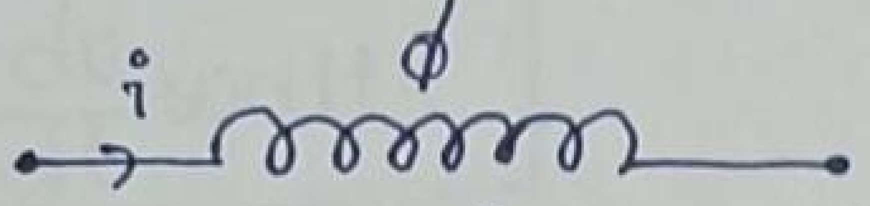
$$\boxed{w = Pt = i^2 R t \text{ (or) } \frac{v^2}{R} t}$$

Inductor (L):

→ stores energy in the form of electromagnetic (flux) field

→ it opposes sudden changes occur in the current flowing through it.

symbol:



$v \rightarrow$ emf induced

unit: Henry (H)

Faradays Laws:

I Law:

whenever flux linking coil changes the emf is induced.

$L = \frac{N\phi}{i}$

N = No. of turns of coil

ϕ = flux

v - i relation

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

$v = L\frac{di}{dt} \Rightarrow di = \frac{1}{L} v dt$

Integrating

$\int di = \int \frac{1}{L} v dt$

$\int di = \frac{1}{L}\int v dt$

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

$\int_0^t di = \frac{1}{L}\int_0^t v dt$

$i(t) - i(0) = \frac{1}{L}\int_0^t v dt$

$i(t) = \frac{1}{L}\int_0^t v dt + i(0)$

$i(0)$ → initial current in coil

$i(t) = \frac{1}{L}\int_0^t v dt$

$v = L\frac{d\phi}{dt}$ $v = L\frac{di}{dt}$

$\frac{1}{L}\int v dt = di$

$i(t) = \frac{1}{L}\int v dt$

$P = vi = \left(L\frac{di}{dt}\right)i = Li\frac{di}{dt}$

$\boxed{P = Li\frac{di}{dt}}$ watts

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

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

$P = Li\frac{di}{dt}$

$\boxed{W = \frac{Li^2}{2}}$

Energy stored by inductor

$W = \int P\,dt$

$= \int Li\frac{di}{dt}\cdot dt$

$= L\int i\,di$

$\boxed{W = L\cdot\frac{i^2}{2}}$

conclusion:

Inductor acts as short circuit (DC supply)

O.C $\rightarrow$ I = 0, V = max

S.C $\rightarrow$ V = 0, I = max

It is a passive element.

Problem:

The current in a 2H inductor varies at a rate of 2 A/s. Find voltage across the inductor and energy stored in the magnetic field after 2 sec.

$V = L\frac{di}{dt} = 2\cdot 4 = 8V$

$\frac{di}{dt} = 2$

$di = 2\times 2$

$i = 4$

$W = \frac{Li^2}{2} = \frac{\cancel{(2)}(4)^2}{\cancel{2}} = 16$ Joules

Problem:

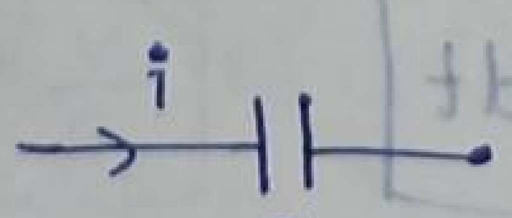
A 10Ω resistor is connected across a 12V battery. How much current flows through the resistor

$I = \frac{12}{10} = \frac{V}{R}$

$I = 1.2\,A$

Capacitor (c):

$C = \frac{Q}{V}$



stores energy in the form of electric field

$c = \frac{Q}{V}$

$i\,dt = C\,dV$

$\int i\,dt = \int C\,dV$

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

$i = C\frac{dV}{dt}$

units: Farads

Voltage across capacitor,

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

$$\frac{dv}{dt} = \frac{1}{c} i$$

$$\boxed{i = c\frac{dv}{dt}}$$

$$i\,dt = c\,dv$$

$$\frac{i}{c} dt = dv$$

$$\frac{1}{c} i\,dt = dv$$

$$\frac{1}{c}\int i\,dt = \int dv$$

$$\boxed{v = \frac{1}{c}\int i\,dt}$$

$$c = \frac{q}{v}$$

$$q = cv \qquad i = \frac{dq}{dt}$$

$$i\,dt = cv$$

$$\int i\,dt = \int c\,dv$$

$$\boxed{\frac{1}{c}\int i\,dt = v}$$

Power $= vi$

$$\boxed{P = v \cdot c\frac{dv}{dt} \text{ watts}}$$

$$E \text{(or)} W = \int P\,dt = \int cv \cdot \frac{dv}{\cancel{dt}} \cancel{dt}$$

$$\boxed{E = \frac{cv^2}{2}}$$

conclusion:

Dc supply means the flow of current is constant

$O.C \rightarrow I = 0$

* energy storing element (electric field)
* non-dissociative passive element

1. A capacitor having capacitance of 2μfarad. It is charged to a voltage of 1000v. Calculate the stored energy in joules

$$E = \frac{cv^2}{2} = \frac{2\times10^{-6}\times(1000)^2}{2} = 10^{-6}\times10^{6} = 1\,J$$

2. Determine the current for the following cases

(i) 75 columbs in 1s $\quad I = q/t = 75/1 = 75\,A$

(ii) 5c in 2s $\quad I = q/t = 5/2 = 2.5\,A$

(iii) 10 c in 0.5sec $\quad I = q/t = 10/0.5 = 20\,A$

3. A 100 ohm resistor is connected across the terminal of a 2.5v battery then what is the power despiation in the resistor.

$$P = \frac{V^2}{R} \Rightarrow \frac{2.5\times2.5}{100} = 0.0625 \text{ watts}$$

4. How much energy is stored by 100mH inductance with current of 1A. $\quad W = \frac{Li^2}{2} = 100\times\frac{1}{2}\times10^{-3} = 0.05$ Joules

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5. Determine the charge when $c = 0.001\mu F$ and $v = 1k$ volts

$c = \frac{Q}{v}$

$Q = cv = 0.001 \times 10^{-6} \times 1 \times 10^{+3}$

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

$= 10^{-6}$

$= 1\mu$coloumbs

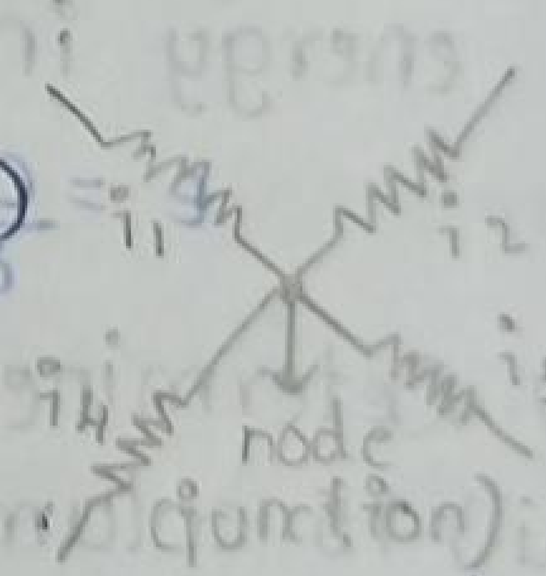
	Resistor (R)	Inductor (L)	capacitor (C)
voltage (v)	$v = iR$	$v = L\frac{di}{dt}$	$v = \frac{1}{c}\int i\,dt$
current (i)	$i = \frac{v}{R}$	$i = \frac{1}{L}\int v\,dt$	$i = c\frac{dv}{dt}$
Power (P)	$P = i^2R$ $P = \frac{v^2}{R}$	$P = Li\frac{di}{dt}$	$P = cv\frac{dv}{dt}$
Energy E (or) ω	$E = \left(\frac{v^2}{R}\right)t$ $E = i^2Rt$	$E = \frac{Li^2}{2}$ $E = \frac{1}{2}Li^2$	$E = \frac{1}{2}cv^2$

Kirchhoff's Laws:

Kirchhoff's current Law: (KCL)

Kirchhoff's current law states that the algebraic sum of currents at a node is zero. $\Sigma i = 0$

This is also called as Junction node (or) law of conservation of charge.

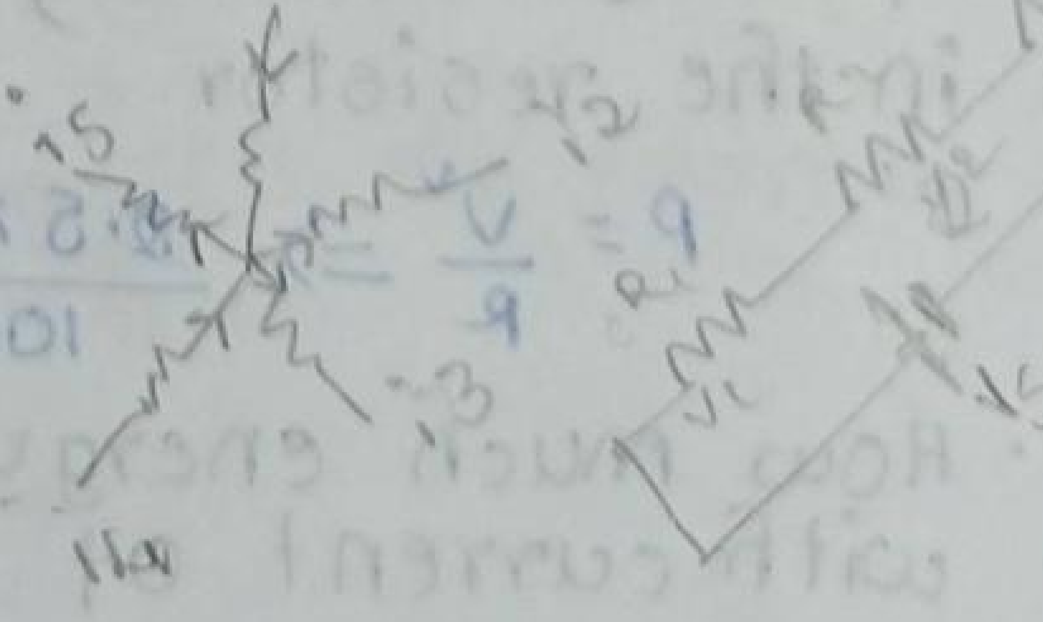


(or)

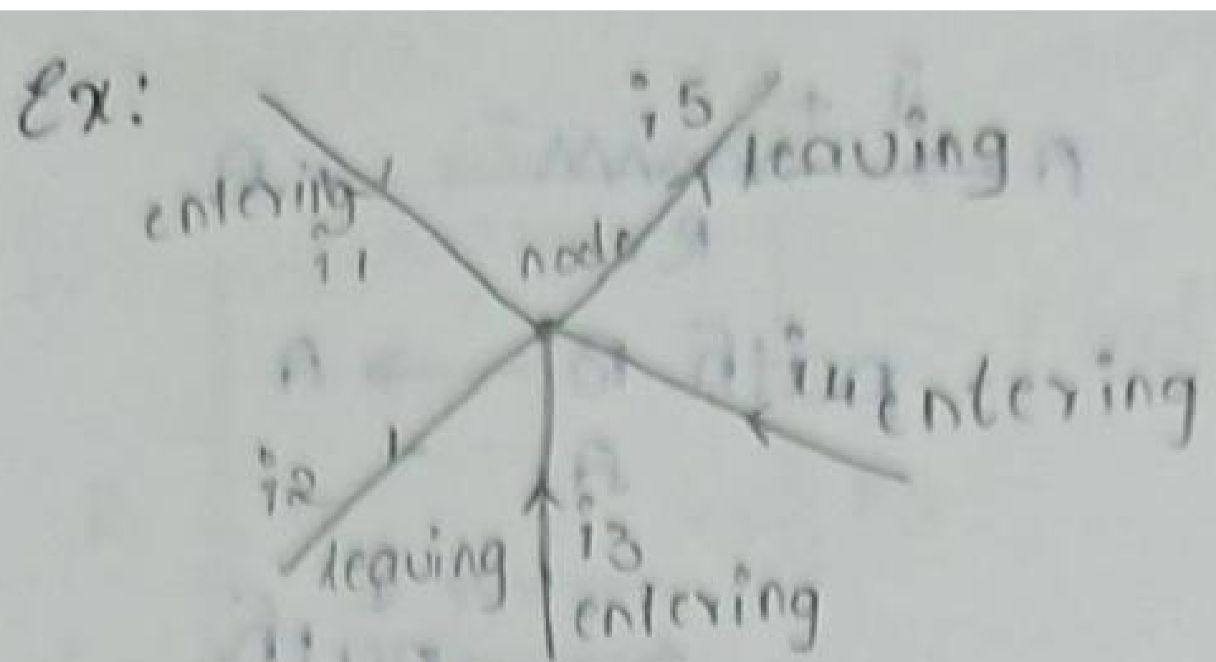
sum of currents entering a node = sum of currents leaving the node

considering entering current (i_1, i_3, i_4) are positive sign

considering leaving current (i_2, i_5) as negative sign



Ex:

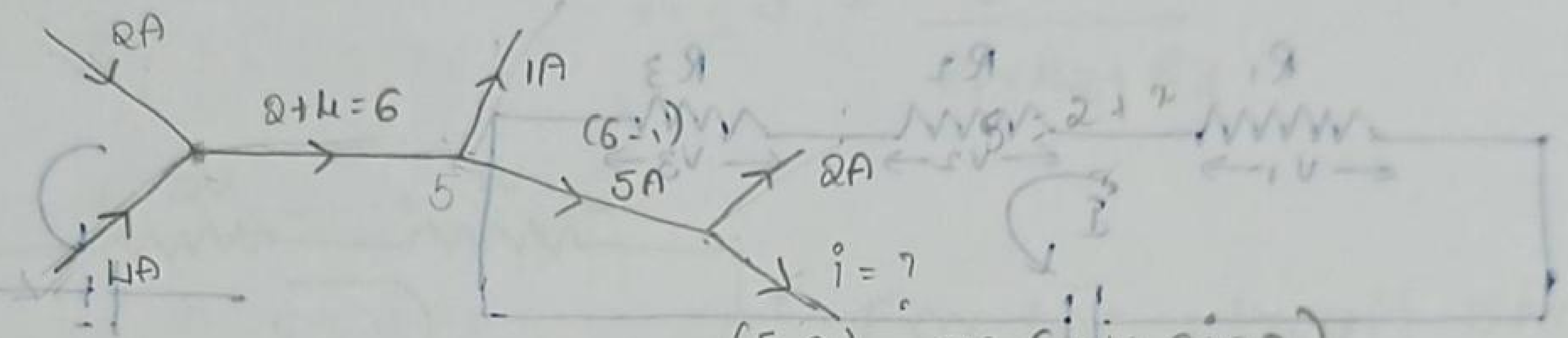


$$i_1 - i_2 + i_3 + i_4 - i_5 = 0$$

$$\underbrace{i_1 + i_3 + i_4}_{\text{entering currents}} = \underbrace{i_2 + i_5}_{\text{leaving currents}}$$

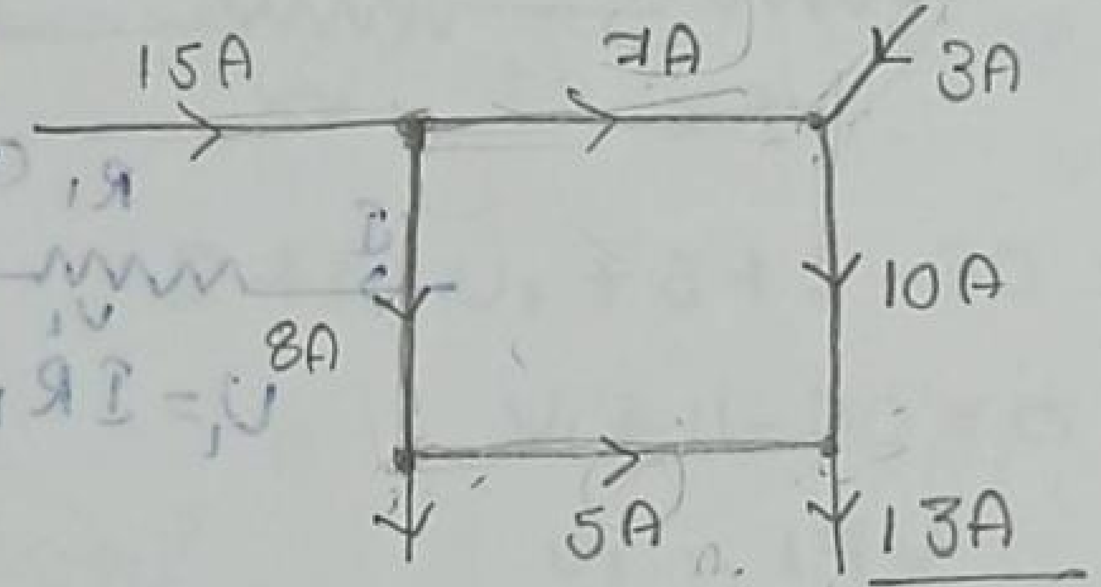
Problems:

(i)



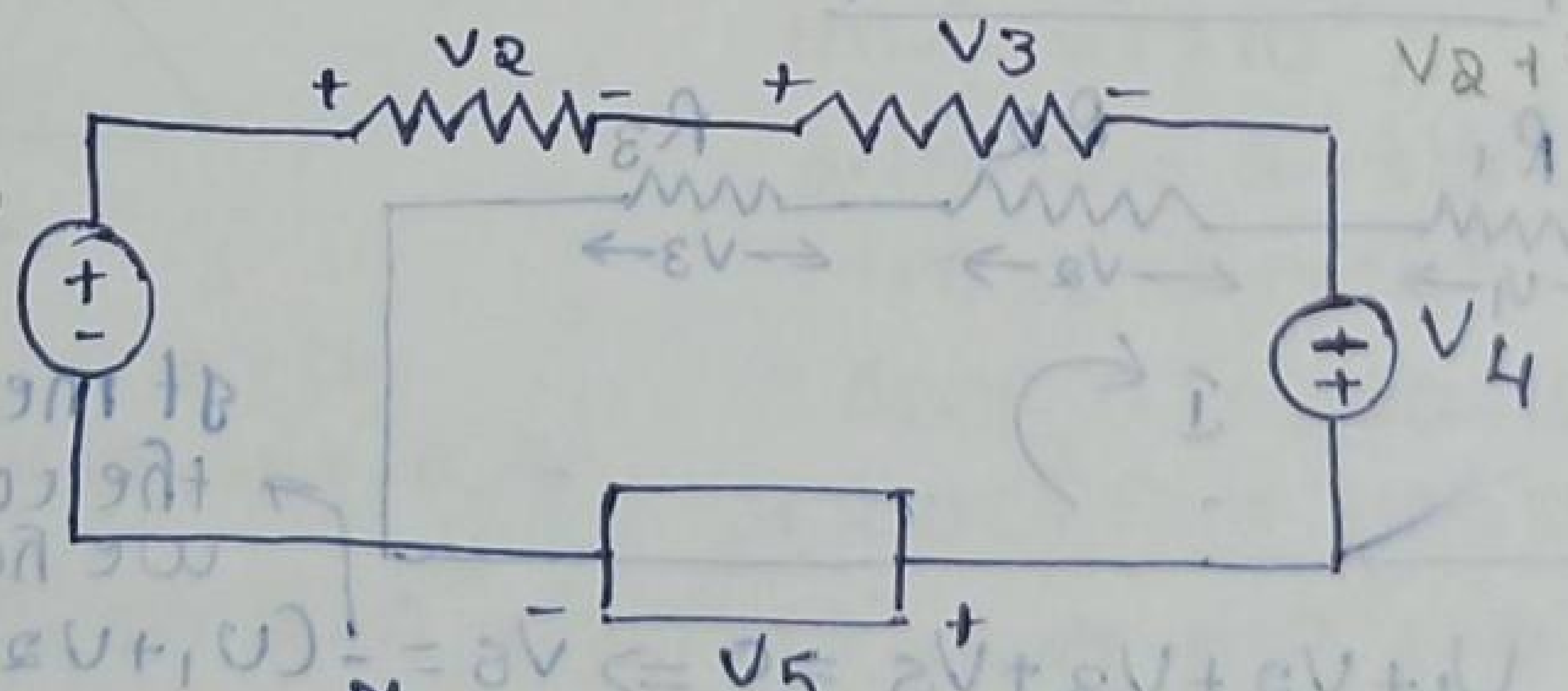
$(5-2) = 3A$ (-ve sign)

(ii)



Kirchhoff's voltage law (or) law of conservation of energy:

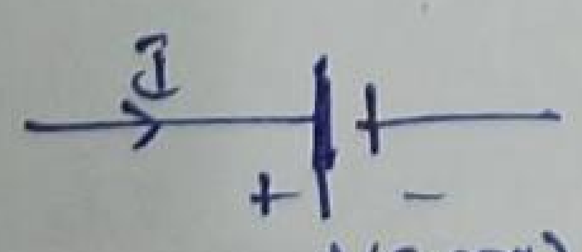
The algebraic sum of all voltages around a closed path (or) loop is zero.



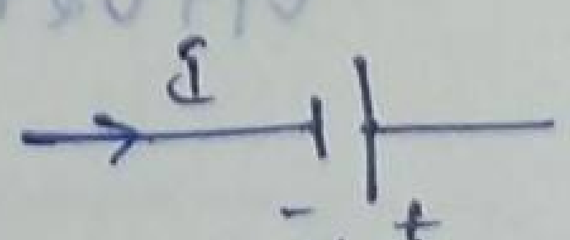
$V_2 + V_3 - V_4 + V_5 - V_1 = 0$

$$\sum_{m=1}^{M} V_m = 0$$

(i)



+Vs Because first current is entering into +ve terminal



-Vs Because first current is entering into -ve terminal

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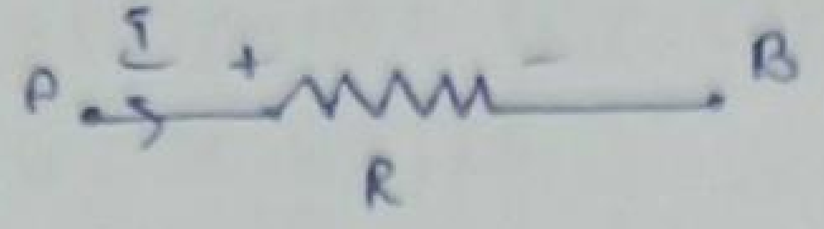
(ii)



$A \longrightarrow B$

Direction path

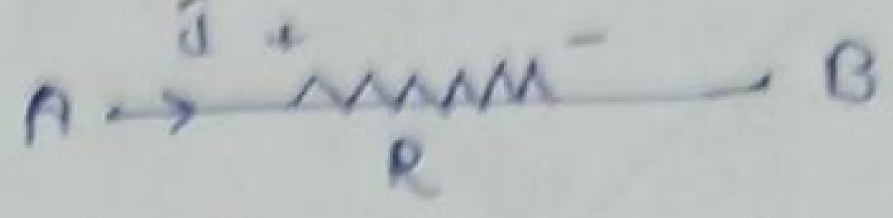
(or)

Tracing path

$\longrightarrow I$

$\longrightarrow$ path

Both current and path are in same direction so sign is negative.



path $B \longrightarrow A$

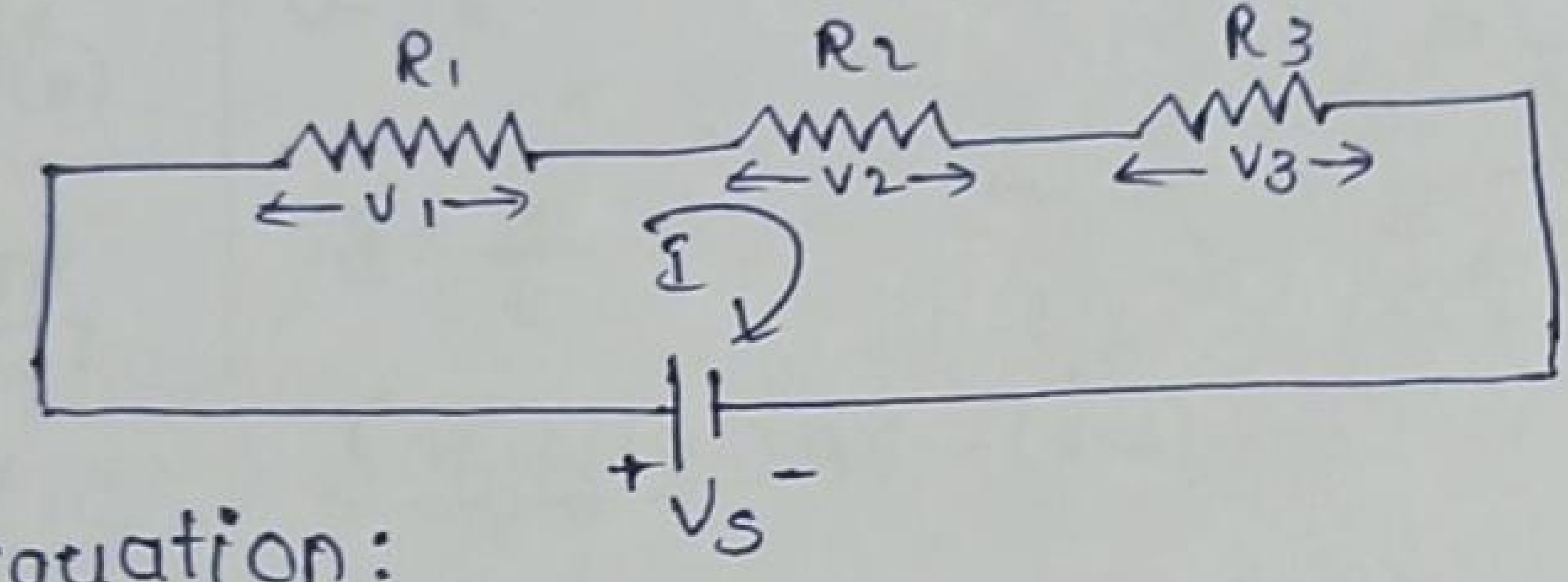
A

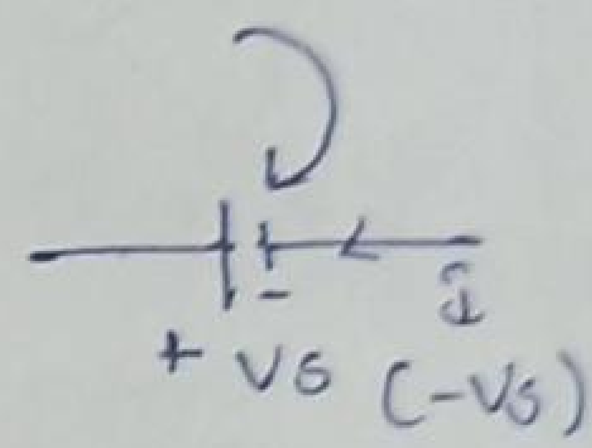
$\longrightarrow i$

$\longleftarrow$ path

Both current and path are inopposite direction so sign is positive

Ex:



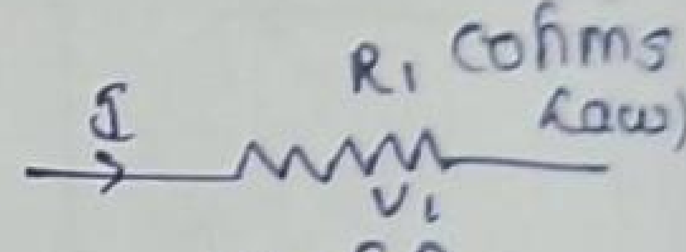


KVL equation:

$-V_S + V_1 + V_2 + V_3 = 0$

$V_S = V_1 + V_2 + V_3$

sum of voltage raise — sum of voltage drops



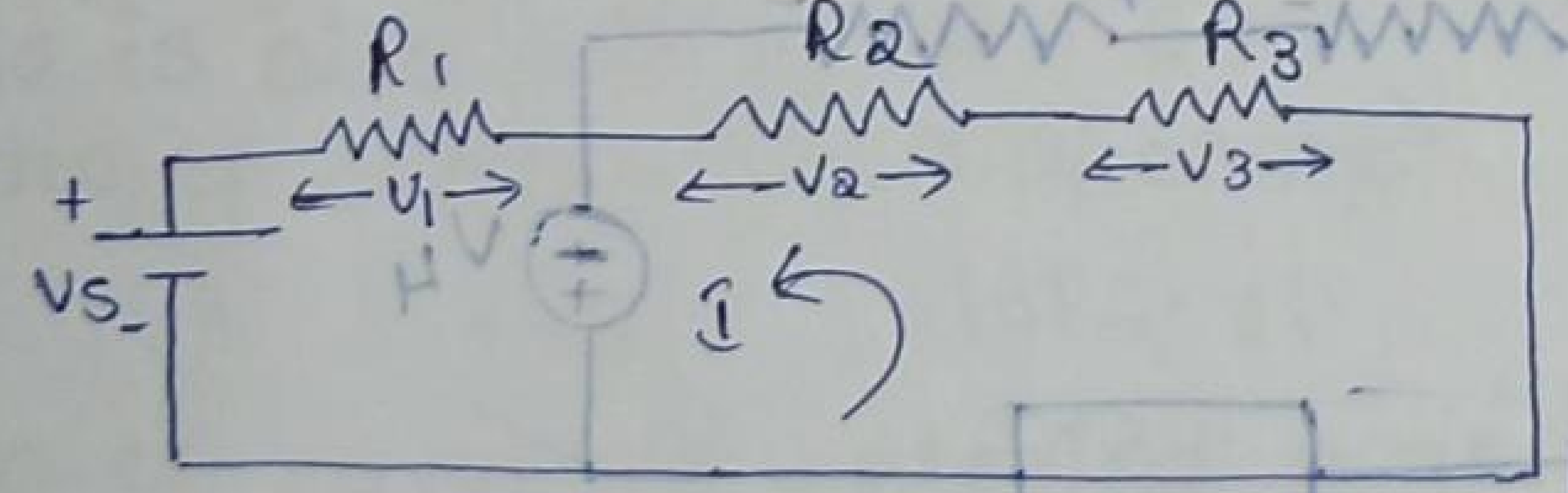
$V_1 = IR_1$

$V_S = IR_1 + IR_2 + IR_3$

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

$$\boxed{I = \frac{V_S}{R_1 + R_2 + R_3}}$$

Ex:



$V_1 + V_2 + V_3 + V_S = 0 \Rightarrow V_S = -(V_1 + V_2 + V_3)$

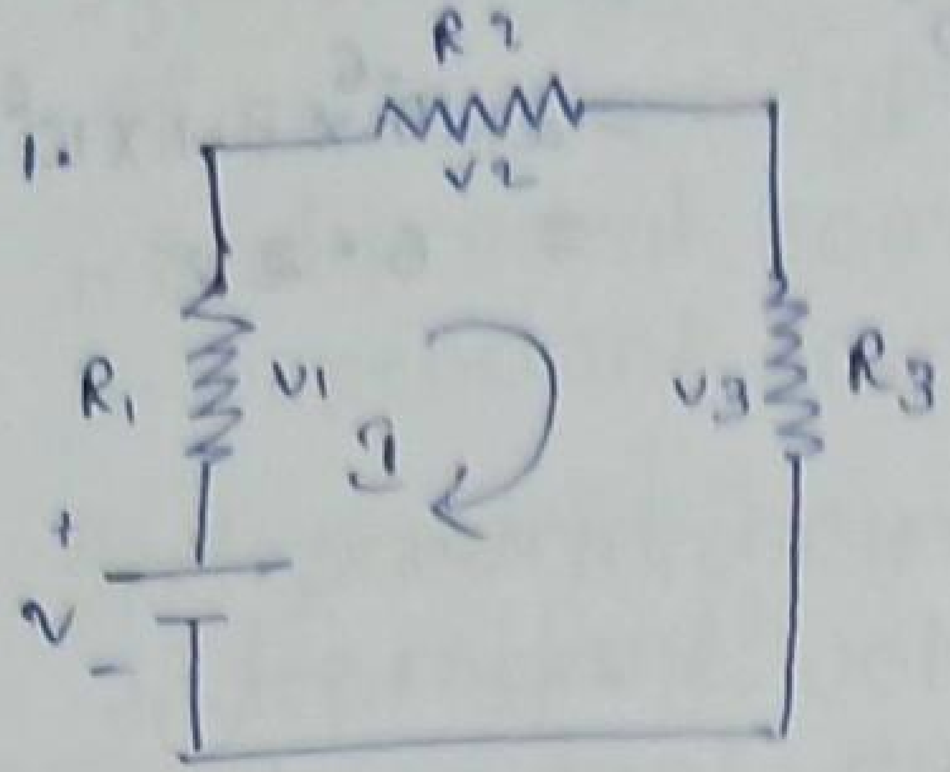
It means that the current direction we had assumed the current in wrong direction

sum of voltage drops = sum of voltate raise

$V_1 + V_2 + V_3 = V_S$

Problem:

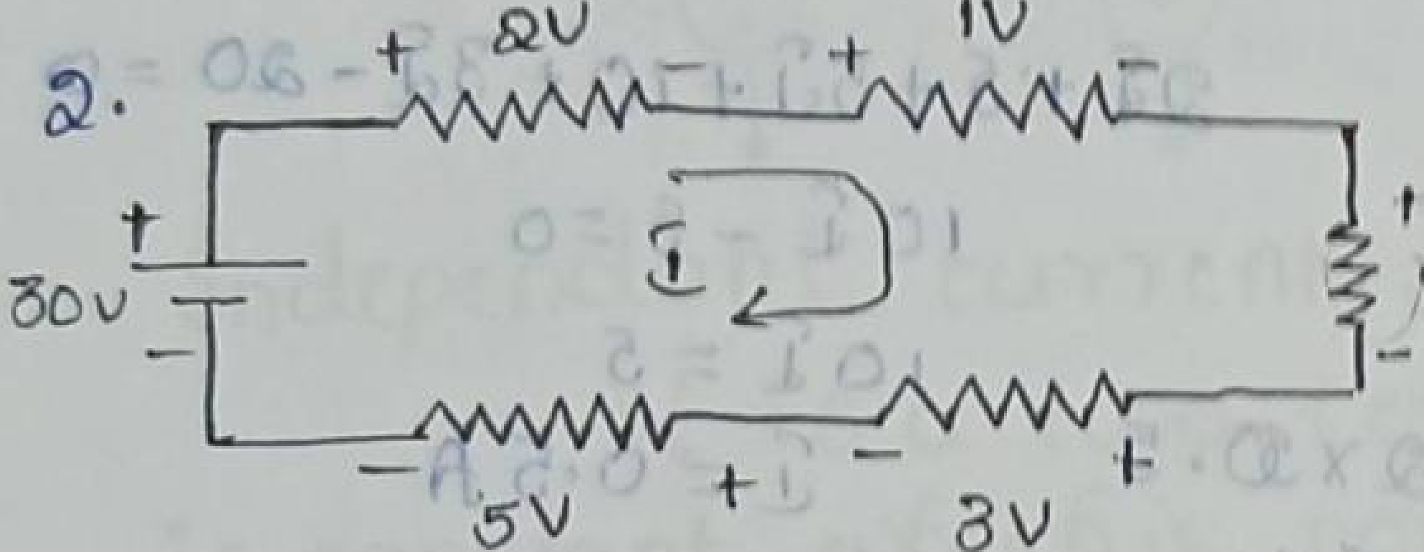
1.



Find current delivered by the source

$$-V+V_1+V_2+V_3=0$$
$$-V=-(V_1+V_2+V_3)$$
$$V=V_1+V_2+V_3$$
$$V=IR_1+IR_2+IR_3$$
$$V=I(R_1+R_2+R_3)$$
$$\therefore I=\frac{V}{R_1+R_2+R_3}$$

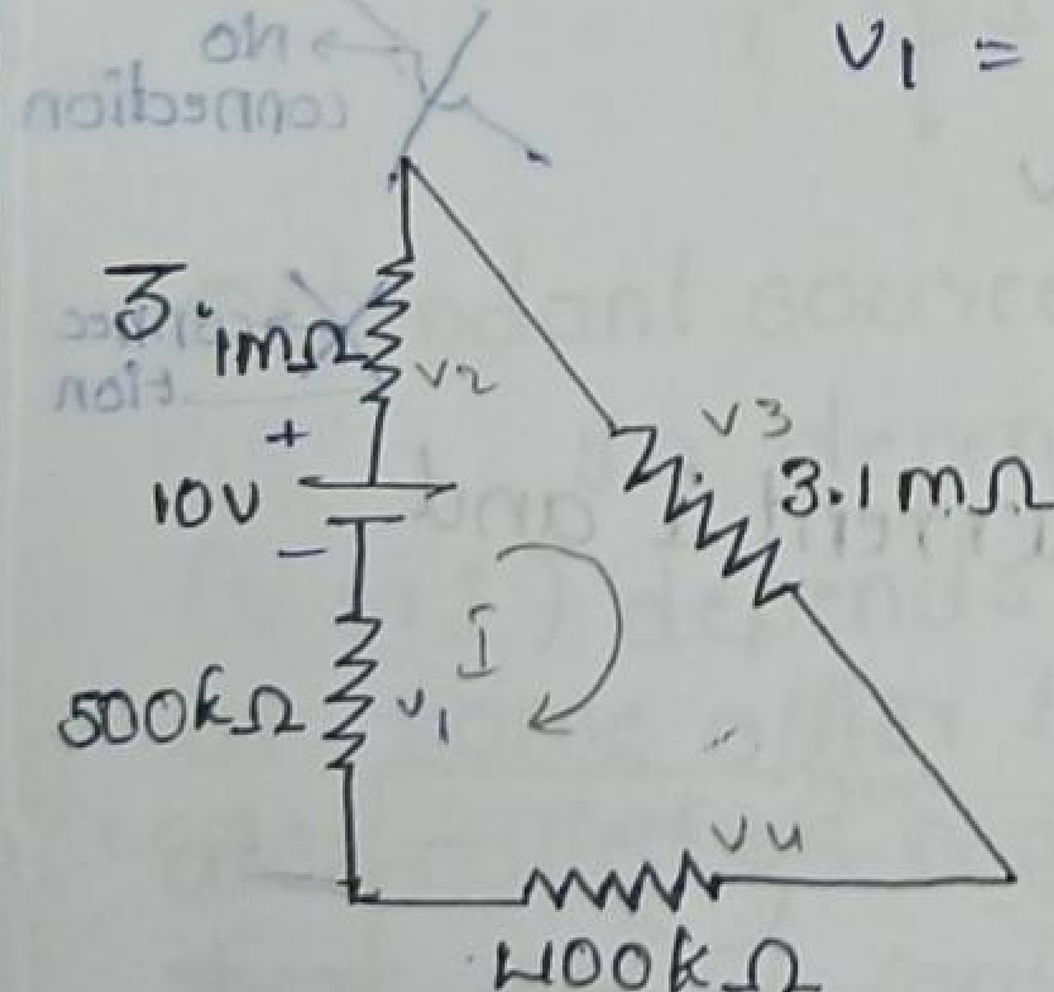
2.



For the circuit shown determine the unknown voltage drop V_1.

Sol:
$$2+1+V_1+3+5-30=0$$
$$V_1+11-30=0$$
$$V_1=19V$$

3.



what is the current in the circuit shown. Determine the voltage across each resistor

$$1m\Omega=1\times10^6\Omega$$
$$3.1m\Omega=3.1\times10^6\Omega$$
$$1m\Omega=1\times10^6\Omega$$
$$500k\Omega=500\times10^{+3}\Omega$$
$$400k\Omega=400\times10^3\Omega$$

$$V_1-V+V_2+V_3+V_4=0$$
$$V=I(R_1+R_2+R_3+R_4)$$
$$I\times500\times10^3-10+I10^6+I3.1\times10^6+I400\times10^3=0$$
$$I0.5\times10^6-10+I10^6+I3.1\times10^6+I0.4\times10^6=0$$
$$-10+10^6(0.5+1+3.1+0.4)I=0$$

$$I=\frac{V}{R_1+R_2+R_3+R_4}=\frac{10}{10^6+0.5\times10^6+3.1\times10^6+0.4\times10^6}$$
$$=\frac{10}{10^6(0.5+1+3.1+0.4)}=\frac{10^2}{10^6\times5}=2\times10^{-6}A$$

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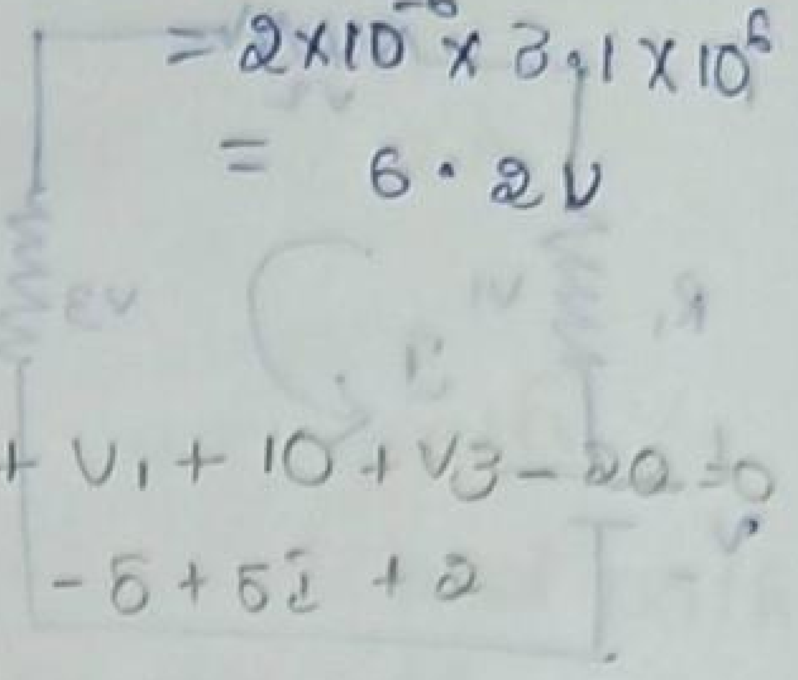
$V_1 = IR_1$
$= 2\times10^{-6} \times 0.5\times10^{6}$
$= 1V$

$V_2 = IR_2$
$= 2\times10^{-6}\times 1\times10^{6}$
$= 2V$

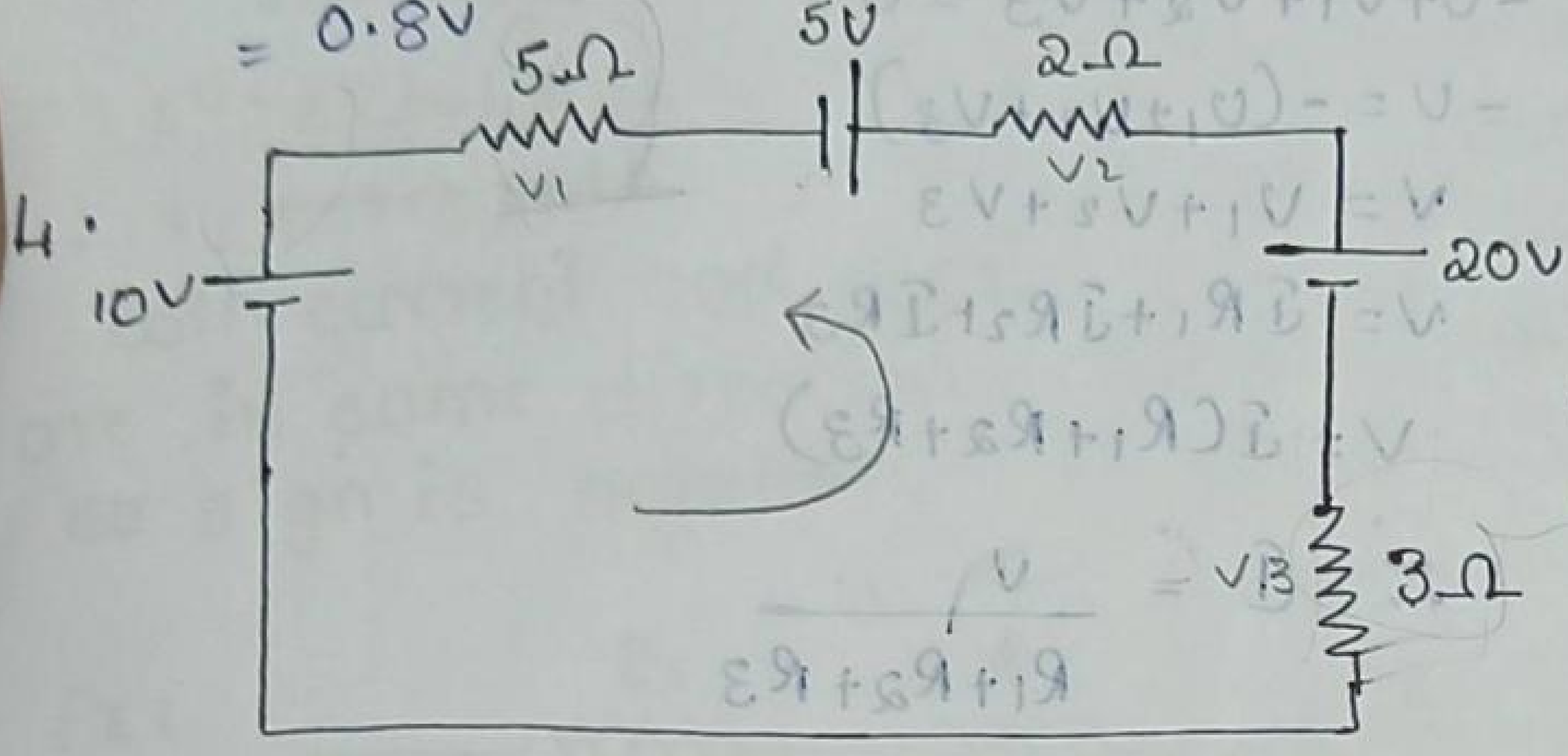
$V_3 = IR_3$
$= 2\times10^{-6} \times 3.1\times10^{6}$
$= 6.2V$

$V_4 = IR_4$
$= 2\times10^{-6} \times 0.4\times10^{6}$
$= 0.8V$



$5 + V_1 + 10 + V_3 - 20 = 0$
$-5 + 5I + 2$

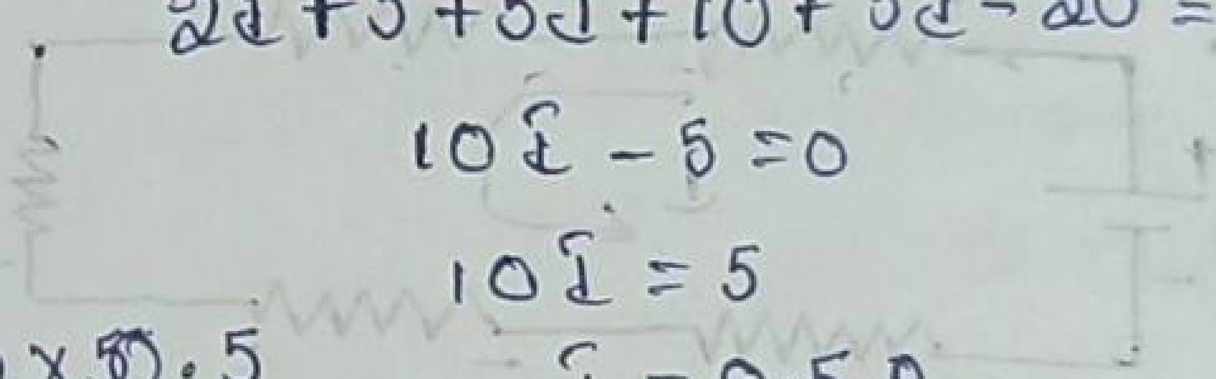
4.



Find 'I' in the circuit shown and determine the voltage drops across each resistor

$V_1 - 5 + V_2 + 20 + V_3 - 10 = 0$

$V_1 + V_2 + V_3 = -5$ (clockwise) → wrong



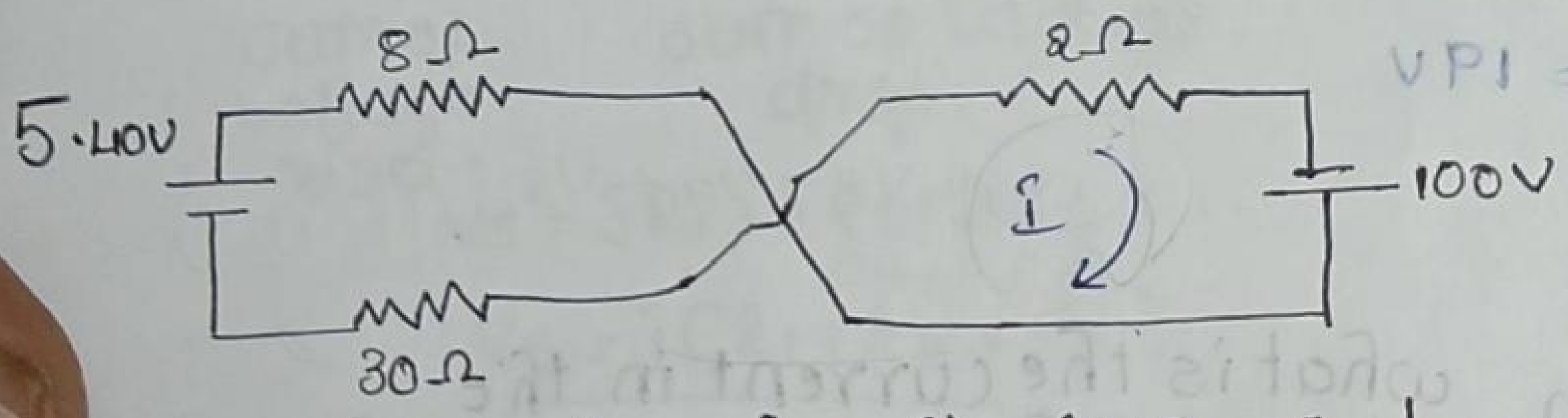
$2I + 5 + 5I + 10 + 3I - 20 = 0$
$10I - 5 = 0$
$10I = 5$
$I = 0.5A$

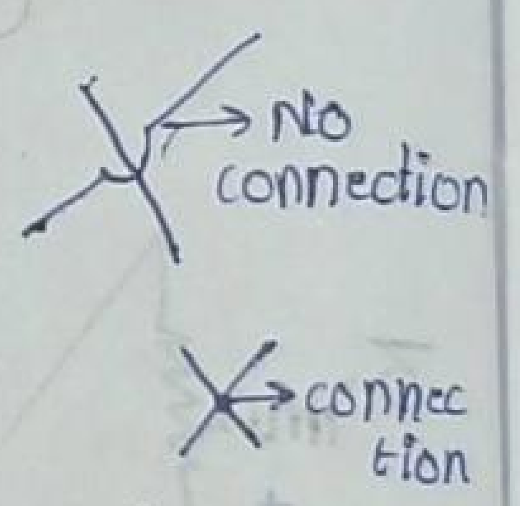
$V_{5\Omega} = 0.5\times5$
$= 2.5V$

$V_{2\Omega} = 2\times0.5$
$= 1V$

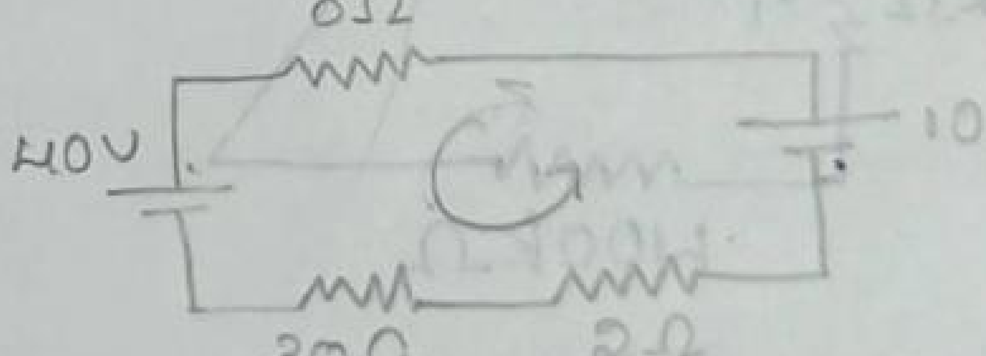
$V_{3\Omega} = 3\times0.5$
$= 1.5V$

5.





In the circuit given find current I and voltage across 30Ω



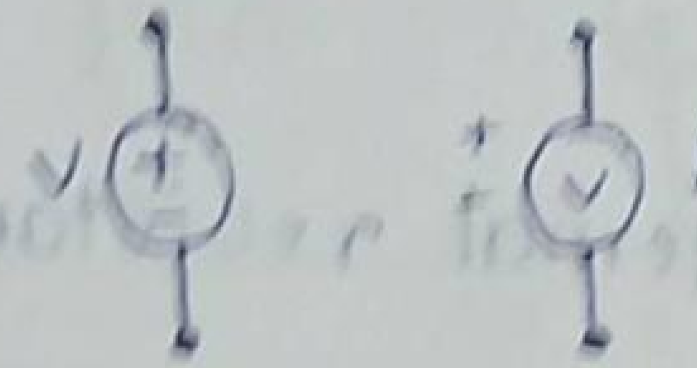
Sol:
$8I + 40 + 30I + 2I - 100 = 0$
$40I - 60 = 0$
$I = \frac{60}{40}$ $I = \frac{3}{2}$
$I = 1.5A$

$V_{30\Omega} = 1.5\times30$
$= 45V$

Types of sources:
There are two types of energy sources
1. Independent sources
2. Dependant sources

Independent sources:
Independant voltage source
Independant current source

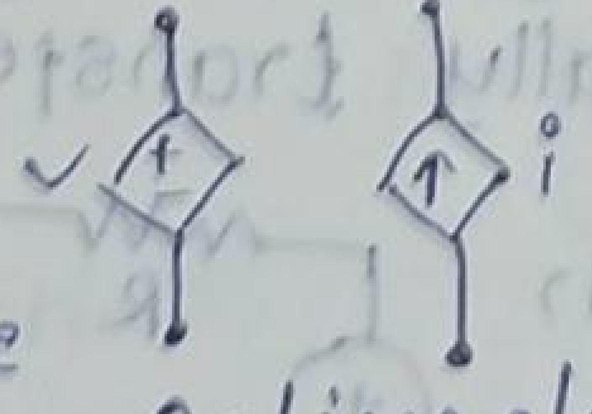
Independant voltage source:
It is a two terminal device whose terminal voltage is constant which is completely independent of current through it


Active elements

Independant current source:
It is a two terminal device whose current is constant which is completely independant of voltage across it.


Active elements

Dependant sources:
In dependant sources, the source quantity (V or i) depends on a voltage (or) current existing at some other location in the circuit. These are also called as controlled sources.
There are of four types
VCVS, CCVS, VCCS, CCCS


Active elements

→ A dependant source is an active element in which the source quantity is controlled by another voltage (or) current
VCVS - voltage controlled voltage source
CCCS - current controlled voltage source
VCCS - voltage controlled current source
CCCS - current controlled current source

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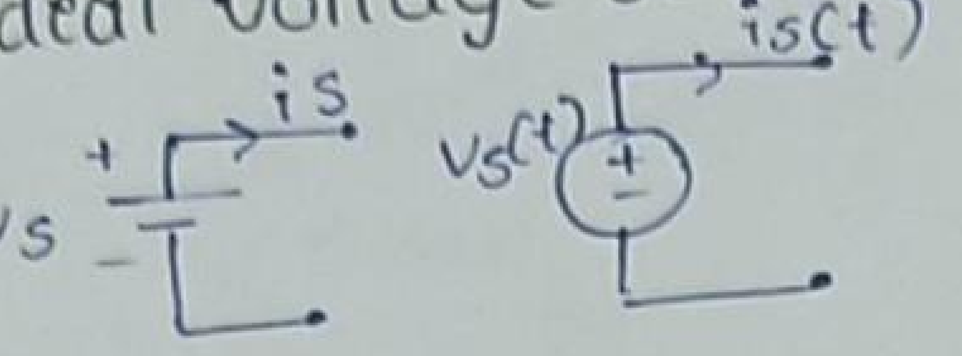
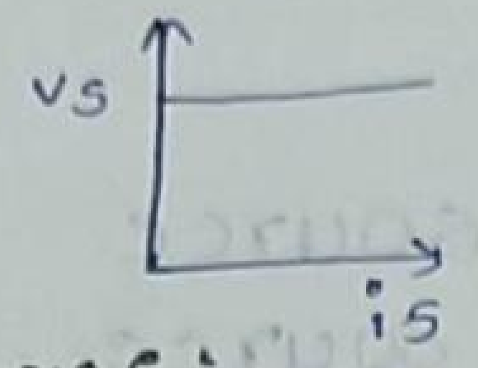
voltage sources: Battrics, generators
current sources: semiconductor devices like transistors

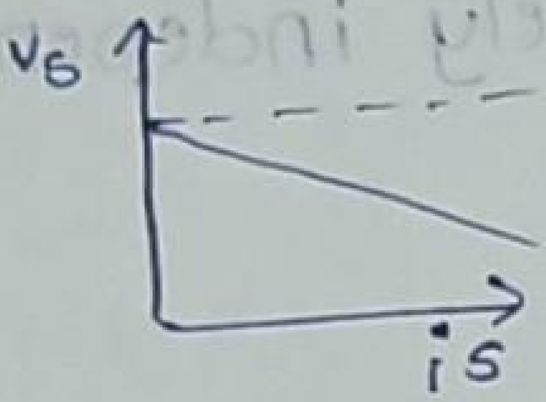
Ideal voltage source:

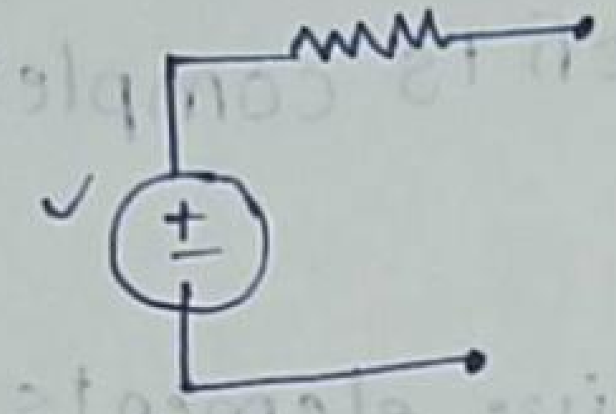




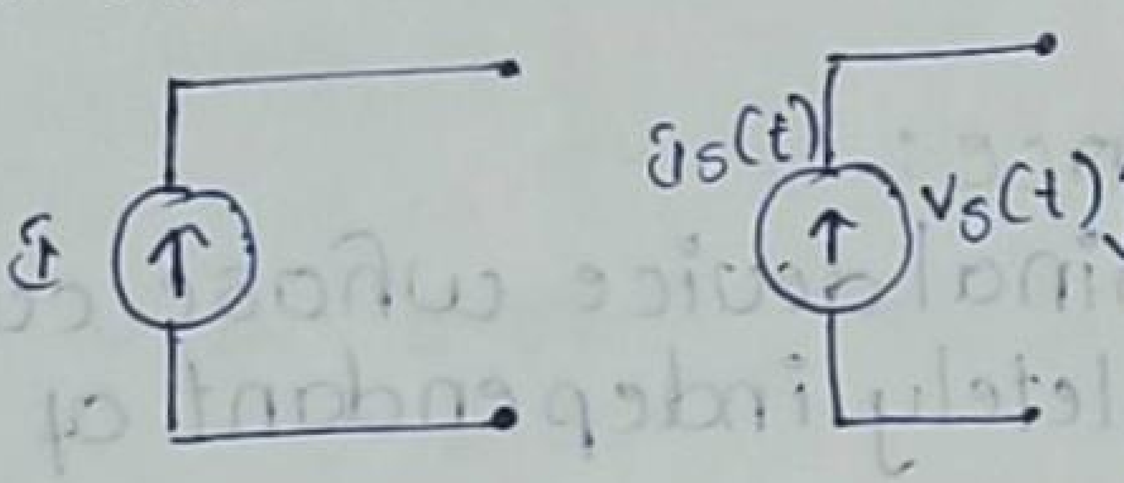
At any time the value of voltage is constant. So this voltage source the impedendence value which is connected is series is zero.

Practical voltage source:
An internal resistance is present here in series

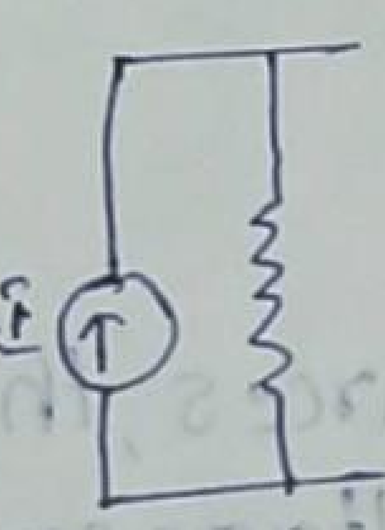




Ideal current source: No internal resistance

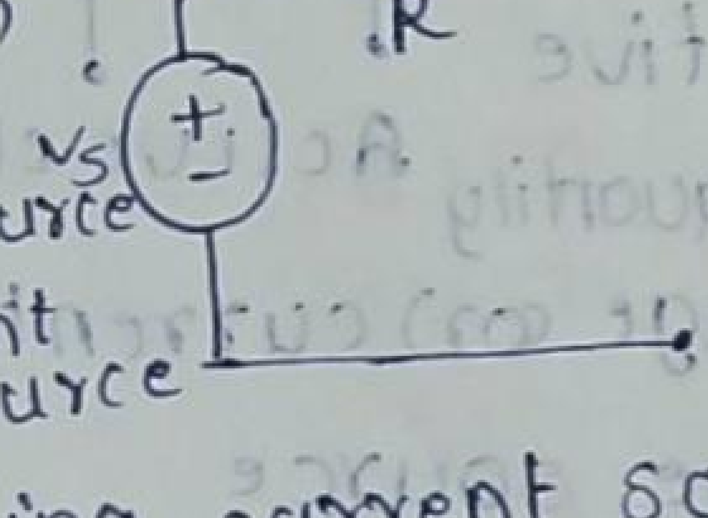


Practical current source:
An internal resistance is connected in parrallel



Source transformation:
The voltage and current sources are mutually transferable.

Ex: (i) converting voltage source to current source



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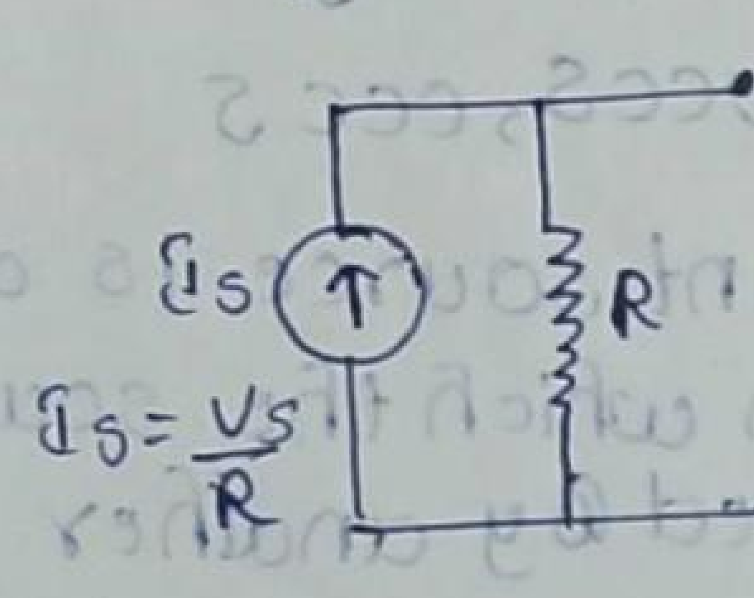
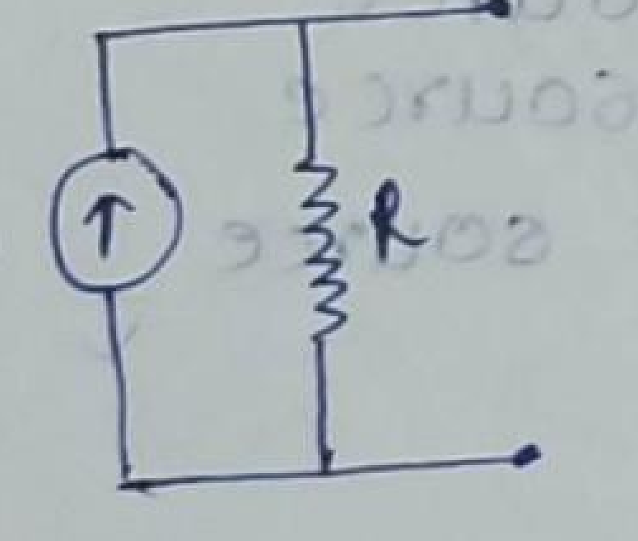


$I_S = \frac{V_S}{R}$

$V_S = 10V$
$R = 2\Omega$
$I_S = \frac{10}{2}$
$I_S = 5A$

(ii) converting current source to voltage source



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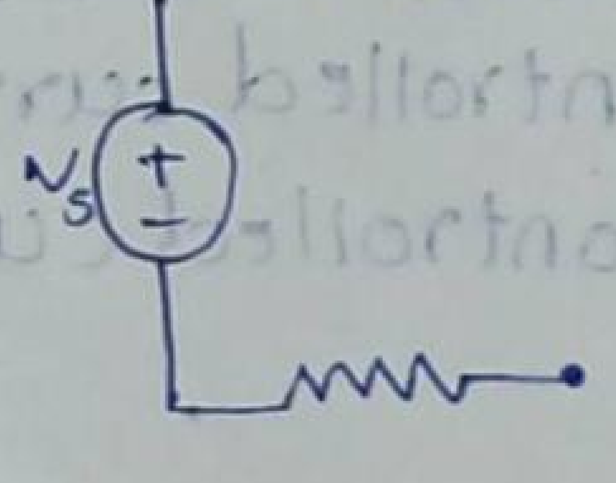

$V_S = I_S R$

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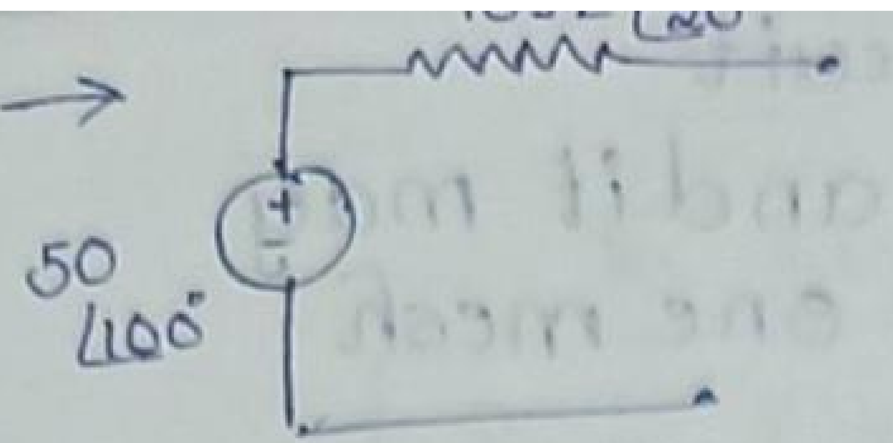

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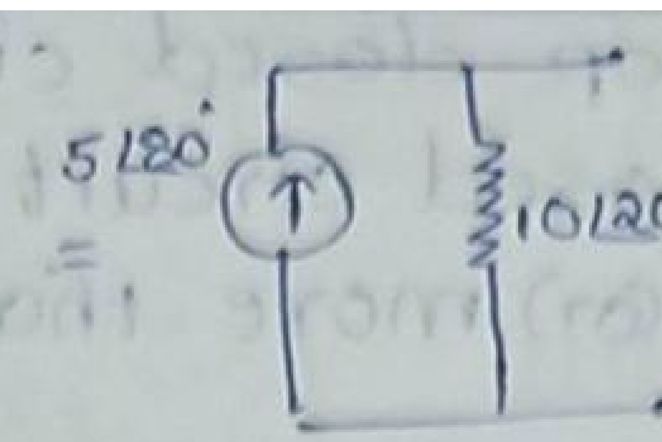


$V = I R$

$= 5\angle 80^\circ \cdot 10\angle 20^\circ$

$= 50\angle 80^\circ + 20^\circ$

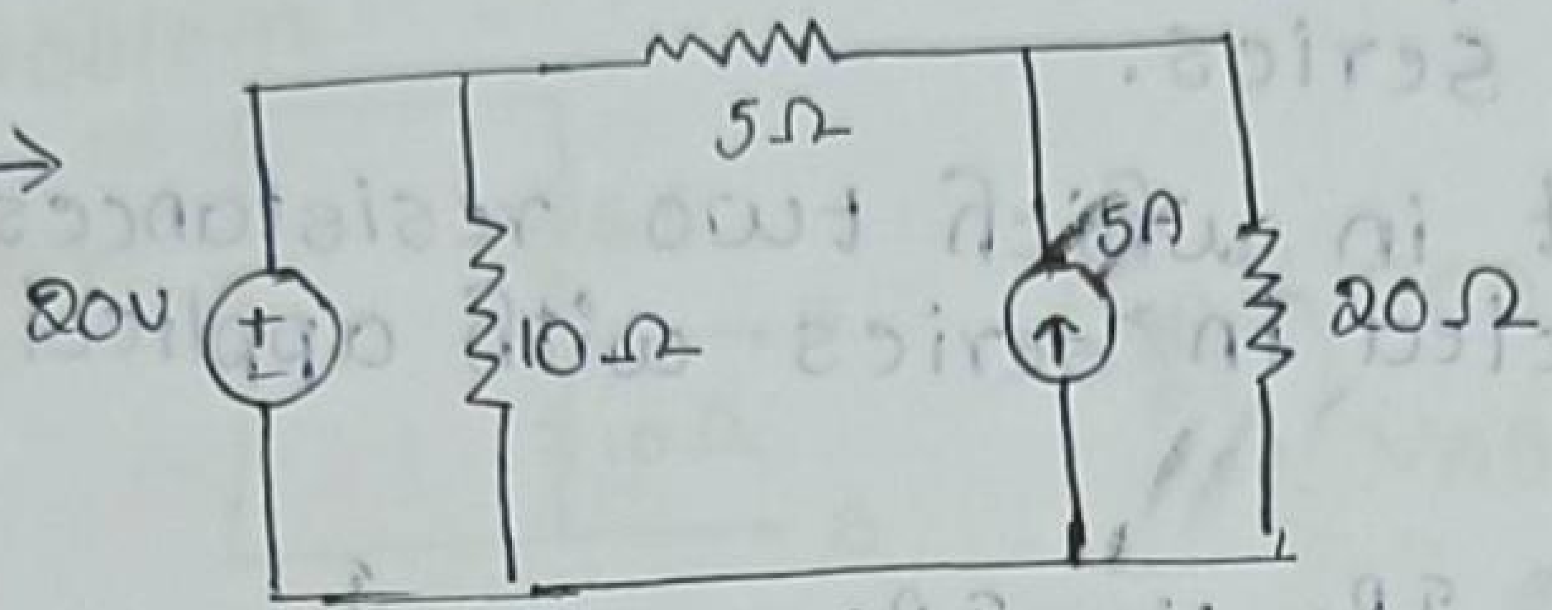
$V_s = 50\angle 100^\circ$

$I_s = \frac{V_s}{R}$

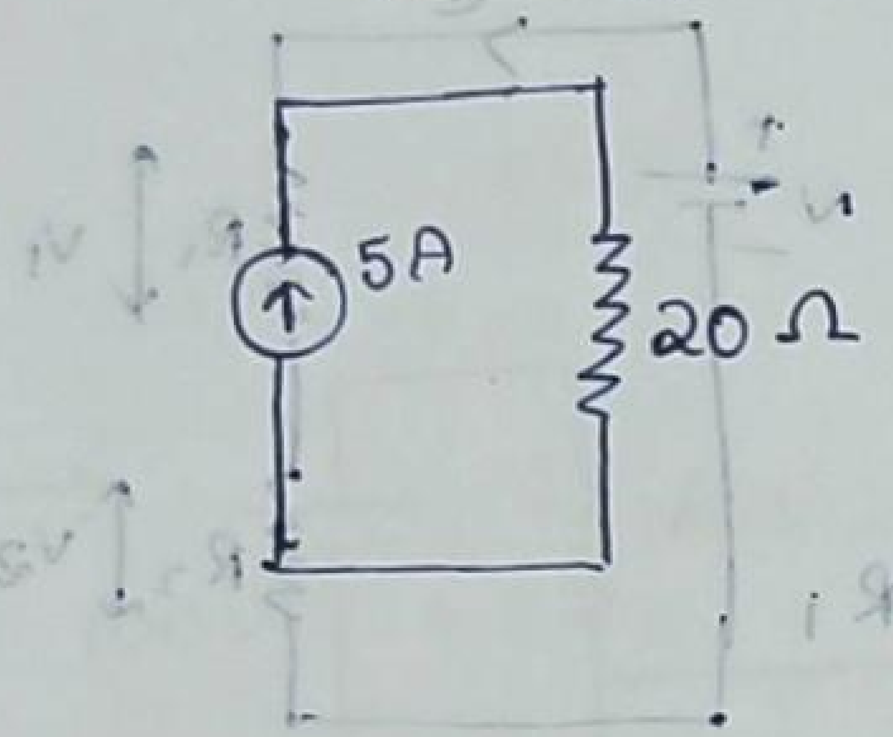
$= \frac{50\angle 100^\circ}{10\angle 20^\circ}$

$= \frac{50}{10} \angle 100^\circ - 20^\circ$

$= 5\angle 80^\circ$

→ 

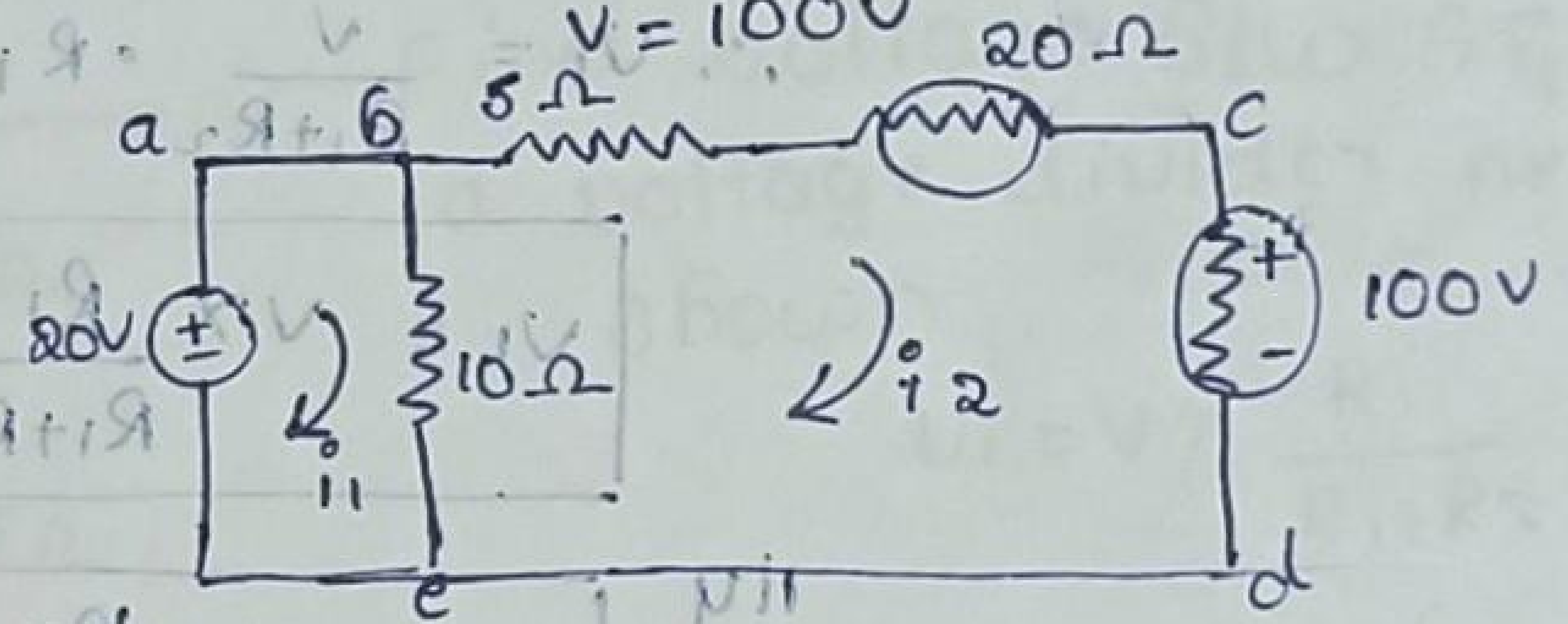
Determine the power loss across the 5Ω resistor in the fig. shown

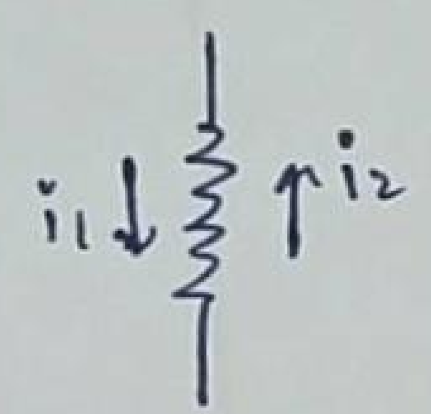


∴ This can be converted into voltage source

$V = I R$

$V = 100V$





"abefa" KVL equation

$-20 + 10(i_1 - i_2) = 0$

$(i_1 - i_2) = 2$

$i_1 - i_2 = 2$

$i_1 = 2 + i_2$

"bcdeb" KVL equation

$20(i_2) + 100 + 10(i_2 - i_1) + 5(i_2 - i_1) = 0$

$20 i_2 + 100 + 10 i_2 - 10 i_1 + 5 i_2 = 0$

$-10 i_1 + 35 i_2 = -100$

$2 i_1 - 7 i_2 = 20$

$2(2 + i_2) - 7 i_2 = 20$

$10 + 5 i_2 - 7 i_2 = 20$

$-2 i_2 = 10$

$\boxed{i_2 = -5A}$

$4 + 2 i_2 - 7 i_2 = 20$

$-5 i_2 = 16$

$i_2 = -3.2A$

$P = i_2^2 R$

$= i_2^2 R$

$= (3.2)^2 (5)$

$P = 51.2W$

$i_1 = 2 + 5$

$\boxed{i_1 = 7A}$

$i_1 = 2 - 3.2$

$i_2 = -1.2A$

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Mesh: It is a single loop closed circuit
Loop: It can be any closed circuit and it may consist of one (or) more than one mesh

→ Every mesh is a loop
→ But every loop is not a mesh.

→ Voltage Division rule:

Voltage applied across elements connected in series is divided proportional to resistance values connected in series.

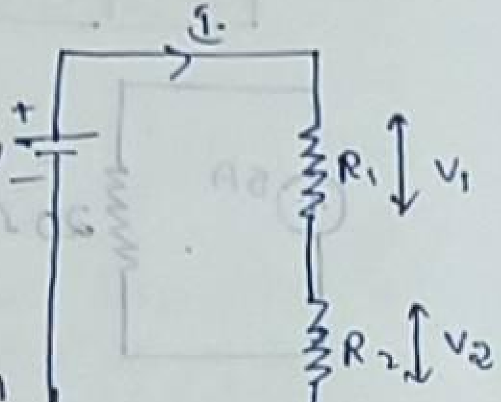
Consider the circuit in which two resistances R_1 and R_2 are connected in series with applied voltage 'v'.

Voltage across $V_1 = IR_1$, $V_2 = IR_2$

Also we have $V = I(R_1+R_2)$

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

$\therefore V_1 = \frac{V}{R_1+R_2} \cdot R_1$



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

Ily

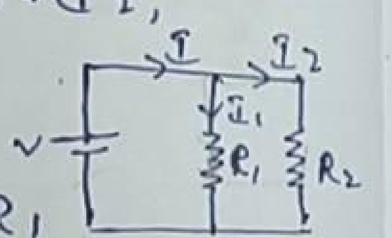
$$\boxed{V_2 = V \times \frac{R_2}{R_1+R_2}}$$

$\therefore$ voltage across any branch = Total voltage × $\frac{\text{same branch resistance}}{\text{sum of resistances in series}}$

→ Current division rule:

Consider the circuit having two resistances R_1, R_2 in parallel. Total current, $I = I_1 + I_2$,

But $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$



I_1 = current flowing through branch R_1

I_2 = current through branch R_2

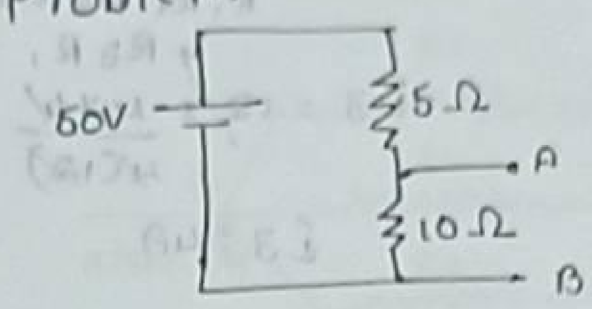
Ratio of branch current I_1 to total current 'I' is given by

$\frac{I_1}{I} = \frac{V/R_1}{\frac{V}{R_1}+\frac{V}{R_2}} = \frac{\cancel{V}}{\cancel{V}\cancel{R_1}}\left(\frac{\cancel{R_1}R_2}{R_1+R_2}\right)$

$$\boxed{I_1 = I \times \frac{R_2}{R_1+R_2}}$$ Ily $$\boxed{I_2 = I \times \frac{R_1}{R_1+R_2}}$$

current flowing through any branch = Total current × $\frac{\text{opposite branch resistance}}{\text{sum of resistances in parallel}}$

Problem



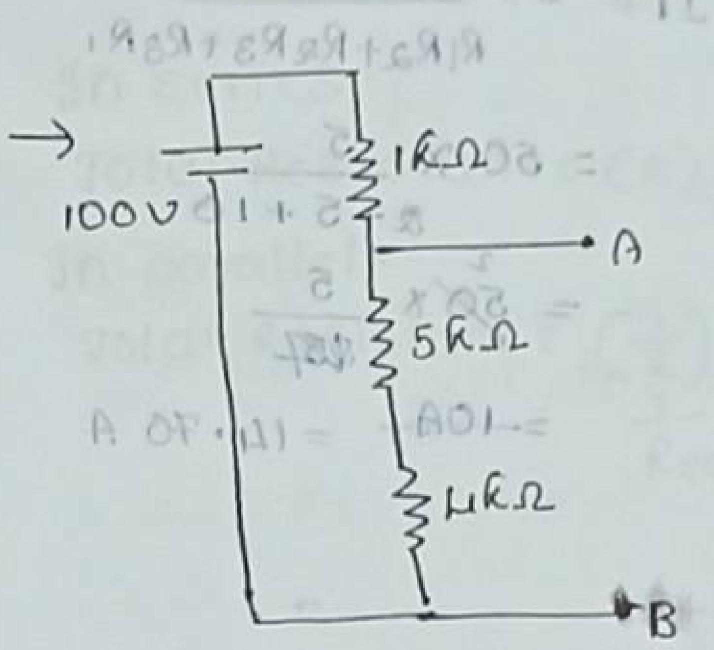
Find V_{AB} across 10Ω resistor

$V_{AB} = V \times \frac{R_1}{R_1+R_2}$

$= 50 \times \frac{\cancel{10}^{2}}{\cancel{15}_{3}}$

$= \frac{100}{3} = 33.3\,V$

→



Find voltage b/w A & B in a voltage divider network shown

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

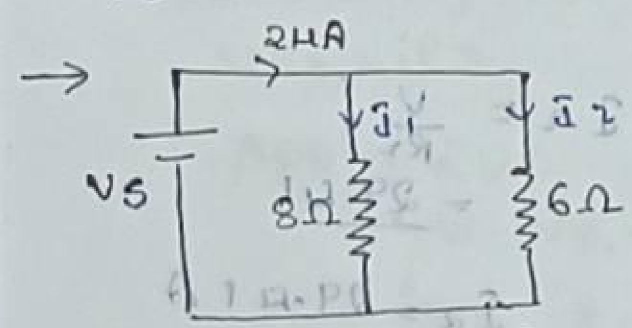
$= 100 \times \frac{(5+4)}{(5+4)+1}$

$= 10\cancel{0} \times \frac{9}{1\cancel{0}}$

$V_1 = 90\,V$

→ In current division the branch having higher resistance current flow is less. If we are having lower resistance current flow is more

→



Determine the current through each resistor in the circuit shown.

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

$= 24 \times \frac{6}{6+8}$

$= \cancel{24}^{12} \times \frac{6}{\cancel{14}_{7}} = \frac{72}{7} = 10.2\,A$

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

$= 24 \times \frac{8}{14} = 13.71\,A$

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Mesh: It is a single loop closed circuit

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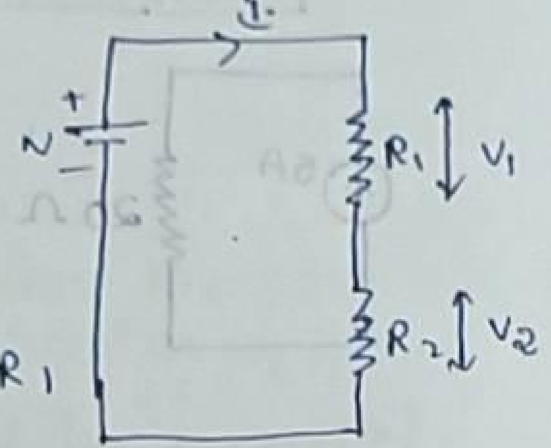


$I = \frac{V}{R_1+R_2}$

$\therefore V_1 = \frac{V}{R_1+R_2} \cdot R_1$

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

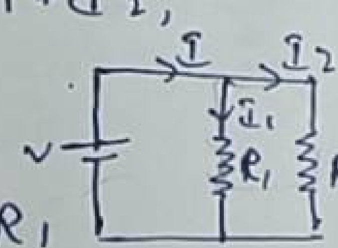
lly $\boxed{V_2 = V \times \frac{R_2}{R_1+R_2}}$

$\therefore$ voltage across any branch = Total Voltage × $\frac{\text{same branch resistance}}{\text{sum of resistances in series}}$

→ current division rule:

Consider the circuit having two resistances R_1, R_2 in parallel. Total current, $I = I_1 + I_2$,

But $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$



I_1 = current flowing through branch R_1

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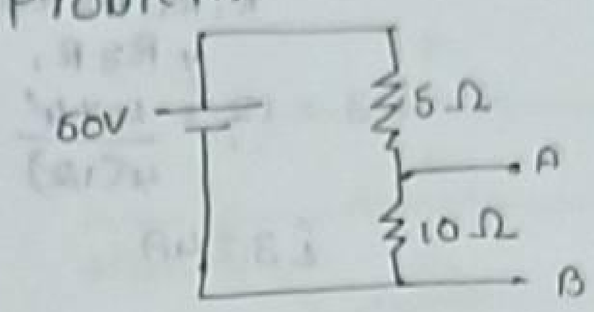
Ratio of branch current 'I_1' to total current 'I' is given by

$\frac{I_1}{I} = \frac{V/R_1}{\frac{V}{R_1}+\frac{V}{R_2}} = \frac{\cancel{V}}{\cancel{V}R_1}\left(\frac{R_1R_2}{R_1+R_2}\right)$

$\boxed{I_1 = I \times \frac{R_2}{R_1+R_2}}$ lly $\boxed{I_2 = I \times \frac{R_1}{R_1+R_2}}$

current flowing through any branch = Total current × $\frac{\text{opposite branch resistance}}{\text{sum of resistances in parallel}}$

Problem



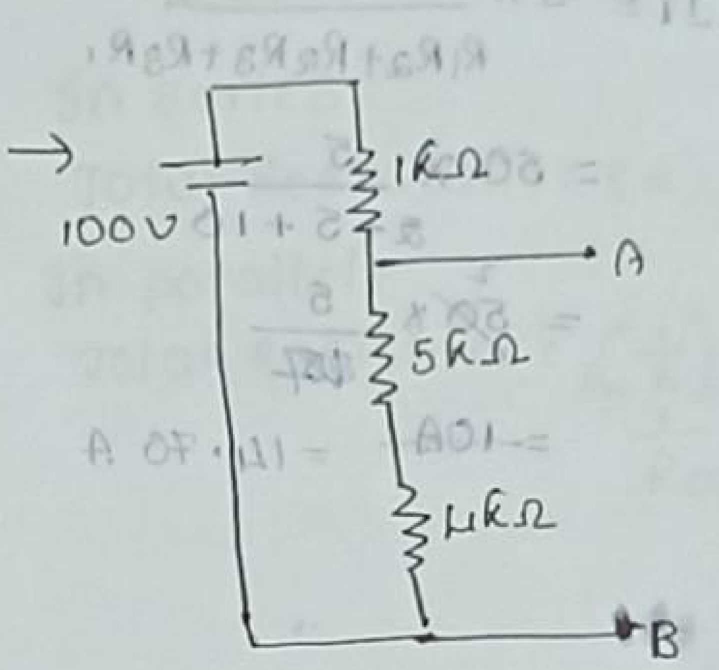
Find V_{AB} across $10\,\Omega$ resistor

$V_{AB} = V \times \frac{R_1}{R_1+R_2}$

$= 50 \times \frac{10}{15}$

$= \frac{100}{3} = 33.3\,V$

→



Find voltage b/w A & B in a voltage divider network shown

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

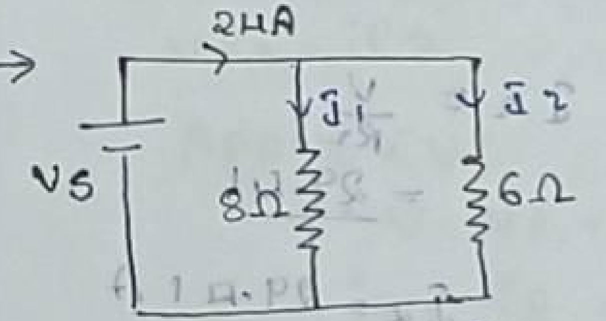
$= 100 \times \frac{(5+4)}{(5+4)+1}$

$= 100 \times \frac{9}{10}$

$V_1 = 90\,V$

→ In current division the branch having higher resistance current flow is less. If we are having lower resistance current flow is more

→



Determine the current through each resistor in the circuit shown.

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

$= 24 \times \frac{6}{6+8}$

$= 24 \times \frac{6}{14} = \frac{72}{7} = 10.2\,A$

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

$= 24 \times \frac{8}{14} = 13.71\,A$

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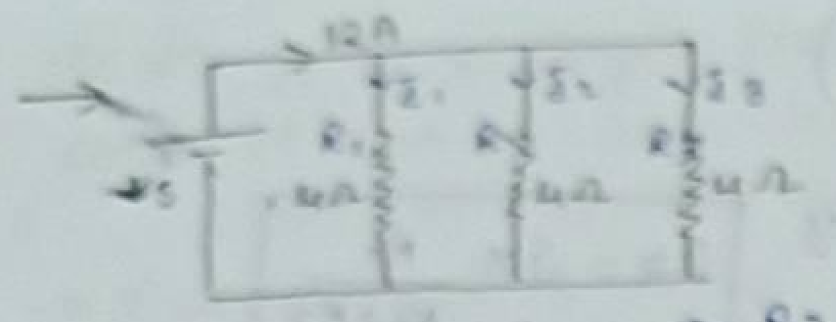


Determine the current through each resistor in circuit shown

$$I_1 = I \times \frac{R_2 R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$= 12 \times \frac{4 \cdot 4}{(4+4+4)4}$$

$$= \cancel{12} \times \frac{4 \times \cancel{4}}{\cancel{12} \times \cancel{4}}$$

$$= 4A$$

$$I_2 = I \times \frac{R_3 R_1}{R_1R_2 + R_2R_3 + R_3R_1}$$

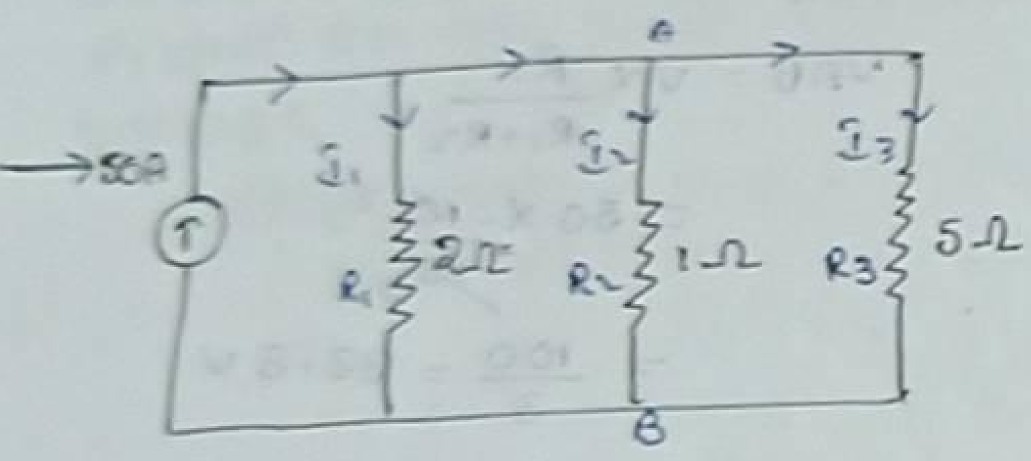
$$= 12 \times \frac{4 \cdot 4}{(4+4+4)4}$$

$$= 4A$$

$$I_3 = I \times \frac{R_1 R_2}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$I_3 = 12 \times \frac{4 \times 4}{4(12)}$$

$$I_3 = 4A$$



$$I_1 = I \times \frac{R_2 R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$= 50 \times \frac{5}{2+5+10}$$

$$= \overset{2}{\cancel{50}} \times \frac{5}{\cancel{17}}$$

$$\cancel{= 10A} = 14.70\ A$$

$$I_2 = 50 \times \frac{10}{17}$$

$$I_2 = 29.41A$$

$$I_3 = 50 \times \frac{2}{17}$$

$$= 5.88A$$

(or)

By applying KCL

$$I = I_1 + I_2 + I_3$$

$$50 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$50 = V\left(\frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1R_2R_3}\right)$$

$$50 = V\left(\frac{17}{10}\right)$$

$$\frac{500}{17} = V$$

$$V = 29.41A$$

$$V = I_1 R_1$$

$$I_1 = \frac{29.41}{2}$$

$$I_1 = 14.70A$$

$$I_2 = \frac{V}{R_2}$$

$$= \frac{29.41}{1}$$

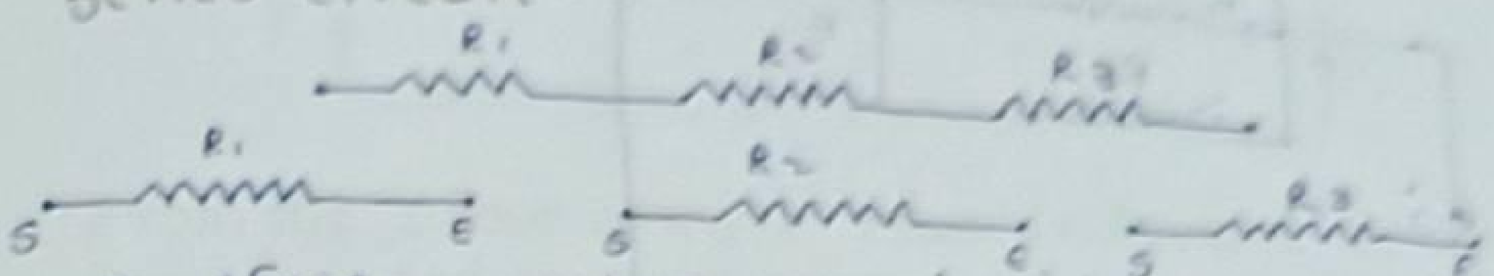
$$I_2 = 29.41\ A$$

$$I_3 = \frac{V}{R_3} = \frac{29.41}{5}$$

$$= 5.88A$$

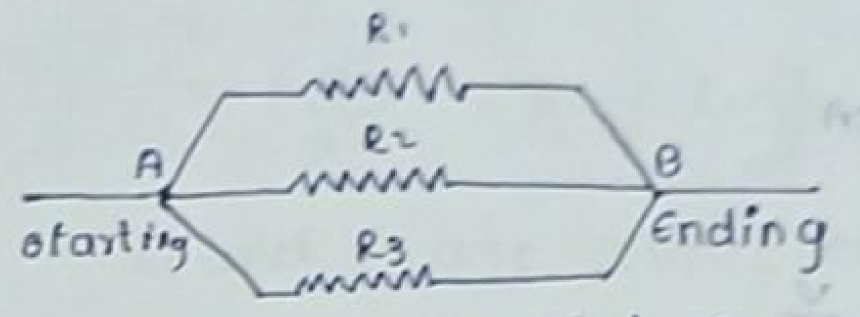
Resistive Networks - (series parallel circuits)

Series circuit:



For these resistors current is same and voltage is different

Parallel circuit:



For these resistors voltage is same and current is different.

In series:

Total Resistance $(R) = R_1 + R_2 + R_3$

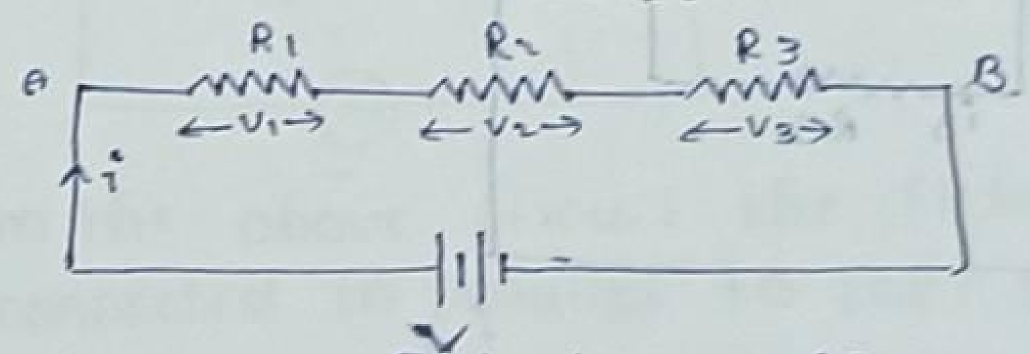
In parallel:

Total Resistance $\left(\frac{1}{R}\right) = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$$\frac{1}{R_{equivalent}} = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1R_2R_3}$$

$$R = \frac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

Resistors connected in series:



According to ohm's Law $V = iR$, $V_{R_1} = iR_1$, $V_{R_2} = iR_2$, $V_{R_3} = iR_3$

Apply KVL

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

$$iR = iR_1 + iR_2 + iR_3$$

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

The total resistance is equal to the sum of individual resistances.

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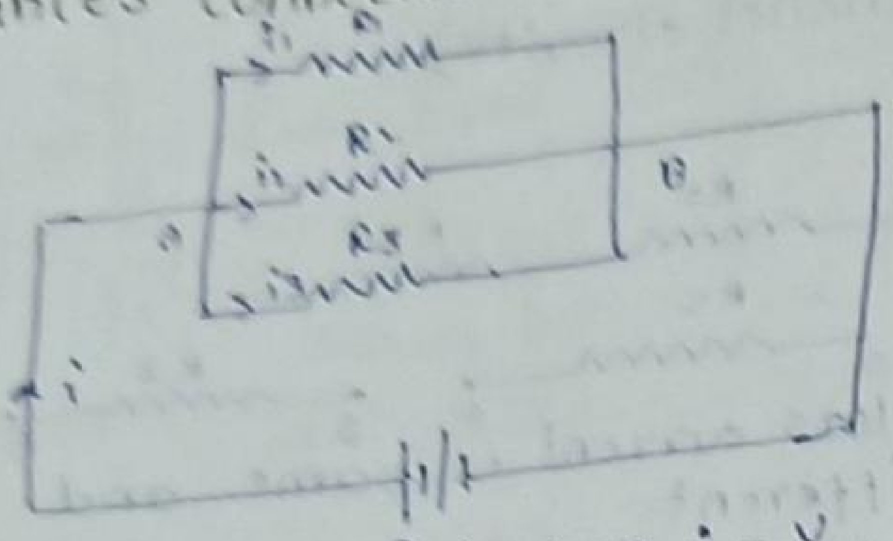
Resistances connected in parallel



According to ohm's Law $i = \frac{V}{R}$, $i_1 = \frac{V}{R_1}$, $i_2 = \frac{V}{R_2}$,

$i_3 = \frac{V}{R_3}$

Apply KCL at nodeA

$$i = i_1 + i_2 + i_3$$

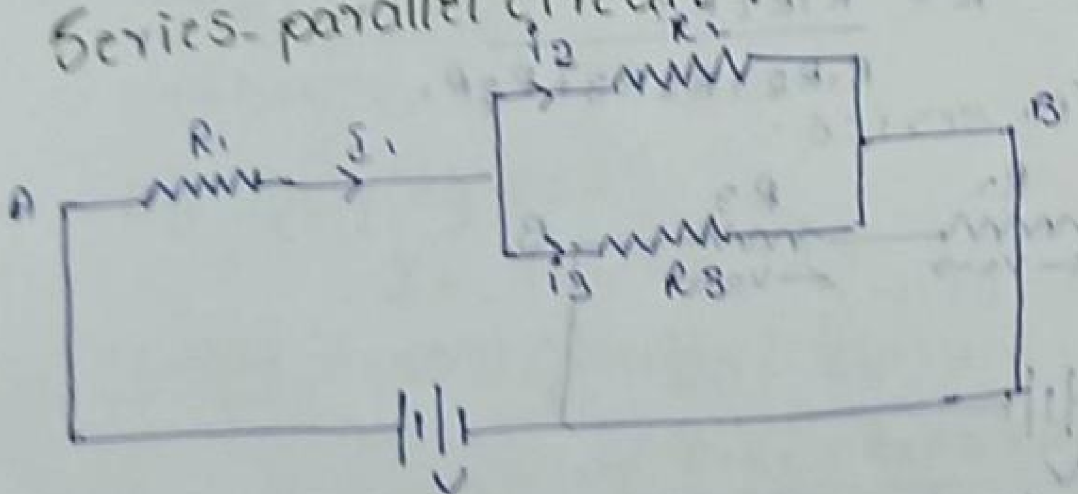
$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

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

$$\boxed{R = \frac{R_1 R_2 R_3}{R_1R_2 + R_2R_3 + R_3R_1}}$$

The reciprocal of total resistance is equal to sum of reciprocals of individual resistances

Series-parallel circuit :



From the above circuit R_2 and R_3 are connected in parallel and is connected in series with R_1

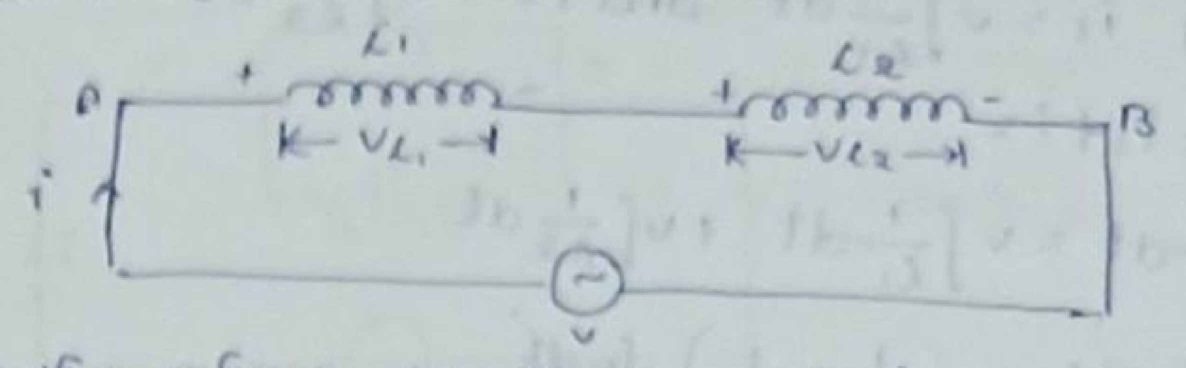
Total resistance

$$R = R_1 + R_2 \| R_3$$

$$R = R_1 + \frac{R_2R_3}{R_2+R_3}$$

$$R = \frac{R_1R_2R + R_1R_3 + R_2R_3}{R_2+R_3}$$

Inductances connected in series:



From the above circuit two inductors L_1 and L_2 are connected in series. The series circuit means current is same and voltage is different

Apply KVL $\quad V = V_{L_1} + V_{LC}$

$$V = L\frac{di}{dt}, \quad V_{L_1} = L_1\frac{di}{dt}, \quad V_{L_2} = L_2\frac{di}{dt}$$

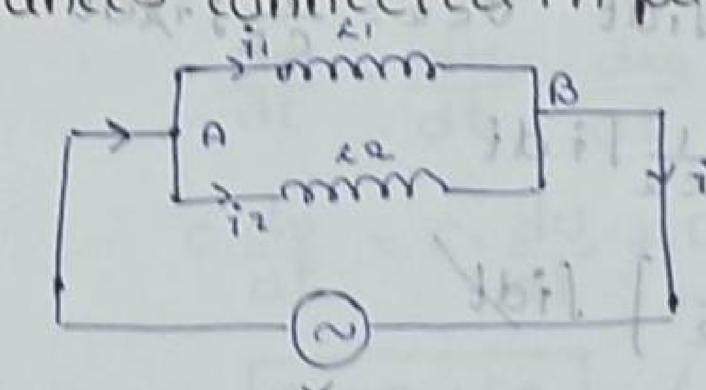
L_1 and L_2 are connected in series i.e. $i = i_1 = i_2$

$$L\frac{di}{dt} = L_1\frac{di}{dt} + L_2\frac{di}{dt}$$

$$\boxed{L = L_1 + L_2}$$

Hence when a no. of inductors are connected in series the total inductance is equal to the sum of individual inductances.

Inductances connected in parallel:



From the above circuit the inductors L_1 and L_2 are connected in parallel to each other. The parallel circuit means voltage is the same and current is different

Apply the KCL at node A

$$i = i + i_2 \qquad V = L\frac{di}{dt}$$

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

$$i = \int \frac{V}{L} dt \qquad i = V \int \frac{1}{L} dt$$

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similarly $i_1 = v\int \frac{1}{L_1} dt$ and $i_2 = v\int \frac{1}{L_2} dt$

$$i = i_1 + i_2$$

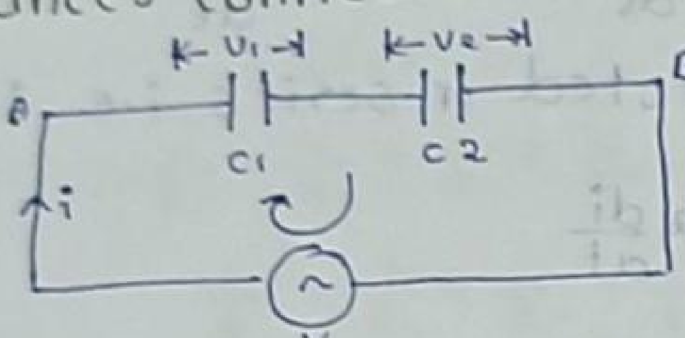
$$v\int \frac{1}{L} dt = v\int \frac{1}{L_1} dt + v\int \frac{1}{L_2} dt$$

$$\frac{1}{L}\int v dt = \left(\frac{1}{L_1} + \frac{1}{L_2}\right)\int v dt$$

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$

$$\boxed{L = \frac{L_1 L_2}{L_1 + L_2}}$$

Capacitances connected in series:



From the above circuit the two capacitances C_1 and C_2 are connected in series. The series circuit means current (or) charge is same and the voltatege is different.

Apply KVL at node 'A' closed circuit

$v = \frac{1}{c}\int i dt$ $\quad v_{c1} = \frac{1}{C_1}\int i dt$ $\quad v_{c2} = \frac{1}{C_2}\int i dt$

$$\frac{1}{c}\int i dt = \frac{1}{C_1}\int i dt + \frac{1}{C_2}\int i dt$$

$$\frac{1}{c}\cancel{\int i dt} = \left[\frac{1}{C_1} + \frac{1}{C_2}\right]\cancel{\int i dt}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\boxed{C = \frac{C_1 C_2}{C_1 + C_2}}$$

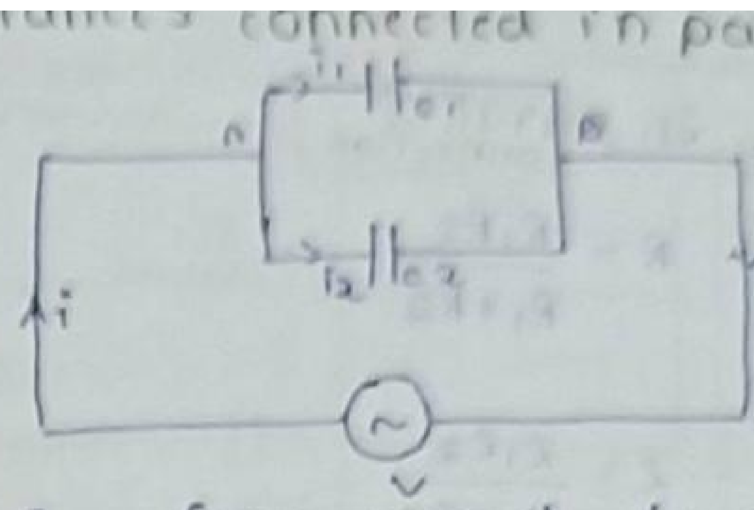
(or) $C = \frac{Q}{V}$

$$Q = CV \Rightarrow V = \frac{Q}{C}$$

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

Capacitances connected in parallel:



From the above circuit two capacitances are C_1 and C_2 are connected in parallel. Parallel means voltage is same and current (or) charge is different.

Apply KCL at node 'A' colosed circuit

$$\boxed{i = i_1 + i_2}$$

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

$$CV = \int i dt$$

$$\frac{dv}{dt} = \frac{i}{c}$$

$$\boxed{i = C\frac{dv}{dt}}$$

$$i_1 = C_1\frac{dv_1}{dt}, \quad i_2 = C_2\frac{dv_2}{dt}$$

$$\frac{dv}{dt} = \frac{dv_1}{dt} = \frac{dv_2}{dt}$$

$$C\frac{dv}{dt} = C_1\frac{dv}{dt} + C_2\frac{dv}{dt}$$

$$\boxed{C = C_1 + C_2}$$

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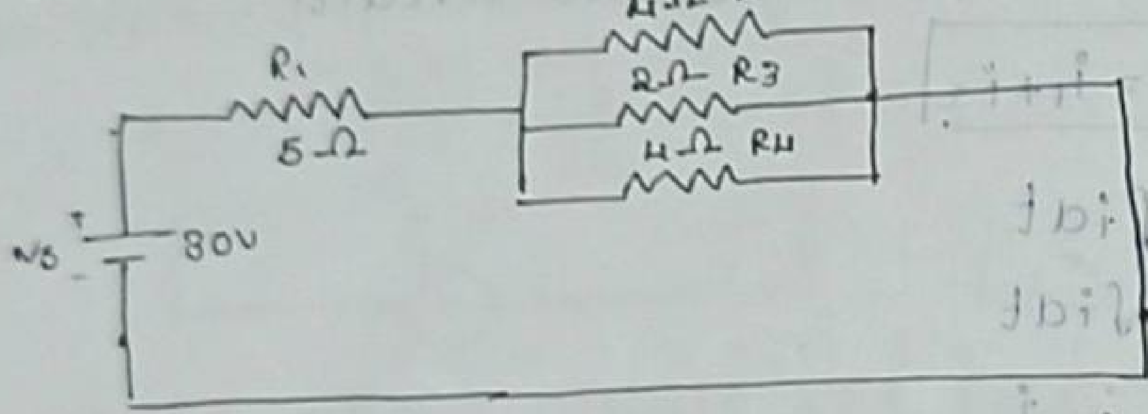
	In series connection	In parallel connection
R	$R = R_1 + R_2$	$R = \frac{R_1 R_2}{R_1 + R_2}$
L	$L = L_1 + L_2$	$L = \frac{L_1 L_2}{L_1 + L_2}$
C	$C = \frac{C_1 C_2}{C_1 + C_2}$	$C = C_1 + C_2$

→ 

Determine the total current in the circuit shown

$$R_2 \| R_3 \| R_4 = \frac{R_2 R_3 R_4}{R_2 R_3 + R_3 R_4 + R_2 R_4}$$

$$= \frac{32}{8+8+16} = \frac{32}{32} = 1\Omega = R_5$$

$R = R_1 + R_5$

$R = 5 + 1$

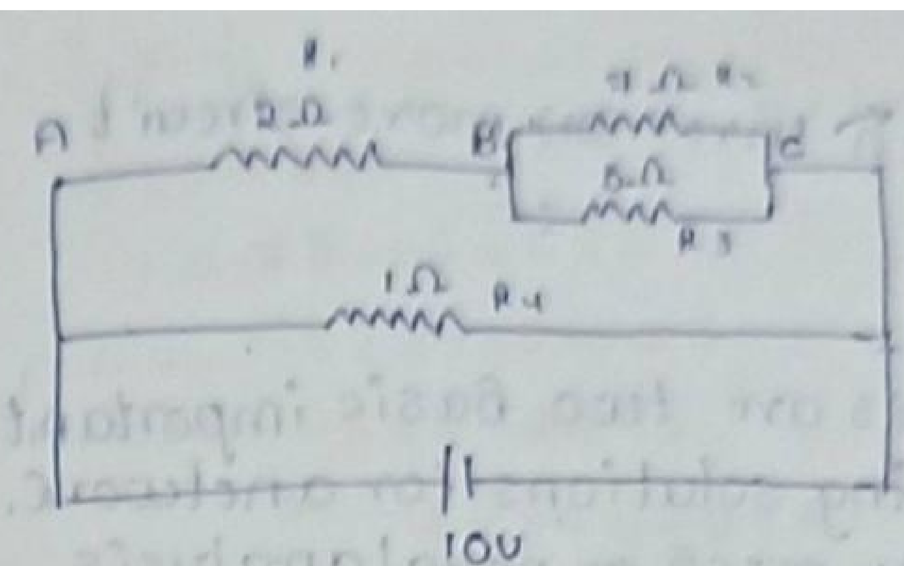
$R = 6\Omega$

$V = IR$

$I = \frac{30}{6}$

$I = 5A$

→ An electric circuit has three terminals A, B, C. Between A and B is connected as 2Ω resistor, between B and C are connected a 7Ω resistor and a 5Ω resistor in parallel and b/w A and C is connected a 1Ω resistor. A battery of 10V is then connected b/w A & C. Calculate (a) total current (b) voltage accross the 2Ω resistor (c) current through 5Ω resistor.



$R_5 = R_1$ series $R_2 \| R_3$

$$= 2 + \frac{R_2 R_3}{R_2 + R_3}$$

$$= 2 + \frac{35}{12}$$

$$= \frac{24 + 35}{12}$$

$$= \frac{59}{12}$$

$$I_1 = \frac{V_1}{R_1} = 10 \times \frac{12}{59} = 2$$

$R = R_5 \| R_4$

$$= \frac{(1)\left(\frac{59}{12}\right)}{1 + \frac{59}{12}} = \frac{59}{71}$$

$$I = \frac{V}{R} = 10 \times \frac{71}{59}$$

$I = 12A$

$V_{2\Omega} = I_1 R_1$

$= 12 \times 2$

$= 4V$

$\cancel{V_{5\Omega} = I \times R_3}$

$\cancel{= 3.4 \times}$

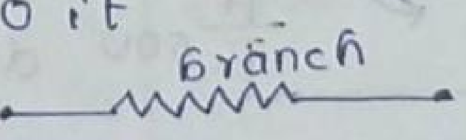
current division rule

$$I \times \frac{R_{7\Omega}}{R_2 + R_3}$$

$$I_{5\Omega} = \frac{2 \times 7}{7 + 5} = \frac{14}{12} = 1.17A$$

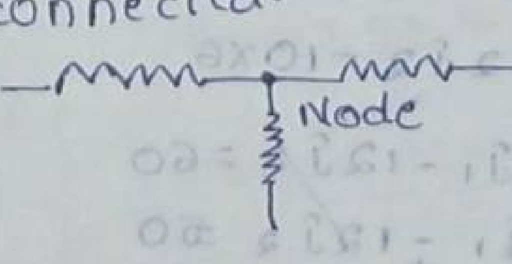
Branch:

A branch is a portion of circuit with two terminals connected to it



Junction:

It is a point at which two (or) more circuit elements are connected.



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junction

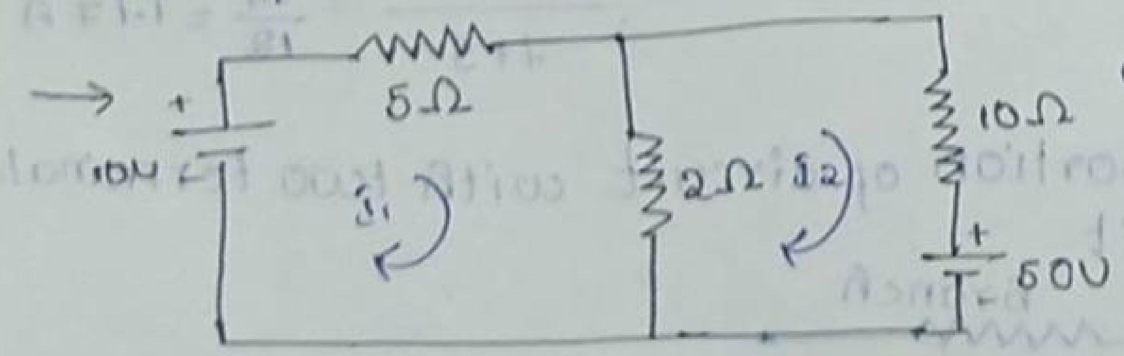
It is a point at which three (or) more circuit elements are connected.

Mesh Analysis:

Mesh and nodal analysis are two basic important techniques used in finding solutions for a network. The suitability of either mesh or nodal analysis to a particular problem depends mainly on the number of voltage sources or current sources. If a network has a large number of voltage sources, it is useful to use mesh analysis: as this analysis requires that all the sources in a circuit be voltage sources. Therefore, if there are any current sources in a circuit they are to be converted into equivalent voltage sources, if on the other hand, the network has more current sources, nodal analysis is more useful.

Steps to apply Mesh analysis:

1. Indicate the loops in given network.
2. Assume mesh currents or loop currents i_1 & i_2 with directions.
3. Write KVL eq's for the loops.
4. Find the values of unknown currents which is the final solution.



write the mesh current eq's in the circuit shown & determine the currents

$-10 + 5i_1 + 2(i_1 - i_2) = 0$

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

$7i_1 - 2i_2 = 10 \times 6$

$42i_1 - 12i_2 = 60$

$\underline{-2i_1 \mp 12i_2 \pm 50}$

$40i_1 = 10$

$2(i_2 - i_1) + 10i_2 + 50 = 0$

$2i_2 - 2i_1 + 10i_2 + 50 = 0$

$-2i_2 + 12i_2 = -50$

$i_2 - 6i_2 = 25 \times 2$

$i_1 = \frac{1}{4}$

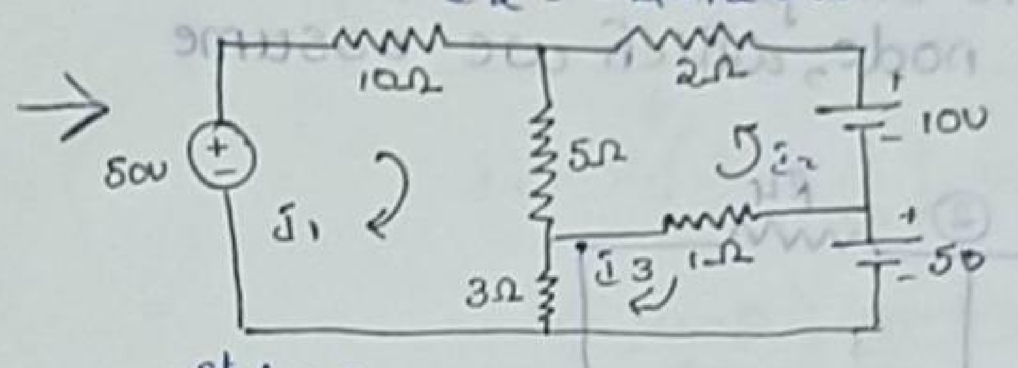
$i_1 = 0.25A$

$0.25 - 6i_2 = 25$

$-6i_2 = 25 - 0.25$

$-6i_2 = 24.75$

$i_2 = -4.125A$



Determine mesh currents i_1, i_2, i_3 for the circuit shown by using cramer's rule.

1st loop

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

$18i_1 + 5i_2 - 3i_3 = 50 \longrightarrow (1)$

2nd loop

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

$8i_2 + 5i_1 + i_3 = 10$

$5i_1 + 8i_2 + i_3 = 10 \longrightarrow (2)$

3rd loop

$5 + 1(i_3 + i_2) + 3(i_3 - i_1) = 0$

$-3i_1 + i_2 + 4i_3 = -5 \longrightarrow (3)$

$$\begin{bmatrix} 18 & 5 & -3 \\ 5 & 8 & 1 \\ -3 & 1 & 4 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 50 \\ 10 \\ -5 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 18 & 5 & -3 \\ 5 & 8 & 1 \\ -3 & 1 & 4 \end{vmatrix} = 356 \qquad \Delta_1 = \begin{vmatrix} 50 & 5 & -3 \\ 10 & 8 & 1 \\ -5 & 1 & 4 \end{vmatrix}$$

$\Delta_1 = 1175$

$i_1 = \frac{\Delta_1}{\Delta} = \frac{1175}{356}$

$i_1 = 3.30A$

$$\Delta_2 = \begin{vmatrix} 18 & 50 & -3 \\ 5 & 10 & 1 \\ -3 & -5 & 4 \end{vmatrix}$$

$i_2 = -\frac{355}{356}$

$= -0.997A$

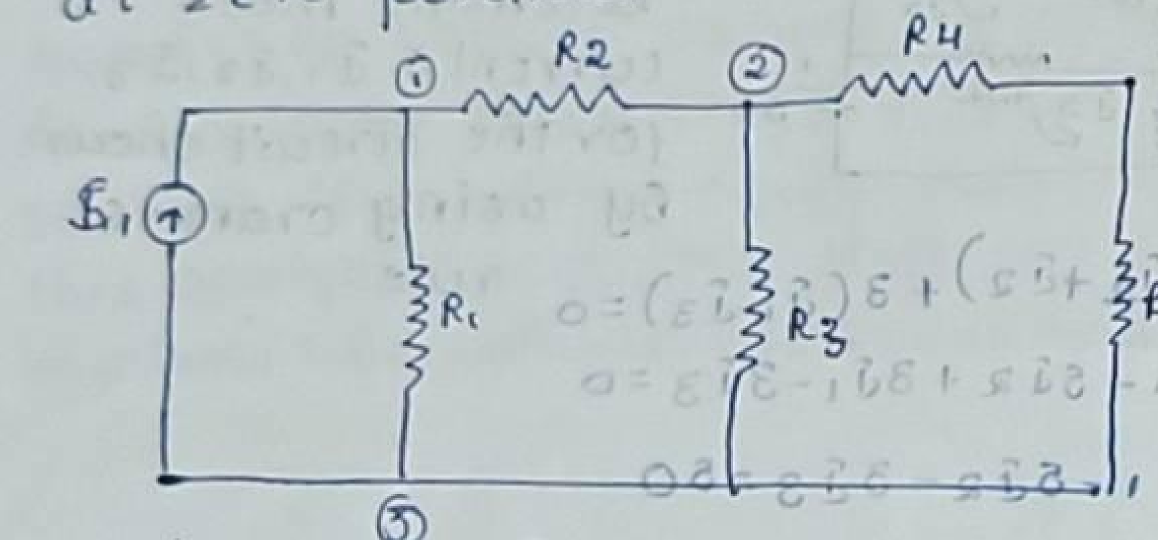
$$\Delta_3 = \begin{vmatrix} 15 & 5 & 50 \\ 5 & 8 & 10 \\ -3 & 1 & -5 \end{vmatrix}$$

$I_3 = \frac{525}{356}$

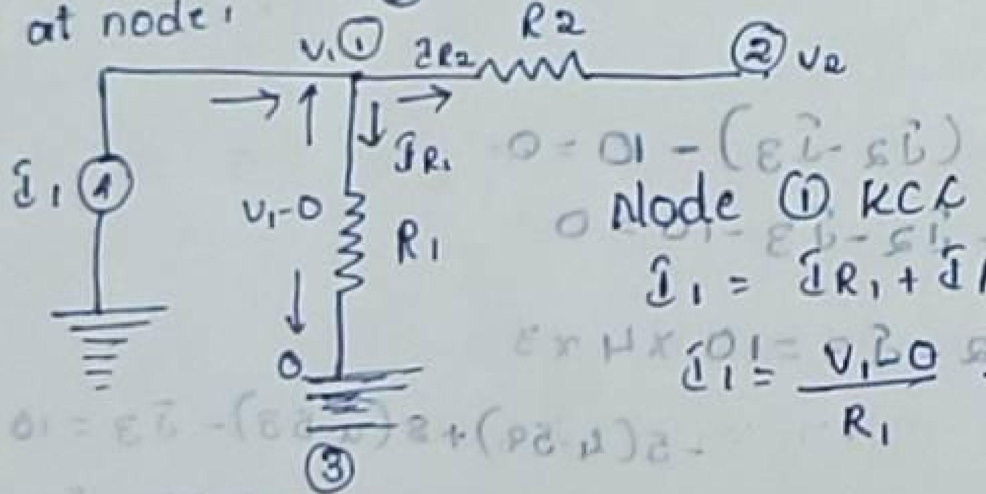
$I_3 = 1.474A$

Node voltage:

The node voltage is the voltage of a given node with respect to one particular node, called the reference node, which we assume at zero potential.



at node 1



Node ① KCL

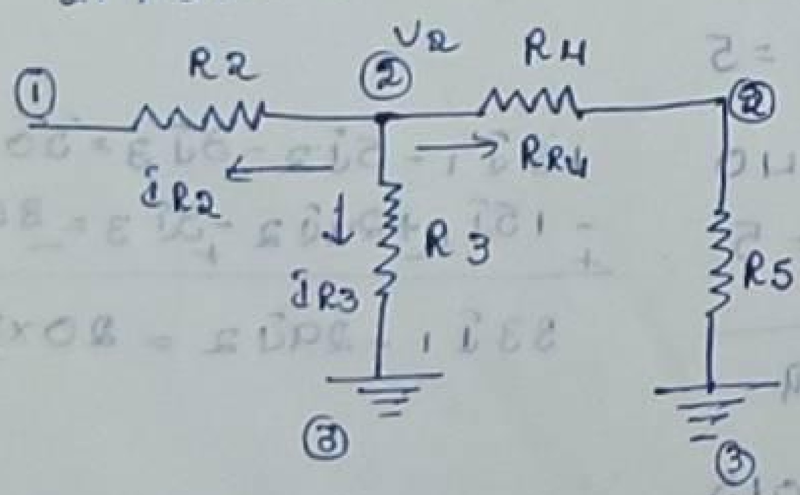
$I_1 = I_{R_1} + I_{R_2}$

$I_1 = \frac{V_1 - 0}{R_1} + \frac{V_1 - V_2}{R_2}$

$I_1 = \frac{V_1}{R_1} + \frac{V_1 - V_2}{R_2}$

$I_1 = V_1\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \left[\frac{V_2}{R_2}\right]$

at node 2



Node ② KCL

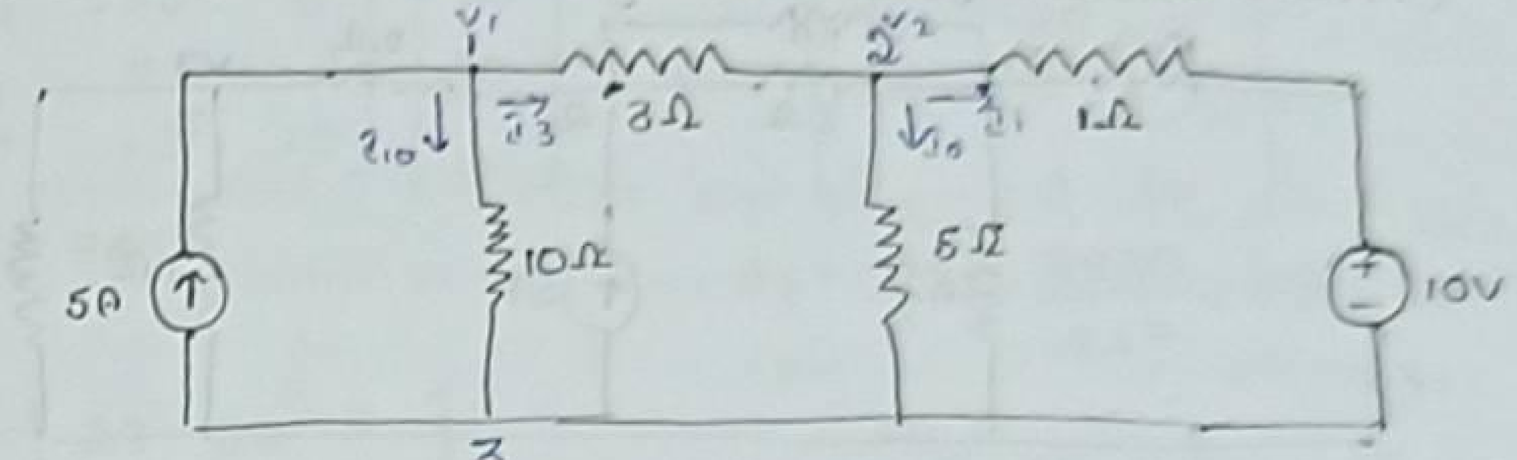
$0 = I_{R_2} + I_{R_3} + I_{R_4}$

$0 = \frac{V_2 - V_1}{R_2} + \frac{V_2 - 0}{R_3} + \frac{V_2 - 0}{R_4 + R_5}$

$-V_1\left[\frac{1}{R_2}\right] + V_2\left[\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4 + R_5}\right] = 0$

From the above equations we can find unknown voltages

→ write the node voltage equations and determine the currents in each branch for the network shown in



$I_1 = V_1\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - V_2\left[\frac{1}{R_2}\right]$

$I_1 = \frac{V_1 - 0}{R_1} + \frac{V_1 - V_2}{R_2}$

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

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

$5 = V_1\left[\frac{3+10}{30}\right] - \frac{10V_2}{30}$

$13V_1 - 10V_2 = 150$ ①

$0 = I_3 + I_5 + I_1$

$0 = \frac{V_2 - V_1}{3} + \frac{V_2}{5} + \frac{V_2 - 10}{1}$

$0 = 5V_2 - 5V_1 + 3V_2 + 15V_2 - 150$

$-5V_1 + 23V_2 = 150$ ②

$65V_1 - 50V_2 = 750$

$-65V_1 + 299V_2 = 1950$

$249V_2 = 2700$

$V_2 = \frac{2700}{249}$

$V_2 = 10.84\,V$

① $13V_1 - 108.4 = 150$

$13V_1 = 258.4$

$V_1 = \frac{258.4}{13}$

$V_1 = 19.87\,V$

$I_{10} = \frac{V_1}{10} = \frac{19.87}{10} = 1.987A$

$I_3 = \frac{V_1 - V_2}{3} = \frac{19.87 - 10.84}{3} = 3.01A$

$I_5 = \frac{V_2}{5} = \frac{10.84}{5} = 2.168A$

$I_1 = \frac{V_2 - 10}{1} = 10.84 - 10 = 0.84A$

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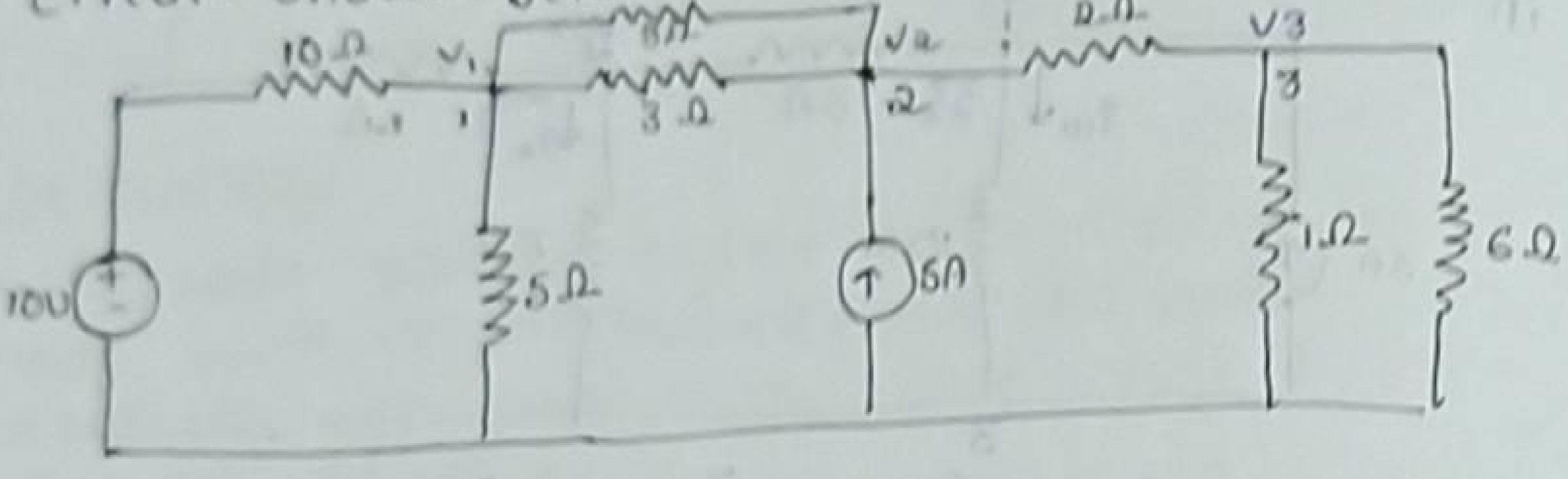
→ Determine the voltages at each node for the circuit shown below using cramers rule



at node 1

$$0 = \frac{-10+V_1}{10} + \frac{V_1}{5} + \frac{V_1 - V_2}{\cancel{2}\ 3}$$

$$0 = \frac{-10+V_1}{10} + \frac{V_1}{5} + \frac{2V_1 - 2V_2}{3}$$

$$0 = \frac{-10+V_1+2V_1}{10} + \frac{2V_1 - 2V_2}{3}$$

$$0 = \frac{-10+3V_1}{10} + \frac{2V_1 - 2V_2}{3}$$

$$0 = -30 + 9V_1 + 20V_1 - 20V_2$$

$$29V_1 - 20V_2 = 30 \rightarrow ①$$

$$0.96V_1 - 0.66V_2 = 1 \rightarrow$$

at node 2

$$5 + 0 = \frac{-2V_1+2V_2}{3} + \frac{V_2 - V_3}{2}$$

$$5 = \frac{-4V_1 + 4V_2 + 3V_2 - 3V_3}{6}$$

$$30 = -4V_1 + 7V_2 - 3V_3$$

$$-4V_1 + 7V_2 - 3V_3 = 30 \rightarrow ②$$

at node 3

$$0 = \frac{V_3 - V_2}{2} + \frac{V_3}{1} + \frac{V_3}{6}$$

$$0 = \frac{3V_3 - 3V_2 + 6V_3 + V_3}{6}$$

$$-3V_2 + 10V_3 = 0 \rightarrow ③$$

$$-4V_1 + 7V_2 - 3V_3 = 30 \times 10$$

$$\begin{bmatrix} 29 & -20 & 0 \\ -4 & 7 & -3 \\ 0 & -3 & 10 \end{bmatrix} \begin{bmatrix} 30 \\ 30 \\ 0 \end{bmatrix} \qquad ① \quad \Delta_1 = \begin{bmatrix} 30 & -20 & 0 \\ 30 & 7 & -3 \\ 0 & -3 & 10 \end{bmatrix}$$

$$\Delta = 969$$

$$\Delta_1 = \frac{\Delta_1}{\Delta} = \frac{2930}{969} = 3.02V \quad (V_1)$$

$$\Delta_2 = \begin{bmatrix} 29 & 30 & 0 \\ -4 & 30 & -3 \\ 0 & 0 & 10 \end{bmatrix} \qquad \Delta_3 = \begin{bmatrix} 29 & -20 & 30 \\ -4 & 7 & 30 \\ 0 & -3 & 0 \end{bmatrix}$$

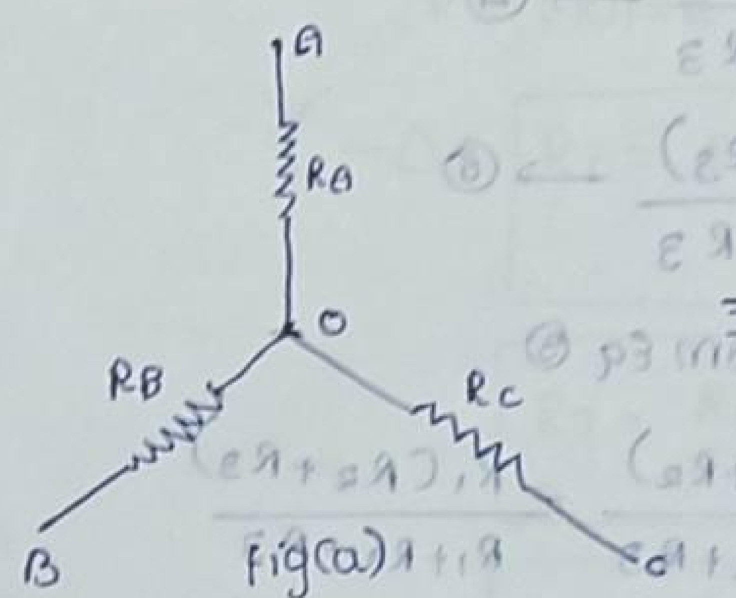
$$V_2 = \frac{\Delta_2}{\Delta} = \frac{9900}{969} = 10.21V \qquad V_3 = \frac{\Delta_3}{\Delta} = \frac{2970}{969} = 3.06V$$

Star Delta transformation:

→ It is another thechnique useful in solving complex networks.

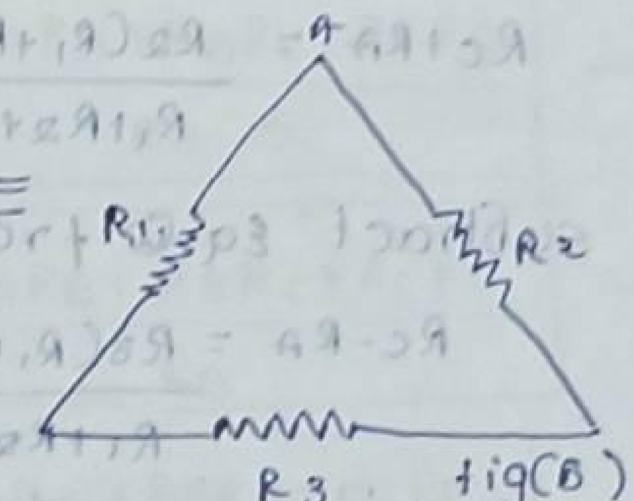
→ Basically, any three circuit elements i.e; resistive, inductive or capacitive may be connected in two different ways

1. Star connection (Y)
2. Delta connection (∇/Δ)



fig(a)

=



fig(B)

→ The above two circuits are equal if their respective resistances form the terminals AB, BC and CA are equal.

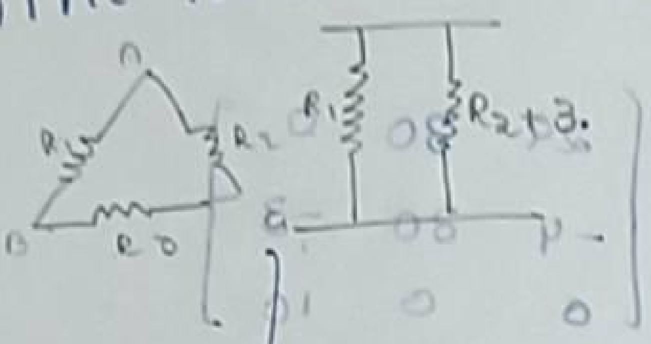
→ Consider the Y-connected circuit in fig(a), the resistance from the terminals AB, BC and CA respectively are

$$\left.\begin{aligned} R_{AB}(Y) &= R_A + R_B \\ R_{BC}(Y) &= R_B + R_C \\ R_{CA}(Y) &= R_C + R_A \end{aligned}\right\} \text{①}$$

$Y \Rightarrow T$

$\Delta \Rightarrow \Pi$

similarly in Δ-connected network shown in fig ⑥, the resistances seen from the terminals AB, BC & CA respectively are



$$\left.\begin{aligned} R_{AB}(\Delta) &= R_1 // R_2 + R_3 = \frac{R_1(R_2+R_3)}{R_1+R_2+R_3} \\ R_{BC}(\Delta) &= R_3 // R_1 + R_2 = \frac{R_3(R_1+R_2)}{R_1+R_2+R_3} \\ R_{CA}(\Delta) &= R_2 // R_1 + R_3 = \frac{R_2(R_1+R_3)}{R_1+R_2+R_3} \end{aligned}\right\} \text{②}$$

Equate the resistances of Y and Δ circuits ① = ②, we get

$$R_A + R_B = \frac{R_1(R_2+R_3)}{R_1+R_2+R_3} \longrightarrow ③$$

$$R_B + R_C = \frac{R_3(R_1+R_2)}{R_1+R_2+R_3} \longrightarrow ④$$

$$R_C + R_A = \frac{R_2(R_1+R_3)}{R_1+R_2+R_3} \longrightarrow ⑤$$

subtract Eq ③ from Eq ④

$$R_C - R_A = \frac{R_3(R_1+R_2)}{R_1+R_2+R_3} - \frac{R_1(R_2+R_3)}{R_1+R_2+R_3}$$

$$R_C - R_A = \frac{\cancel{R_3R_1} + R_3R_2 - R_1R_2 - \cancel{R_1R_3}}{R_1+R_2+R_3}$$

$$R_C - R_A = \frac{R_3R_2 - R_1R_2}{R_1+R_2+R_3}$$ then add ⑤

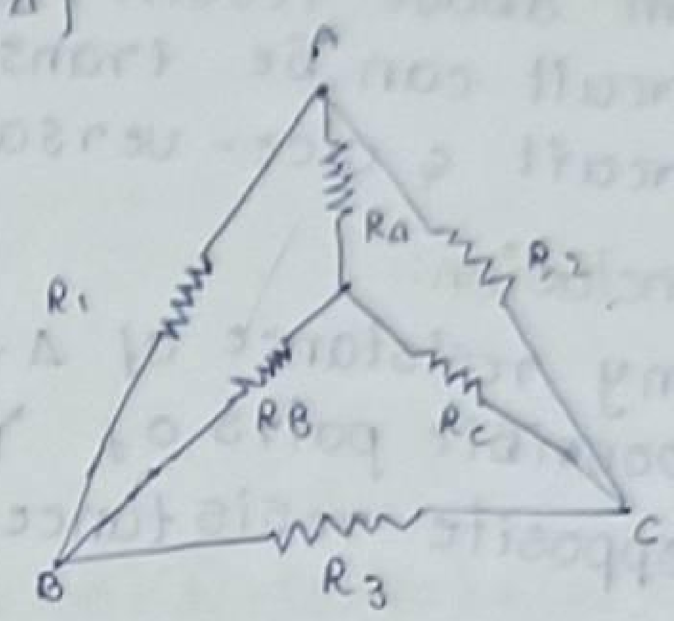
$$2R_C = \frac{R_3R_2 - \cancel{R_1R_2} + \cancel{R_2R_1} + R_2R_3}{R_1+R_2+R_3}$$

$$\boxed{R_C = \frac{R_2R_3}{R_1+R_2+R_3}} \longrightarrow ⑥\ [Y \to \Delta]$$

$$\boxed{R_B = \frac{R_1R_3}{R_1+R_2+R_3}} \longrightarrow ⑦$$

$$\boxed{R_A = \frac{R_2R_1}{R_1+R_2+R_3}} \longrightarrow ⑧$$

$\Delta \rightarrow Y$



$Y-\Delta$:-

Multiplying ⑥ & ⑦, ⑦ & ⑧, ⑧ & ⑥ and add the three we get

$$R_CR_B + R_BR_A + R_AR_C = \frac{R_1R_2R_3^2}{(R_1+R_2+R_3)^2} + \frac{R_1^2R_2R_3}{(R_1+R_2+R_3)^2} + \frac{R_1R_2^2R_3}{(R_1+R_2+R_3)^2}$$

$$= \frac{R_1R_2R_3\,\cancel{(R_1+R_2+R_3)}}{(R_1+R_2+R_3)^{\cancel{2}}}$$

$$R_CR_B + R_BR_A + R_AR_C = \frac{R_1R_2R_3}{R_1+R_2+R_3}$$

$$R_1 = [R_AR_B + R_BR_C + R_CR_A]\frac{(R_1+R_2+R_3)}{R_2R_3}$$

$$R_1 = [R_AR_B + R_BR_C + R_CR_A] \times \frac{1}{R_C}$$

$Y-\Delta$: $$\boxed{R_1 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_C}} \longrightarrow ⑨$$

$$\boxed{R_2 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_B}} \longrightarrow ⑩$$

$$\boxed{R_3 = \frac{R_AR_B + R_BR_C + R_CR_A}{R_A}} \longrightarrow ⑪$$

(or) $R_1 = \frac{R_AR_B}{R_C} + R_B + R_A$

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

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

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from above results, we can say that a Y-connected circuit can be transformed into a Δ-connected circuit & vice-versa.

Conclusion:

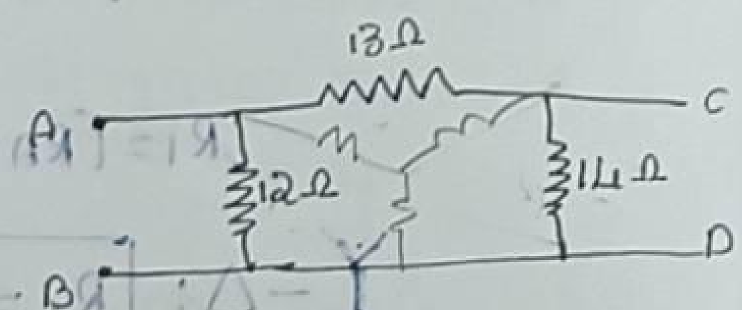
1. Any resistance of Δ-circuit = sum of all possible pairs of Y-resistances divided by opposite resistance of Y-circuit.

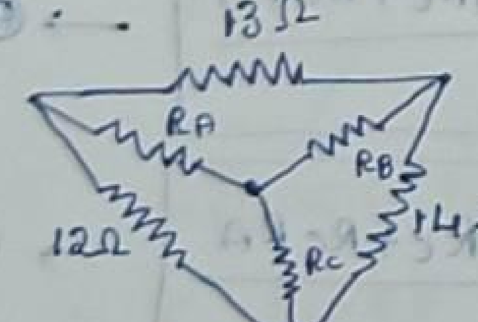
$$\therefore \Delta\text{-circuit resistance} = \frac{\text{sum of products of pairs of Y-resistances}}{\text{opposite resistance of Y circuit}}$$

2. Any resistance of Y-circuit = product of two adjacent resistances in the Δ-connected circuit divided by the sum of all resistances in Δ-connected circuit.

$$\therefore \text{Y-circuit resistance} = \frac{\text{Product of two adjacent resistances in Δ-circuit}}{\text{sum of all resistances in Δ-circuit}}$$

→ Obtain the Y-connected eq^n for the Δ-connected crt shown in fig



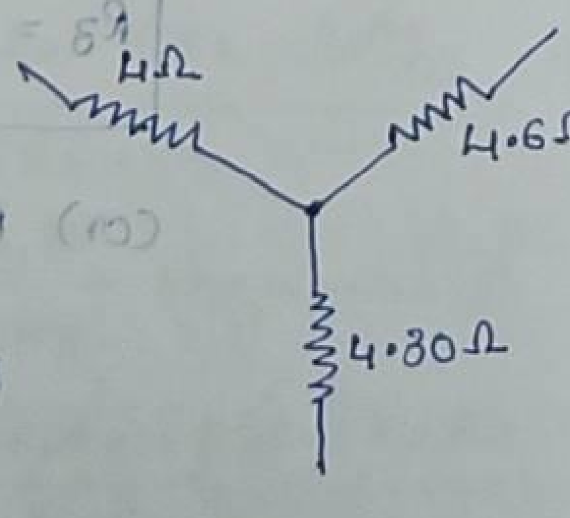


$$R_A = \frac{(13)(12)}{13+12+14}$$

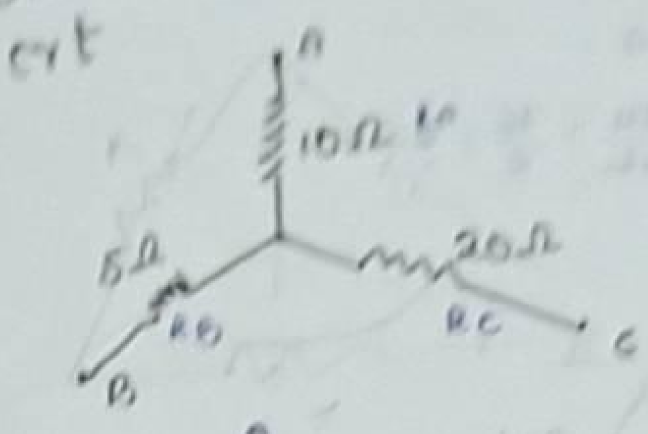
$$R_A = \frac{(\cancel{13})(12)}{\cancel{39}_3} = 4\Omega$$

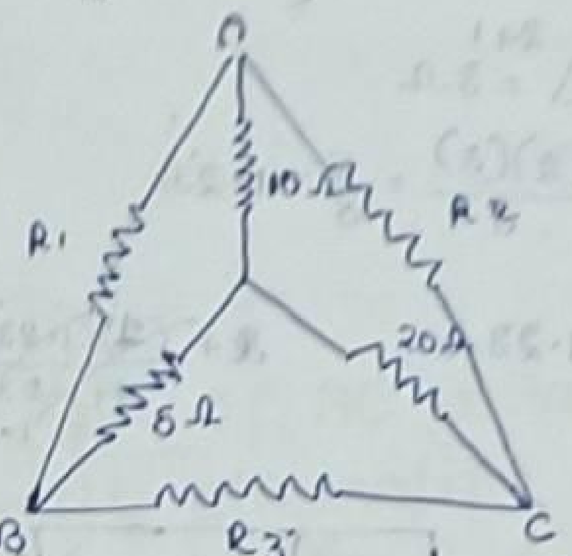
$$R_B = \frac{(\cancel{13})(14)}{\cancel{39}\,3} = 4.6\Omega$$

$$R_C = \frac{(12)(14)}{39} = 4.30$$



→ Obtain the Δ-connected eq^n for the Y-connected crt





$$R_1 = \frac{(10)(5)+(5)(20)+(20)(10)}{20}$$

$$= \frac{50+100+200}{20}$$

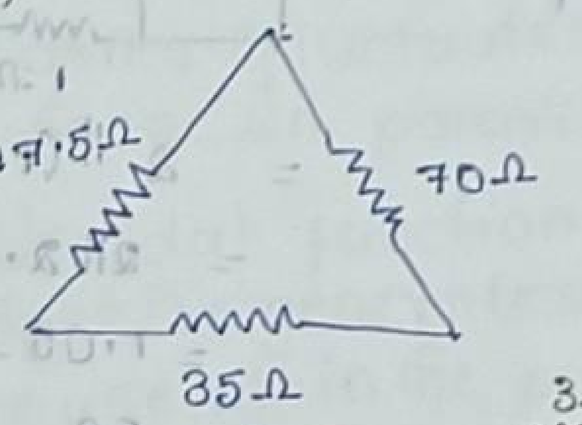
$$= \frac{35\cancel{0}}{2\cancel{0}}$$

$$R_1 = 17.5\,\Omega$$

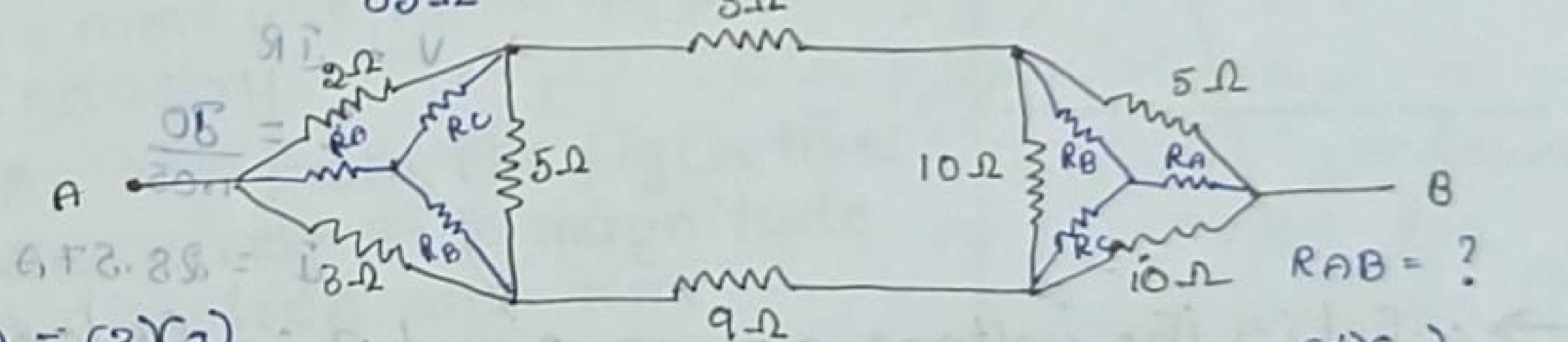
$$R_2 = \frac{350}{5} = 70\Omega \quad R_3 = \frac{350}{10} = 35\Omega$$

Δ - $\frac{R_1R_2+R_2R_3+R_3R_1}{R}$

Y - $\frac{R_1R_2}{R_1+R_2+R_3}$



→



R_{AB} = ?

$$R_A = \frac{(3)(2)}{2+3+5} = \frac{6}{10} = 0.6\Omega$$

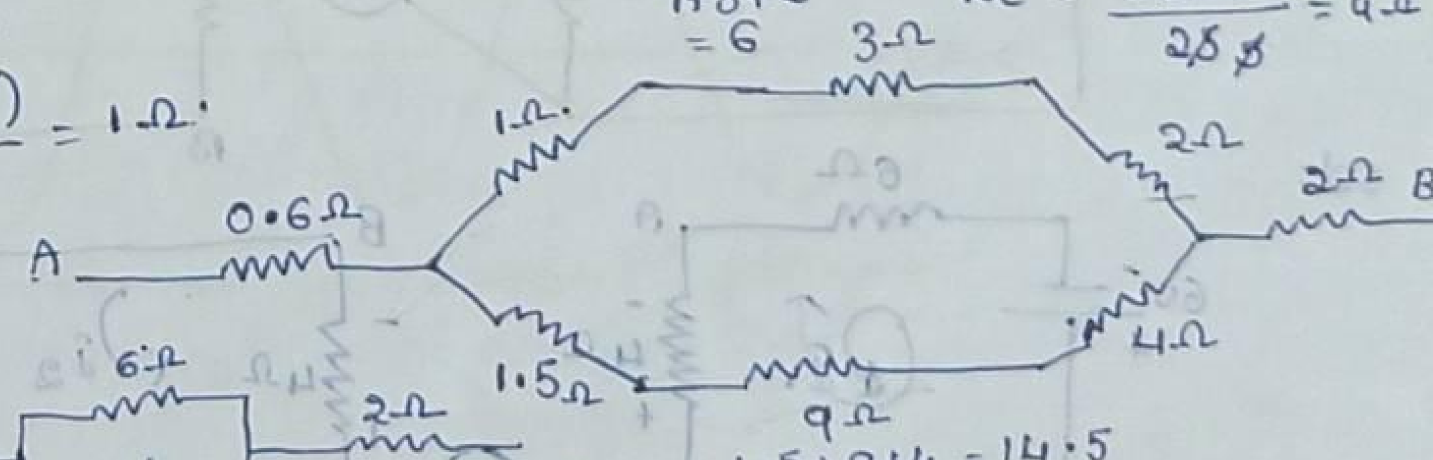
$$R_B = \frac{(3)(\cancel{5})}{\cancel{10}\,2} = 1.5\Omega$$

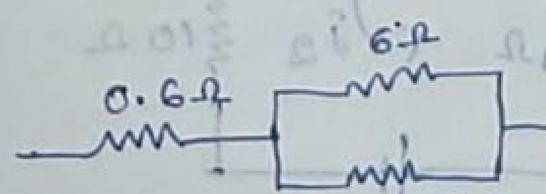
$$R_C = \frac{(2)(5)}{10} = 1\Omega$$

$$R_A = \frac{(\cancel{5})(10)}{\cancel{25}} = 2\Omega$$

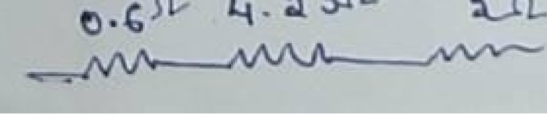
$$R_B = \frac{(10)(\cancel{5})}{\cancel{25}} = 2\Omega$$

$$R_C = \frac{(10)(\cancel{10})}{\cancel{25}} = 4\Omega$$





$$\frac{(6)(14.5)}{6+14.5} = 4.24\Omega$$



$$= 0.6+4.25+2 = 6.85\,\Omega$$

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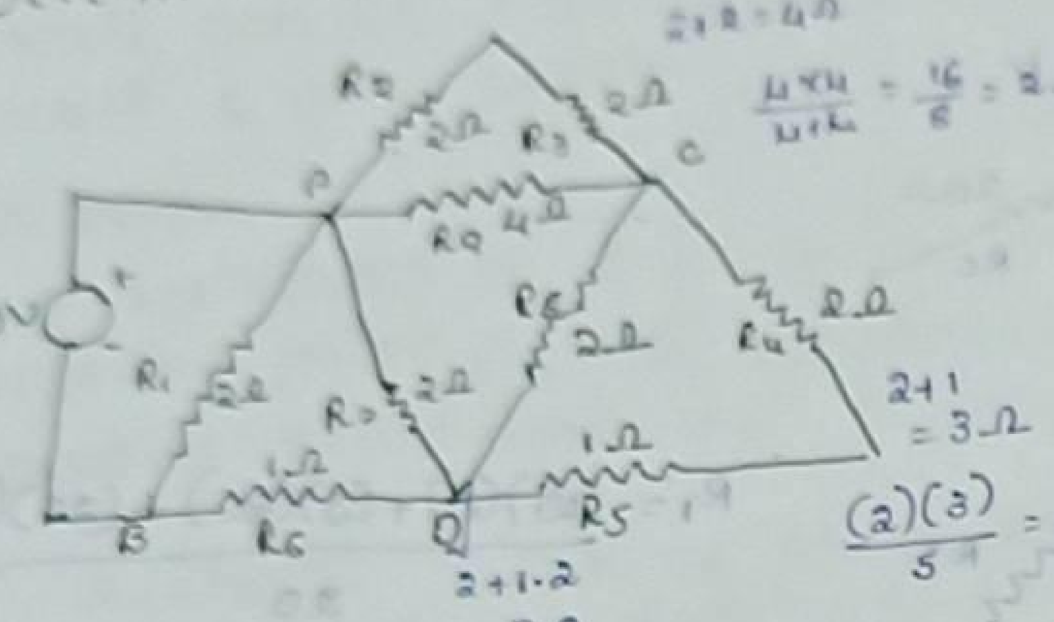
→ Determin the current delivered



$2+2=4\Omega$

$\frac{4\times4}{4+4}=\frac{16}{8}=2\Omega$

$2+1 = 3\Omega$

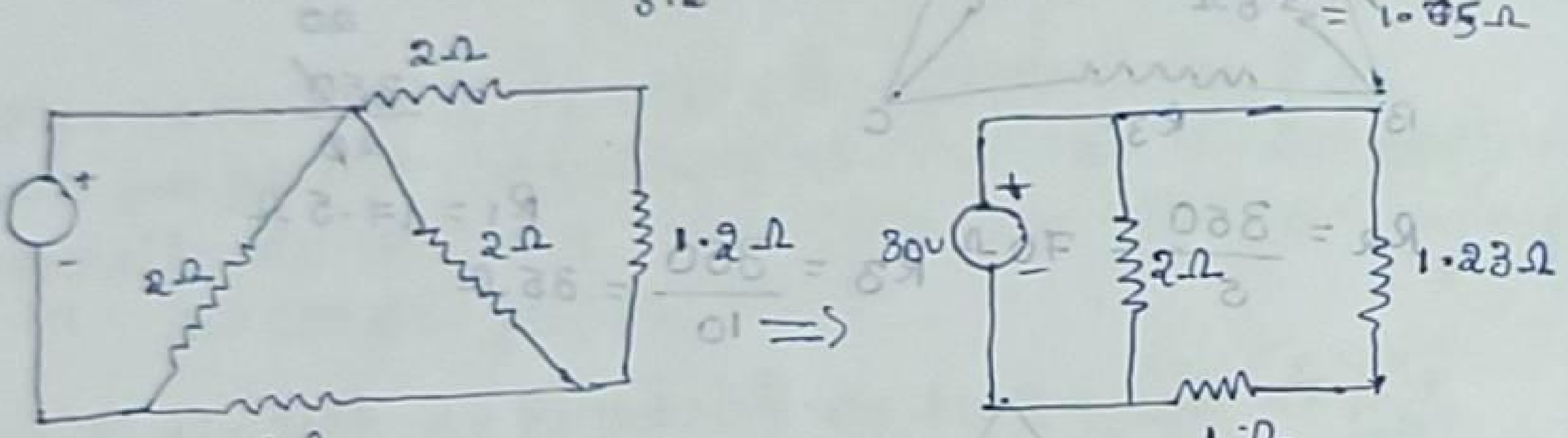
$\frac{(2)(3)}{5}=\frac{6}{5}=1.2\Omega$

$2+1.2$

3.2

$=\frac{(3.2)(2)}{5.2}=1.23\Omega$

$\cancel{2+\frac{(2)(1.23)}{2+1.23}}$ (last) $= 1.75\Omega$



$= 2 \parallel (1+1.23)$

$= 2 \parallel 2.23$

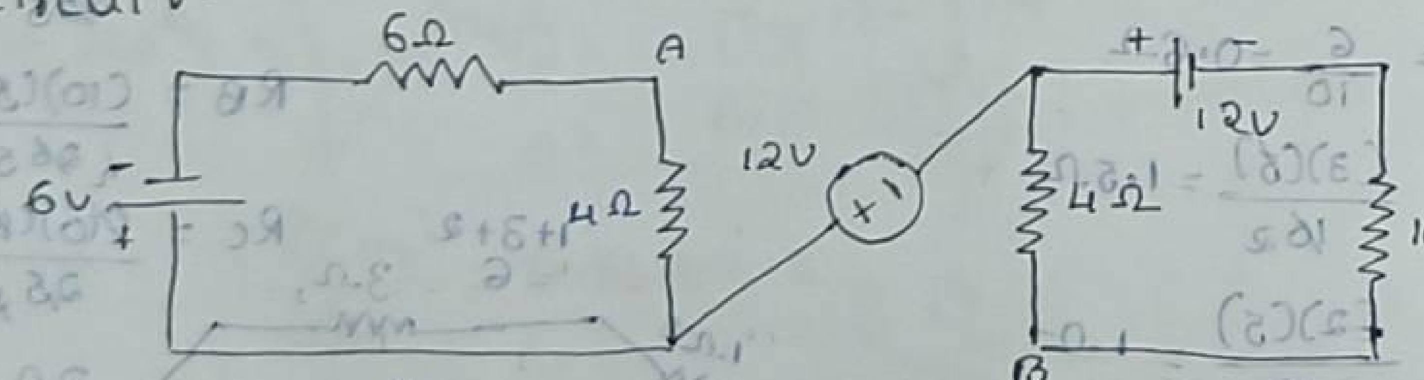
$= 1.05\Omega$

$V = IR$

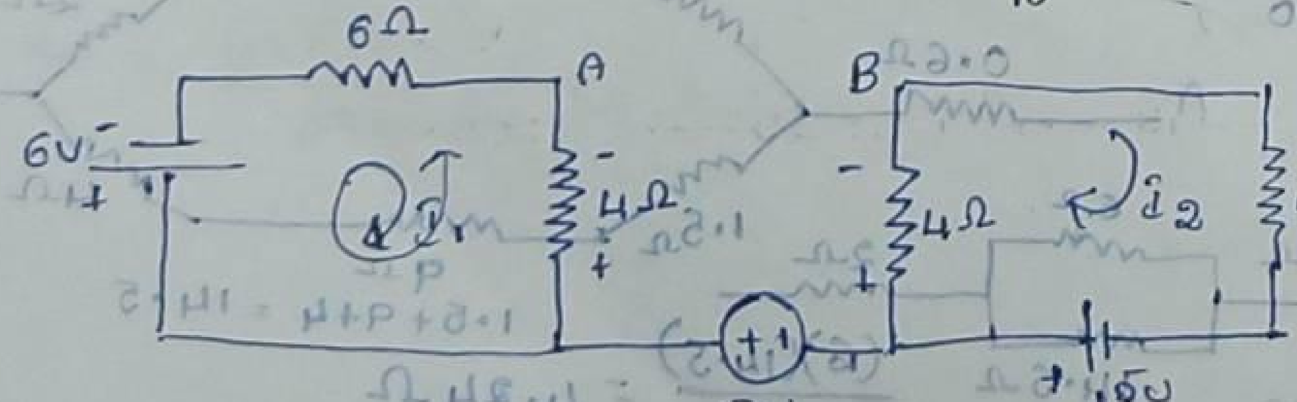
$I = \frac{30}{1.05}$

$I = 28.57A$

→ what is the voltage across A and B in below circuit.



Sol:



Principle of AC voltages:

→ Mostly alternating votages and currents are represented by a sinusoidal wave or a sinusoid.

→ Basically an alternating voltage (current) wave form is defined as the voltage (current) that varies (fluctuates) with time periodically with change in polarity and direction.

→ A sinusoidal function is easy to analyse, to generate & it is more useful in the power industry.

→ As seen from the fig ①, the wave changes its magnitude & direction with time.

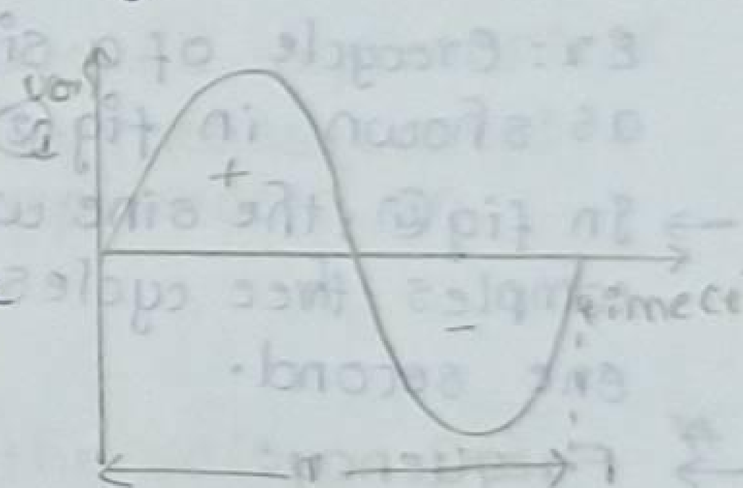


fig ① sinusoidal wave form

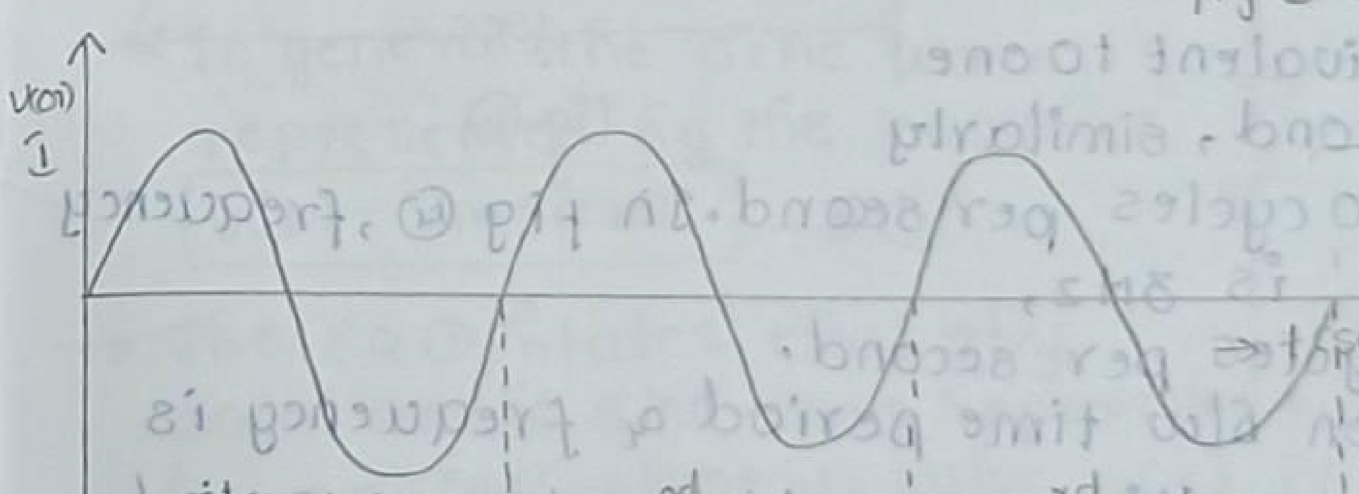


fig (2)

→ If we start at time t=0, the wave goes to a maximum value and returns to zero, and then decreases to a negative maximum value before returning to zero. The sine wave changes with time in an orderly manner.

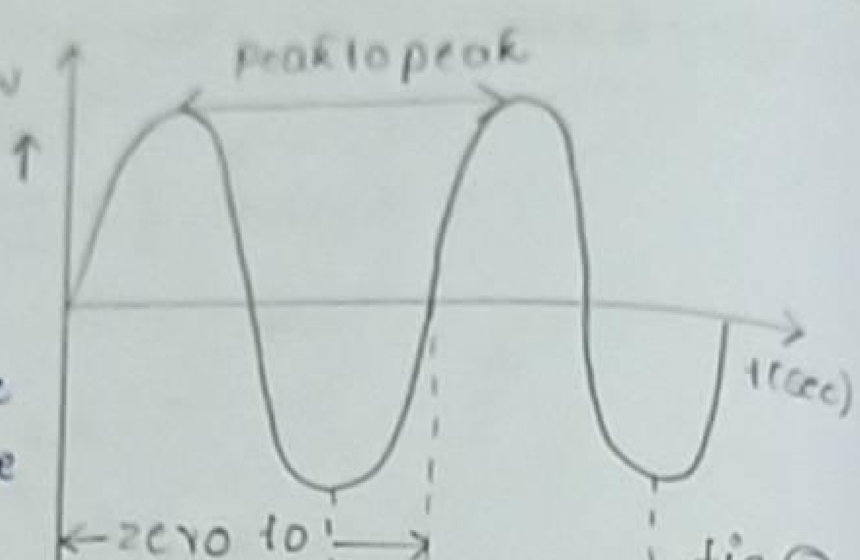


fig ③

→ During the positive portion of voltage, the current flows in one direction & during the negative portion of voltage, the current flows in opposite direction. The complete +ve and -ve portion of the wave is one cycle of the sine wave. Time is designated by "t".

Time period:

The time taken for any wave to complete one full cycle is called the period (T). In general, any periodic wave constitutes a no. of such cycles.

Ex: One cycle of a sine wave repeats a no. of times as shown in fig ④

→ In fig ④, the sine wave completes three cycles in one second.

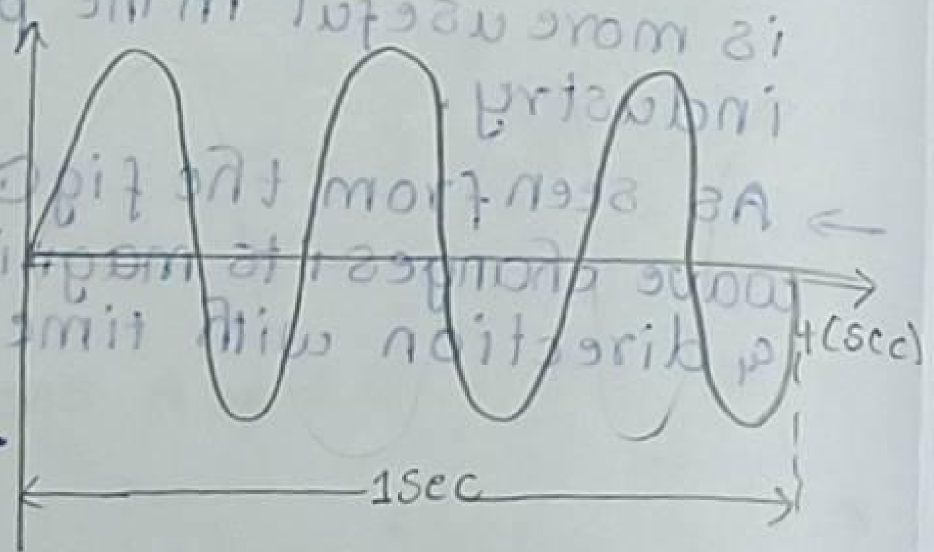


fig ④

Frequency:

It is measured in hertz.

1 hertz is equivalent to one cycle per second, similarly 60 hertz is 60 cycles per second. In fig ④, frequency denoted by 'f' is 3Hz, i.e. three cycles per second.

The relation b/w time period & frequency is

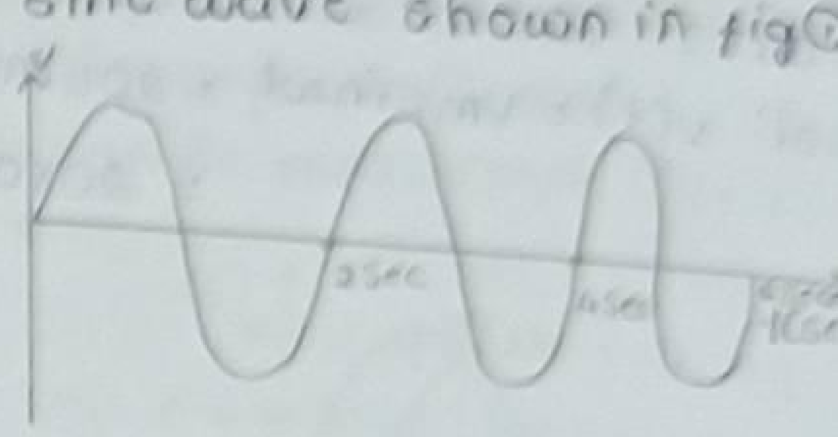
$$\boxed{f = \frac{1}{T}}$$

• A sine wave with a longer period consists of fewer cycles than one with a shorter period.

1. What is the period of sine wave shown in fig ⑤

sol: It can be seen that the sine wave takes 2 sec to complete one period in each cycle.

T = 2sec



2. The period of a sine wave is 20ms. What is the frequency.

sol: $f = \frac{1}{T} = \frac{1}{20\times10^{-3}} = \frac{100\cancel{0}}{2\cancel{0}} = 50\,Hz$

3. The frequency of a sine wave is 30 Hz. What is its time period.

sol: $T = \frac{1}{f} = \frac{1}{30} = 0.0333\,sec$

$= 33.33\,msec$

Sine wave equation:

→ A sine wave is graphically represented as shown in fig 1@ below.

→ The amplitude of a sine wave is represented on vertical axis. The angular measurement (in degrees or radians) is represented on horizontal axis.

→ Amplitude: (A)

The maximum value of the voltage (or) current on the y-axis.

→ In general, the sine wave is represented by the equation,

$\boxed{v(t) = V_m \sin\omega t}$ → ①

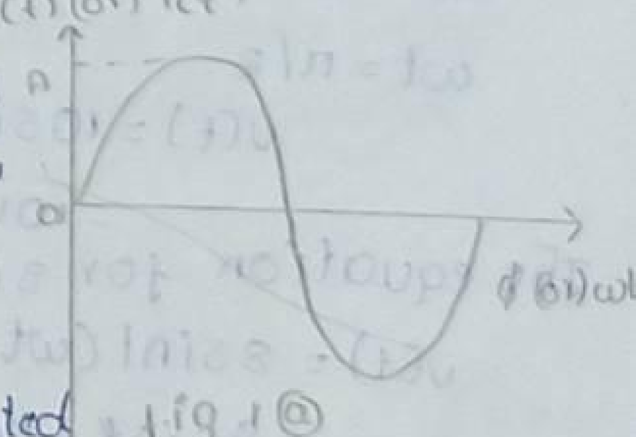


fig 1@

→ The eq ① states that any point on the sine wave represented by an instantaneous value v(t) is equal to the maximum value times the sine of the angular frequency at that point.

Ex: If a certain sine wave voltage has peak value of 20V, the instantaneous voltage at a point π/4 radians along the horizontal axis can be calculated as

sol: $v(t) = V_m \sin \omega t = 20 \sin\left(\frac{\pi}{4}\right)$

$= 20 \times 0.707 = 14.14V$

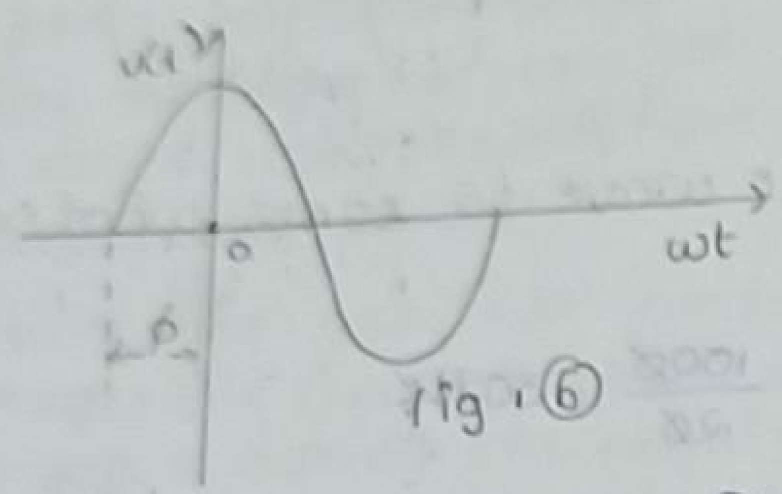


fig.ⓑ

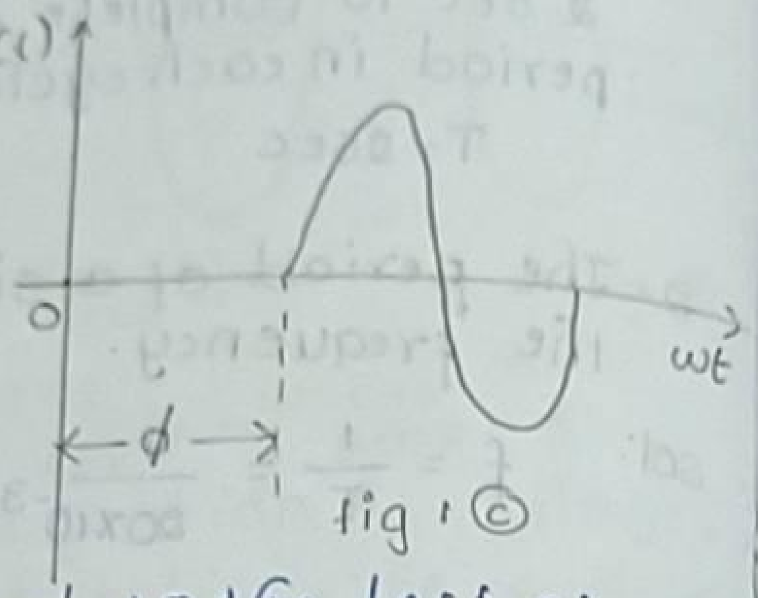


fig.ⓒ

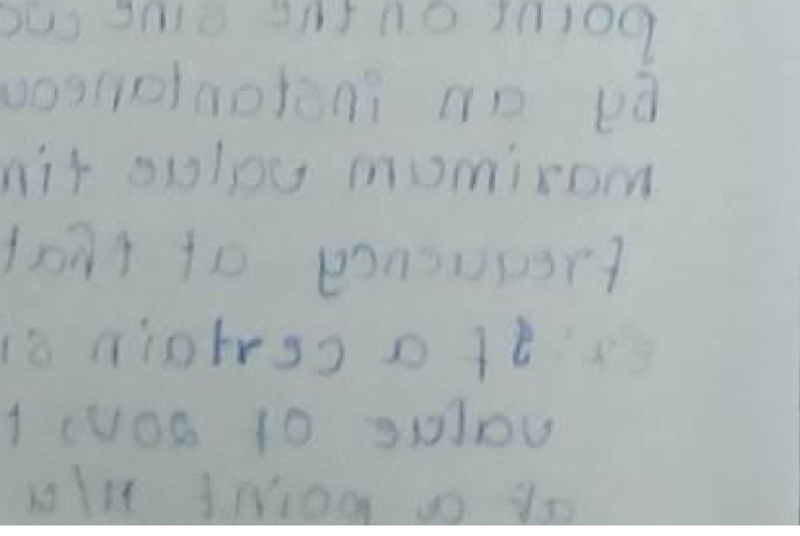
→ when a sine wave is shifted to the left of the reference wave by a certain angle ϕ as shown in fig.ⓑ, the general expression is

$$\boxed{\therefore v(t) = V_m \sin(\omega t + \phi)} \longrightarrow ②$$

→ when a sine wave is shifted to the right of the reference wave by a certain angle ϕ. as shown in fig.ⓒ, the general expression is

$$\boxed{\therefore v(t) = V_m \sin(\omega t - \phi)} \longrightarrow ③$$

Ex. Determine the instantaneous value at the 90° point on the x-axis for each sine wave shown in fig.



sol: From the fig, the Eq^n for the sine wave 'A' is $v(t) = 10 \sin \omega t$

$\omega t = \pi/2$

$v(t) = 10 \sin \frac{\pi}{2}$

$= 10V$

The equation for sine wave 'B' is

$v(t) = 8 \sin(\omega t - \pi/4)$

$= 8 \sin(\pi/2 - \pi/4)$

$= 8(0.707) = 5.66V$

Voltage & current values of a sine wave:

As the magnitude of the waveform is not constant, the waveform can be measured in different ways. They are

1. Instantaneous value
2. peak value
3. Peak to peak value
4. Average value
5. Root Mean Square (RMS) value

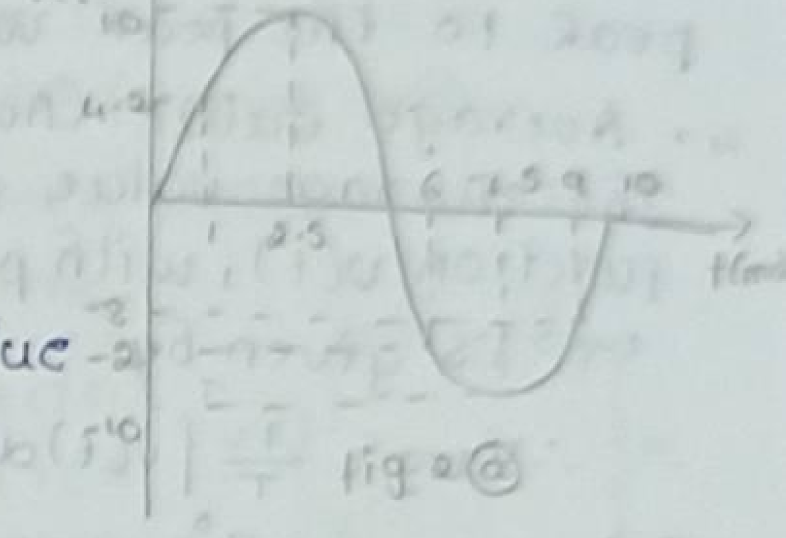


fig 2ⓐ

1. Instantaneous value:

Consider the sine wave shown in fig 2ⓐ. At any given time, it has some instantaneous value. This value is different at different points along the waveform.

In fig 2ⓐ, during the positive cycle, the instantaneous values are positive & during the negative cycle, the instantaneous values are negative. It is shown at time 1ms → the value is 4.2V

At 2.5ms ⟶ 10V

At 6ms ⟶ -2V

At 7.5ms ⟶ -10V

2. Peak value:

The peak value of the sine wave is the maximum value of the wave during positive half cycle, (or) maximum value of the wave during negative half cycle.

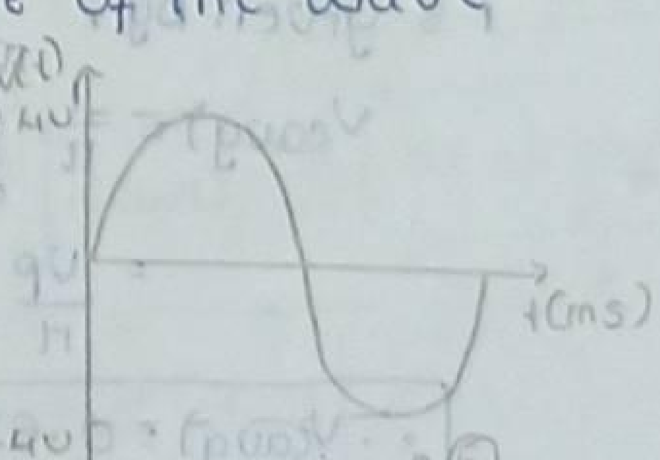


fig. 2ⓑ

Since the value of these two are equal in magnitude, a sine wave is characterised by a single peak value.

→ The peak value of the sine wave is shown in fig 2ⓑ, there the peak value of the sine wave is '4V'.

3. Peak to peak value:

The peak to peak value of a sine wave is the value from the positive peak to the negative peak as shown in fig 2(b). There the peak to the peak value is 8V.

4. Average value: (Avg)

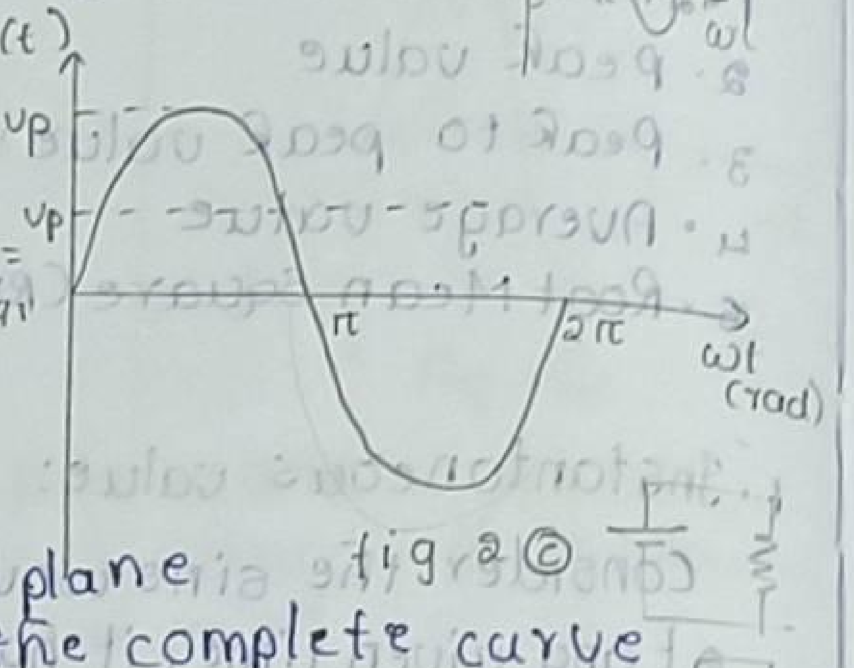


fig 2(c)

The average value of any function v(t), with period (T) is given by

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

That means the average value of a curve in the x-y plane is the total area under the complete curve divided by the distance of the curve.

→ The avg value of a sine wave over one complete cycle is always zero. So the avg value of a sine wave is defined over a half cycle and not a full cycle period.

→ The avg value of the sine wave is the total area under the half cycle curve divided by the distance of the curve.

$$\therefore \left.\begin{matrix}\text{Avg value of}\\ \text{sine wave}\end{matrix}\right\} = \frac{\text{Total area under half-cycle curve}}{\text{Distance of the curve}}$$

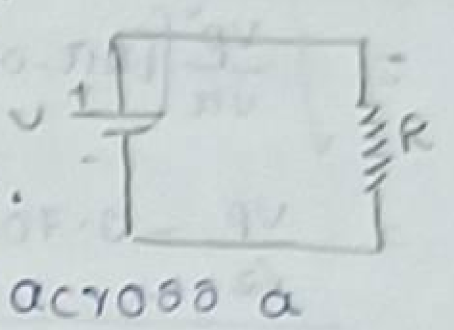
The avg value of the sine wave $v(t) = V_p \sin\omega t$ is given by,

$$V_{(avg)} = \frac{1}{\pi}\int_0^{\pi} V_p \sin\omega t\, d(\omega t)$$

$$= \frac{V_p}{\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{2V_p}{\pi} = 0.687V_p$$

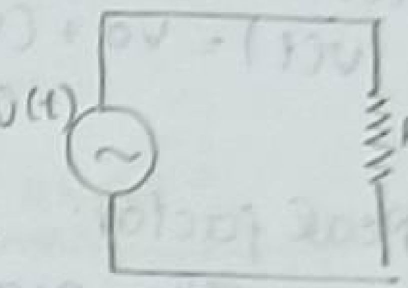
$$\boxed{\therefore V_{(avg)} = 0.687V_p}$$

5. Root Mean Square value (or) Effective value:



The root mean square (rms) value of a sine wave is a measure of the heating effect of the wave.

→ when a resistor is connected across a dc voltage source as shown in fig 1(a), a certain amount of heat is produced in the resistor in a given time.



→ A similar resistor is connected across an ac voltage source for the same time as shown in fig 1(b). The value of the ac voltage is adjusted such that the same amount of heat is produced in the resistor of in the case of the dc source. This value is called the rms value.

→ That means the rms value of a sine wave is equal to the dc voltage, that produces the same heating effect.

→ In general, the rms value of any function with period (T) has an effective value given by,

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

consider a function $v(t) = V_p \sin\omega t$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T (V_p \sin\omega t)^2\, d(\omega t)}$$

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

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

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

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$$= \sqrt{\frac{V_p^2}{4\pi}\left[(2\pi - 0) - \frac{1}{2}(0)\right]}$$

$$= \frac{V_p}{\sqrt{2}} = 0.707 V_p$$

$$\boxed{\therefore V_{rms} = 0.707 V_p}$$

If the function consists of a no. of sinusoidal terms

$$v(t) = V_0 + (V_{c1}\cos\omega t + V_{c2}\cos 2\omega t + \ldots) + (V_{s1}\sin\omega t + V_{s2}\sin 2\omega t + \ldots)$$

→ Peak factor:

The peak factor of any waveform is defined as the ratio of the peak value of the wave to the rms value of the wave.

$$\boxed{\text{peak factor} = \frac{V_p}{V_{rms}}}$$

peak factor of the sinusoidal waveform

$$\frac{V_p}{V_p/\sqrt{2}} = \sqrt{2} = 1.414$$

→ Form factor:

Form factor of a waveform is defined as the ratio of rms value to the avg value of the wave.

$$\boxed{\therefore \text{Form factor} = \frac{V_{rms}}{V_{avg}}}$$

Form factor of a sinusoidal waveform

$$= \frac{V_p/\sqrt{2}}{0.637 V_p}$$

$$= 1.11$$

→ A sine wave has a peak value of 12V. Determine the following values.

a. rms $= 0.707 \times 12 = 8.48\,V$

b. avg $= 0.637 \times V_p = 0.637 \times 12 = 7.64\,V$

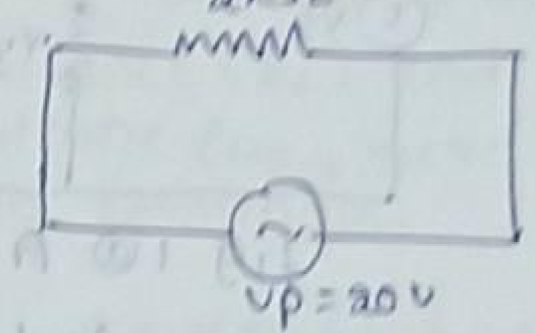
c. crest factor $\frac{V_p}{V_{rms}} = \frac{12}{8.48} = 1.415$

d. Form factor $\frac{V_{rms}}{V_{avg}} = \frac{8.48}{7.64} = 1.11$

e. peak to peak

$V_{pp} = 2V_p = 2 \times 12 = 24\,V$

→ A sinusoidal voltage is applied to the resistive circuit shown in fig.
Determine I_{rms}, I_{avg}, I_p, I_{pp}



sol: $v(t) = V_p \sin\omega t$

$= 20 \sin\omega t$

$$i(t) = \frac{v(t)}{R} = \frac{20}{2\times10^3}\sin\omega t$$

$$= 10\times10^{-3}\,Am$$

$i(t) = 10\,mA$

$I_p = 10\,mA$

$I_{pp} = 2\times10 = 20\,mA$

$I_{rms} = 0.707 I_p$

$= 0.707\times10$

$= 7.07\,mA$

$$\boxed{I_{avg} = 0.637\times10 = 6.37\,mA}$$

Network Theorms:

(applied to analyze electrical & electronic circuits)

Thevenin's Theorm:

It is applicable where it is derived to determine the current through (or) voltage across any element in a network without going through the rigorous method of solving a set of new equations.

Statement:

Any two terminal bilateral linear d.c circuits can be replaced by an equivalent circuit consisting of a voltage source and a series resistor.

Explanation:

1. Let us consider a simple d.c circuit as shown in fig 1ⓐ. Now find 'I_L' by Thevenin's Theorm

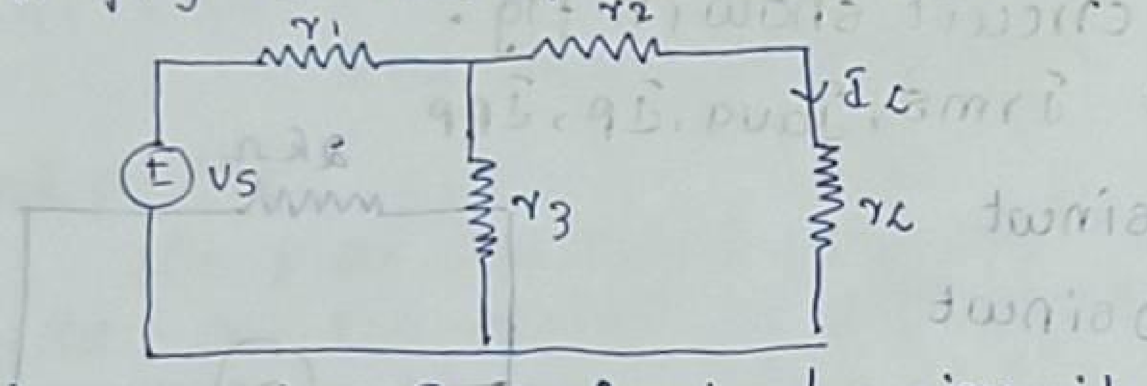


fig 1ⓐ A simple d.c circuit

2. In order to find the voltage source, r_L is removed shown in fig 1ⓑ and $V_{o.c}$ is calculated.

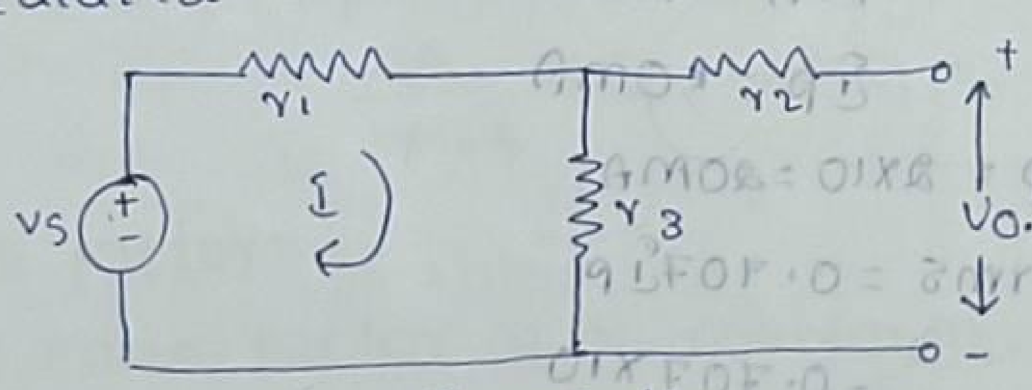
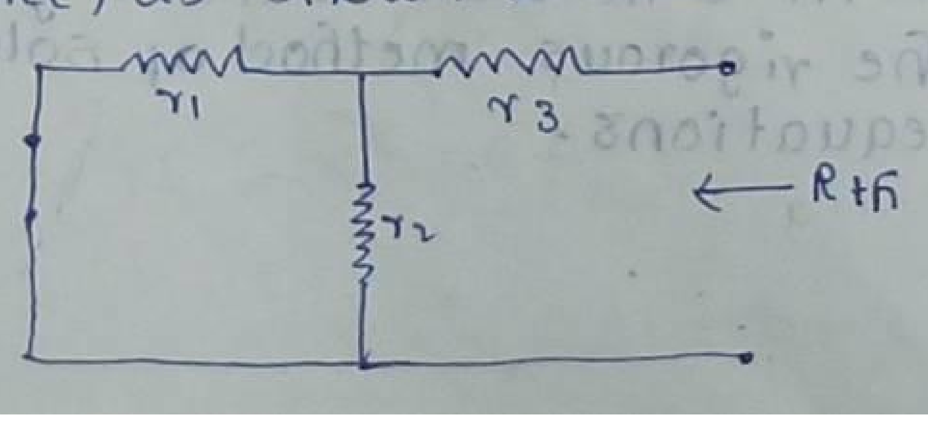


fig. 1ⓑ Finding Vo.c

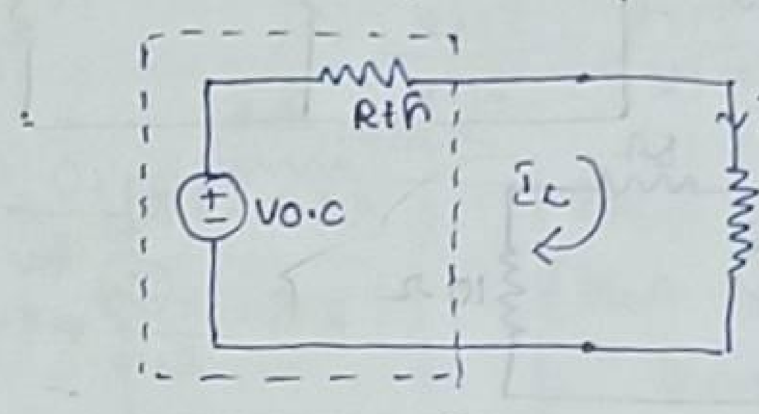
$$\boxed{\therefore V_{o.c} = V_S \times \frac{r_3}{r_1+r_3}}$$

3. Next to find the internal resistance of the network (Thevenin's resistance (or) equivalent resistance) in series with $V_{o.c}$, the voltage source is removed by a short circuit (as the source does not have any internal resistance) as shown below



$$\boxed{\therefore R_{th} = r_2 + \frac{r_1 r_3}{r_1+r_3}}$$

4. Finding of 'I_L' from Thevenins eqt circuit shown in below



$$\boxed{\therefore I_L = \frac{V_{o.c}}{R_{th}+R_L}}$$

Steps for solving a network using Thevenin's theorm:

Step ①: Remove the load resistance (R_L) and find the open circuit voltage ($V_{o.c}$) across the open circuted load terminals.

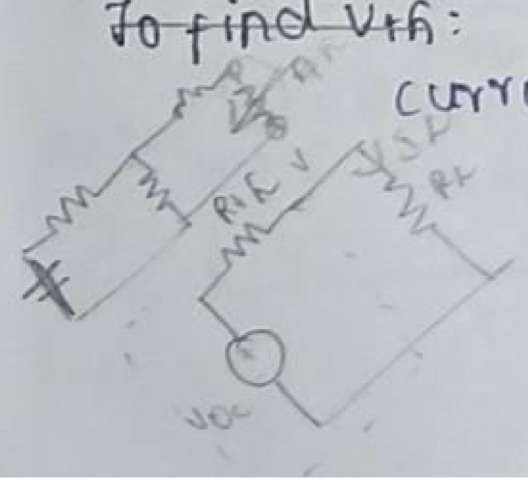
Step ②: Deactive the constant sources (for voltage source, remove it by internal resistance and for current source delete the source by open circuit) and find the internal resistance (Thevenin's resistance) of the source side looking through the open circuited load terminals. Let this resistance be R_{th}.

Step ③: Obtain Thevenins equation circuit by placing R_{th} in series with $V_{o.c}$

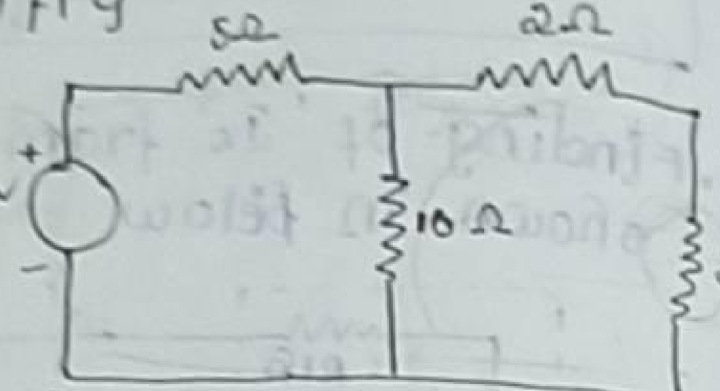
Step ④: Reconnect 'R_L' across the load terminals. as shown above.

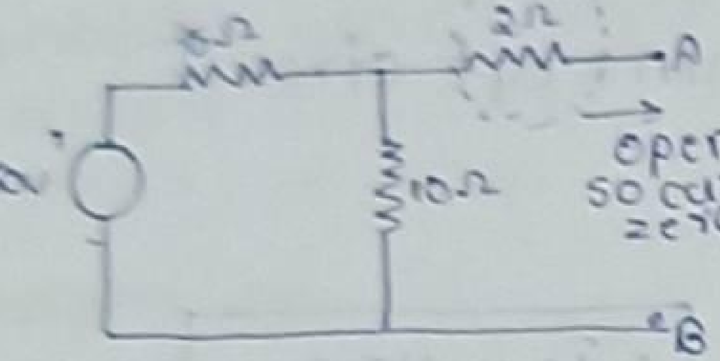
To find R_{th}: voltage source is deactivated by shorting (assuming its internal resistance is zero).

~~To find~~ V_{th}: current source is open circuited.



→ In thevenins theorm to find the current in 3Ω resistor shown in fig





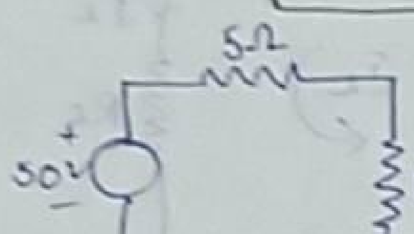
→ open circuit so current is zero

$V_{th} = V_{oc} = \frac{10}{5+10} \times 50$

$V_{th} = V_{oc} = \frac{\cancel{10}^{2}}{\cancel{15}_{3}} \times 50$

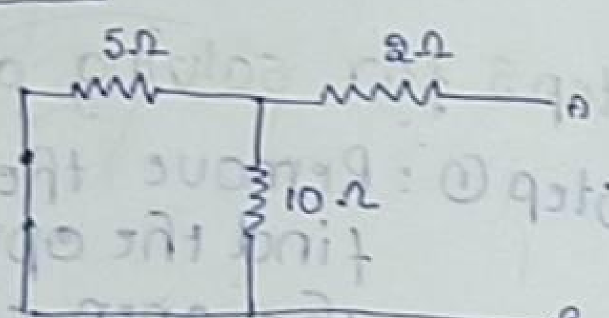
$= \frac{100}{3}$

$V_{th} = 33.33V$



$V_{oc} = 50 \times \frac{10}{15}$

$R_{th} = \frac{2\times10}{2+10} + 5$

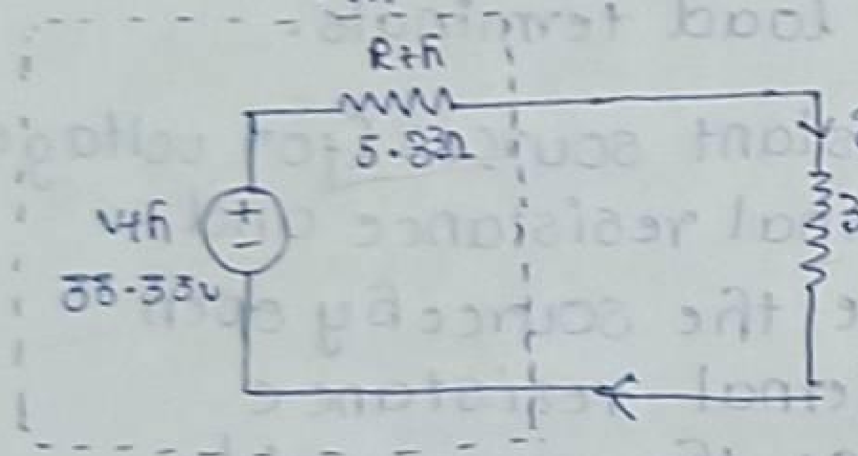


$R_{TH} = (5 \| 10) + 2$

$= \frac{5\times10}{\cancel{15}_{3}} + 2$

$= \frac{10+6}{3} = \frac{16}{3}$

$R_{th} = 5.33Ω$



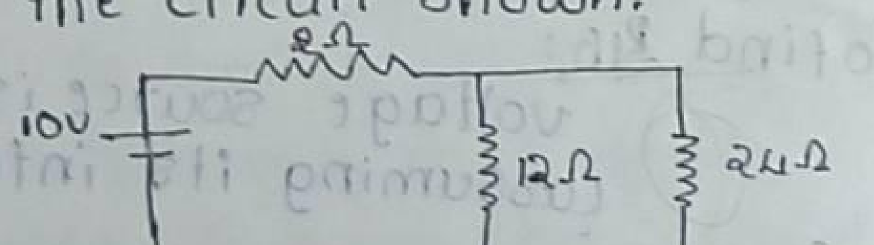
$i_L = \frac{V_{th}}{R_{th}+R_L}$

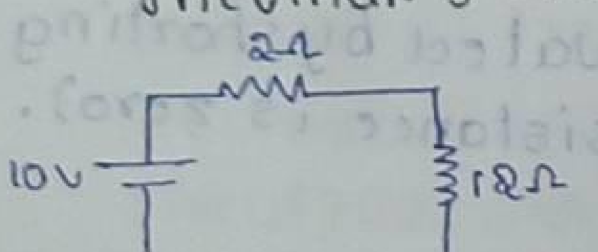
$i_L = \frac{33.33}{5.33+3}$

$i_L = \frac{33.33}{8.33}$

$i_L = 4A$

→ Find the current through 24Ω resistor using Thevinan's theorm for the circuit shown.

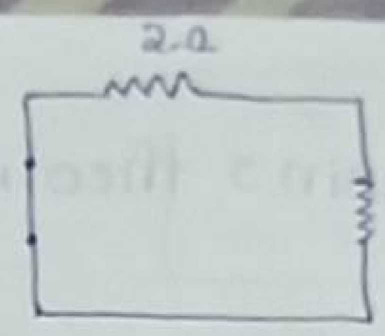




$V_{oc} = V_{th} = 10 \times \frac{12}{12+2}$

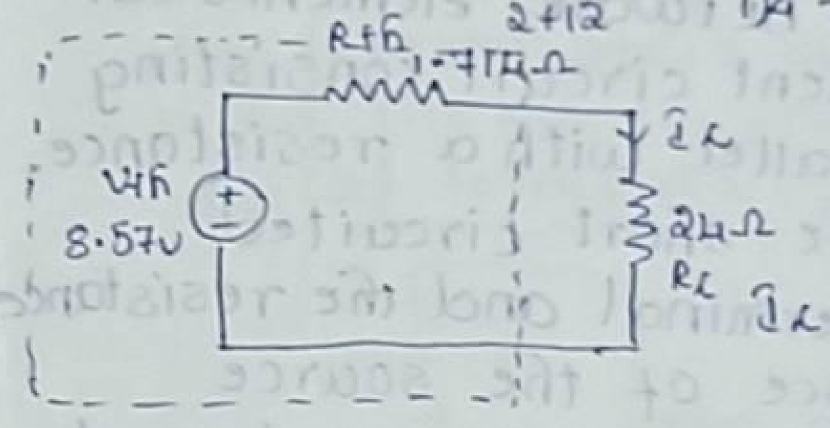
$= 10 \times \frac{\cancel{12}6}{\cancel{14}7} = \frac{60}{7}$

$V_{th} = 8.57V$



$R_{th} = 2\|12$

$= \frac{2\times12}{2+12} = \frac{2\times12}{\cancel{14}7} = 1.714Ω$



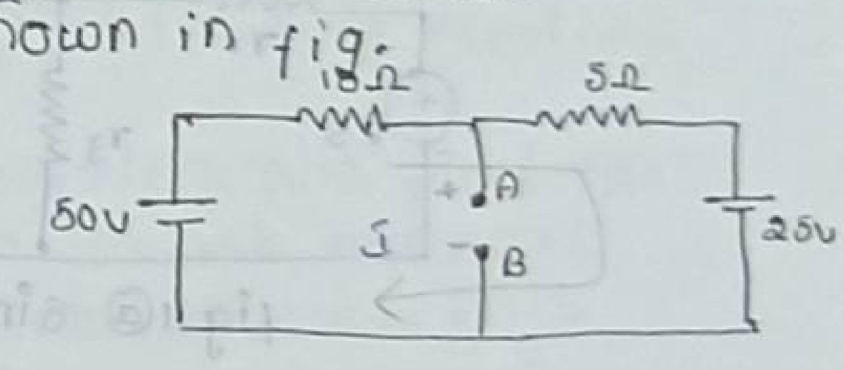
$i_L = \frac{V_{th}}{R_{th}+R_L}$

$i_L = \frac{8.57}{1.714+24}$

$i_L = \frac{8.57}{25.714}$

$i_L = 0.33A$

→ Determine the Thevenin's eq^n circuit across 'AB' for the given circuit shown in fig.



$-50 + 10I + 5I + 25 = 0$

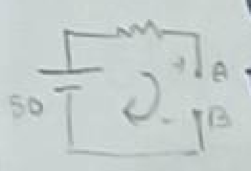
$15I = 25$

$I = \frac{25}{15}$

$I = 1.67A$

voltage acrros 10Ω is $V_{10Ω} = 10\times1.67 = 16.7V$

voltage acrro's 5Ω is $V_{5Ω} = 5\times1.67 = 8.35V$



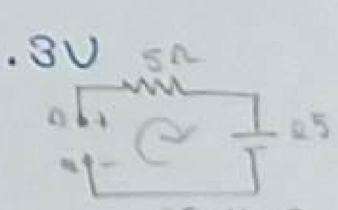
$-50 + 10\times1.67 + V_{AB} = 0$

$V_{AB} = 50 - 16.7$

$V_{AB} = 33.3$

← $V_{th} = V_{AB} = 50 - V_{10} = 50 - 16.7 = 33.3V$

(or)



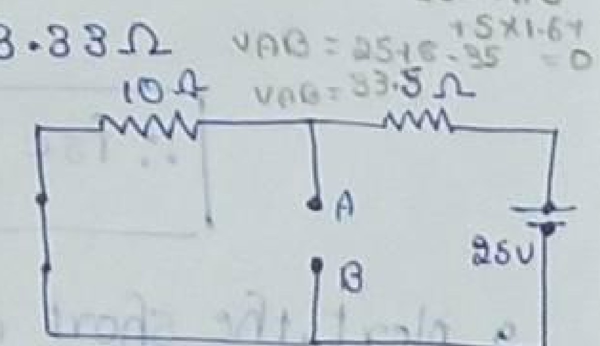
$25 - V_{AB} + 5\times1.67 = 0$

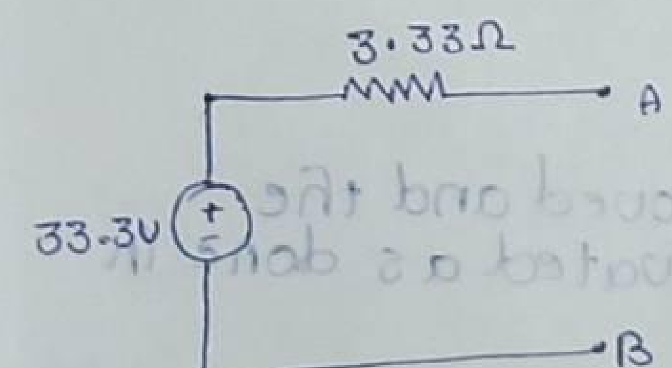
$V_{AB} = 25 + 8.35$

$V_{AB} = 33.35$

$R_{th} = 10\|5$

$= \frac{10\times5}{10+5} = \frac{50}{15} = 3.33Ω$





Norton's Theorm:

It is converse of Thevenins theorm

Statement:

"A linear active network consisting of independent and or dependent voltage and current sources and linear bilateral network elements can be replaced by and equivalent circuit consisting of a current source in parallel with a resistance, the current source being the short circuited current across the load terminal and the resistance being the internal resistance of the source network looking through the open circuited load terminals.

Explanation:

1. In order to find the current through r_L, the load resistance (fig 1@), by norton's theorm, Let us replace 'r_L' by short circuit (fig 1ⓑ).

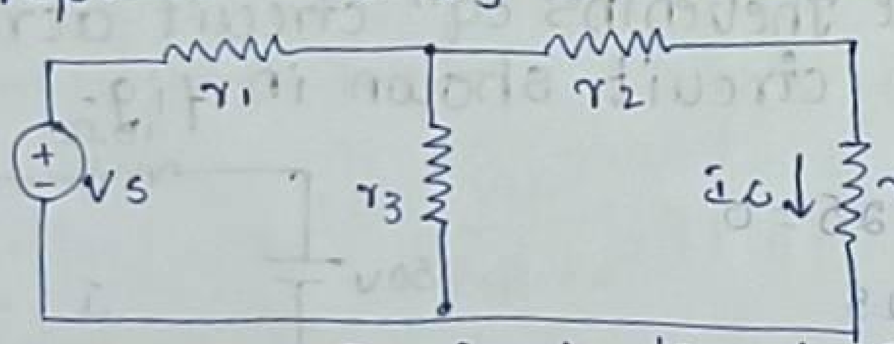


fig 1@ simple dc network

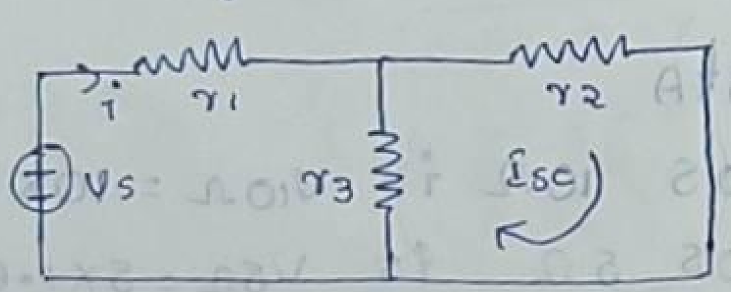


fig 1ⓑ Finding of i_{sc}

$$i = \frac{V_S}{r_1 + \frac{r_2 r_3}{r_2 + r_3}}$$

$$\boxed{\therefore i_{sc} = i \times \frac{r_3}{r_3 + r_2}}$$

2. Next, the short circuit is removed and the independent source is deactivated as done in Thevenins theorm. (fig 1ⓒ).

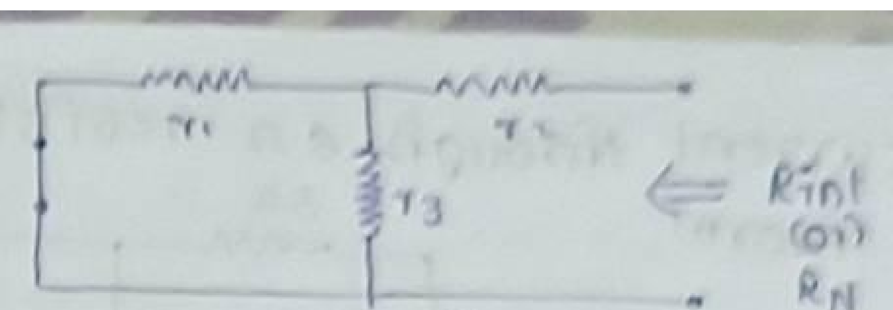


fig 1ⓒ Finding of Rint

3. As per Nortons theorm, the equation source circuit would contain a current source in parallel to the internal resistance, the current source being the short circuited current across the shorted terminals of the load resistor (fig ⓓ)

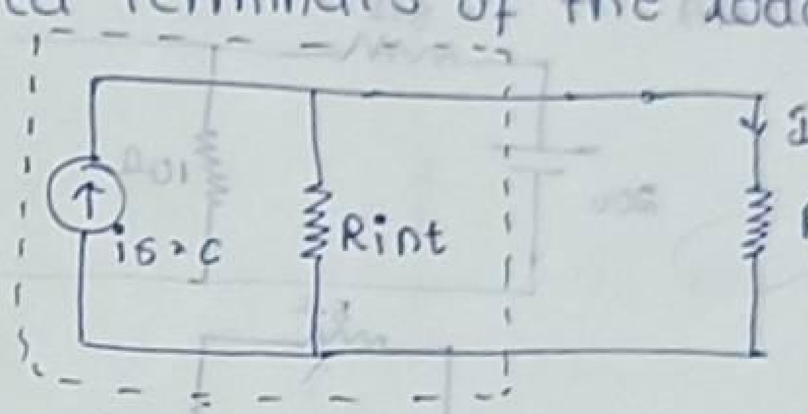


fig 1ⓓ Norton's Equation circuit

Note:
Findind Rint for source system is same in both Norton's & Thevenin's Theorems.

Steps for solving a network utilizing Norton's theorm:

Step①: Remove the load resistor and find the internal resistance of the source network by deactivating the constant sources. This procedure is same as described for Thevenin's theorm. Let this resistance be 'Rint'.

Step②: Next, short the load terminals and find the short circuit current flowing through the shorted load terminals using conventional network analysis. Let this current to 'i_{sc}'.

Step③: Norton's equation circuit is drawn by keeping Rint in parallel to isc as shown in fig 1ⓓ

Step④: Reconnect the load resistor (R_L) across the load terminals and the current through it (I_L) is then given by.

$$\boxed{\therefore I_L = i_{sc} \cdot \frac{R_{int}}{R_{int} + R_L}}$$

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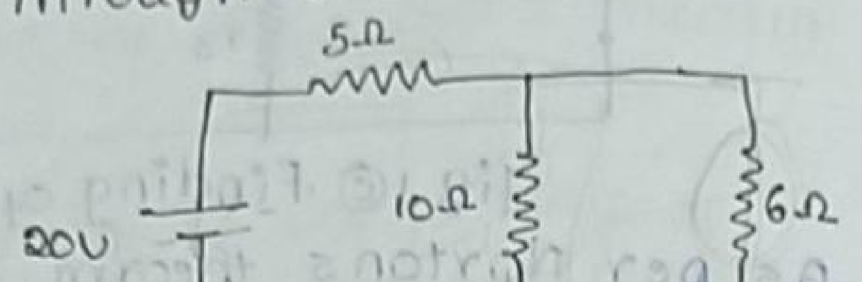
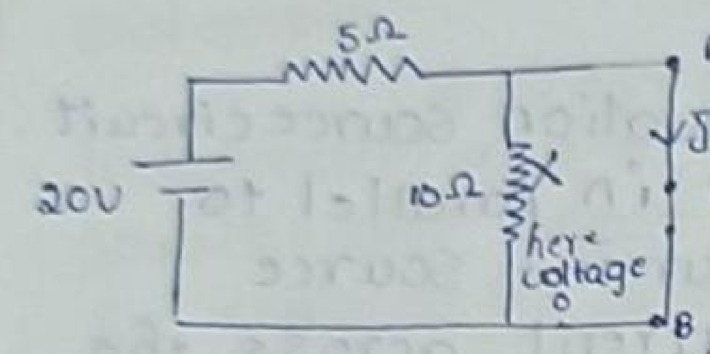
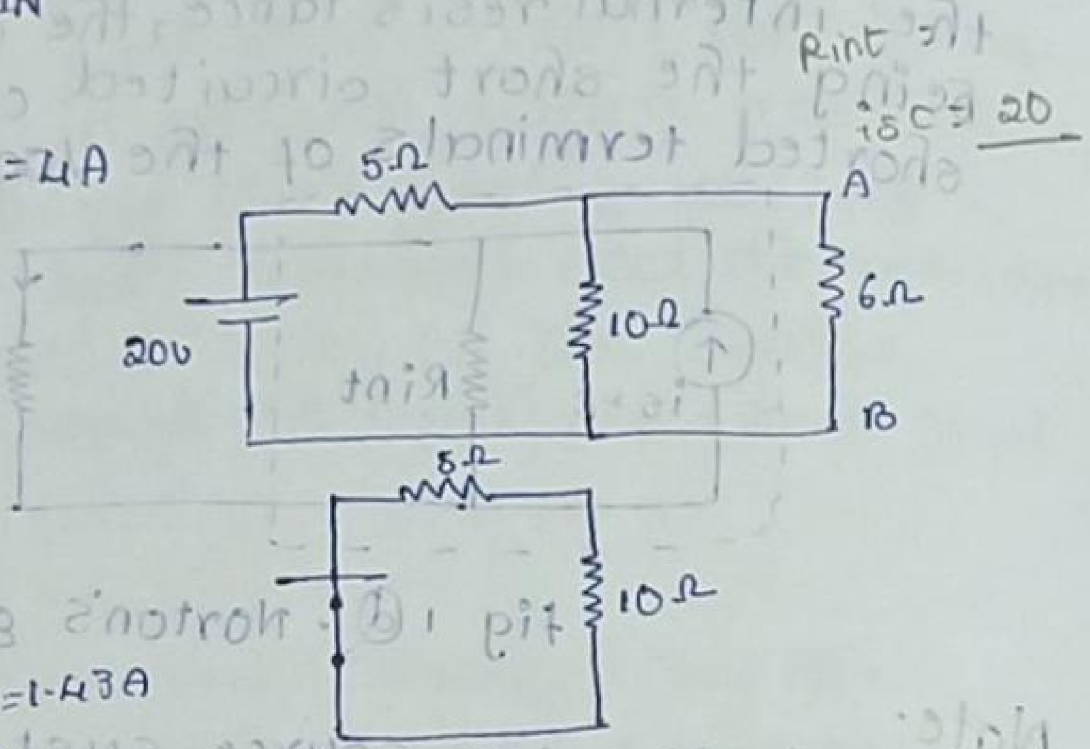
→ Determine the current through 6Ω resistor using Norton's theorm





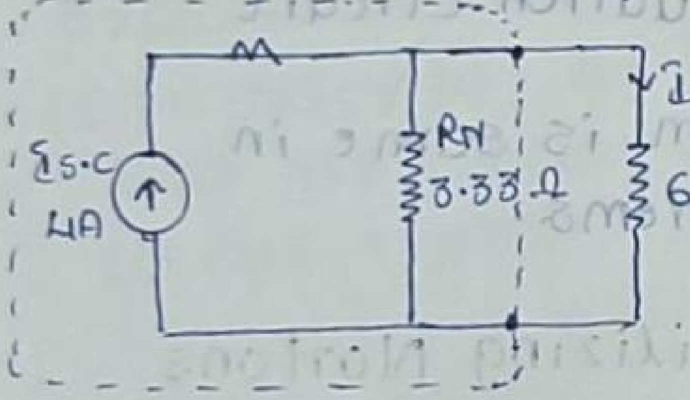
$I_N = I_{s.c} = \frac{V}{R} = \frac{20}{5} = 4A$



Rint (or) $R_N = \frac{5 \times 10}{10+5}$

$= \frac{5 \times 10}{15_3}$

$R_N = 3.33\,\Omega$



$I_L = I_{s.c} \times \frac{R_N}{R_N + R_L}$

$I_L = 4 \times \frac{3.33}{3.33+6}$

$I_L = 4 \times \frac{3.33}{9.33}$

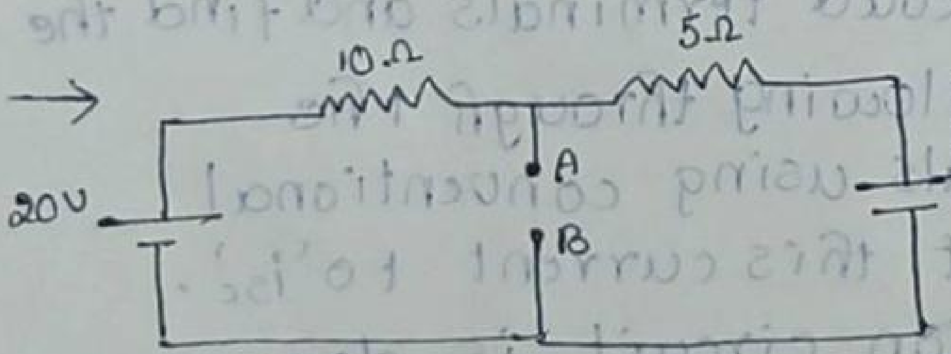
$I_L = 1.427\,A$

$V = IR$

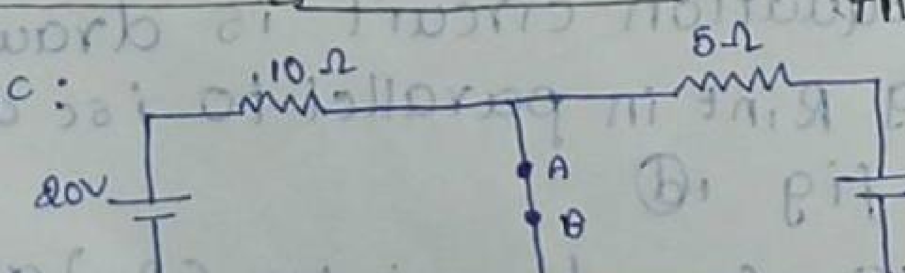
$= 1.427 \times 6$

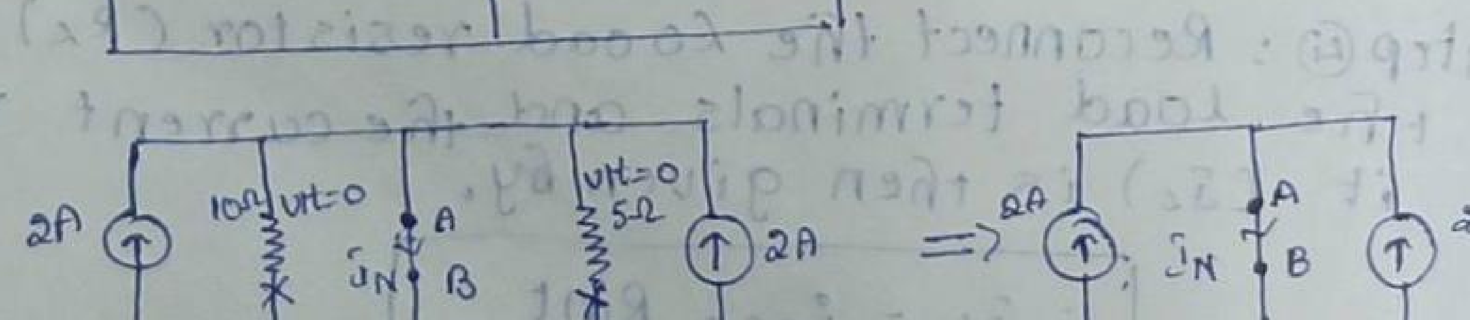
$V = 8.562$

→ Determine Norton's equivalent circuit at the terminals AB for the circuit shown



To find I_{sc}:

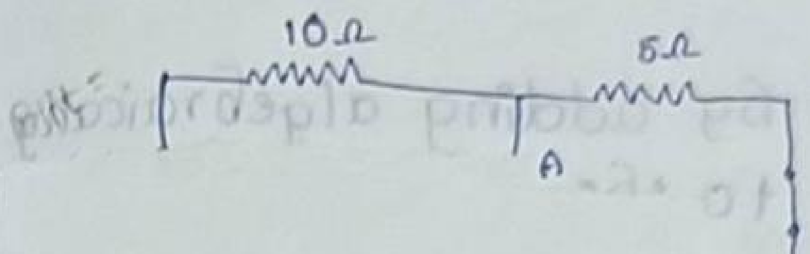




KCL at Node A

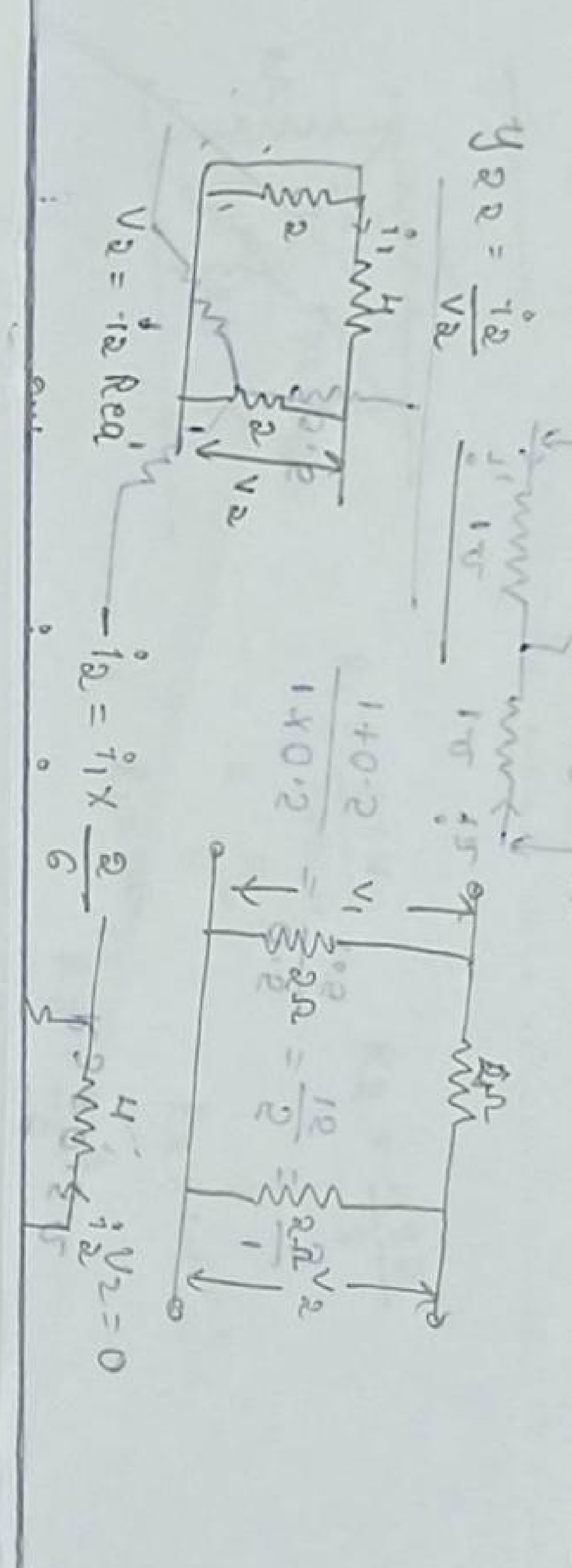
$2+2 = I_N$

$I_{s.c}$ (or) $I_N = 4A$



Rint (or) $R_N = \frac{10 \times 5}{10+5}$

$R_N = 3.33\,\Omega$



heorm:

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r circuit with more than one
je sources sometimes it is
ut the voltage across (or) current
the circuit by considering the
source at a time by replacing the
oith their ideal internal resistances

xteral two terminal network
ore than one sources, the total
: in any part of a network is
ebraic sum of the currents or
: required branch with each
source acting individually while other sources are replaced by their ideal internal resistances. (i-e, voltage sources by a short circuit & current sources by open circuit)

Steps to Apply superposition principle:

1. Replace all independent sources with their internal resistances except one source. Find the output (voltage or current) due to that

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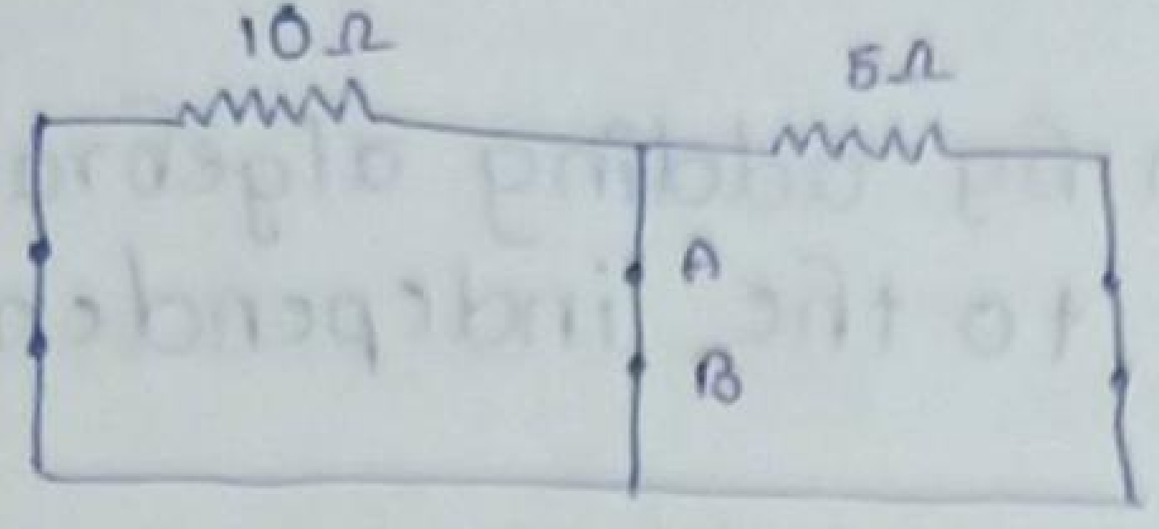
KCL at Node A

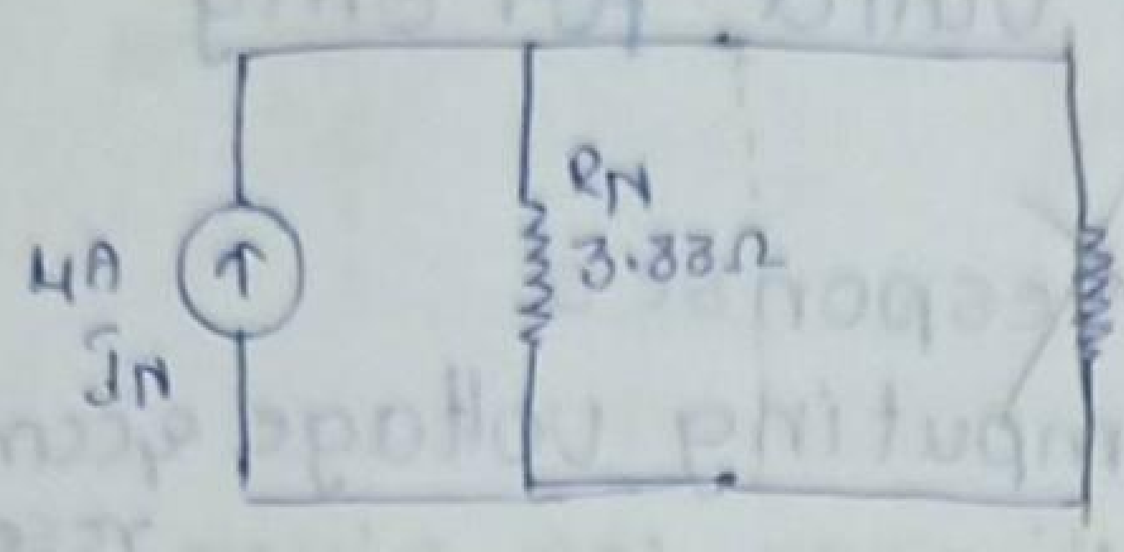
$2+2 = I_N$

$I_{s.c}$ (or) $I_N = 4A$



R_{int} (or) $R_N = \frac{10 \times 5}{10+5}$

$R_N = 3.33\,\Omega$



→ Superposition Theorm:

The principle of superposition helps us to analyze a linear circuit with more than one current or voltage sources sometimes it is easier to find out the voltage across (or) current in a branch of the circuit by considering the effect of one source at a time by replacing the other sources with their ideal internal resistances

Statement:

Any linear, bilateral two terminal network consisting of more than one sources, the total current or voltage in any part of a network is equal to the algebraic sum of the currents or voltages in the required branch with each source acting individually while other sources are replaced by their ideal internal resistances. (i.e., voltage sources by a short circuit & current sources by open circuit)

Steps to Apply superposition principle:

1. Replace all independent sources with their internal resistances except one source. Find the output (voltage or, current) due to that

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active source using nodal or mesh analysis.

2. Repeat step ① for each of the other independent sources.

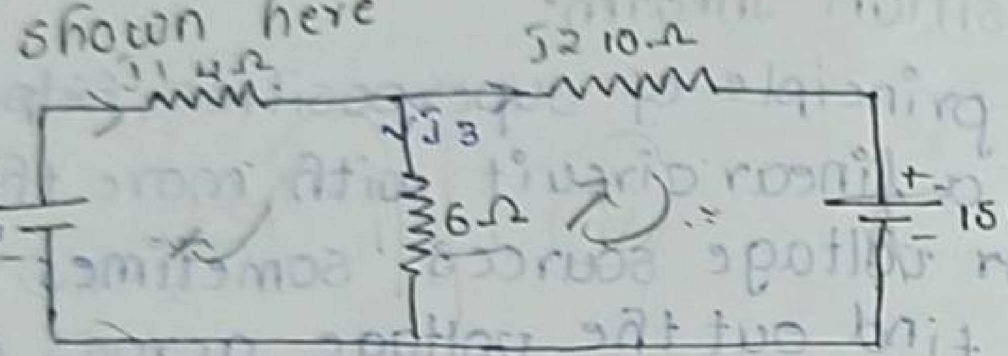
3. Find the total contribution by adding algebraically all the contributions due to the independent sources.

→ superposition principle is valid for only linear systems.

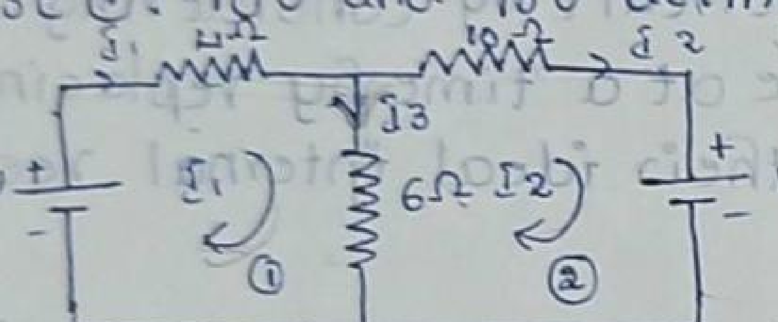
→ It is not valid for power responses

→ It is applicable only for computing voltage & current responses

→ Verify the super position theorm for given circuit shown here



Sol: case ①:- 10V and 15V acting



KVL for LOOP ①

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

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

$10i_1-6i_2=10 \longrightarrow ①$

KVL for Loop ②

$6(i_2-i_1)+10i_2+15=0$

$6i_2-6i_1+10i_2+15=0$

$-6i_1+16i_2+15=0$

$6i_1-16i_2=15 \longrightarrow ②$

$\cancel{60}i_1-36i_2=60$

$\cancel{60}i_1-160i_2=150$

$124i_2=-90$

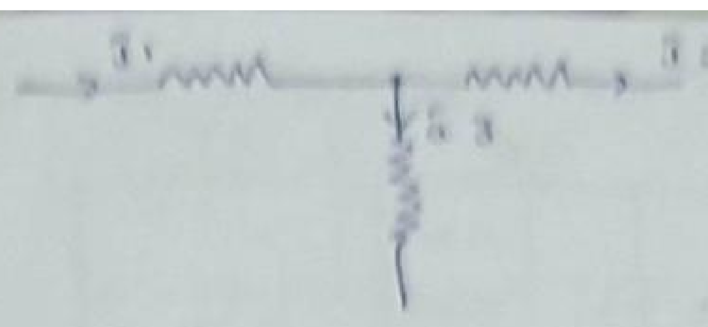
$i_2=-0.72,\ i_1=0.56A$

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

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

$10i_1-6i_2=10$

$6(i_2-i_1)+10i_2=-15$



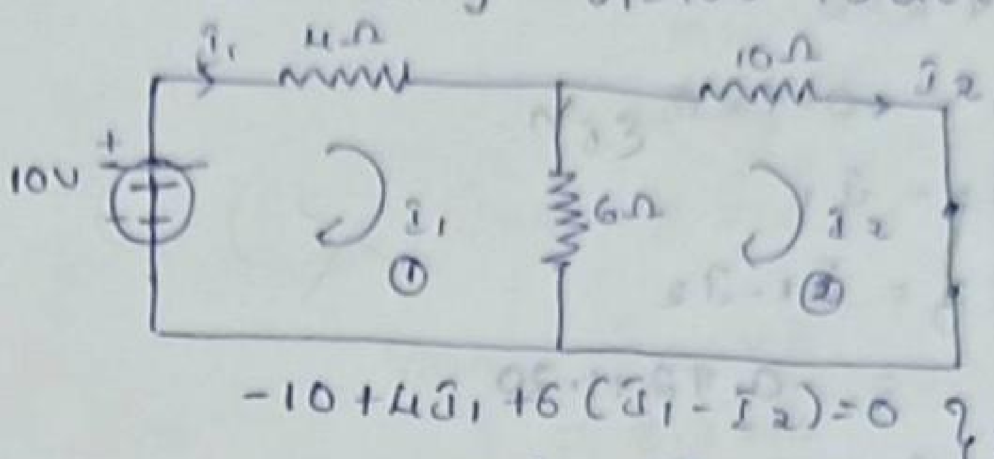
$i_1=i_2+i_3$

$i_3=i_1-i_2$

$i_3=0.56-(-0.72)$

$i_3=1.28A$

case ② when only $v_1=10V$ is acting



$-10+4i_1+6(i_1-i_2)=0$
$10i_1-6i_2=10$ } loop ①

loop ②

$6(i_2-i_1)+10i_2=0$

$-6i_1+16i_2=0$

$6i_1-16i_2=0$

$\cancel{60}i_1-36i_2=60$

$\cancel{60}i_1-160i_2=0$

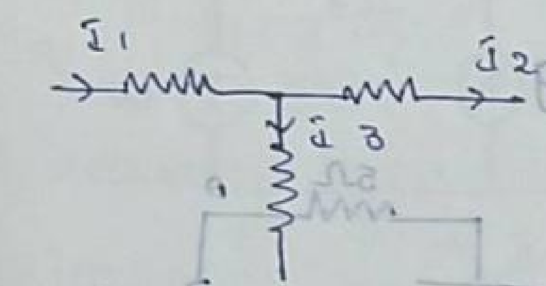
$124i_2=60$

$i_2=0.48A$

$10i_1-6(0.48)=10$

$10i_1=12.88$

$i_1=1.288A$

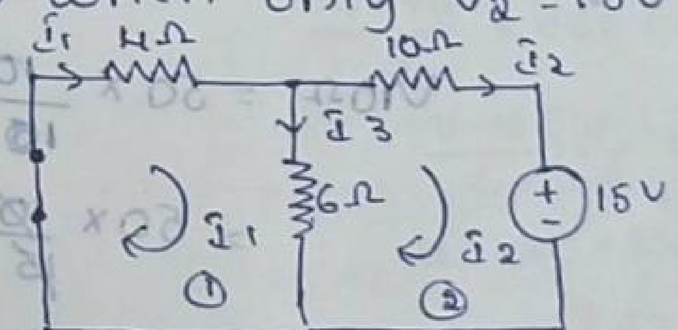


$i_1=i_3+i_2$

$i_3=i_1-i_2$

$i_3=0.808A$

case ③ when only $v_2=15V$ is acting



Loop ①

$4i_1+6(i_1-i_2)=0$

$10i_1-6i_2=0$

Loop ②

$6i_1-16i_2=15$

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$60I_1 - 36I_2 = 0$

$60I_2 - 100I_2 = 150$

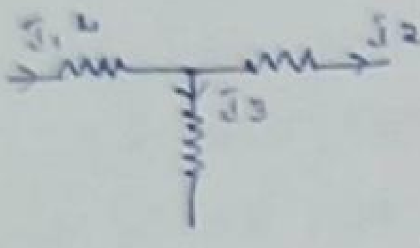
$124I_2 = -150$

$I_2 = -1.20A$

$10I_1 - 6(-1.20) = 0$

$10I_1 + 7.2 = 0$

$I_1 = -0.72A$



$I_3 + I_2 = I_1$

$I_3 = I_1 - I_2$

$= -0.72 + 1.20$

$I_3 = 0.48A$

Now applying super position pripciple

$I_1 = I_1' + I_1''$, $I_2 = I_2' + I_2''$

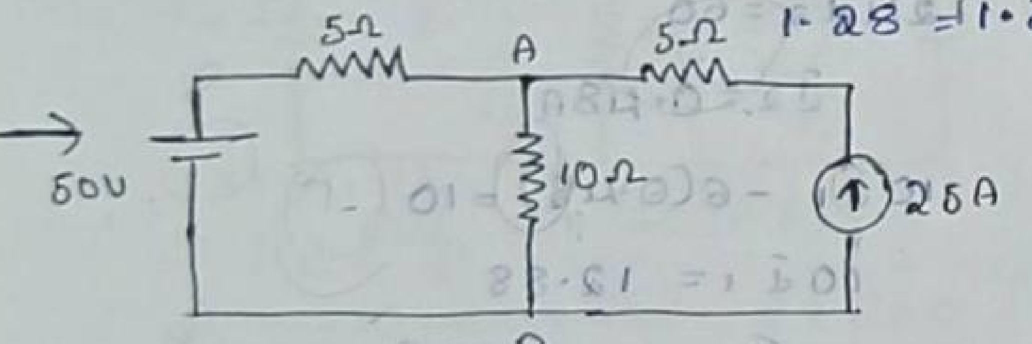
$0.56 = 1.28 - 0.72$, $-0.72 = 0.48 - 1.20$

$0.56 = 0.56$, $-0.72 = -0.72$

$I_3 = I_3' + I_3''$

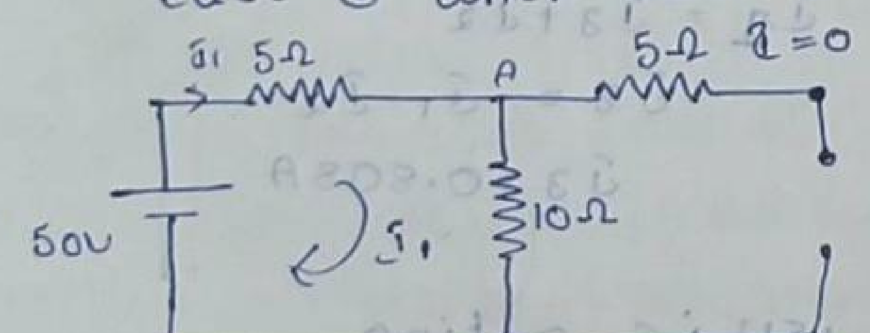
$1.28 = 0.808 + 0.48$

$1.28 = 1.28$



Find voltage across 10Ω resistor using super position theorm

case ① when 50V is acting



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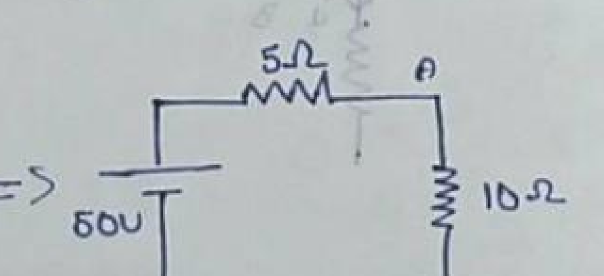


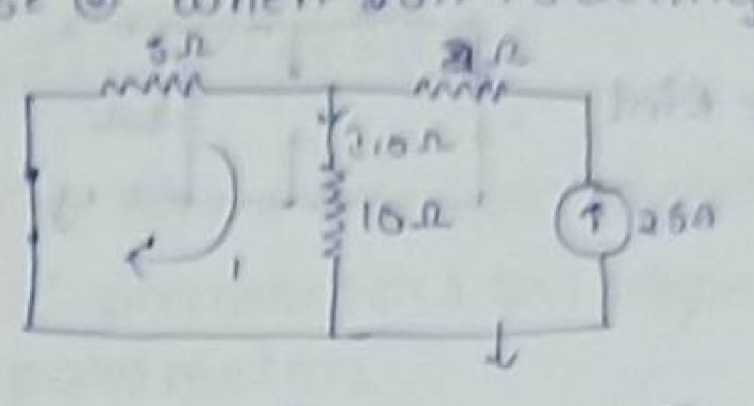
$V_{10\Omega} = 50 \times \frac{10}{10+5}$

$= 50 \times \frac{\cancel{10}\,2}{\cancel{15}\,3}$

$= \frac{100}{3}$

$V_{10\Omega} = 33.33\Omega$

case ② when 25A is acting



$I_{10\Omega} = 25 \times \frac{5}{10+5}$

$= 25 \times \frac{\cancel{5}\,1}{\cancel{15}\,3}$

$I_{10\Omega} = 8.33A$

$V_{10\Omega} = I_{10\Omega} \times R$

$= 8.3 \times 10$

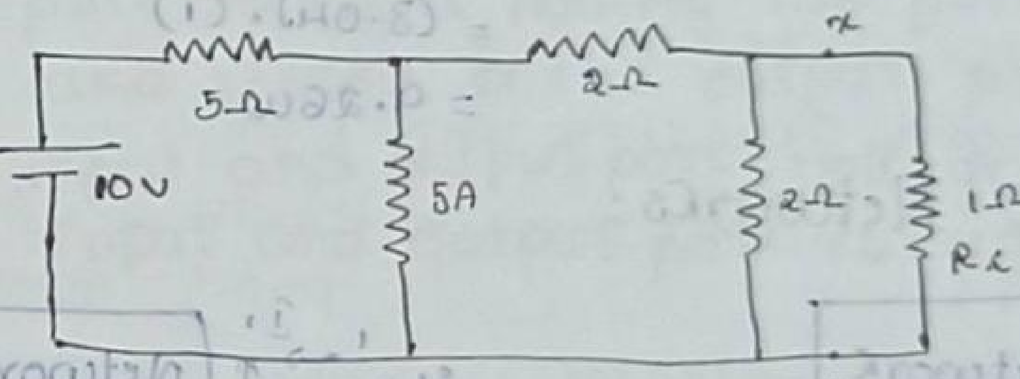
$= 83V$

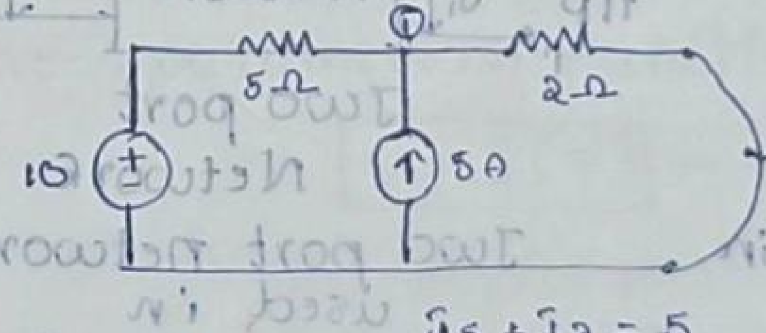
$\therefore V_{total} = V_{①} + V_{②}$

$= 33.33 + 83.33$

$V_{total} = 116.66V$

→ Find the power loss in 1Ω resistor using Norton's theorm





$I_5 + I_2 = 5$

$\frac{V_5}{5} + \frac{V_2}{2} = 5$

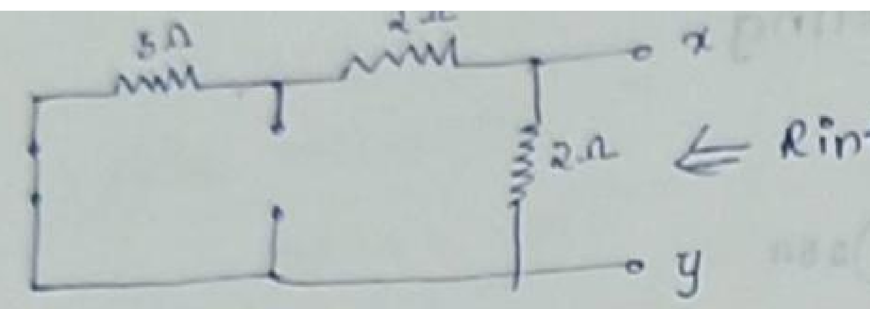
$\frac{V-10}{5} + I_{SC} = 5$

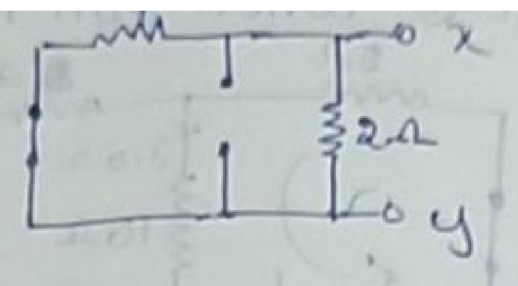
$\frac{V-10}{5} + \frac{V}{2} = 5$

$2V - 20 + 5V = 50$

$7V = 70$

$\boxed{V = 10}$ $I_{SC} = \frac{10}{2} = 5A$





$$R_{int} = 7 \| 2 = \frac{7\times 2}{7+2} = \frac{14}{9}$$

$R_{int} = 1.56\,\Omega$

$z_{12} = \frac{V_1}{I_2}$, $z_{22} = \frac{V_2}{I_2}$

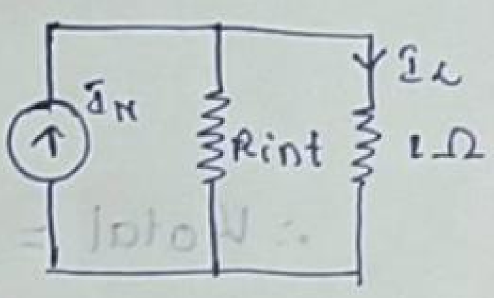
$z_{11} = \frac{V_1}{I_1}$, $z_{21} = \frac{V_2}{I_1}$

$$I_L = I_N \times \frac{R_{int}}{R_{int}+R_L}$$

$$= 5 \times \frac{1.56}{1.56+1}$$

$$= 5 \times \frac{1.56}{2.56}$$

$I_L = 3.04\,A$



$V = I[Z]$

$V_1 = z_{11}i_1 + z_{12}i_2$

$V_2 = z_{21}i_1 + z_{22}i_2$

$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix}$

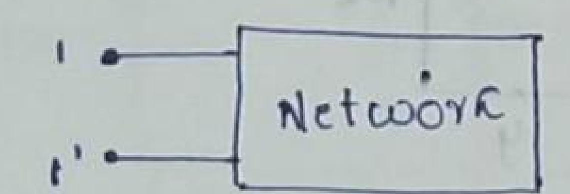
$\therefore$ Power Loss $= I^2R$

$= I_L^2 R$

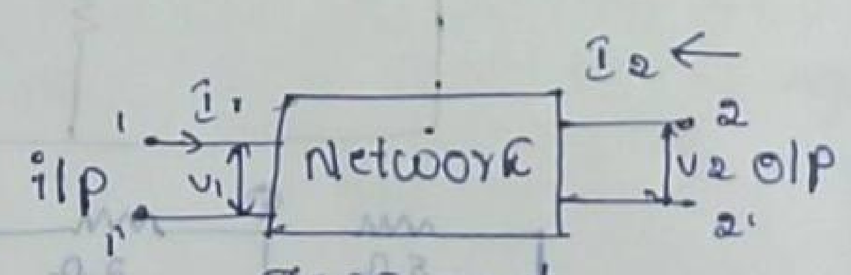
$= (3.04)^2 \cdot (1)$

$= 9.26\,W$

Two - Port Networks:



One port (or) single port Network



Two port Network

One port network is used in
1. electronics
2. communication
3. Transmission & distribution

Two port network is used in
1. Power transmission lines
2. Transformers.

There are two types of ports in Two port Network
1. Passive ports - not having sources
2. Active ports - sources are present

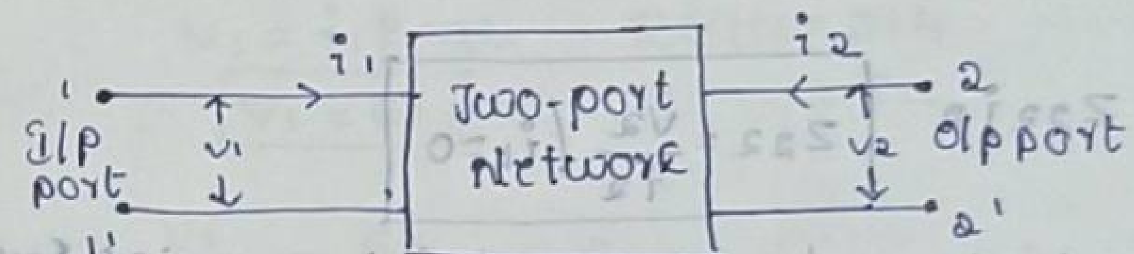
port - pair of terminals

$V_1, V_2 \rightarrow$ independent
$I_1, I_2 \rightarrow$ dependent

There are some parameters for two port Network
1. Z-parameters (or) Impedence (or) open circuit parameters
2. Y-parameters (or) Admittance parameters (or) short circuit parameters
3. ABCD parameters (or) Transmission
4. h-parameters (or) Hybrid

Two port Network & Network Teorems

1. z parameter (or) Impedence parameter (or) open-circuit parameter



A two-port Network having two ports one is Input port and second one is output port. V_1 and V_2 are the input and output port voltages. I_1 and I_2 are the input and output port currents.

Function:
The zparameters function is given by

$$\boxed{V = I[Z]} \longrightarrow (1)$$

The z-parameters equations are

$$V_1 = z_{11}i_1 + z_{12}i_2 \longrightarrow (2)$$

$$V_2 = z_{21}i_1 + z_{22}i_2 \longrightarrow (3)$$

The matrix form of the z-parameters is given by

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} \longrightarrow (4)$$

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To - Findout ...

case-I

open the output port i.e $\boxed{i_2 = 0}$

$v_1 = z_{11} i_1 + z_{12} i_2$

$v_2 = z_{21} i_1 + z_{22} i_2$

$v_1 = z_{11} i_1 \quad \boxed{z_{11} = \frac{v_1}{i_1} \Big/ i_2 = 0}$

$i_2 = 0$

$v_2 = z_{21} i_1 \quad \boxed{z_{21} = \frac{v_2}{i_1} \Big/ i_2 = 0}$

case-II open the input port i.e $\boxed{i_1 = 0}$

$v_1 = z_{12} i_2 \quad \boxed{z_{12} = \frac{v_1}{i_2} \Big/ i_1 = 0}$

$v_2 = z_{22} i_2 \quad \boxed{z_{22} = \frac{v_2}{i_2} \Big/ i_1 = 0}$

z_{11} = Input port Impedence (or) driving point Impedence

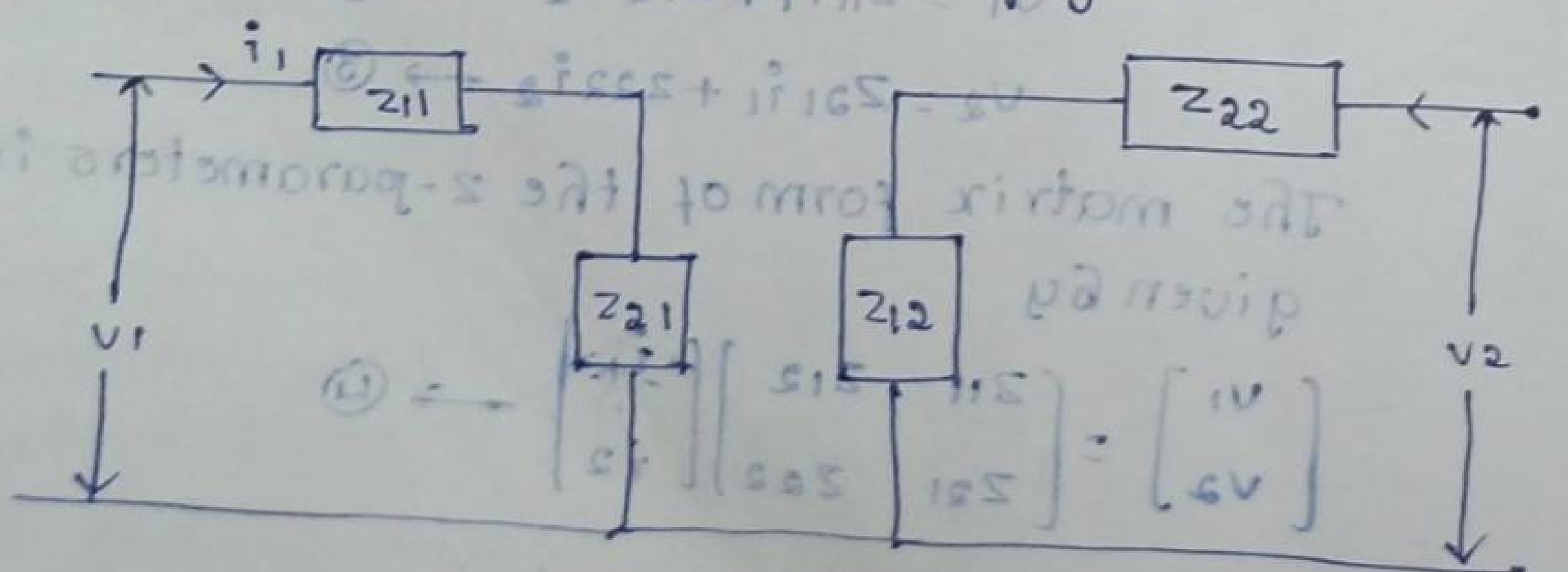
z_{12} = Reverse Transfer impedance

z_{21} = Forward Transfer impedance

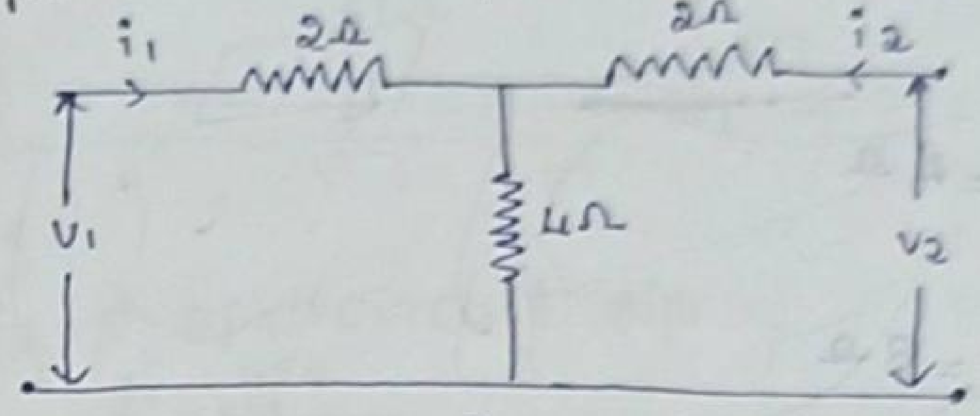
z_{22} = Out port impedance (or) open circuit driving point impedance

The impedance parameters are open circuit parameters because the z-parameters calculated by using open-circuit concepts.

The equivalent circuit diagram of the z-parameter is shown below figure



→ Find out z (or) open circuit (or) Impedence parameters of circuit shown



$z_{11} = \frac{v_1}{i_1}$

$z_{22} = \frac{v_2}{i_2}$

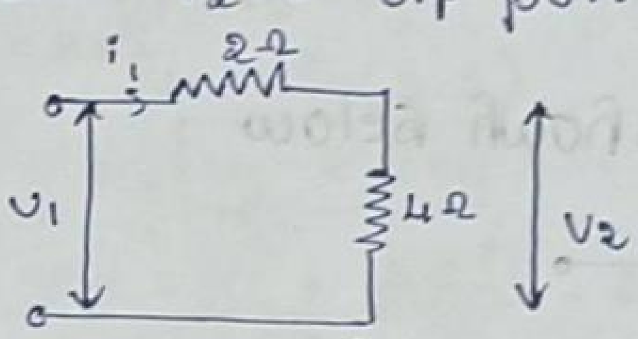
$z_{12} = \frac{v_1}{i_2}$

$z_{22} = \frac{v_2}{i_1}$

w.k.t $z_{11} i_1 + z_{12} i_2$

$z_{21} i_1 + z_{22} i_2$

case - i $i_2 = 0$ o/p port is open circuited



$v_1 = i_1 R_{equ}$ $\quad R_{equ} = 2+4 = 6\Omega$

$\boxed{v_1 = 6 i_1}$

$z_{11} = \frac{v_1}{i_1} = \frac{6 i_1}{i_1} = 6\Omega$

$\boxed{z_{11} = 6\Omega}$

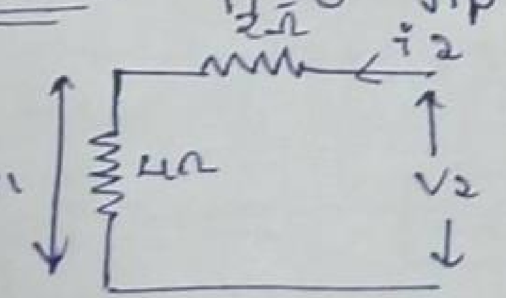
$v_2 = v_1 \times \frac{4}{4+2} \Rightarrow \cancel{6} i_1 \times \frac{4}{\cancel{6}}$

$\boxed{v_2 = 4 i_1}$

$z_{21} = \frac{v_2}{i_1} = \frac{4 i_1}{i_1} = 4\Omega$

$\boxed{z_{21} = 4\Omega}$

case II $i_1 = 0$ I/p port is open circuited



$v_2 = i_2 R_{eq} = 6 i_2$

$\boxed{v_2 = 6 i_2}$

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$v_1 = v_2 \times \frac{4}{4+2}$

$\boxed{v_1 = 4i_2}$

$z_{12} = \frac{v_1}{i_2} = \frac{4\cancel{i_2}}{\cancel{i_2}} = 4\,\Omega$

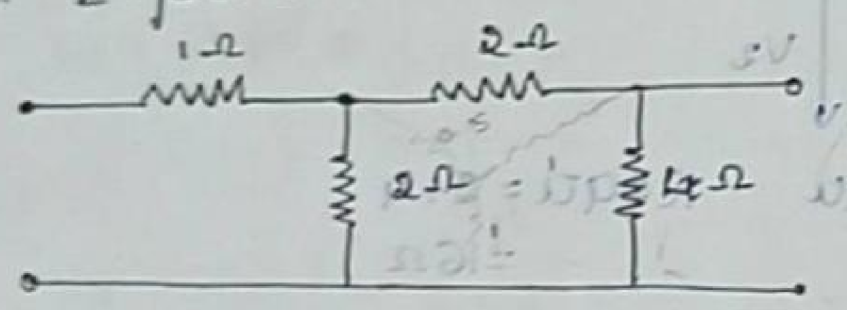
$z_{22} = \frac{v_2}{i_2} = \frac{6i_2}{i_2} = 6\,\Omega$

$z_{11} = 6\,\Omega,\ z_{12} = 4\,\Omega$

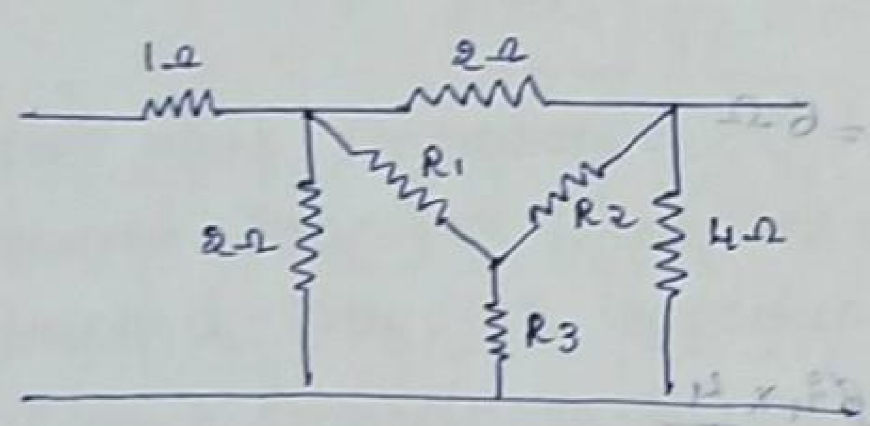
$z_{21} = 4\,\Omega,\ z_{22} = 6\,\Omega$

$\therefore z_{11} = z_{22}$ & $z_{12} = z_{21}$

→ Find z-parameters as shown below



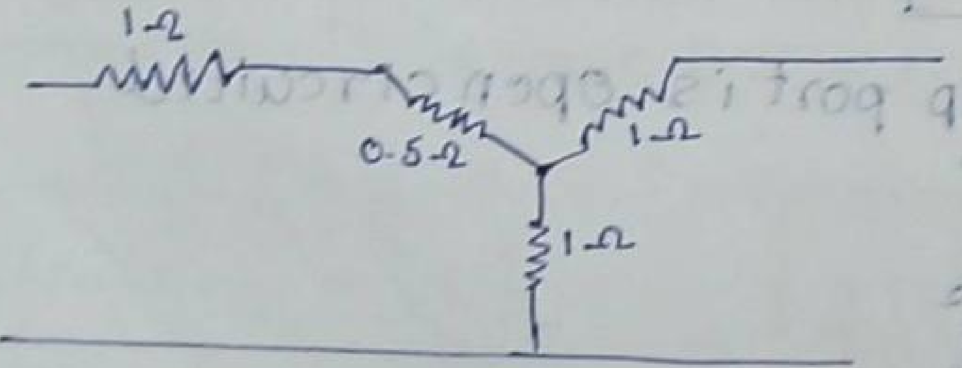
sol.

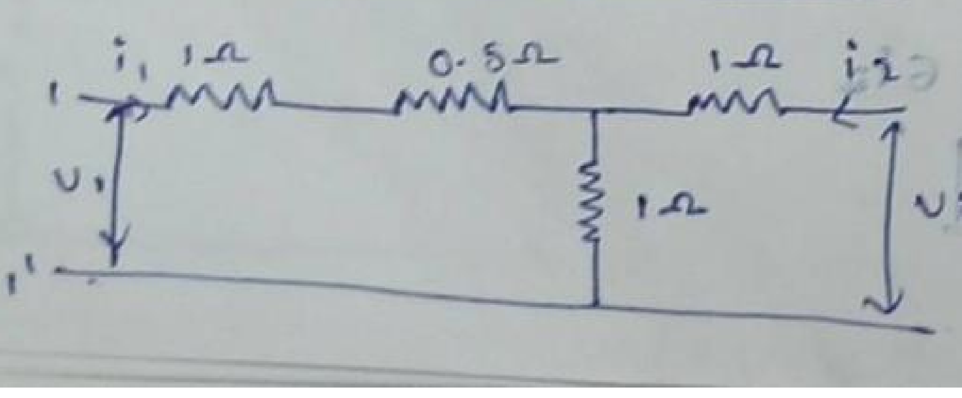


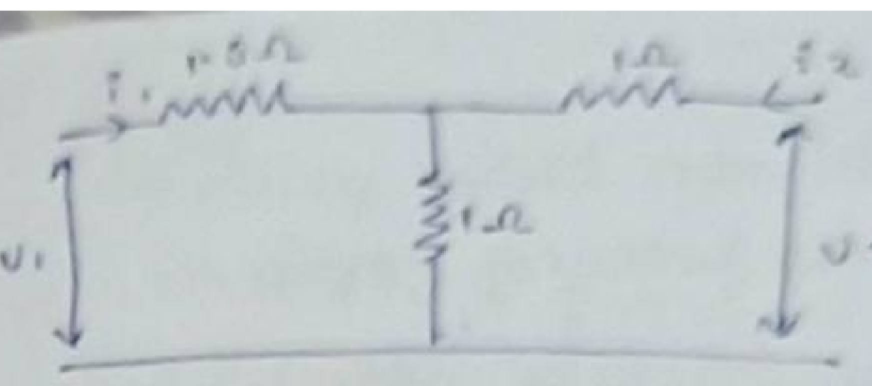
$R_1 = \frac{2\times 2}{2+2+4} = 0.5\,\Omega$

$R_2 = \frac{2\times 4}{8} = 1\,\Omega$

$R_3 = \frac{2\times 4}{8} = 1\,\Omega$

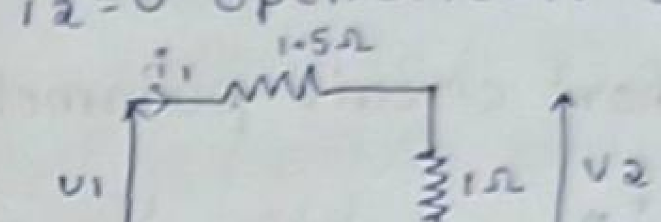






case i

$i_2 = 0$ opencircuit o/p



$v_1 = i_1 R_{equ}$

$v_1 = i_1(2.5)$

$\boxed{v_1 = 2.5i_1}$

$z_{11} = \frac{v_1}{i_1} = \frac{2.5i_1}{i_1} = 2.5\,\Omega$

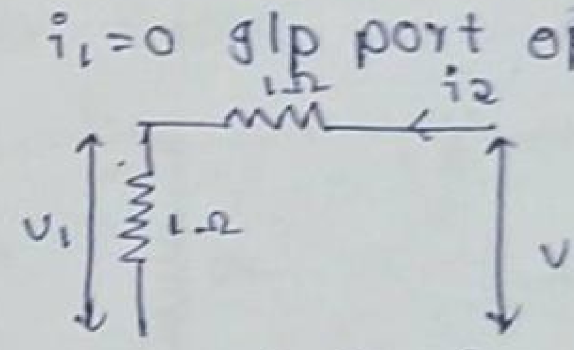
$v_2 = v_1 \times \frac{1}{2.5}$

$v_2 = \cancel{2.5} \times i_1 \times \frac{1}{\cancel{2.5}}$

$\boxed{v_2 = i_1}$

$z_{21} = \frac{v_2}{i_1} = \frac{i_1}{i_1} = 1\,\Omega$

case ii $i_1 = 0$ i/p port open circuted



$v_2 = i_2(R_{eq})$

$\boxed{v_2 = 2i_2}$

$z_{22} = \frac{v_2}{i_2} = \frac{2\cancel{i_2}}{\cancel{i_2}}$

$\boxed{z_{22} = 2\,\Omega}$

$z_{12} = v_1 = v_2 \times \frac{1}{\cancel{2}}$

$v_1 = \frac{2i_2}{2}$

$\boxed{v_1 = i_2}$

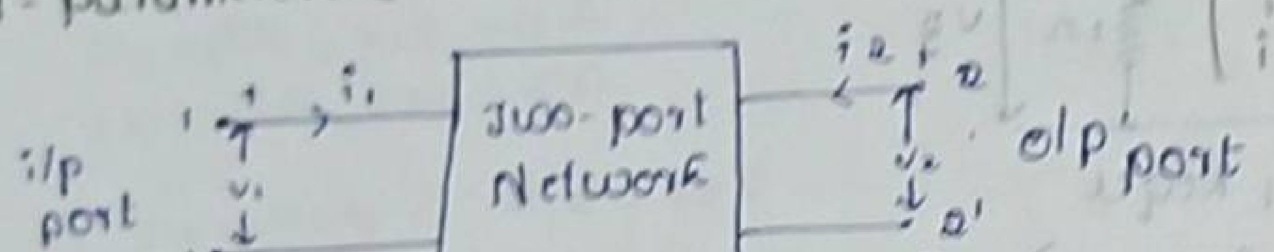
$z_{12} = \frac{V_1}{I_2} = 1\Omega$

$\boxed{z_{12} = 1\Omega}$

$$z = \begin{bmatrix} 0.5 & 1 \\ 1 & 2 \end{bmatrix}$$

∴ Reciprocality of parameters satisfies.

Y-parameters (Admitance (or) short circuit parameters)



The function of the Y-parameters is given by

$I = V[Y] \longrightarrow (1)$

Admitance is a reciprocal of impedance $\frac{1}{z} = Y$

$i_1 = y_{11}v_1 + y_{12}v_2 \longrightarrow (2)$

$i_2 = y_{21}v_1 + y_{22}v_2 \longrightarrow (3)$

· The matrix form of Y-parameters

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \longrightarrow (4)$$

Finding out Y-parameters

$i_1 = y_{11}v_1 + y_{12}v_2$

$i_2 = y_{21}v_1 + y_{22}v_2$

Case - I

o/p port is short circuit

$v_2 = 0$

$i_1 = y_{11}v_1$

$\boxed{y_{11} = \frac{i_1}{v_1}\Big|_{v_2=0}}$

$i_2 = y_{21}v_1$

$\boxed{y_{21} = \frac{i_2}{v_1}\Big|_{v_2=0}}$

case - II

i/p port is short circuit

$v_1 = 0$

$i_1 = y_{12}v_2$

$\boxed{y_{12} = \frac{i_1}{v_2}\Big|_{v_1=0}}$

$i_2 = y_{22}v_2$

$\boxed{y_{22} = \frac{i_2}{v_2}\Big|_{v_1=0}}$

Here

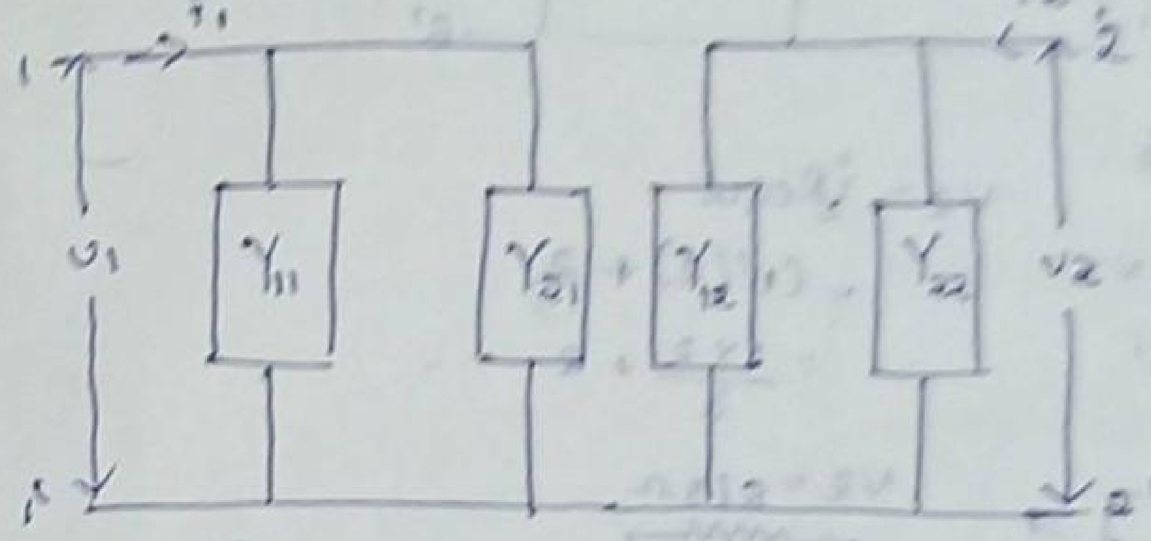
y_{11} = Driving point admitance (or) Input port admitance

y_{12} = Transfer forward admitance

y_{21} = Transfer reverse admitance

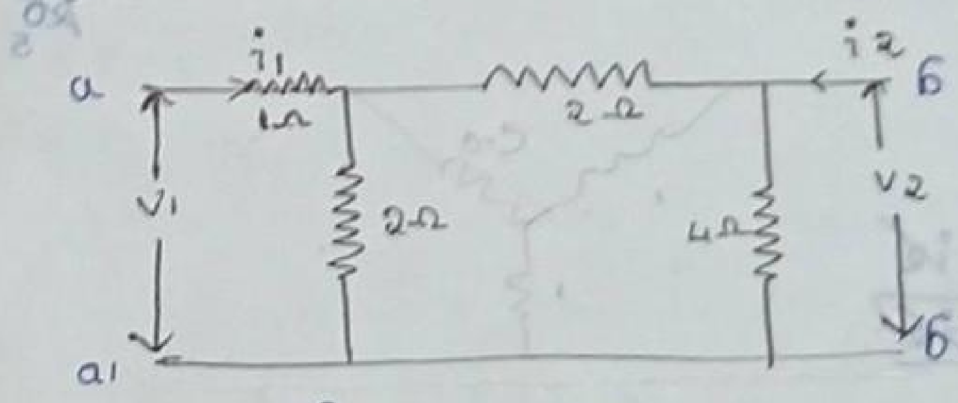
y_{22} = Output port admitance (or) driving point admitance (or) short circuit output admitance

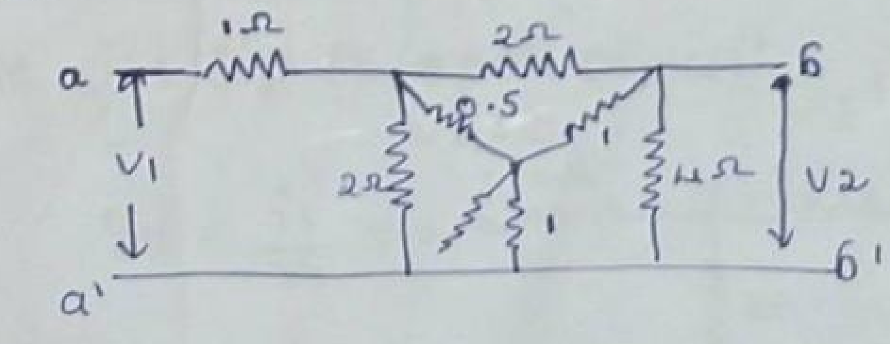
The equivalent circuit of the Y-parameters are shown below



The Y-parameters are also called as short circuit parameters because the Y-parameters are calculated by using short-circuit concept.

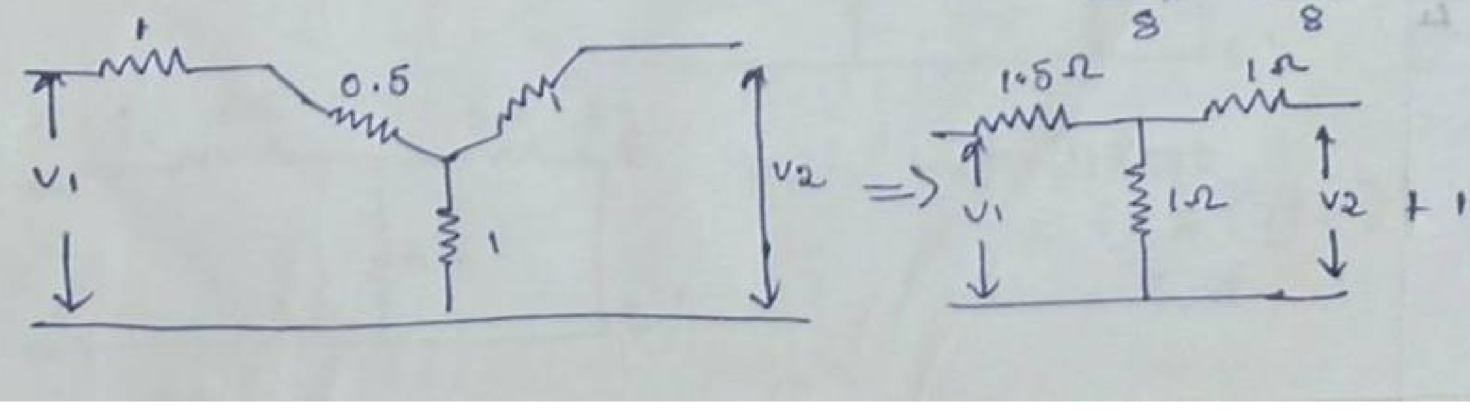
→ Find the Y-parameters for the network shown below

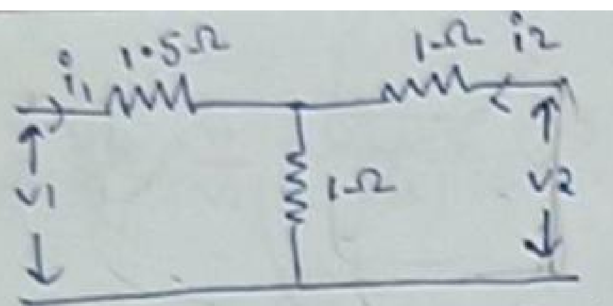




$\frac{2\times 2}{2+2+4} = \frac{4}{8}$

$\frac{2\times 4}{8}$ $\frac{2\times 4}{8}$





case(i): Output shortcircuit
$V_2=0$

$y_{11}=\frac{i_1}{V_1}$, $y_{22}=\frac{i_2}{V_1}$

$V_1 = i_1 R_{equiva}$

$R_{equivalent} = \frac{1\times1}{1+1}+1.5$
$= 0.5+1.5$
$= 2\Omega$

$V_1 = 2i_1$

$y_{11} = \frac{\cancel{i_1}}{2\cancel{i_1}} = 0.5\mho$

case(ii): Input shortcircuit
$V_1=0$

$y_{12}=\frac{i_1}{V_2}$, $y_{22}=\frac{i_2}{V_2}$

$V_2 = i_2 \times R_{equi}$

$R_{equi} = \frac{1.5\times1}{1.5+1}+1$
$= \frac{1.5}{2.5}+1$
$= \frac{15+25}{25} = \frac{40}{25} = \frac{8}{5}$

$R_{equi} = \frac{8}{5}$

$V_2 = \frac{8i_2}{5}$

$y_{22} = \frac{i_2}{8i_2}\times5$

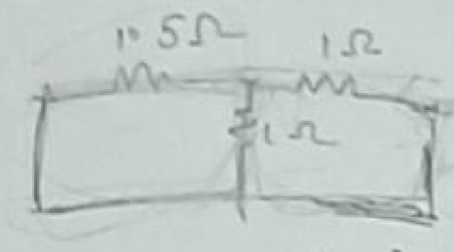
$y_{22} = 0.625\mho$

$y_{11} = 0.5\mho$
$y_{21} = -\frac{1}{4} = 0.25\mho$
$y_{22} = 0.625\mho$
$y_{12} = -0.25\mho$

$y_{11} \neq y_{22}$ - symmetrical condition is not satisfied

$y_{21}=y_{12}$ Reciprocality is satisfied

$\frac{i_1}{V_1}$ $V_1 = i_1 \times$



$V_1 = i_1\times 2\frac{1}{1+1}$

$-i_2 = i_1\times\frac{1}{1+1}$ $-i_1\times$

$-i_2 = \frac{i_1}{2}$

$y_{21} = \frac{\cancel{i_1}}{2\times2\cancel{i_1}}$

$y_{21} = -0.25\mho$

$V_2 = i_2\left(\frac{8}{5}\right)$

$-i_1 \times i_2$

$-i_2 = i_2\times\frac{1}{1+1.5}$

$= -i_2\times\frac{1}{2.5}$

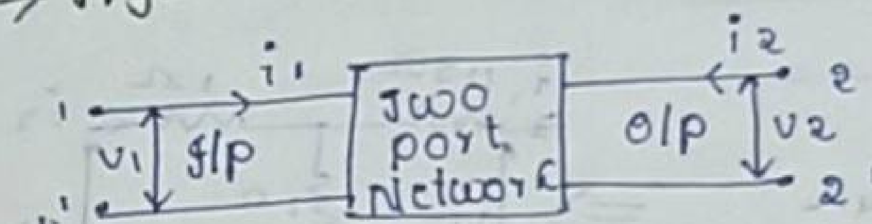
$y_{12} = \frac{-i_2}{2.5}\times\frac{5}{8i_2}$

$y_{12} = \frac{-5}{25\times8}$

$y_{12} = -0.25\mho$

$I_1 = y_{11}V_1 + y_{12}V_2 = 0.5V_1 - 0.25V_2$
$I_2 = y_{21}V_1 + y_{22}V_2 = -0.25V_1 + 0.625V_2$

→ Hybrid parameters



The hybrid parameters are

$V_1 = h_{11}i_1 + h_{12}V_2 \rightarrow (1)$
$i_2 = h_{21}i_1 + h_{22}V_2 \rightarrow (2)$

The matrix form of H-parameters are

$$\begin{bmatrix} V_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}\begin{bmatrix} i_1 \\ V_2 \end{bmatrix} \rightarrow (3)$$

$V_1 = h_{11}i_1 + h_{12}V_2$
$i_2 = h_{21}i_1 + h_{22}V_2$
$h_{11} = \frac{V_1}{i_1}$ $h_{21} = \frac{i_2}{i_1}$ $h_{22} = \frac{i_2}{V_2}$ $h_{12} = \frac{V_1}{V_2}$

Findout H-parameters

$V_1 = h_{11}i_1 + h_{12}V_2$ and $i_2 = h_{21}i_1 + h_{22}V_2$

case I
$V_2=0$ short circuit o/p port terminals

$\boxed{h_{11} = \frac{V_1}{i_1}, \text{when } V_2=0}$ and $\boxed{h_{21} = \frac{i_2}{i_1}, \text{when } V_2=0}$

Impedence current gain

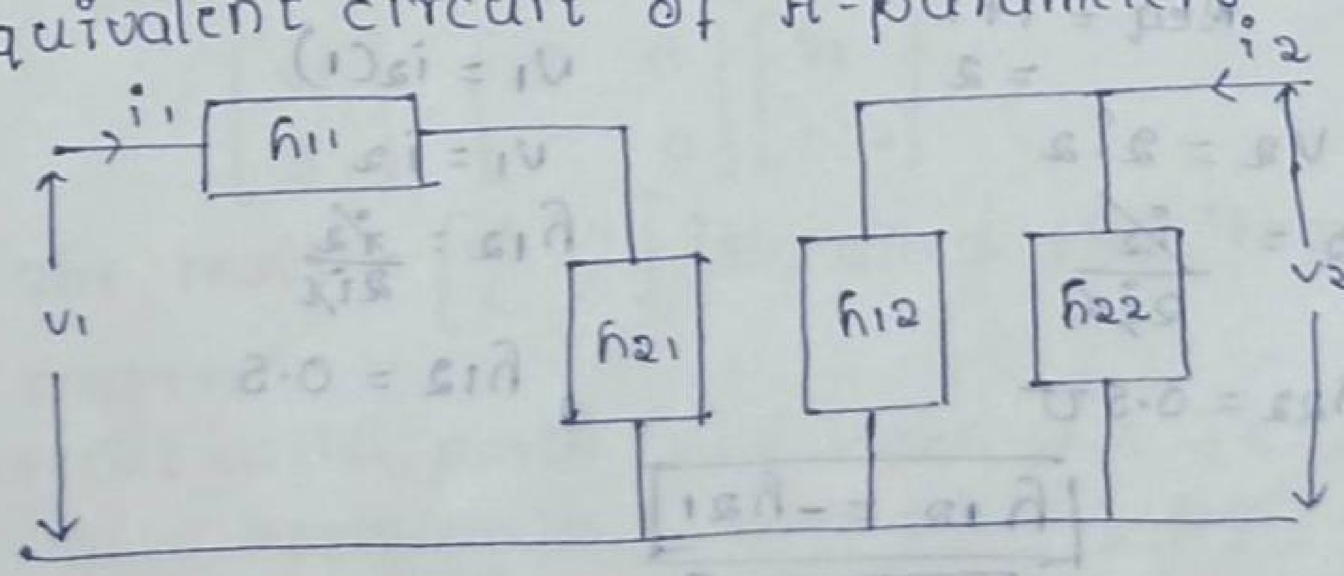
case - II
$i_1=0$ I/p port is open circuit

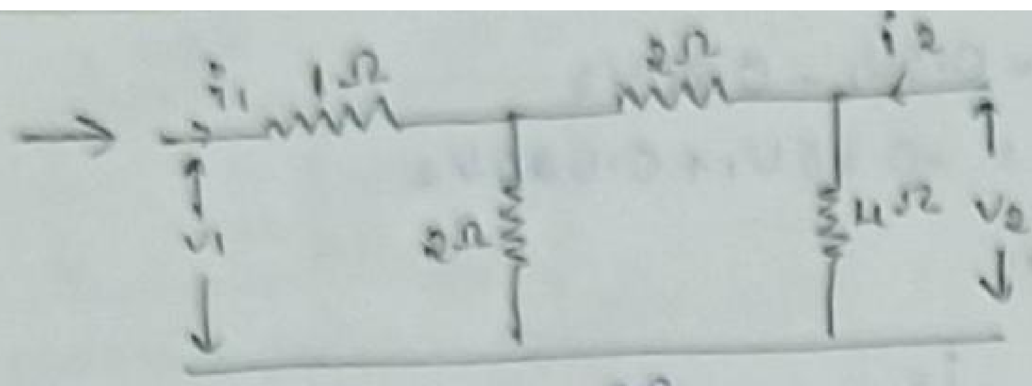
$V_1 = h_{12}V_2$

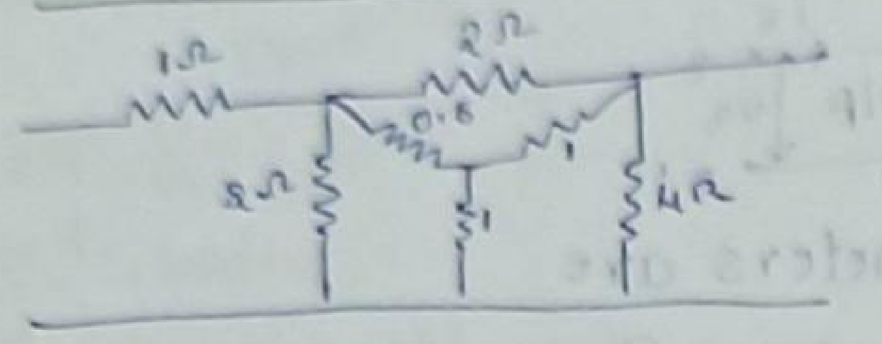
$\boxed{h_{12} = V_1/V_2, \text{when } i_1=0}$, $\boxed{h_{22} = \frac{i_2}{V_2}, \text{when } i_1=0}$

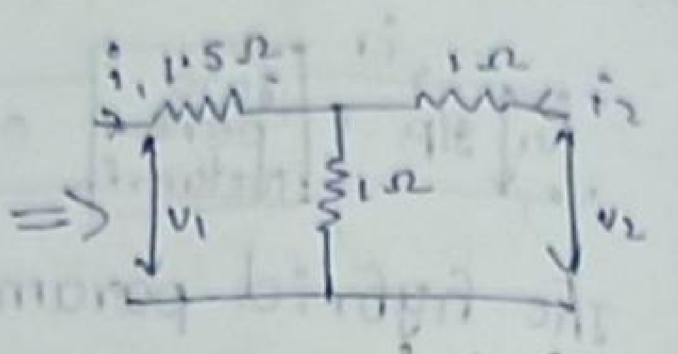
voltage gain
Opencircuit input voltagegain open circuit ~~input~~ output admittance.

Equivalent circuit of H-parameters









$V_1 = i_1 \times 1.5 + \frac{1}{2}$

$V_1 = 2i_1$

$h_{11} = 2$ $\quad \frac{i_2}{i_1}$

case(i):
Output short circuit
$V_2 = 0$

$h_{11} = \frac{V_1}{i_1}, \quad h_{21} = \frac{i_2}{i_1}$

$-i_2 = i_1 \times \frac{1}{1+1}$ $\quad -i_2 = i_1 \times \frac{1}{2}$

$V_1 = i_1 R_{equi}$

$\frac{V_1}{V_2}$

$R_{equi} = \frac{1 \times 1}{1+1} + 1.5$

$i_2 = \frac{-i_1}{2}$

$= 0.5 + 1.5$

$h_{21} = \frac{-\cancel{i_1}}{2\cancel{i_1}}$

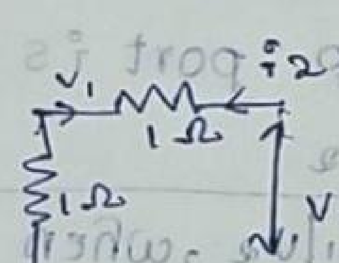
$R_{equ} = 2$ $\quad V_2 = V_1 \times \frac{1}{2}$ $\quad h_{21} = \frac{-1}{2} = -0.5$

$V_1 = 2i_1$

$h_{11} = \frac{2\cancel{i_1}}{\cancel{i_1}}$

$h_{11} = 2\,\Omega$

case(ii):
Input open circuit
$i_1 = 0$



$V_2 = \frac{i_2}{}$

$h_{12} = V_1/V_2 \quad h_{22} = \frac{i_2}{V_2}$

$V_2 = i_2 R_{ea}$ $\quad V_1 = i_2 R_{ea}$

$R_{eq} = 1+1$
$= 2$

$V_1 = i_2(1)$

$V_2 = 2i_2$

$V_1 = i_2$

$h_{22} = \frac{\cancel{i_2}}{2\cancel{i_2}}$

$h_{12} = \frac{\cancel{i_2}}{2\cancel{i_2}}$

$h_{12} = 0.5$

$h_{22} = 0.5\,\mho$

$h_{11} = 2\,\Omega$
$h_{21} = \frac{-1}{2}$
$h_{12} = \frac{1}{2}$
$h_{22} = \frac{1}{2}\,\mho$

$\boxed{h_{12} = -h_{21}}$

$\boxed{h_{11} \neq h_{22}}$

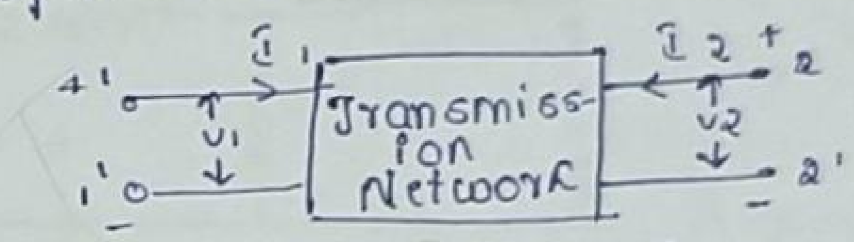
→ Transmission (or) ABCD parameters:

→ ABCD parameters are widely used in transmission line theory, cascade networks
Ex: design of telephone systems, microwave networks etc.

→ Transmission parameters provide a direct relationship between i/p and o/p. These are also called as general circuit parameters (or) chain parameters.

→ In describing the transmission parameters, the i/p variables V_1 & I_1 at port 1-1', usually called the sending end, are expressed in terms of the o/p variables V_2 & I_2 at port 2-2', called the Receiving end. They are defined by

$V_1 = AV_2 - BI_2$
$V_2 = CV_2 - DI_2$



$V_1 = AV_2 - BI_2 \longrightarrow (1)$
$I_1 = CV_2 - DI_2 \longrightarrow (2)$

The -ve sign is used with I_2, and not for the parameter B and D. Both port currents I_1 and '$-I_2$' are directed to the right, i.e with a -ve sign in Eqs (1) & (2) the current at port 2-2' which leaves the port is designated as positive. The parameters A, B, C & D are called the transmission parameters.

The matrix form of Eq (1) & (2) are expressed as

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

The matrix $\begin{bmatrix} A & B \\ C & D \end{bmatrix}$ is called the "transmission matrix".

case(1): with port 2-2' open, i.e $I_2 = 0$

Applying a vtg V_1 at the port 1-1'

$V_1 = AV_2 \Rightarrow \boxed{A = \frac{V_1}{V_2}\Big|_{I_2=0}}$

$I_1 = CV_2 \Rightarrow \boxed{C = I_1/V_2, \text{ when } I_2 = 0}$

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$\frac{1}{A}$ = open circuit voltage gain, a dimensionless parameter

$\frac{1}{C} = z_{21}$ = open circuit transfer impedence

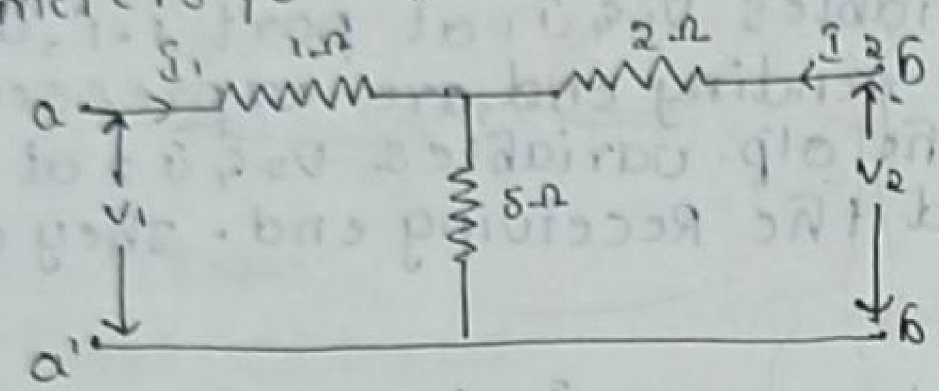
case ②: with port 2-2' short circuited i.e., $V_2 = 0$

Applying voltage V_1 at port 1-1'

$V_1 = -B i_2 \Rightarrow \boxed{-B = \frac{V_1}{i_2}}$, when $V_2 = 0$ short circuit transfer admitance

$i_1 = -D i_2 \Rightarrow \boxed{-D = \frac{i_1}{i_2}}$, when $V_2 = 0$ short circuit current gain

→ Find the transmission (or) general circuit parameters for the circuit shown.



$V_1 = V_2 \times \frac{5}{6}$

$A = \frac{6}{5}$

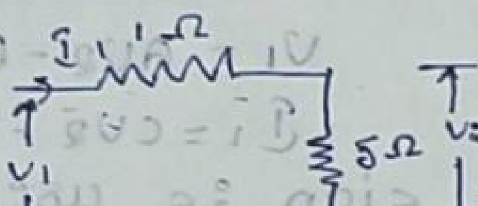
$C = \frac{i_1}{V_2}$

$V_1 = AV_2 - Bi_2$

$i_1 = CV_2 - Di_2$

case(i) -

when b-b' is open $i_2 = 0$



$V_1 = i_1 \times$

$\cancel{-B} = A = \frac{V_1}{V_2}$

$V_1 = i_1 Requt$

$= i_1 \cdot \frac{1+5}{1+5}$

$V_2 = V_1 \times \frac{5}{1+5}$

$V_1 = 5 i_1$

$V_2 = \frac{5V_1}{6} = \frac{5}{6}(6 i_1) = 5 i_1$

$A = \frac{V_1}{V_2} = \frac{6\cancel{i_1}}{5\cancel{i_1}}$

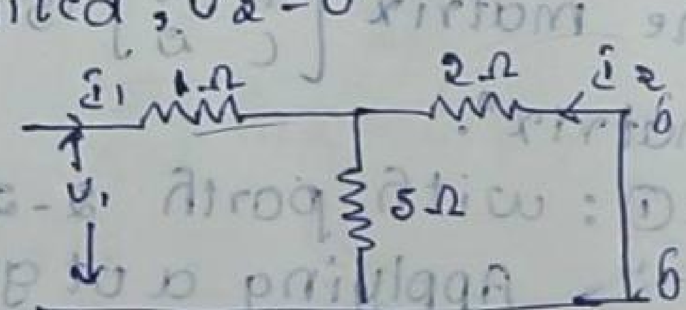
$A = \frac{6}{5}$

$C = \frac{i_1}{V_2} = \frac{i_1}{5 i_1} = \frac{1}{5}$ ℧

case (ii) -

when b-b' is short circuited, $V_2 = 0$

$-B = \frac{V_1}{i_2}$, $-D = \frac{i_1}{i_2}$



$V_1 = i_1 Requi$

$Requi = 1 + \frac{5 \times 2}{5+2}$

$= 1 + \frac{10}{7}$

$= \frac{17}{7}$

$V_1 = \frac{17 i_1}{7}$

$-i_2 = i_1 \times \frac{5}{7} = \frac{5 i_1}{7}$

$B = -\frac{\frac{17 i_1}{7}}{\frac{5 i_1}{7}}$

$B = -\frac{17 \cancel{i_1}}{\cancel{7}} \times \frac{\cancel{7}}{-5\cancel{i_1}}$

$B = \frac{17}{5}$ Ω

$D = \frac{-\cancel{i_1}}{-5\cancel{i_1}} \times 7$

$D = \frac{7}{5}$

$A = \frac{6}{5}$, $B = \frac{17}{5}$ Ω

$C = \frac{1}{5}$ ℧, $D = \frac{7}{5}$

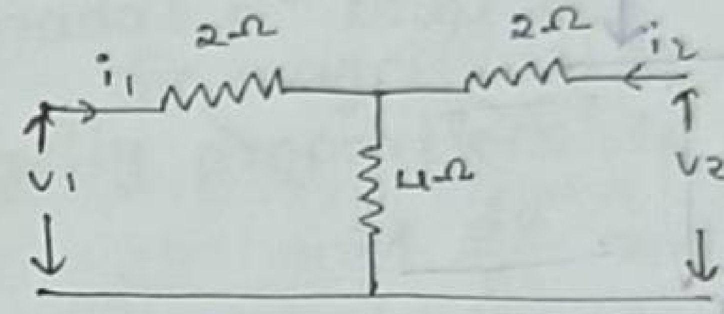
$AD - BC = 1$

$\frac{42}{25} - \frac{17}{25} = 1$

$\frac{25}{25} = 1$

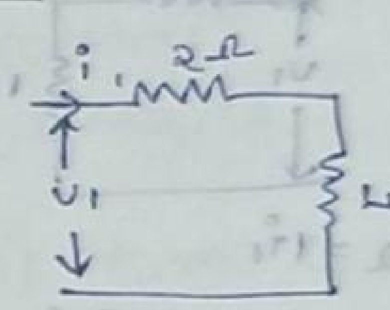
$1 = 1$

→



case(i): $i_2 = 0$

$A = \frac{V_1}{V_2}$, $C = \frac{i_1}{V_2}$



$V_1 = i_1 Reaq$

$Rea = 2 + 4 = 6$

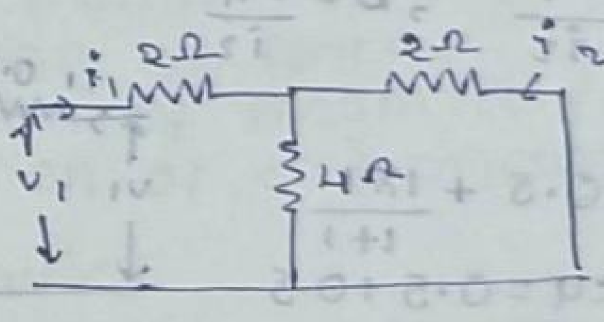
$V_1 = 6 i_1 \Rightarrow V_2 = V_1 \times 4$

$V_2 = 4V_1 \Rightarrow 4 i_1$

$A = \frac{6\cancel{i_1}}{4\cancel{i_1}}$ $A = \frac{3}{2}$ $C = \frac{i_1}{4 i_1} = \frac{1}{4}$ ℧

case (ii) = $V_2 = 0$

$B = -\frac{V_1}{i_2}$, $D = \frac{-i_1}{i_2}$



$V = iR$
$R = \frac{V}{i}$

$V_1 = i_1 Rea$

$= \frac{i_1 10}{3}$

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

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

$= \frac{10}{3}$

$-i_2 = i_1 \times \frac{4}{6} = \frac{2 i_1}{3}$

$B = -\frac{10\cancel{i_1}}{\cancel{3}} \times \frac{\cancel{3}}{2\cancel{i_1}}$

$B = 5$ Ω

$D = \frac{-\cancel{i_1}}{-2\cancel{i_1}} \times 3$ $D = \frac{3}{2}$

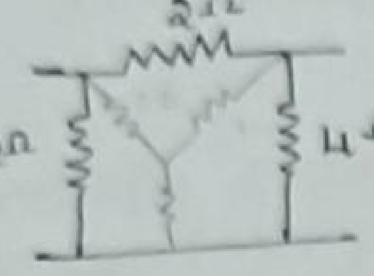
$AD \cdot BC = \left(\frac{3}{2}\right)\left(\frac{3}{2}\right) - \left(\frac{1}{4}\right)(5)$

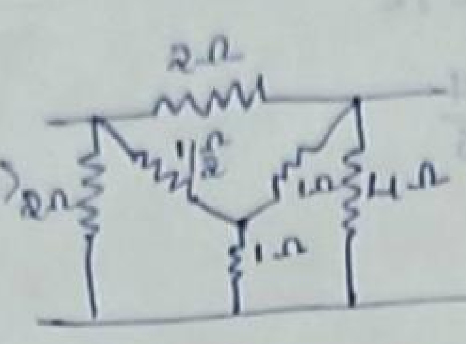
$= \frac{9}{4} - \frac{5}{4}$

$= \frac{4}{4} = 1$

$AD \cdot BC = 1$

$A = D$

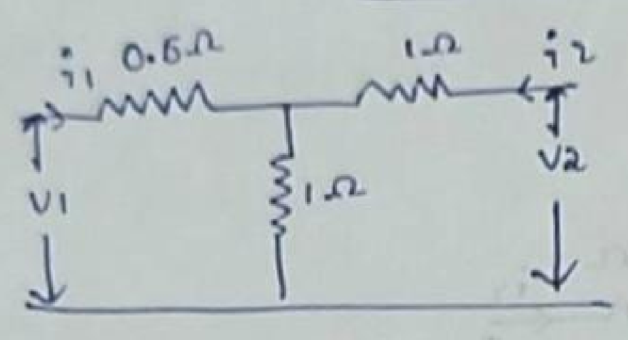
→ 

$\Rightarrow$ 

$\frac{2\times2}{2+2+4} = \frac{4}{8}$

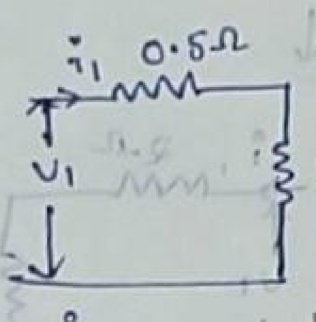
$\frac{2\times4}{2+4+2} = \frac{8}{8}$

$\frac{4\times2}{8} = 1$



case(i): $i_2 = 0$

$A = \frac{V_1}{V_2}, \quad C = \frac{i_1}{V_2}$



$V_1 = i_1 R_{equi}$

$R_{equi} = 1.5$

$V_1 = 1.5 i_1$

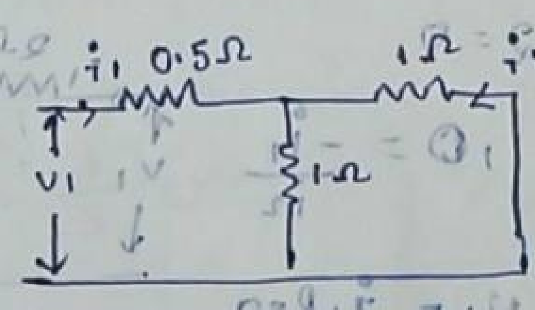
$V_2 = 1 i_1$

$A = \frac{1.5 \cancel{i_1}}{1 \cancel{i_1}} \qquad C = \frac{\cancel{i_1}}{1 \cancel{i_1}}$

$A = 1.5 \qquad C = 1\,\mho$

case(ii): $V_2 = 0$

$B = -\frac{V_1}{i_2}, \quad D = \frac{-i_1}{i_2}$



$V_1 = i_1 R_{eq}$

$R_{eq} = 0.5 + \frac{1\times1}{1+1}$

$R_{eq} = 0.5 + 0.5$

$R_{eq} = 1$

$V_1 = i_1 \qquad -i_2 = i_1 \times \frac{1}{2}$

$i_2 = \frac{-i_1}{2}$

$B = \frac{-i_1}{-i_1} \times 2$

$B = 2$

$D = \frac{-\cancel{i_1}}{-\cancel{i_1}} \times 2$

$D = 2$

$AD - BC$
$= (1.5)(2) - 2$
$= 1$
$AD - BC = 1$

UNIT-II

DC MACHINES

DC Generators

Faraday's Laws

Faraday's 1st law:

When ever the magnetic flux linking the coil changes, then an emf is induced in the coil.

Faraday's 2nd law:

The magnitude of emf induced in the coil is directly proportional to flux linkages

$e \propto \frac{d\phi}{dt} \Rightarrow e = N\frac{d\phi}{dt}$

ϕ = flux (webers)

ψ = flux linkages

$\psi = N\phi$

N = No. of turns of a coil

Lenz's law:

The direction of induced emf in a coil is such that it opposes the cause producing by it

Fleming's Right rule:

thumb - direction of motion of conductor (or) direction of force

index finger - direction of magnetic field

middle finger - direction of emf (or) current

Flemings left hand rule:

thumb - direction of force (or) motion of conductor

index finger - direction of magnetic field

middle finger - direction of current

→ Generators → dynamically induced emf

Transformers - statically induced emf

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Dynamically induced emf:

emf induced with the rotation of conductor

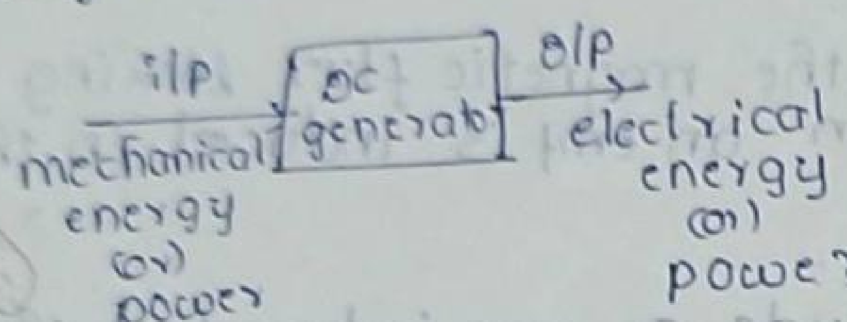
Statically induced emf:

emf induced without any rotation of conductor.

Principle of operation of DC generator:

→ converts mechanical energy into electrical energy.

→ A generator works on the principle of Faraday's laws of electromagnetic induction.

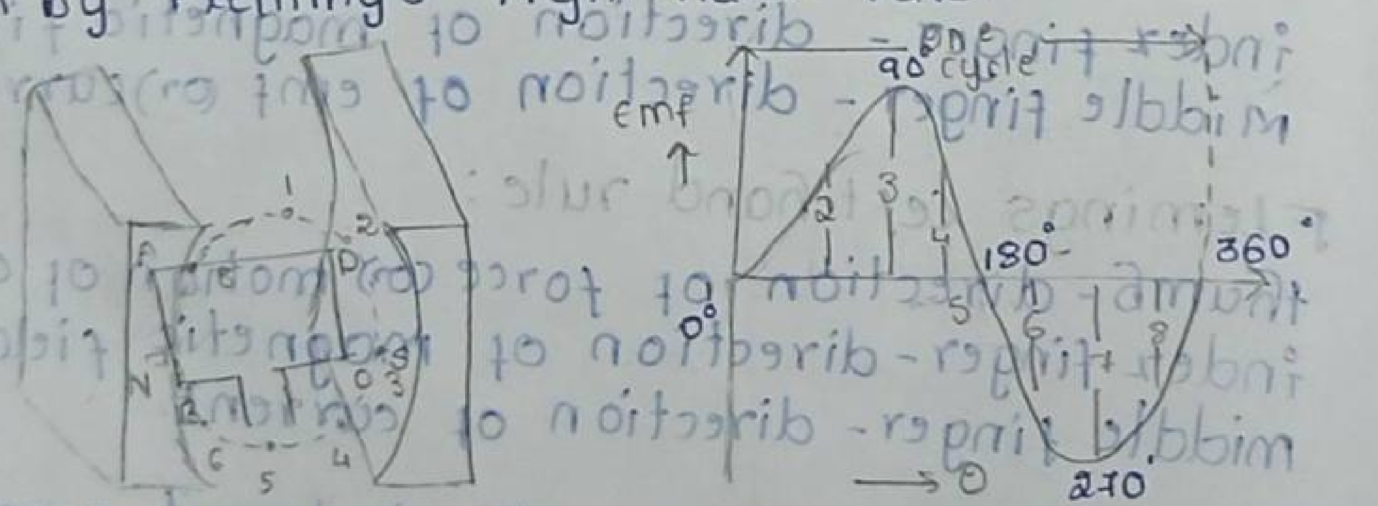


Principle: Whenever a rotating conductor is moved in the magnetic field, an e.m.f is induced and the magnitude of the induced emf is directly proportional to the rate of change of flux linkage. This e.m.f causes a current flow if the conductor circuit is closed.

The essential components of generator are:

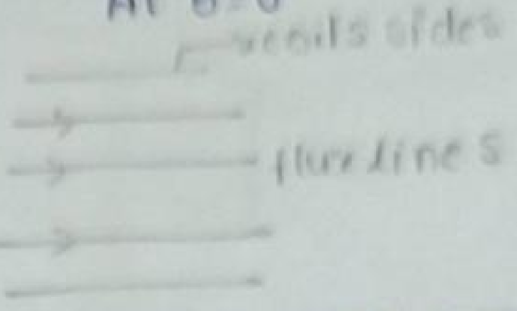
1. a magnetic field (magnets)
2. conductor or a group of conductors
3. motion of conductor w.r.t magnetic field

→ The direction of induced emf (and hence current) is given by Flemings right hand rule.



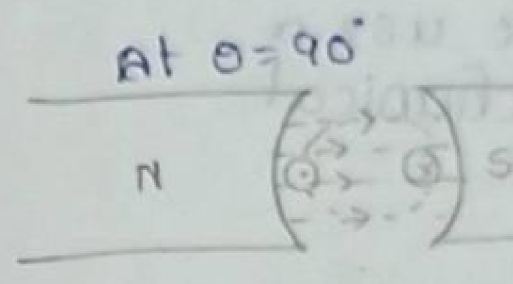
Magnetic flux lines passes from North to south pole

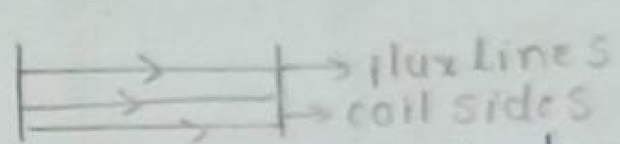
At θ=0°



flux lines are parallel to the coil side
the emf induced is zero

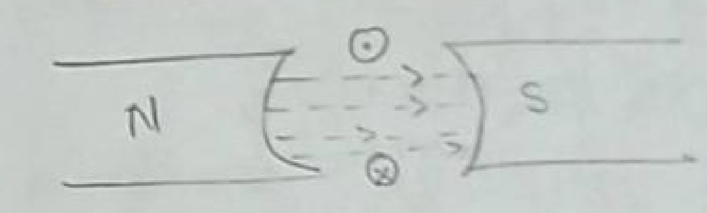
At θ=90°

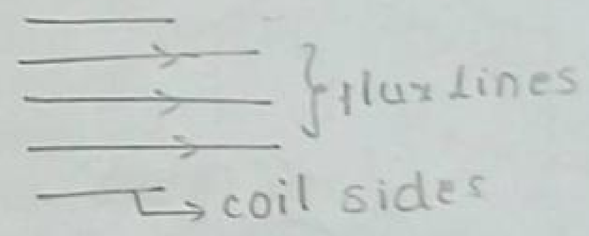




Maximum emf is induced here

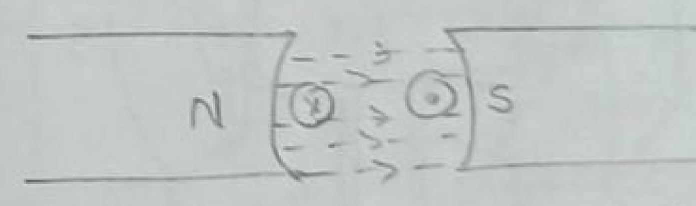
At θ=180°

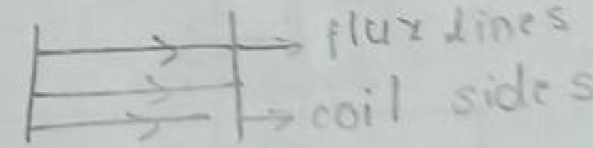




flux lines are parallel to the coil sides
the emf induced is zero

At θ = 270°





flux lines are perpendicular to coil sides
hence the emf induced here is maximum

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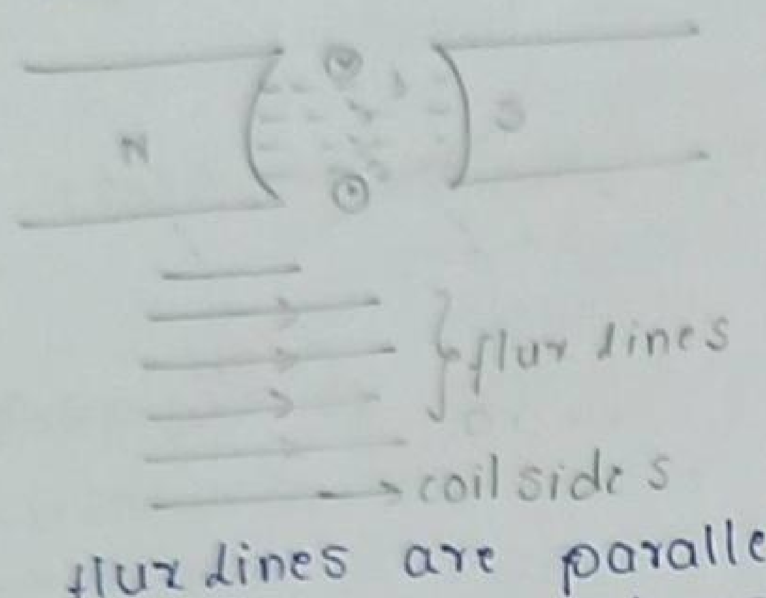
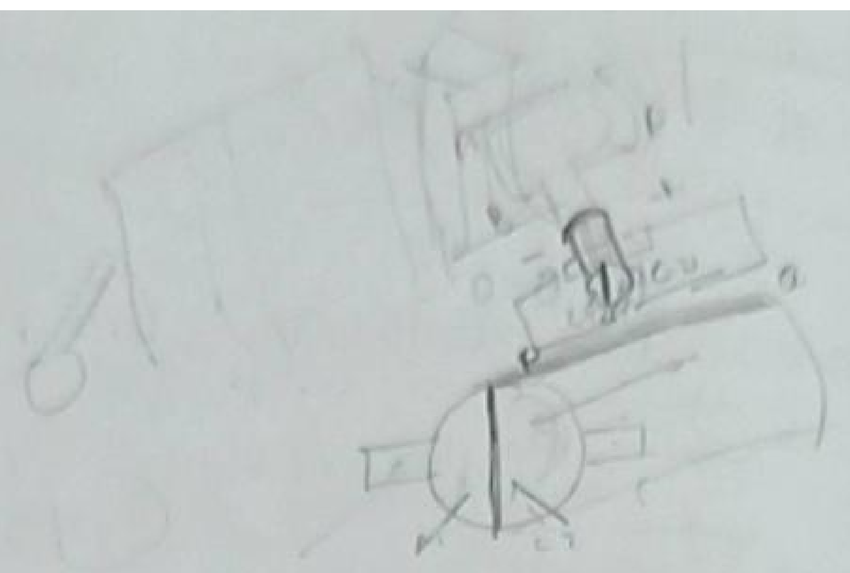
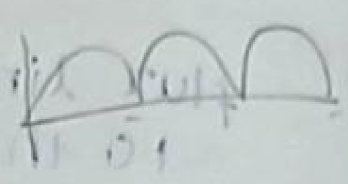
At $\theta = 360°$

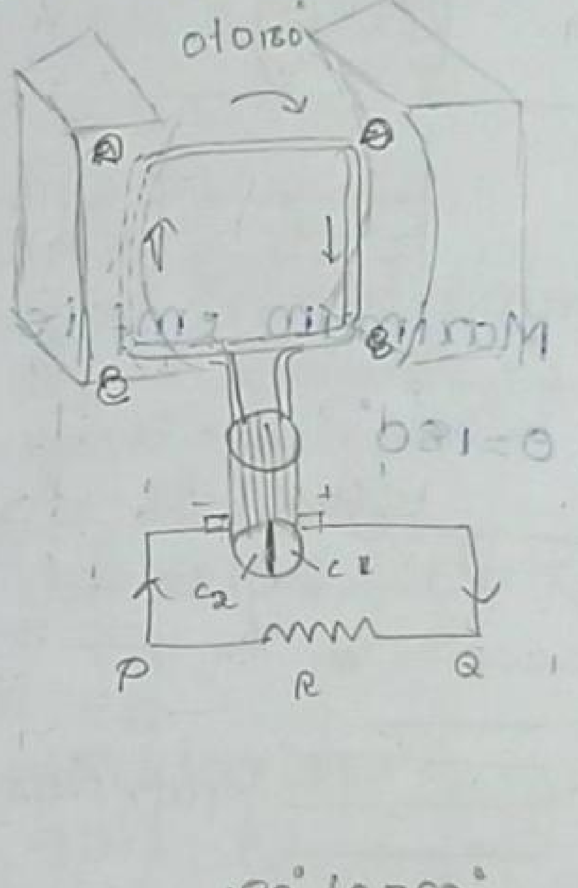






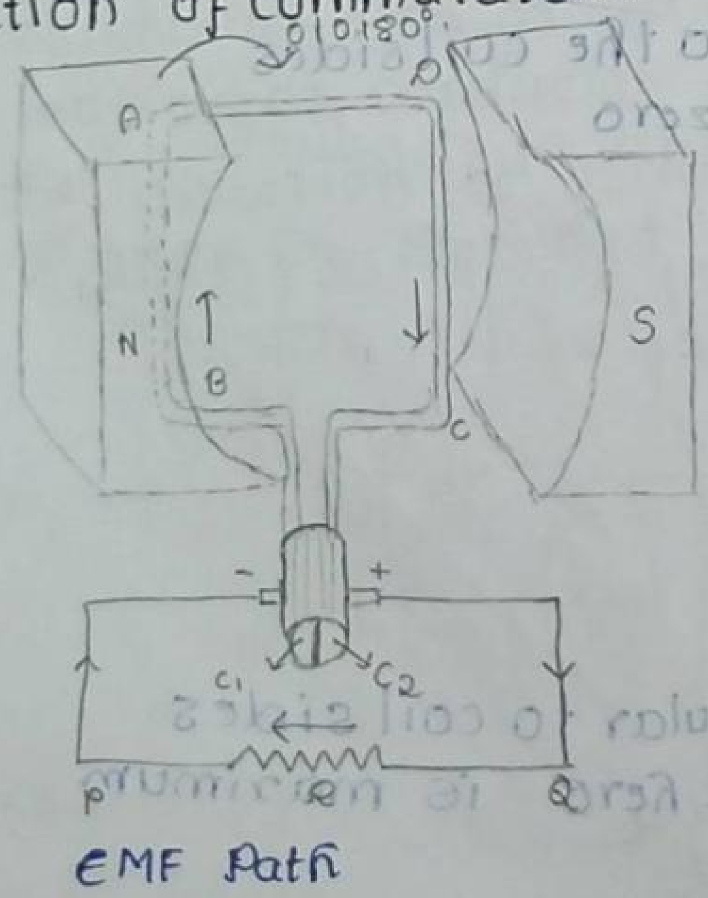
flux lines are parallel to coil sides
Hence emf induces is zero.

→ To convert AC emf to DC emf we use a device called commutator. (or) mechanical rectifier. (ac to d.c)

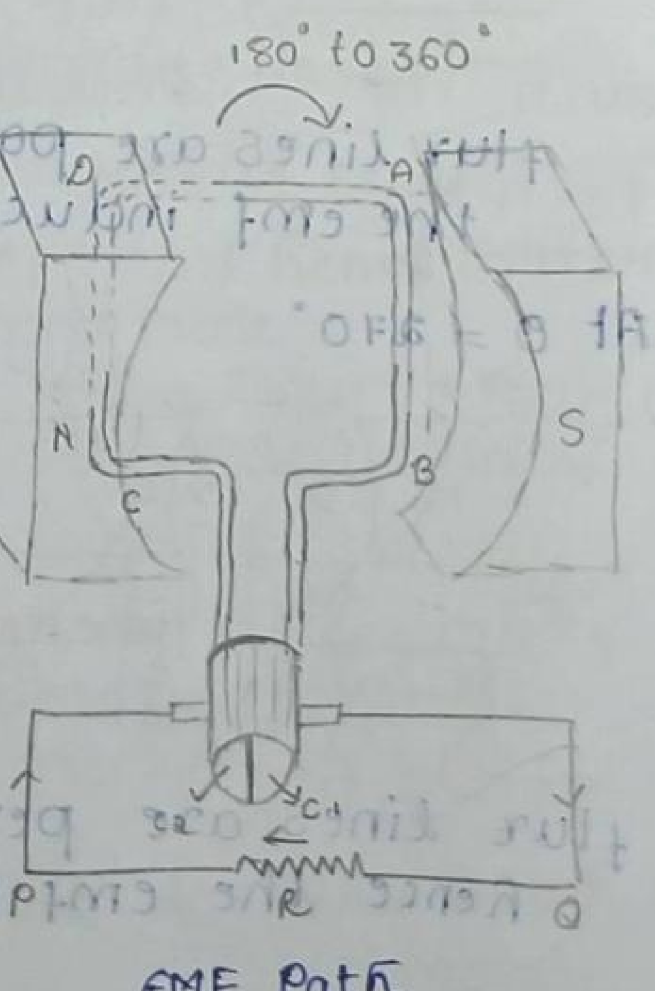


Coil post	Angle θ	emf
1.	0°	0
3	90°	max
5	180°	0
7	270°	max
9	360°	0

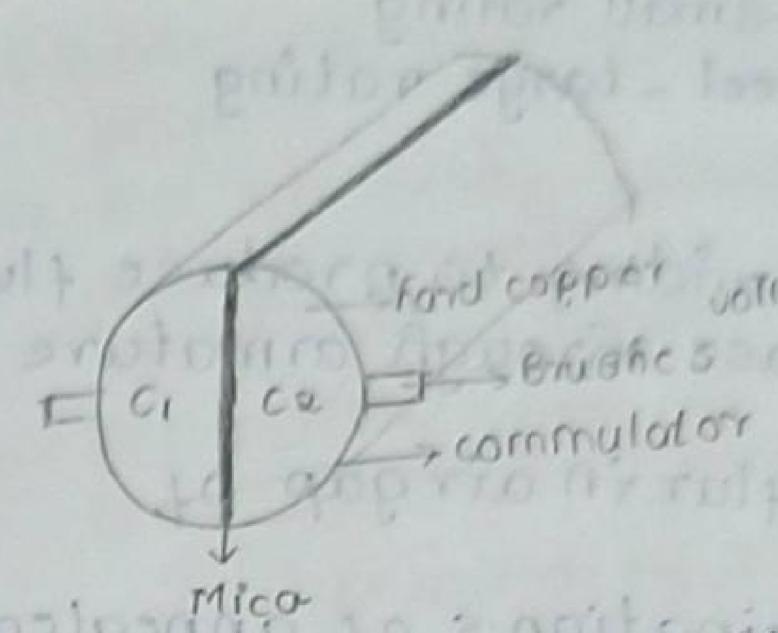
Action of commutator:

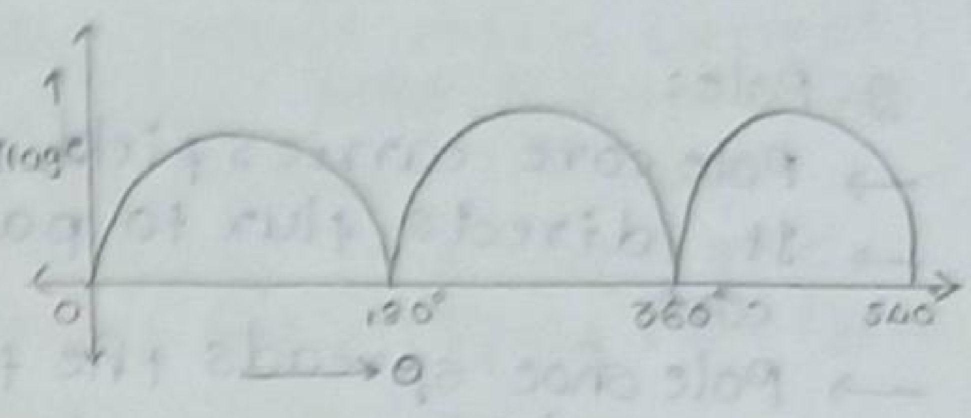


EMF Path
BAECQPB

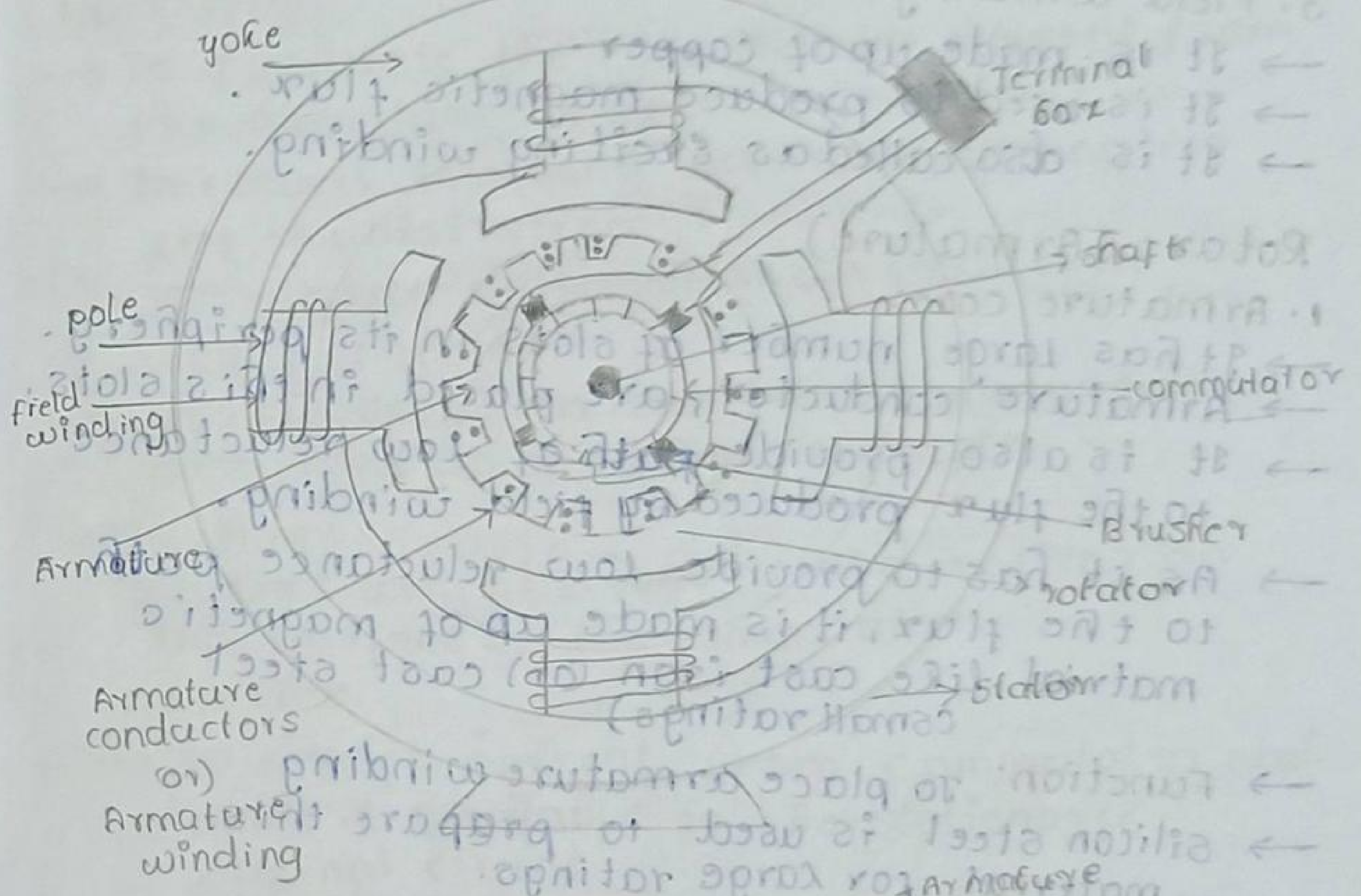


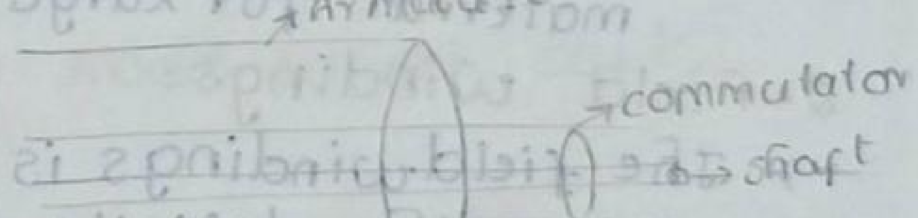
EMF Path
CDABQPC

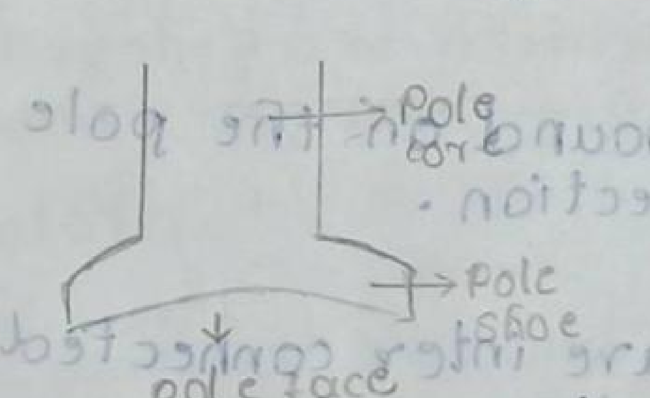




DC - Machine construction:
Generator (or) Motor







Stator:
1. Yoke:
→ It acts as a much support to poles.
→ Acts like a protective cover.
→ It carries flux.

→ made up of cast iron - small rating
cast steel (or) rolled steel - large rating

2. Pole:
→ Pole core carries field widing to produce flux.
→ It directs flux to pass through armature core
→ Pole shoe spreads the flux in air gap of armature
→ It is built of thin laminations of annealed steel.

3. Field winding:
→ It is made up of copper.
→ It is used to produce magnetic flux.
→ It is also called as exciting winding.

Rotor: (Armature)
1. Armature core:
→ It has large number of slots in its periphery.
→ Armature conductor, are placed in this slots.
→ It is also provide path of low reluctance to the flux produced by field winding.
→ As it has to provide low reluctance path to the flux, it is made up of magnetic matrial like cast iron (or) cast steel (small ratings)

→ Function: To place armature winding
→ Silicon steel is used to prepare this material for large ratings.

2. Field windings:
→ The field windings is wound on the pole core with a definite direction.

2. Armature windings:
→ Armature conductors are inter connected to form armature winding.
→ When armature winding is rotated using prime mover in case of generator, the magnetic flux gets cut by the armature conductors and emf gets induced in them.
→ Armature winding is connected to external circuit
→ As armature winding carries entire current, which depends on external load, it has to be made up of conducting material i.e. copper
→ Depending upon the way of connecting the armature windings are basically of two types.
Lap winding $A = P$
Wave winding $A = 2$

Commutator:
Functions:
→ To facilitate the collection of current from the armature conductor.
→ To convert internally developed alternating emf to unidirectional (D.C) emf
→ To produce unidirectional torque in case of motor.
→ As it collects current from armature, it is also made up of copper segments.

Brushes:
Brushes are stationary and resting on the surface of the commutator.
Function:
→ To collect current from commutator and make it available to the stationary external circuit
→ Brushes are normally made up of soft material like carbon.

Stator	Rotor:
→ Yoke	→ Armature core
→ Pole core, pole shoe and Interpoles	→ Armature winding
→ Field windings	→ Commutator, shaft
→ Compensating windings	
→ Brushes	

Required parameters for deriving an equation of EMF of DC Generator

Let ϕ = flux/pole in wb
Z = total number of armature conductors
P = number of poles
A = number of parallel paths
= 2 for wave winding
= P for lap winding
N = speed of armature in r.p.m
E_g = emf of the generator = emf / parrel path

Flux cut by one conductor in one revolution of the armature $= d\phi = P\phi$ webers

Time taken to complete one revolution $= dt = 60/N$ second

emf generated /conductor $= \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60}$ volts

emf of generator $\frac{P\phi N}{60} \times \frac{Z}{A} = \frac{\phi ZNP}{60A}$

E_g = emf per parallel path

$= \frac{\text{emf}}{\text{conductor}} \times$ No. of conductors in series per parallel path

$\frac{P\phi N}{60} \times \frac{Z}{A}$, $\frac{\phi ZNP}{60A}$

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

$$\boxed{E_g = \frac{\phi ZNP}{60A} \text{ volts}}$$

where $A = 2$ for wave winding
$= P$ for lap winding

→ calculate the emf generated by 4 pole, wave wound generator having 65 slots with 12 conductors per slot calculate the emf gen when driven at 1200 rpm. The flux for pole is 0.02 wb

$P = 4$, $Z = 65 \times 12$, $N = 1200$, $\phi = 0.02$, $A = 2$

$$E_g = \frac{0.02 \times 65 \times 12 \times 1200 \times 4}{60 \times 2} = 624 \text{ volts}$$

→ A 6 pole lap wound dc generator has 600 conductors on its armature. The flux per pole is 0.02wb. Calculate
(i) speed at which the generator must be run to generate 300volts.
(ii) what would be the speed if generator is wave wounded

$A = P = 6$, $P = 6$, $Z = 600$, $\phi = 0.02$wb

(i) $300 = \frac{0.02 \times 600 \times N \times \cancel{6}}{60 \times \cancel{6}}$

$$N = \frac{\cancel{300} \times \cancel{60}\ 30}{\cancel{600} \times 0.02}$$

$$N = \frac{3000}{2}$$

$N = 1500$ rpm

(ii) If $A = 2$

$$300 = \frac{0.02 \times \cancel{600} \times N \times \cancel{6}}{\cancel{60} \times 2}$$

$$\frac{\cancel{300}}{0.02 \times \cancel{30}} = N$$

$$\frac{1000}{2} = N$$

$N = 500$ rpm

→ An 8pole lap wound armature rotated at 350 rpm is required to generate 260volts. The useful flux/pole is 0.05wb. If the armature has 120 slots calculate the no. of conductors per slot

$$E_g = \frac{\phi ZNP}{60A}$$

$$260 = \frac{0.05 \times Z \times 350 \times \cancel{8}}{60 \times \cancel{8}}$$

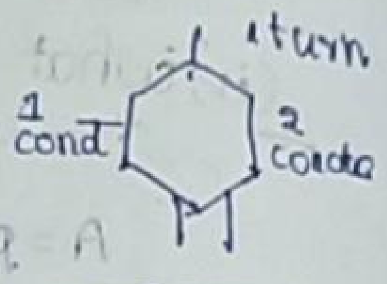
$$Z = \frac{260 \times 60}{0.05 \times 350} = \frac{15600}{17.5} = 891.42$$

$891.42 = 120 \times x$

$x = \frac{891.42}{120} = \frac{89\cancel{0}}{12\cancel{0}} = 7.41 \approx 8$ always even

→ The armature of a 6pole, 600 rpm, lap wound generator has 90 slots if each coil has 4 turns, calculate flux/pole required to generate an emf of 288 V.

$$288 = \frac{\phi \times 6 \times 600 \times 4 \times 2 \times 90}{60 \times 6}$$



$$\phi = \frac{288}{10 \times 4 \times 2 \times 90} \qquad Z = 4 \times 2 \times 90$$

$$= \frac{288}{7200}$$

$$\phi = 0.04\ wb$$

→ Armature Resistance: (R_a)

The resistance offered by the armature circuit is called armature Resistance.

$R_a < 1$

→ Types of DC generators

Based on field excitation

- Separately Excited DC Generators
- Self Excited DC Generator
  - Series wound DC Generator
  - Shunt wount DC Generator
  - Compound wound DC generator
    - Long shunt
      - commulative
      - Differential
    - Short shunt
      - commulative
      - Differential

Seperately - excited DC generator:

This dc generator has a field magnet winding which is excited using a seperate dc voltage source. Ex: battery.

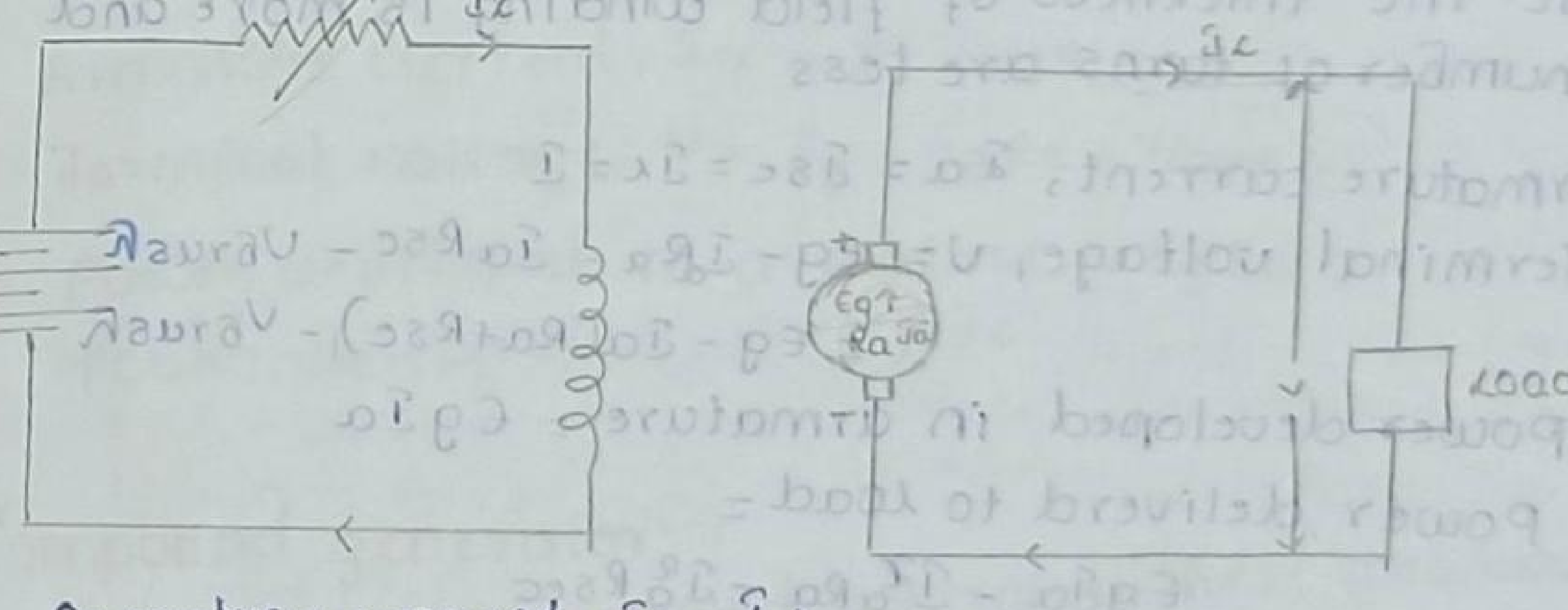
Self - excited DC generator

These are the generators in which the field winding is excited by the output of the generator itself. In this machine, residual magnetism must be present in the magnetic circuit of the machine inorder to start the self-excilation process.

There are three types of self-excited dc generators

1. Series
2. Shunt
3. Compound

Separately excited D.C. generators



Armature current, $I_a = I_L$

Terminal voltage, $V = E_g - I_a R_a$

Electric power developed $= E_g I_a - V_{brush}$

power delivered to load $= E_g I_a - I_a^2 R_a$

$= I_a(E_g - I_a R_a)$

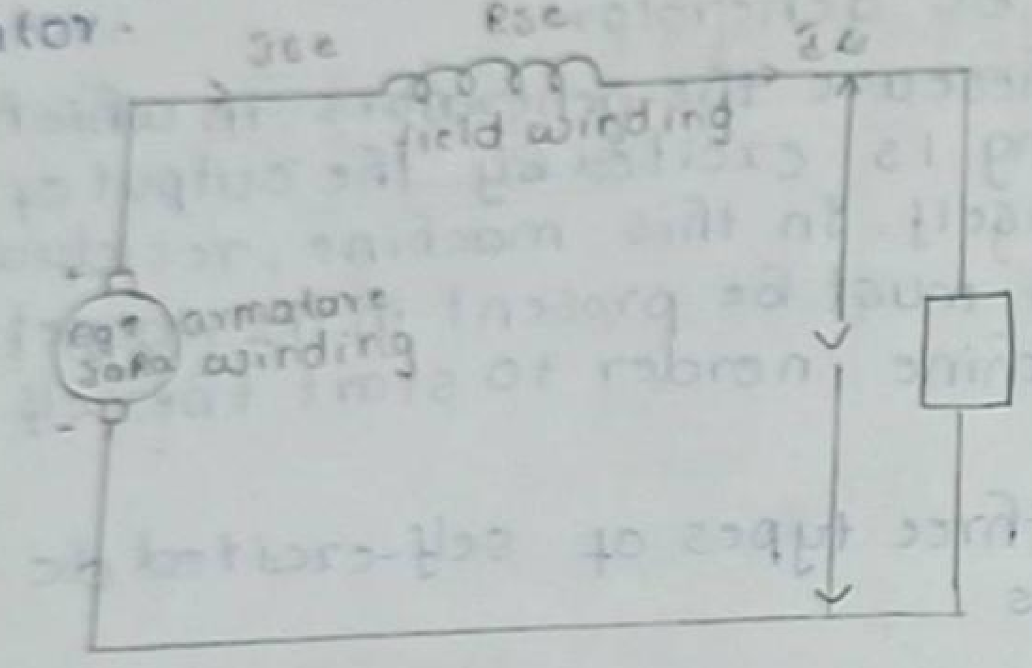
$= V I_a$

where R_L = Resistance of armature winding + Resistance of brushes

Self-Excited Generators:

Series Generator:

If a field winding is connected in series with armature winding then it is called a series generator.



Applications:

→ Series generators are used as Boosters on DC feeders in Traction service.

→ As Lighting arc lamps.

Here the thickness of field winding is more and number of turns are less

Armature current, $I_a = I_{se} = I_L = I$

Terminal voltage, $V = E_g - I_a R_a - I_a R_{se} - V_{brush}$

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

power developed in armature $= E_g I_a$

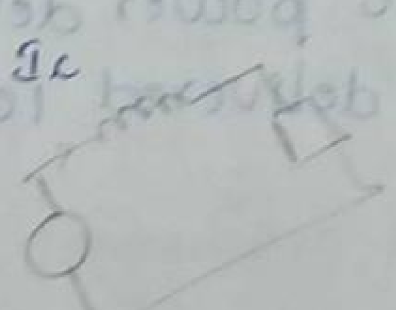
power deliverd to load $=$

$E_g I_a - I_a^2 R_a - I_a^2 R_{sec}$

$= E_g I_a - I_a^2 (R_a - R_{sec})$

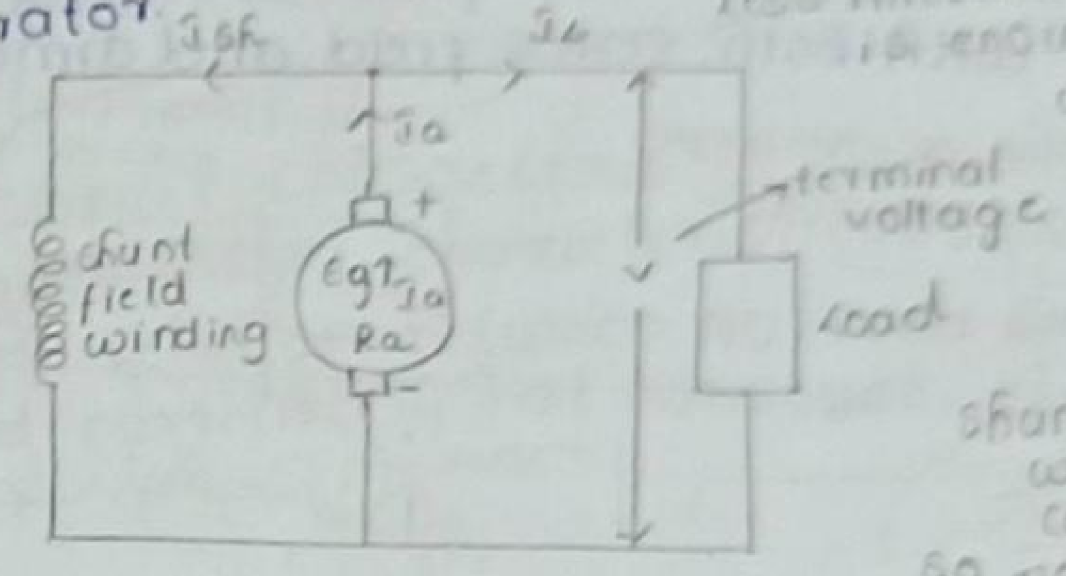
$= I_a[E_g - I_a(R_a - R_{sec})]$

$= V I_a$ (or) $V I_L$



Shunt generator:

If a field winding is connected in parallel with armature winding then it is called shunt generator.



less thickness of wire is enough in field winding

Shunt field winding - less current is flown so voltage drop across shunt field winding is neg.

Applications:

→ Shunt Generators are used for ordinary lighting and power supply purposes

→ For charging batteries

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

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

Terminal voltage, $V = E_g - I_a R_a - V_{brush}$

power developed in armature $= E_g I_a$

power delevered $= V I_L$

Compound generator:

→ In a compound-wound generator, there are two sets of field windings on each pole - one is in series and the other in parallel with the armature

(i) Cumulative compound generator - if two sets of field winding (series flux & shunt flux) may be connected to aid with each other is called cumulative compounding.

(ii) Differential compound generator - if two sets of field windings fluxes (series flux & shunt flux) oppose with each other is called differential compounding

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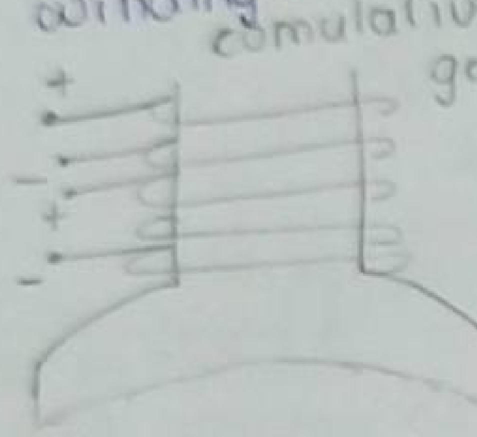
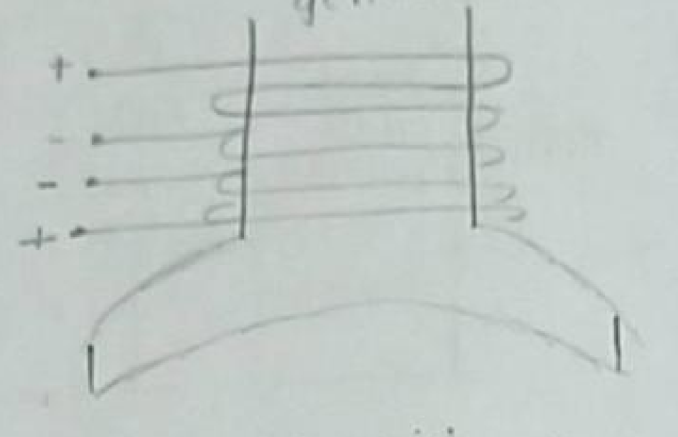
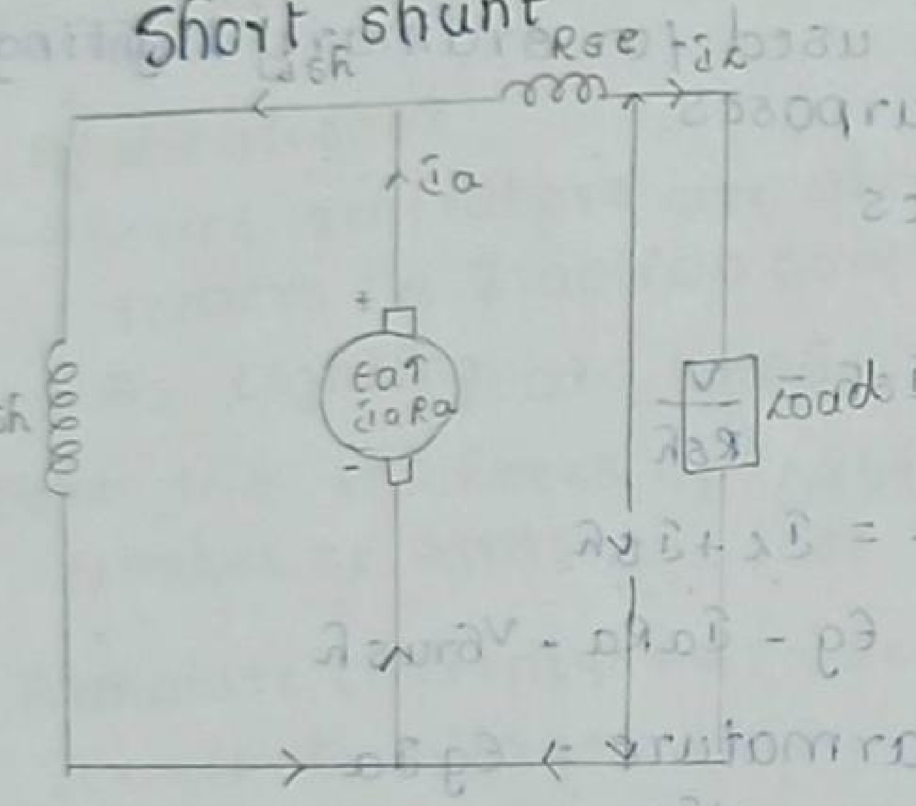
→ A compound wound generator may be
(a) short shunt in which only shunt field winding is in parallel with the armature winding.
(b) Long shunt in which shunt field winding is in parallel with both series field and armature winding.

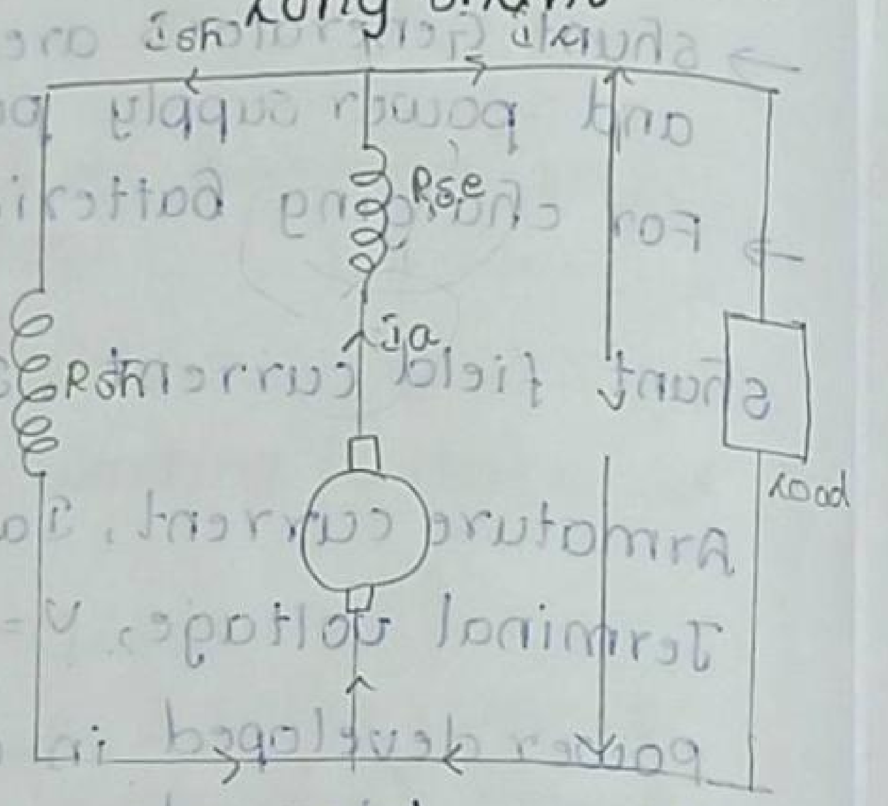




Short shunt



Long shunt



Series field current,
$I_{se} = I_L \Rightarrow I_a = I_{sh} + I_{se} = I_{sh} + I_L$

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

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

Power developed in armature
$= E_gI_a$

Power delivered to Load
$= VI_L$

series field current
$I_{se} = I_a = I_L + I_{sh}$

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

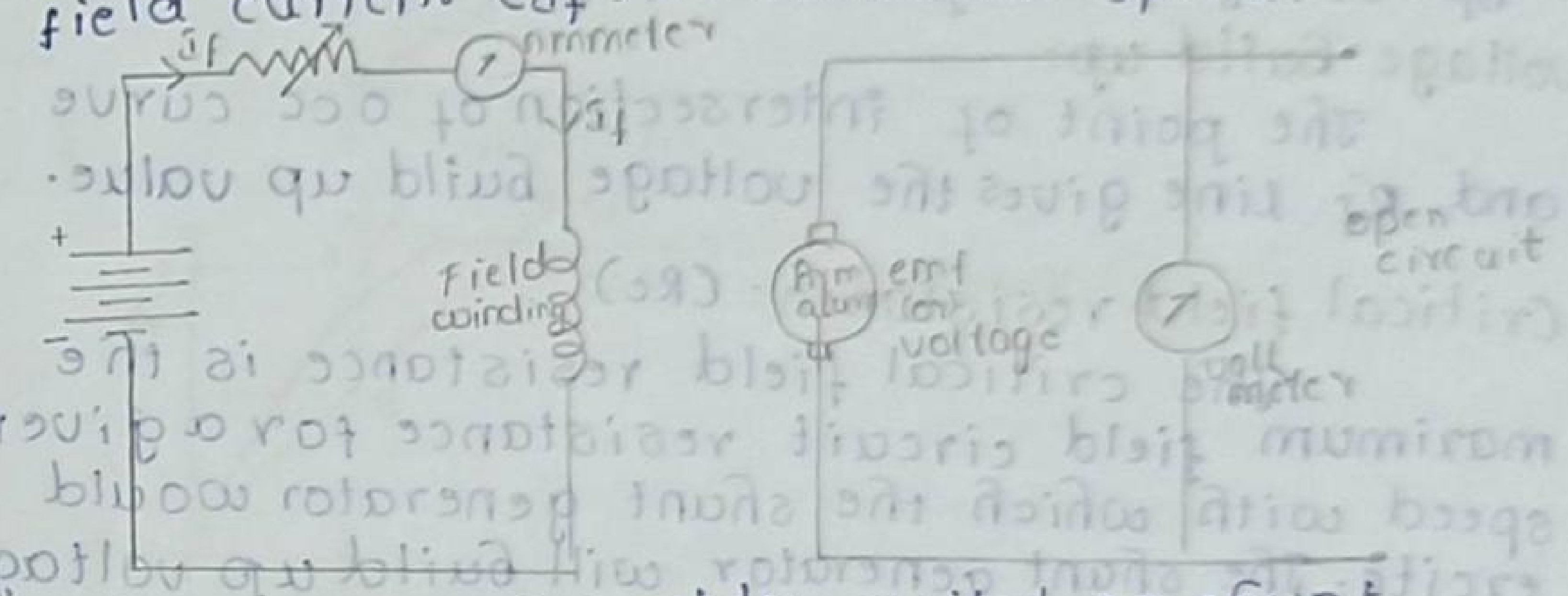
Terminal voltage
$V = E_g - I_a(R_a + R_{se}) - V_{Brush}$

power developed in armature $= E_gI_a$

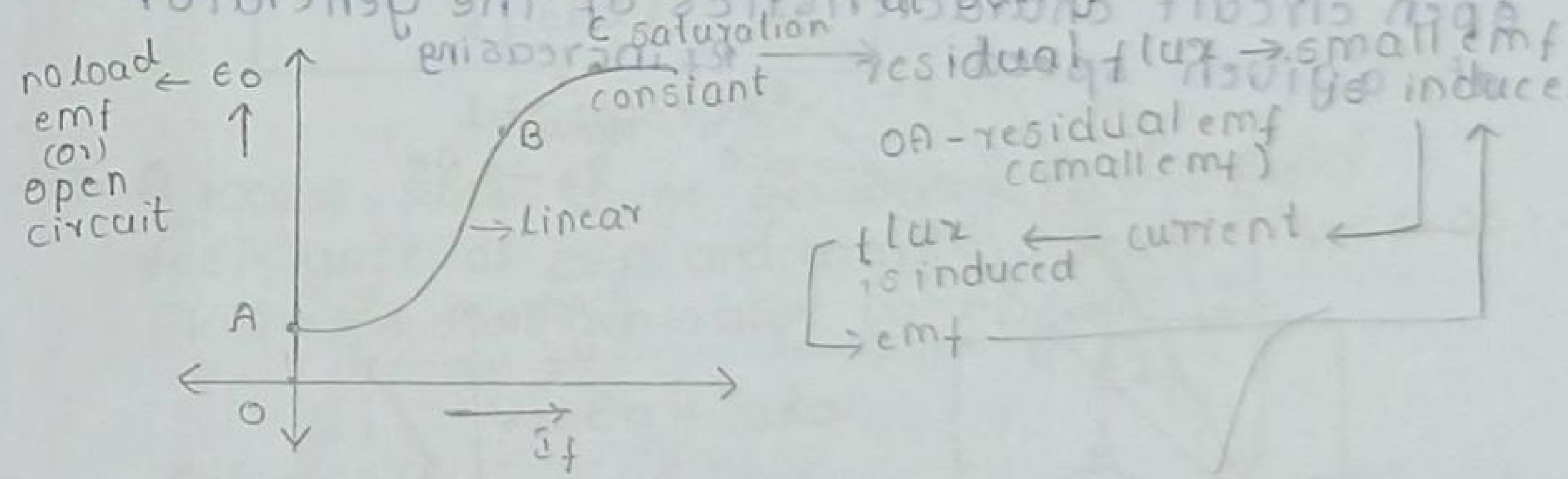
Power delivered to Load $= VI_L$

→ Load characteristics are of three types
1. No-Load characteristics (or) open circuit characteristics
2. Internal characteristics } Load characteristics.
3. External characteristics }

Open Circuit Characteristic (O.C.C)(or) Magnetisation characteristics(or) No-Load saturation curve:
gives relation between No-load Emf (E_0) and field current (I_f) at constant speed.

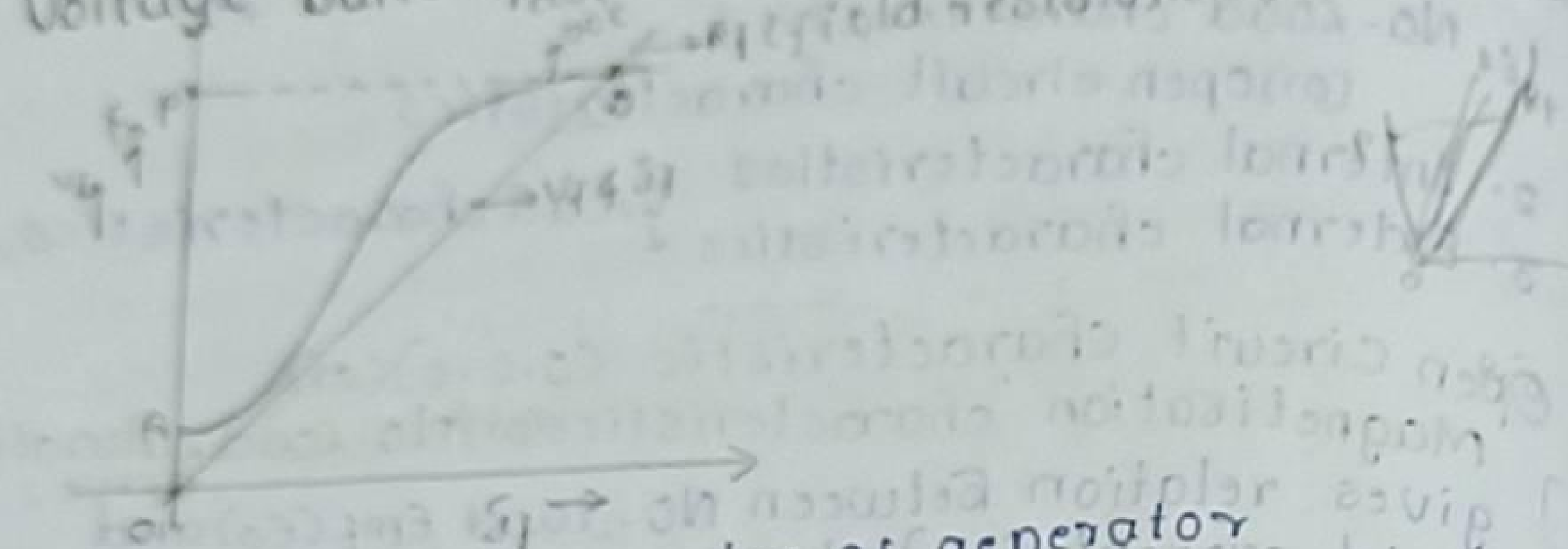


Seperately excited DC shunt generator



From OCC characteristics we can determine critical field resistance and critical speed and voltage build up.
At starting the generator will have small amount of emf which is called as residual emf. And from them the emf get increased till B. And it is a Linear curve till B. after B the emf becomes constants. It means it is in saturation.

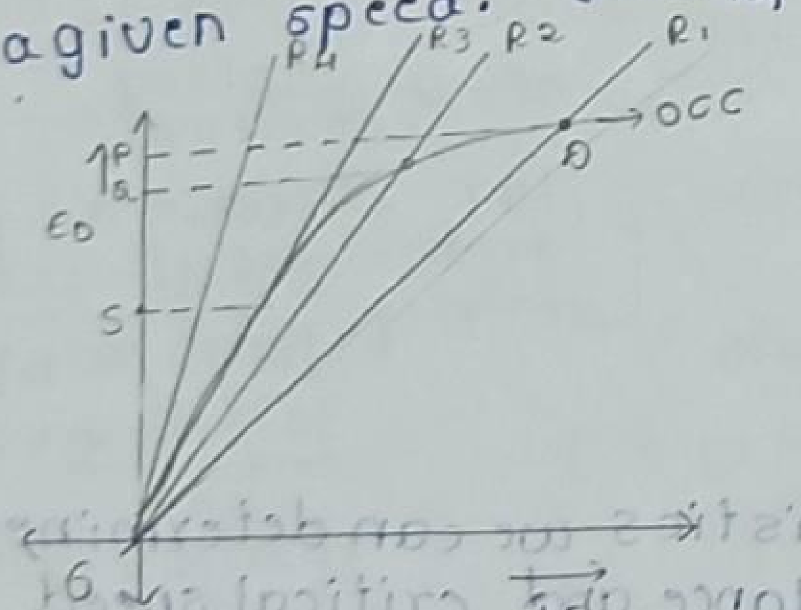
Voltage build up



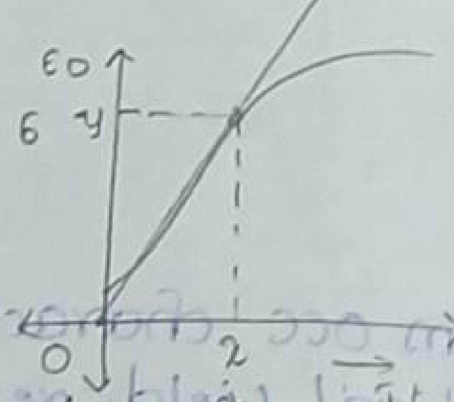
op = voltage build up value of generator

voltage build up:
The point of intersection of OCC curve and Rf Line gives the voltage build up value.

Critical field resistance: (Rc)
The critical field resistance is the maximum field circuit resistance for a given speed with which the shunt generator would excite. The shunt generator will build up voltage only if field circuit resistance is less than critical field resistance. It is a tangent to the open circuit characteristics of the generator at a given speed. ⟵ Rf increasing



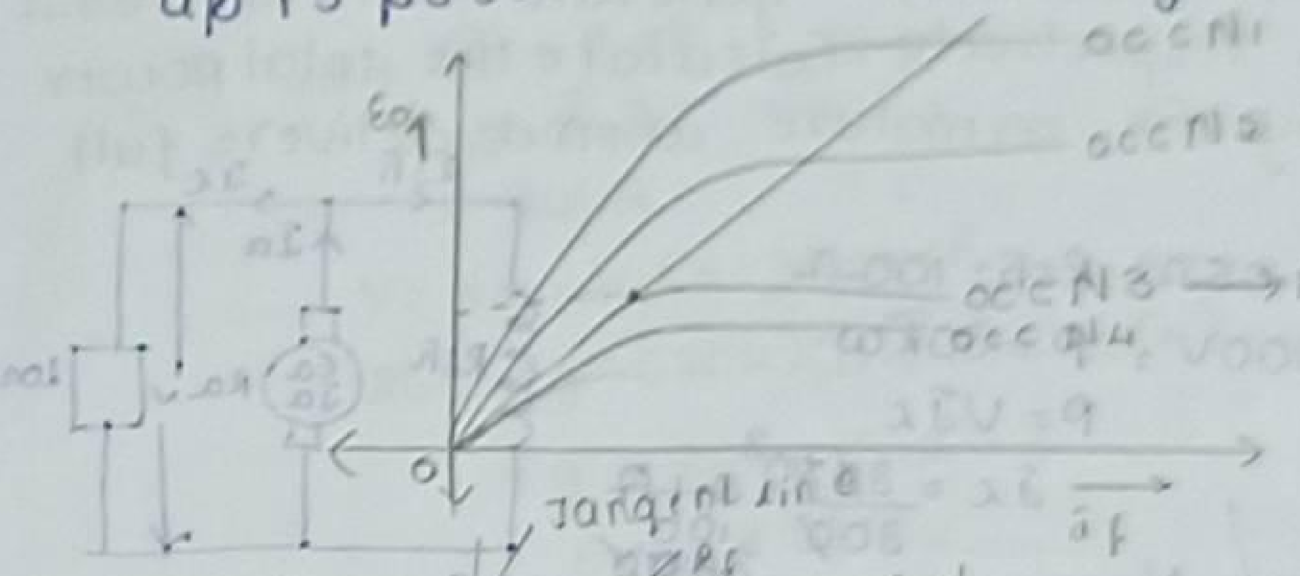
Now
R3 → Rc

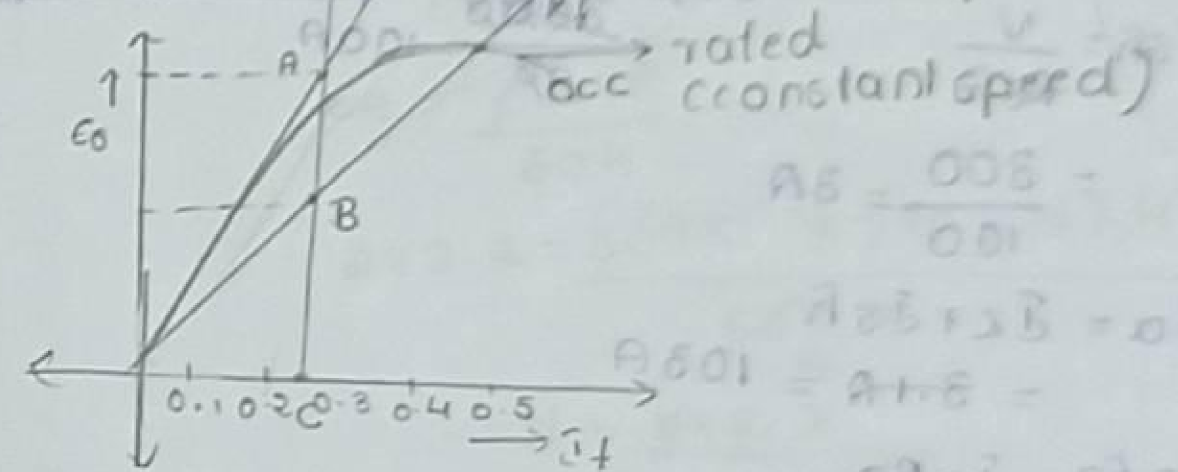


$$R_C = \frac{\text{slope of y-axis}}{\text{slope of x-axis}} = \frac{OY}{OX}$$

Critical speed: (Nc)
Suppose a shunt generator has built up voltage at a certain speed. Now if the speed of the prime mover is reduced without changing Rf, the developed voltage will be less as because the OCC at lower speed will com down.

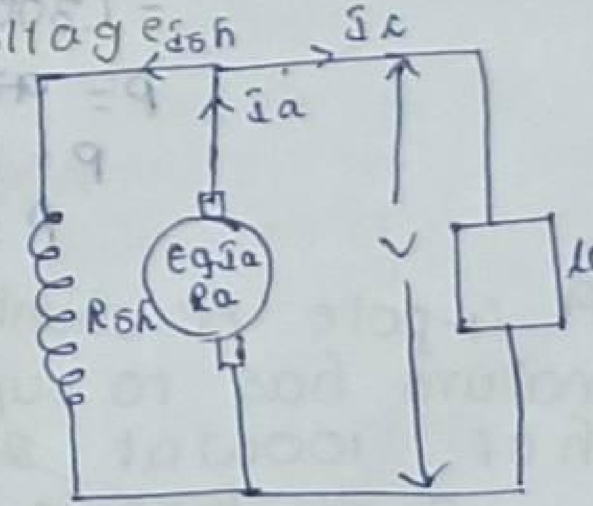
If speed is further reduced to a certain critial speed (ncr), the present field resistance line will become tangential to the OCC at ncr. For any speed below ncr, no voltage built up is possible in a shunt generator.





$$\boxed{N_C = \left(\begin{matrix}\text{rated}\\ \text{speed}\end{matrix}\right) \times \frac{AB}{AC}}$$
Like 1500 rpm

→ A 100kw, 240V shunt generator has a field resistance of 55 Ω and armature resistance 0.067 Ω. Find the Full load generator voltage.



$V = E_g - I_a R_a$

$R_{sh} = 55\,\Omega$
$R_a = 0.067\,\Omega$
$V = 240V$
Power rating = 100kw
$P = V I_L$

$I_L = \frac{P}{V}$

$I_L = \frac{100 \times 10^3}{240} = 416.66A$

$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{55} = 4.36\,A$

$I_a = 416.\cancel{7} + 4.36$
$= 421.1\,A$

$I_a = I_L + I_{sh}$
$I_{sh} = \frac{V}{R_{sh}}$
$V = E_g - I_a R_a - V_{brush}$
Powdelive – $V I_L$
Powdeve – $E_g I_a$

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

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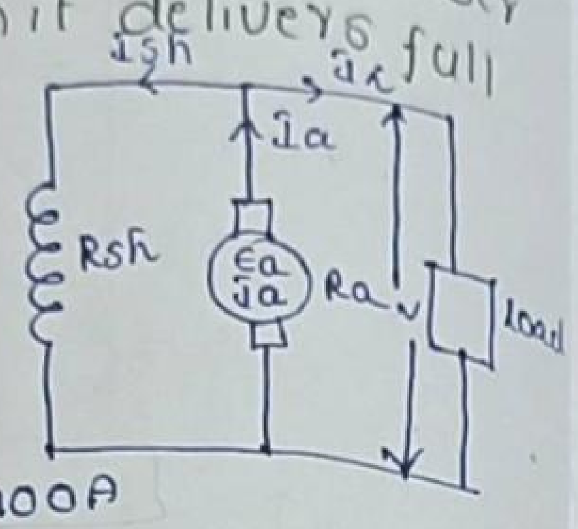
$240 = E_g - (4\cancel{8}.1)(0.0\ldots)$

$E_g = 240 + 28.21$

$E_g = 268.21\,V$

→ A 30kW, 300V dc shunt generator has $R_a = 0.05\,\Omega$ and $R_f = 100\,\Omega$ respectively. Calculate the total power developed by the armature when it delivers full load output



$R_a = 0.05\,\Omega,\ R_{sh} = 100\,\Omega$

$V = 300V,\ P = 30kW$

$P = V I_L$

$I_L = \frac{3\cancel{0}\times10^3}{30\cancel{0}} = \cancel{0.1A}\ \ \frac{100}{\frac{30\cancel{00}}{3\cancel{0}}}$ 100A

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

$= \frac{300}{100} = 3A$

$I_a = I_L + I_{sh}$

$= \cancel{3.1A} = 103A$

$V = E_g - I_a R_a$

$300 = E_g - (\cancel{1}03)(0.05)$

$E_g = 300 + 5.155$

$E_g = 305.155\,V$

$P = E_g I_a$

$= (305.155)(\cancel{3.1})\,103$

$P = \cancel{930.480}$

$P = 31430.45\,W$

$P = 31.430\,kW$

→ A 4-pole DC shunt generator with a wave wound armature has to supply a load of 500 lamps each of 100W at 250V. Allowing 10 volts for the voltage drop in the connecting leads b/w the generator and the load and drop of 1V per brush, calculate the speed at which the generator should be driven. The flux/pole is 30mWb and R_a is $0.05\,\Omega$, $R_{sh} = 65\,\Omega$. The number of armature conductors is 390.

$I_L = \frac{P}{V} = \frac{\overset{20}{5\cancel{00}} \times 10\cancel{0}}{\cancel{250}} = 200A$

vtg across the shunt field $= 250 + 10 = 260V$

$I_{sh} = \frac{V}{R_{sh}} = \frac{260}{65} = 4A$

$I_a = I_L + I_{sh}$

$= 200 + 4$

$= 204A$

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

$260 = E_g - (204)(0.05) - 2(1)$

$E_g = 260 + 10.2 + 2$

$E_g = 272.2V$

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

$272.2 = \frac{\cancel{3}0\times10^{-3} \times 390 \times N \times \cancel{4}}{\cancel{60}\times\cancel{2}}$

$N = \frac{272.2}{390 \times 10^{-3}}$

$N = 697.94$ rpm

$N = 698$ rpm

→ A 20kW, 200V shunt generator has an armature resistance of $0.05\,\Omega$ and $r_{sh} = 200\,\Omega$. Calculate the power developed in the armature when it delivers rated output

$P = 20kW$

$I_L = \frac{P}{V} = \frac{\cancel{20}\times10^3}{\cancel{200}_{10}} = 100A$

$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{200} = 1A$

$I_a = 101A$

$V = E_g - (101)(0.05)$

$E_g = 200 + 5.05$

$E_g = 205.05V$

$P = E_g I_a$

$= (205.05)(101)$

$P = 20710.05\,W$

$P = 20.71\,kW$

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→ An 8 pole ... 960 conductors, a flux of 40mWb ... speed of 400rpm calculate the Emf generated on open circuit. if the same armature is wave wound at what speed must it be driven to generate 400V.

$$Eg = \frac{40\times10^{-3}\times\cancel{960}^{16}\times400\times\cancel{8}}{\cancel{60}\times\cancel{8}} \qquad Eg = \frac{\phi NZP}{60A}$$

$$= 16\times16000$$

$$Eg = \cancel{64V}\ 256V$$

$$400 = \frac{40\times10^{-3}\times\cancel{960}\times x\times\cancel{8}^{4}}{\cancel{60}\times\cancel{2}}$$

$$x = \frac{400}{160\times16\times10^{-3}}$$

$$= \frac{400}{256\times10^{-2}}$$

$$x = 156.25\ rpm$$

Critical field resistance:

It is defined as the maximum field circuit resistance for a given speed with which the shunt generator would just excite (build up the voltage).

Critical speed:

It is defined as the value of speed below which the shunt generator fails to excite (or fails to build up voltage)

→ The armature of the 6p DC generator having 650 conductors, generates an induced emf of 536.25V. when running at a speed of 300rpm. The flux/pole beigng 55mWb. what is the type of the symplex winding used.

$$536.25 = \frac{55\times10^{-3}\times65\cancel{0}\times300\times\cancel{6}}{\cancel{60}\times A} \qquad Eg = \frac{\phi NZP}{60A}$$

$$A = \frac{55\times65\times0.3}{536.25} = \frac{1072.5}{536.25} = 2$$

wave winding

→ The armature of 6p generator has a wave winding containing 664 conductors. Calculate the generated emf when flux/pole is 0.06Wb and speed is 250rpm. At what speed must the armature be driven to generate an emf of 250V if flux/pole is reduced to 0.058Wb

$$Eg = \frac{\cancel{6}\times\cancel{664}^{332}\times0.06\times25\cancel{0}}{\cancel{60}\times\cancel{2}} \qquad Eg = \frac{\phi NZP}{60A}$$

$$Eg = 498V$$

$$250 = \frac{0.058\times\cancel{664}^{332}\times x\times\cancel{6}}{\cancel{60}_{10}\times\cancel{2}}$$

$$x = \frac{250\times10}{0.058\times332}$$

$$x = \frac{2500}{19.25}$$

$$x = 129.870\ rpm$$

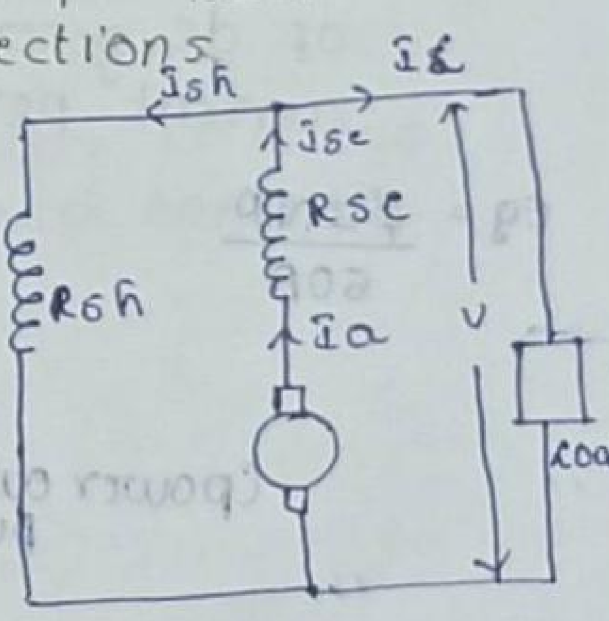
→ A 440V dc generator has a armature - series field and shunt field resistance of 0.5Ω, 1Ω & 200Ω respectively. Calculate generated emf while delivering 35A to external circuit for both long shunt and short shunt connections.

~~Short~~ shunt:
Long

$V = 440V$, $R_{sh} = 200\Omega$

$R_a = 0.5\Omega$, $R_{se} = 1\Omega$

$I_L = 35A$



$I_a = I_{se}$

$I_a = I_L + I_{sh}$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{440}{200} = 2.2A$$

$I_a = 35 + 2.2$

$I_a = 37.2A$

$V = Eg - I_aR_a - I_{se}R_{se}$

$440 = Eg - (37.2)(0.5) - (37.2)(1)$

$Eg = 495.8V$

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short shunt

$I_{se} = I_L$

$I_a = I_{sh} + I_{se}$ (or) I_L

$I_{sh} = \frac{V + I_{se} R_{se}}{R_{sh}}$ A

$440 + (85)(1)$

$I_{sh} = 2.84$ A

$I_a = 2.84 + 85$

$I_a = 87.84$ A

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

$440 = E_g - (87.84)(0.5) - (85)(1)$

$E_g = 493.6$ V

→ A 4pole generator having wave wounding, then armature has 48 slots with 20 conductors in each slot. calculate E_g $N = 1500$ rpm, $\phi = 7$ mwb

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

$E_g = \frac{7 \times 10^{-3} \times 48 \times 20 \times 1500 \times \cancel{4}\ 2}{\cancel{60} \times \cancel{2}}$

$E_g = 336$ V

→ A 4pole machine, at 1000 rpm it has an armature with 90 slots having 6 conductors in each slot, $\phi = 6 \times 10^{-2}$ wb determine induced emf of dc generature having lap winding. If the current per conductor is given as 50 Amp

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

$E_g = \frac{6 \times 10^{-2} \times 540 \times 1000 \times \cancel{4}}{\cancel{60} \times \cancel{4}}$

$E_g = 540$ V

$I_a = 50 \times 4 = 200$

(power out put) $P = E_g I_a$

$= 540 \times 50 \times 4$

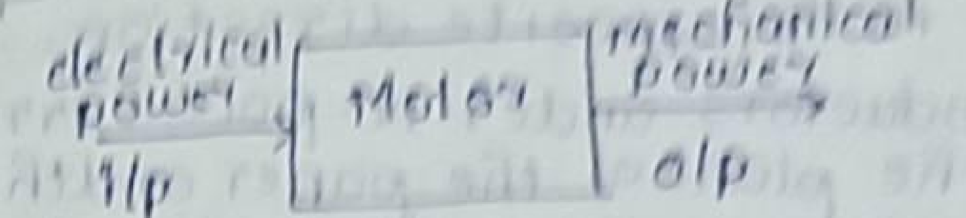
$= 27,000 \times 4$

$P = 108,000$

$P = 108$ kW

DC MOTORS

Principle of operation of DC Motors



→ A DC motor is a mechanical rotating device which converts electrical energy into mechanical energy. It is base on the principle of force acting on a current carrying wire in a magnetic field.

principle:
whenever the current carrying conductor is placed in a magnetic field then the conductor experiences a mechanical force.

→ Here the direction of this force is given by Fleming's left-hand rule and magnitute is given by

$F = BIL$

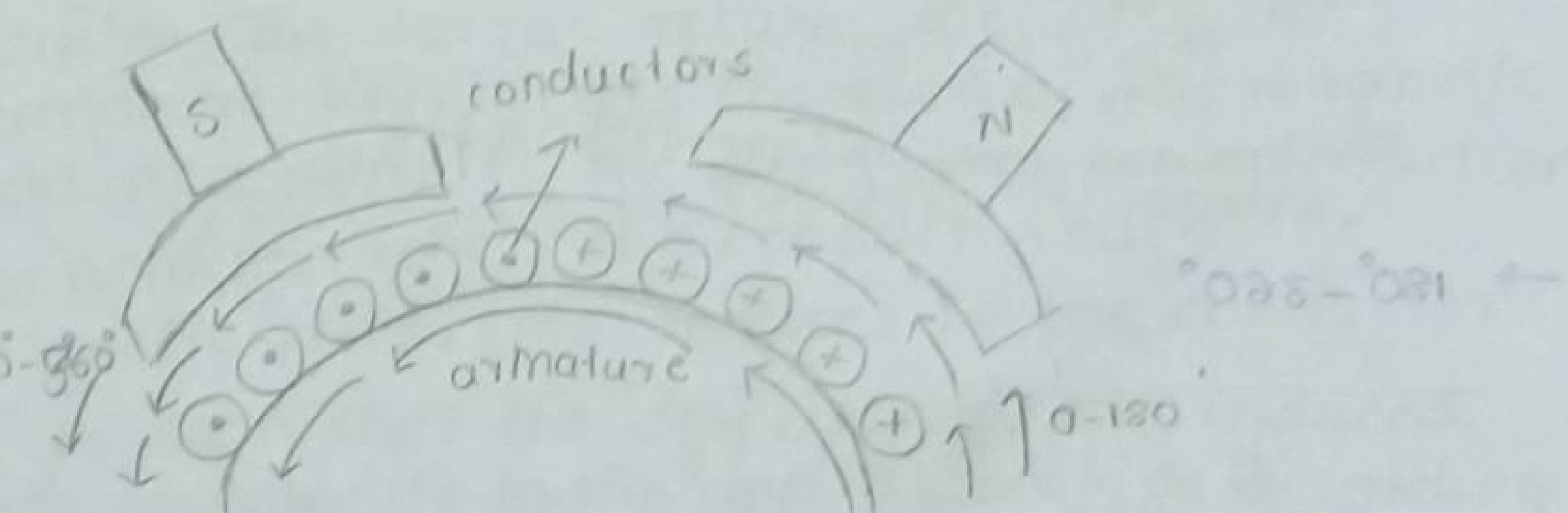
B = magnetic flux density

I = current flowing through conductor

L = Length of conductor.

→ The main advantage of DC motor it change the speed by wide range. (speed control)

Operation of DC Motor:



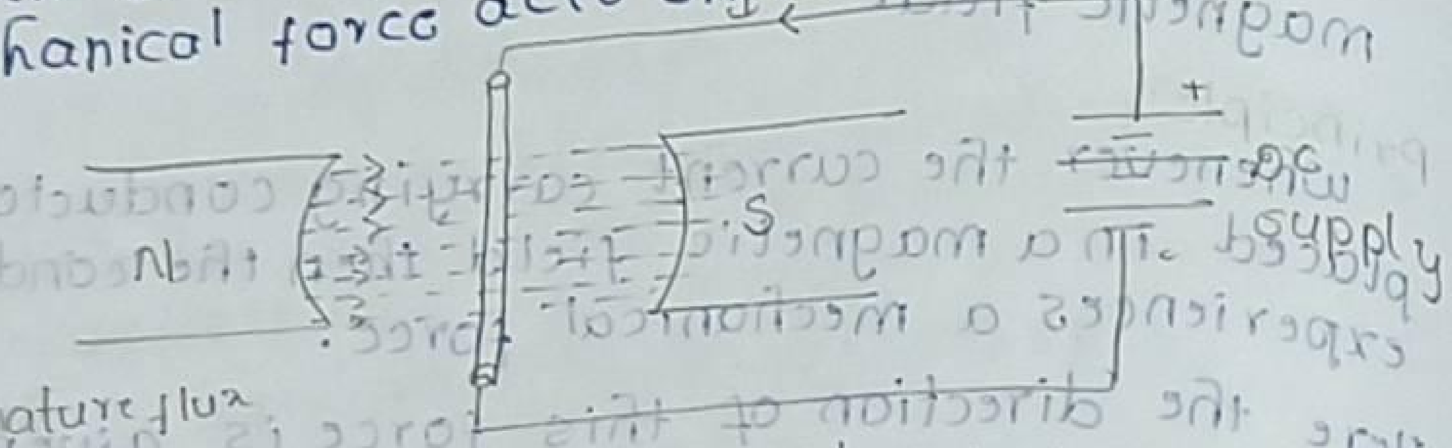
→ when the terminals of the motor are connected to an external source of d.c supply

(i) The field magnets are excited developing alternate N and S poles.

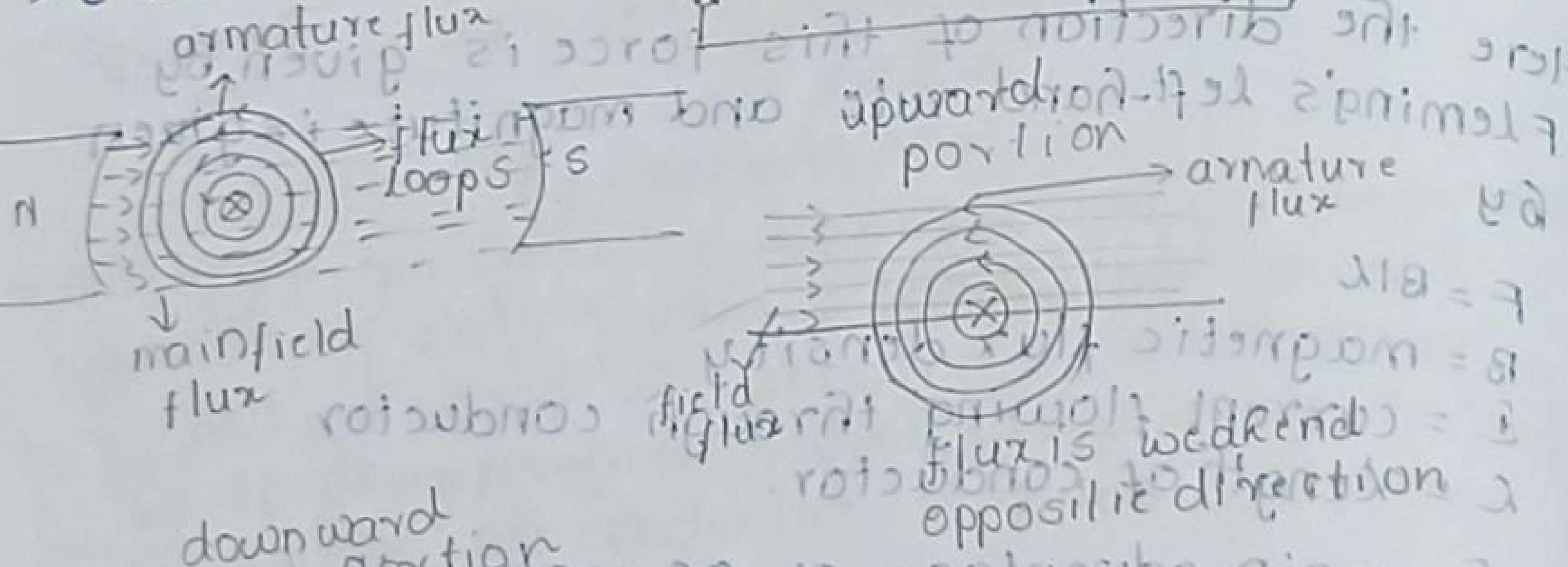
(ii) The armature conductors carry ... All conductors under N-pole carry currents in one direction, while all the conductors under S-pole carry currents in the opposite direction.

→ suppose the conductors under N-pole carry currents into the plane of the paper and those under S-pole carry currents out of the plane of the paper.

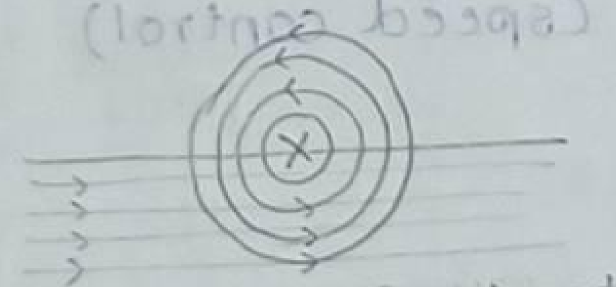
→ since each armature conductor is carrying current and is placed in the magnetic field, mechanical force acts on it.



→ 0-180°

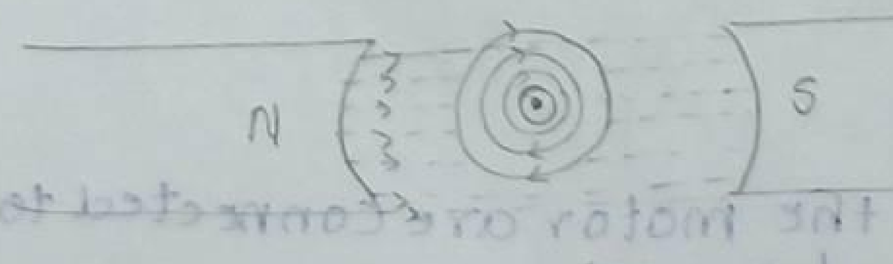


downward portion

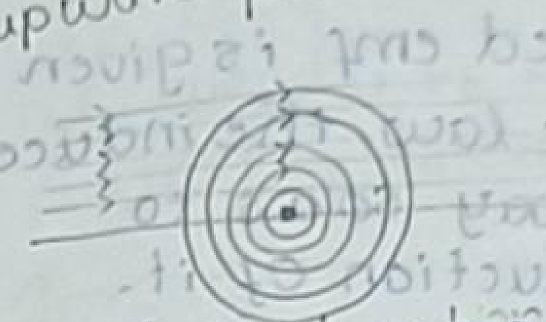


flux is stregthened
same direction
An upward force is exerted on the armature conductor

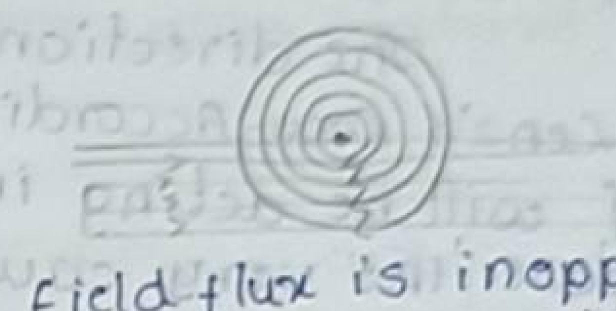
→ 180°-360°



upward polion



downward portion



field flux is same direction of armature flux.
Flux is strengtened
downward force is produced.

field flux is in opposite direction of armature flux.
Flux is weakened
less flux

→ Applying Fleming's left hand rule, it is clear that force on each conductor is tending to rotate the armature in anticlock wise direction.

→ All these forces add together to produce a driving torque which sets the armature rotating.

→ when the conductor moves from one side of a brush to the other, the current in that conductor is reversed and at the same time it comes under the influence of next pole which is of opposite polarity.

→ consequently, the direction of force on the conductor remains the same.

Back EMF in DC Motor:

→ when the current carrying conductor placed in a magnetic field, the torque induces on the conductor. The torque rotates the conductor (armature) which cuts the flux of the magnetic field. According to the Electromagnetic induction phenomenon when the conductor cuts the magnetic field, EMF induces in the conductor.

→ It is seen that the direction of the induced emf is opposite to the applied voltage according to Lenz's Law. Thereby the emf is known as the counter emf or back EMF (E_b)

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

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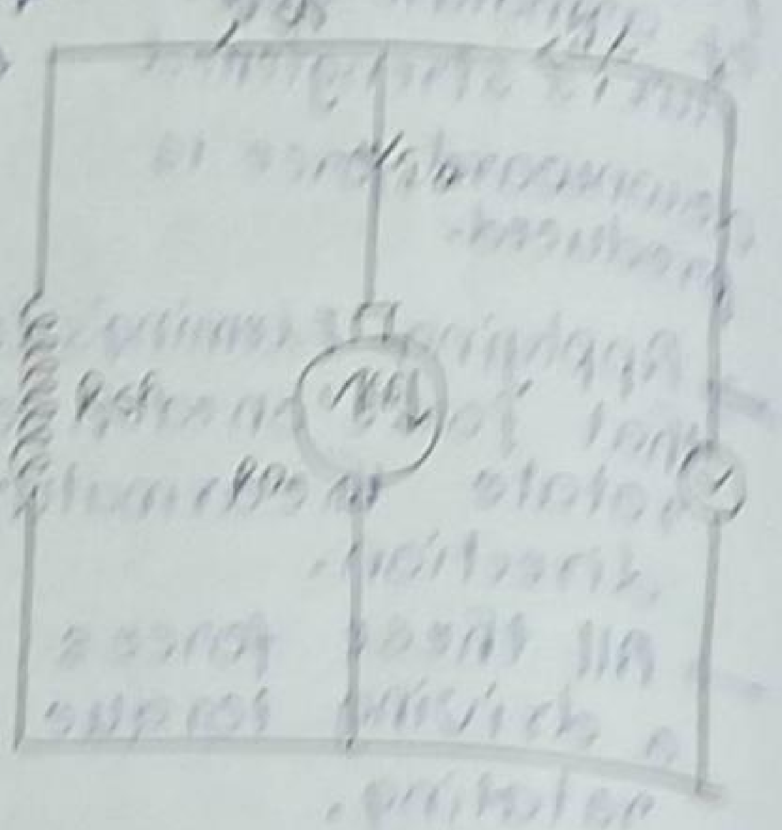
→ Lenz's law:
The direction of induced emf is given by Lenz's law. According to this law, the induced emf will be acting in such a way so as to oppose the very cause of production of it.
∴ E_b is obtained by applied voltage (V)



→ The induced emf acts in opposite direction to the applied voltage V.

→ Net voltage across armature circuit $= V - E_b$

→ $\boxed{I_a = \frac{(V - E_b)}{R_a}}$ armature current

→ Voltage equation
$$\boxed{V = E_b + I_a R_a}$$

→ Power equation
$$V I_a = E_b I_a + I_a^2 R_a$$

→ The back emf opposes the supply voltage. The supply voltage induces the current in the coil which rotates the armature. The electrical work required by the motor for causing the current against the back emf is converted into the mechanical energy. And that energy is induced in the armature of the motor. Thus, we can say that energy conversion in DC motor is possible only because of the back emf.

→ The back emf makes the DC motor self-regulating machine, i.e. the back emf develops the armature current according to the need of the motor.

→ If load is increased:
N ↓ (speed), E_b ↓ (Back EMF), I_a ↑ (armature current increases), T ↑ (Torque)

→ If load is decreased
N ↑ (speed), E_b ↑ (Back EMF), I_a ↓ (armature current), T ↓ (Torque)

Torque equation of a DC motor

→ When armature conductors of DC motor carry current in the presence of stator field flux, a mechanical torque is developed between the armature and the stator. Torque is given by the product of the force and the radius at which this force acts.

→ Torque $T = F \times r$ (N-m)
where, F = force and r = radius of the armature

→ Work done by this force in one revolution
= Force × distance
= $F \times 2\pi r$ ($2\pi r$ = circumference of the armature)

→ Net power developed in the armature
$$= \frac{\text{work done}}{\text{time}}$$
= (force × circumference × no. of revolutions)/time
= $(F \times 2\pi r \times N)/60$ (Joules per second)

→ But, $F \times r = T$ and $2\pi N/60$ = angular velocity ω in radians per second. Putting these in the above equation

Net power developed in the armature
$$P = T \times \omega \quad \frac{\text{Joules}}{\text{second}}$$

Armature torque (T_a)

→ The power developed in the armature can be given as
$$P_a = T_a \times \omega = T_a \times \frac{2\pi N}{60}$$

→ The mechanical power developed in the armature is converted from the electrical power,

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Therefore, mech...

(Mechanical power) $T_a \times \frac{2\pi N}{60} = E_b \cdot I_a$ (P_a) (electrical power)

we know $E_b = \frac{\phi Z N P}{60 A}$

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

$$T_a = \frac{ZP}{2\pi A} \cdot \phi I_a$$

$$\boxed{T_a = \frac{0.159\, \phi I_a Z P}{A}} \left(\frac{N}{m}\right) \longrightarrow (1)$$

$$\boxed{T_a = 9.55 \frac{E_a I_a}{N}}$$

→ Calculate the value of torque established by the armature of a 4-pole motor having 774 conductors, two paths in parallel, 24 mwb flux/pole when the Total armature current is 50A.

$$T_a = \frac{0.159\, \phi I_a Z P}{A}$$

$$= \frac{0.159 \times 24 \times 10^{-3} \times 50 \times 774 \times \cancel{4}\, 2}{\cancel{2}}$$

$$T_a = 295.35 \text{ N-m}$$

Speed control of DC shunt Motor -

Flux and armature voltage control method

The speed of DC motor is

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

$$V = E_b + I_a R_a$$

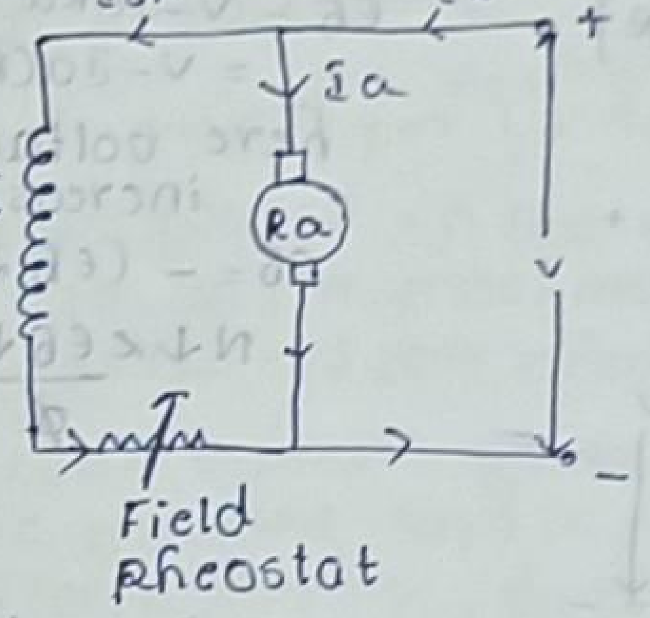
$$N = K \cdot \frac{[V - I_a R_a]}{\phi} \text{ rpm} \qquad E_b = V - I_a R_a$$

where $R = R_a$ for shunt motor

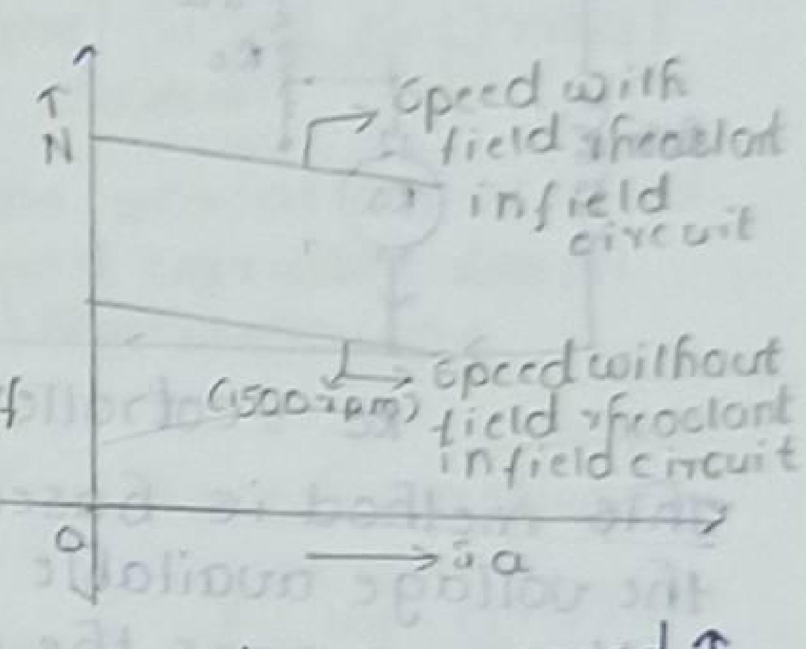
$R = R_a + R_{se}$ for series motor

(i) Flux control method:

This method is used to increase the speed of motor i.e > N_{rated} = 1500rpm to 3000rpm speeds above the normal speed



I_L - Line current



voltage → current → flux → emf

$$\uparrow N \propto \frac{1}{\phi \downarrow}$$

As Resistance ↑ → current ↓ → flux ↓ → speed ↑

→ It is based on the fact that by varying the flux ϕ, the motor speed can be changed and hence the name flux/field control method.

→ In this method a variable resistance is placed in series with field winding as shown in figure.

→ The field rheosat reduces the field current I_f. Hence the flux is reduced, therefore we can only raise the speed of the motor above the normal speed.

Advantages:

(i) This is an easy and convenient method.

(ii) It is an (experience) inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value I_{sh}.

Disadvantage:

(i) Only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below R_{sh}.

Note: The field of a shunt motor in operation should never be opened because its speed will increas to an extremly high value.

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Aramature voltage ...

This method used to decrease the speed of motor. i.e. < 1500 rpm to 300 rpm (speed is below the normal speed)

$N \propto \frac{E_b}{\phi}$ [$E_b = V - I_a R$]

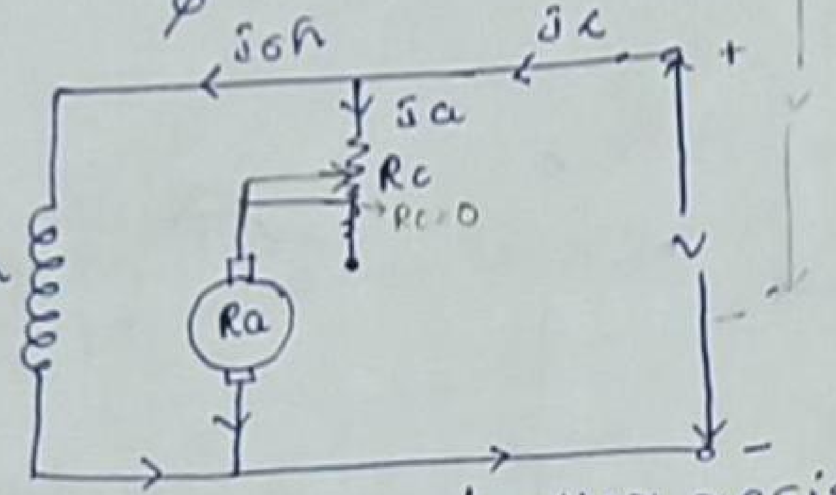
$E_b = V - I_a R_a - I_a R_c$

$= V - I_a(R_a + R_c)$

here voltage drop increases

$E_b = -(E_b \downarrow)$

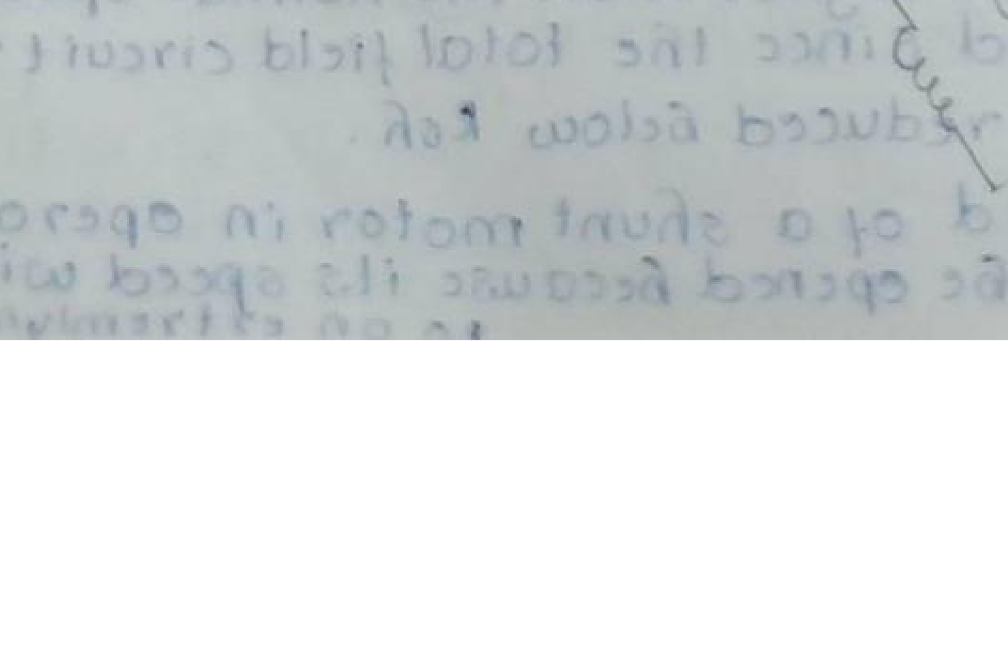
$N \downarrow \propto \frac{E_b \downarrow}{\phi}$



Rc = cotroller resistance (or) variable resistance

This method is based on the fact that by varying the voltage available across the armature. The voltage across the armature is varied by inserting a variable resistance (Rheostat) in series with the armature circuit as shown in fig.

when R increases voltage drop increases then
(Ra+Rc)
Eb decreases. The heighest speed obtainable is normal speed (1500 rpm). Hence this method is used when speed below the normal speeds are required.



Types of losses in DC machine

→ electrical or copper losses (i^2R losses)

→ core losses (or) Iron losses

→ Mechanical losses

→ stray load losses

Electrical or Copper losses: (Power loss) (variable losses)

→ Resistive losses in the armature and field windings of the machine are called electrical (or) copper losses (or) ohmic losses.

→ This loss varies with the variation of load on the machine and is called variable loss. When a motor is loaded, its armature current increases.

The various copper losses in the DC machine are as follows.

$P = VI$ - constant loss

$P = I^2R$ - variable loss

1. Armature copper loss $= I_a^2 R_a$
This is variable loss

2. Shunt field copper loss $= V I_{sh}$
This is constant loss

3. Series field copper loss $= I_{se}^2 R_{se}$
This is variable loss

Core losses (or) Iron losses: (constant losses)

→ core losses are also known as iron losses (or) Magnetic losses. Core losses can be classified into two types

pole core
armature core

1. Hysteresis losses:

→ The armature core is made up of magnetic material and is subjected to variations in magnetic flux. when the armature rotates it comes under North and south poles alternatively.

→ Hysteresis loss occurs due to the alternate magnetization of the atoms, forming domains in the magnetic material of the core.

→ Hysteresis loss $= k_h \cdot V \cdot f \cdot B_m^{1.6}$

V = volume of core
f = frequency
B = magnetic flux density

W_H (or) $P_H = k_h \cdot v \cdot f \cdot B_m^{1.6}$ W

k_h = hysteresis constant (or) steinmitz hysteris constant

2. Eddy current loss: -

→ Eddy current loss is due to the presence of circulating current in the core material. The armature core cuts the magnetic flux during its rotation and EMF is induced in the body of the core according to the laws of electromagnetic induction. This emf is very small but it sets up a large current in the body of the core.

k_e - eddy current constant
t - thickness of a laminated core.

→ Eddy current losses $= k_e \times B_m^2 \times f^2 \times t^2$

P_e (or) $W_e = k_e \times B_m^2 \times f^2 \times t^2$

Mechanical losses:

→ The mechanical losses in a dc machine are the losses associated with mechanical effects. Mechanical losses occur at the bearing and shaft and air friction due to rotation of the armature.

→ There are two basic types of mechanical losses:

Frictional losses
windage losses

Stray load losses

→ The magnetic and mechanical losses are known as stray losses. stray losses are also known as rotational losses

→ $\boxed{\text{Total Losses} = \text{Constant losses} + \text{Variable losses}}$

Efficiency of a DC Machine:

Efficiency (η): It is defined as the ratio of output power to the input power

$$\%\text{efficiency}, \eta = \frac{\text{output}}{\text{input}} \times 100 = \frac{\text{output}}{\text{output + losses}} \times 100$$

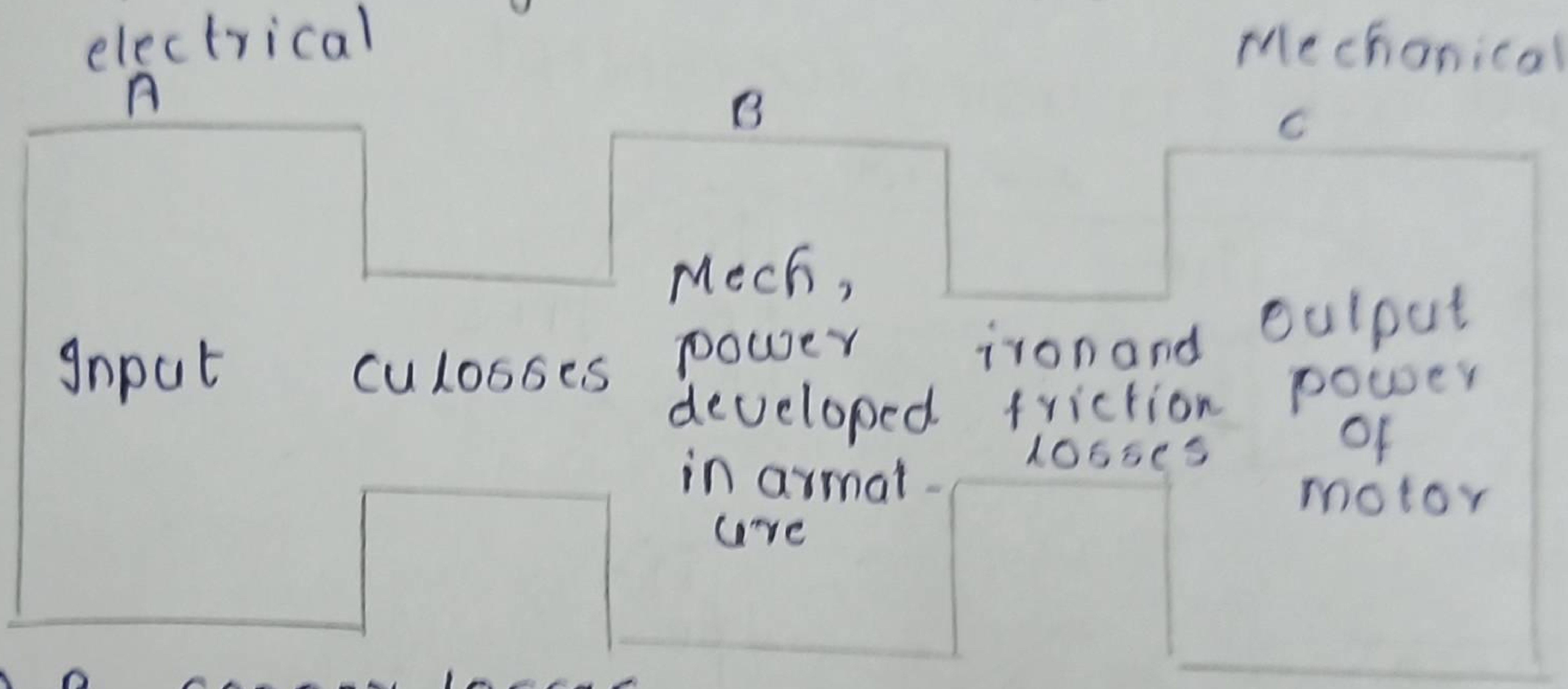
i/p power = o/p power + losses

o/p power = i/p power - losses

$$= \frac{\text{input} - \text{losses}}{\text{input}} \times 100$$

→ The efficiency of a DC machine will be maximum when variable losses = constant losses (or) copper losses = iron losses

Power stages in a DC Motor



A-B = copper losses

B-C = Iron and friction losses

Overall efficiency, $\eta_o = C/A$

Electrical efficiency, $\eta_e = B/A$

Mechanical effeciency, $\eta_m = C/B$

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UNIT-II
continuation

Swinburner's Test:

→ It is an indirect method of testing of DC machienes. This test is also known as Indirect test (or) NO-Load Test. In this method the losses are measured separately and the efficiency at any desired load is predetermined. Machines are tested for find out losses, efficiency and temperature rise. For small machines direct loading test is performed. For large shunt machines, indirect methods are used like Swinburne's test. This test is not possible for series machines.

Procedure:

1. It is a simple indirect test which is applicable where flux is constant like shunt machine.
2. The machine is run as motor at no load at its rated speed with the help of shunt field resistance.

Output of the generator = VI

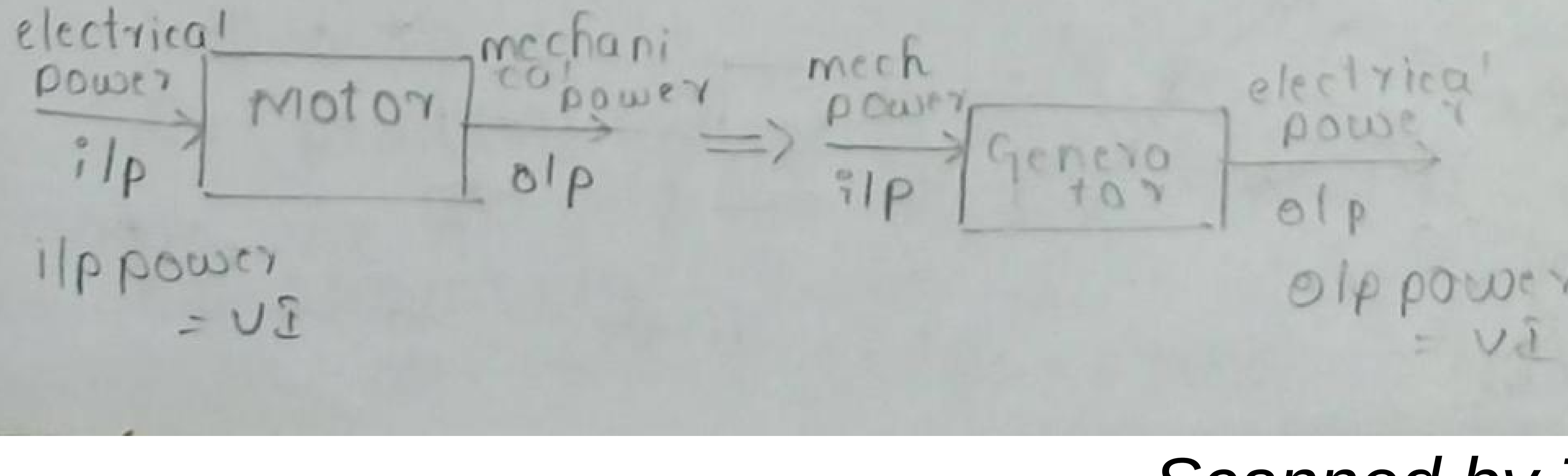
Input = output + Losses

$$= VI + (\underbrace{W_c}_{\text{cons. los}} + \underbrace{I_a^2 R_a}_{\text{varia loss (or. cu loss)}}) \text{ watts}$$

$$I_a = I + I_{sh} \qquad (\because I = I_L)$$

$$\%\text{ Efficiency of generator} = \frac{\text{output}}{\text{input}} \times 100$$

$$\%\eta = \frac{VI}{VI + (W_c + I_a^2 R_a)} \times 100$$

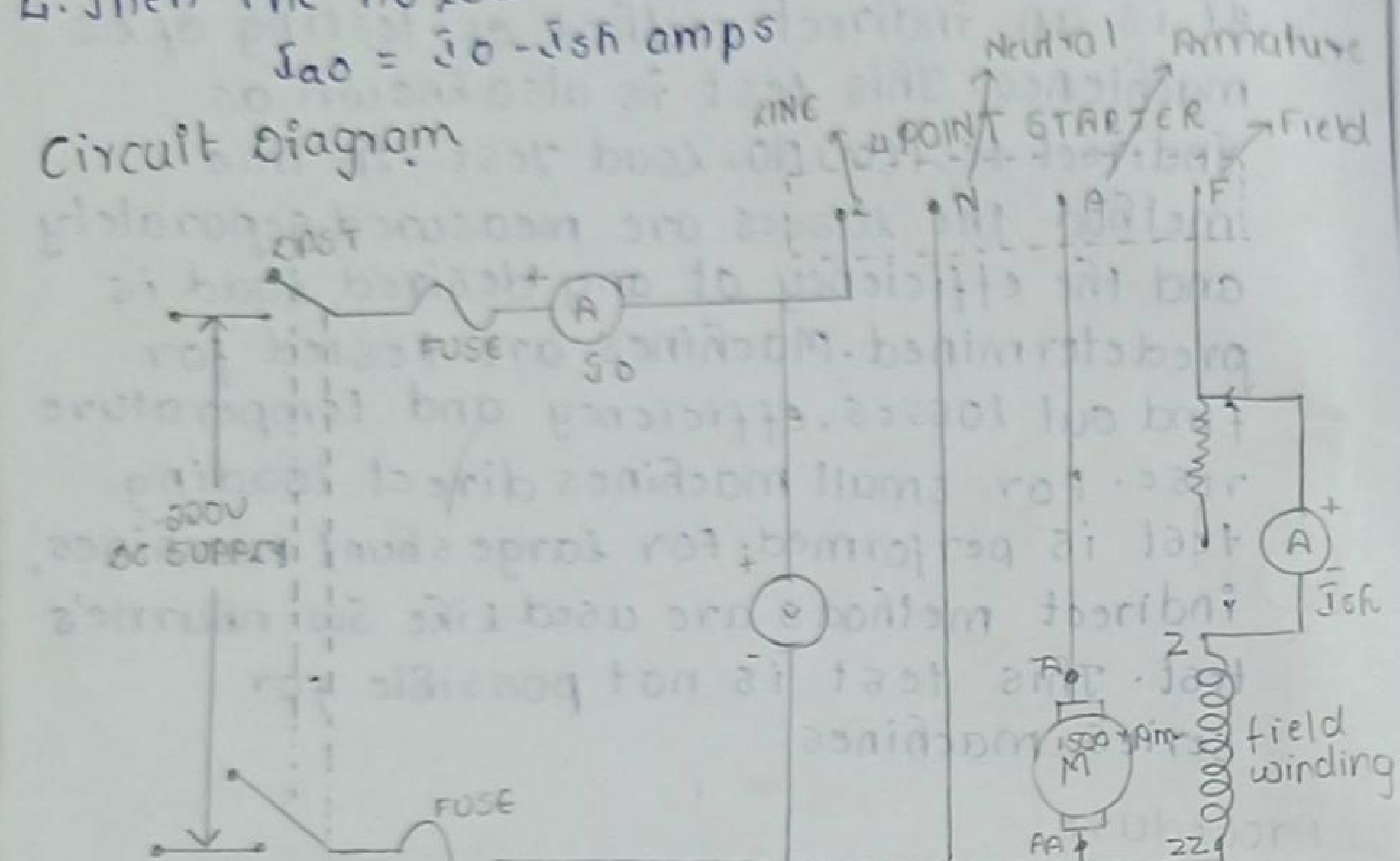


3. The supply voltage, no load input current and field current are measured by ammeter.

4. Then the no load armature current

$I_{ao} = I_0 - I_{sh}$ amps

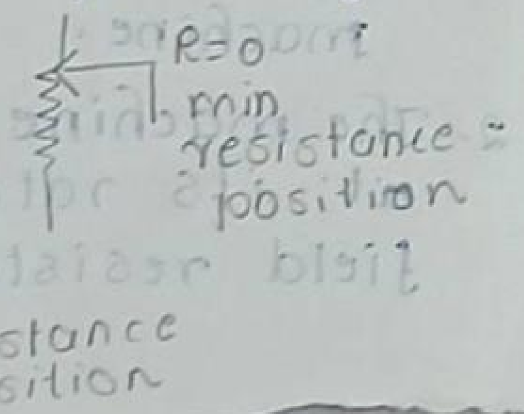
Circuit Diagram

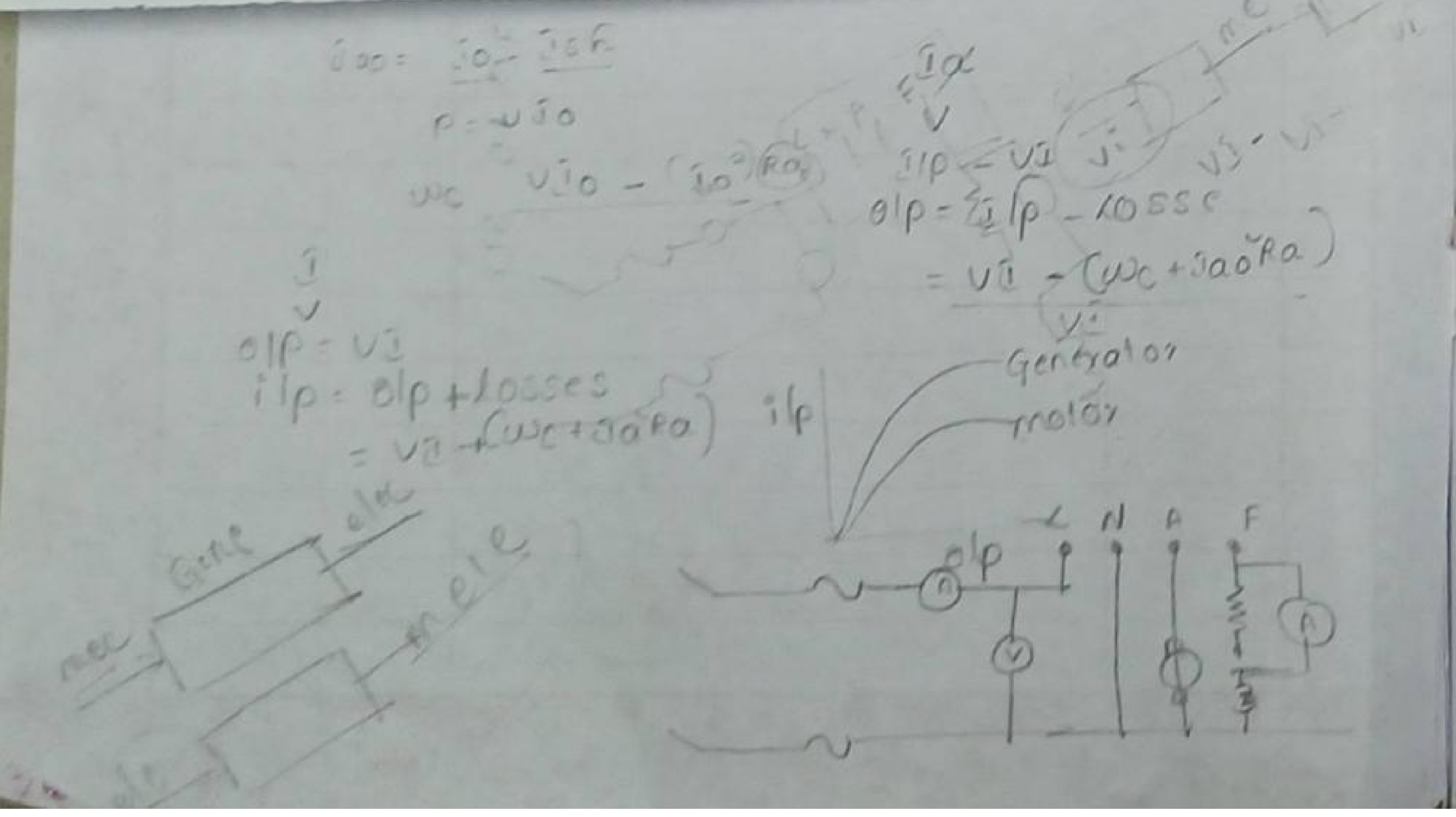


Starter function: It projects motor from high starting current

DPST - Dipole single Throw

Speed is measured with help of Tachometer.





where I_0 = No load input current

I_{sh} = Shunt field current

No load input power = $V \times I_0$ watts

constant losses (W_c) (or) (P_c)

= No Load input power − Ar.cu.losses

$W_c = VI_0 - (I_{ao})^2 R_a$ $[\because I_{ao} = I_0 - I_{sh}]$

where R_a = armature resistance.

Efficiency of Machine as a motor: (Predetermined)

Let motor input current = I amps

Terminal voltage = V volts

Input power = VI watts

Output power = Input − Losses

$= VI - (W_c + I_a^2 R_a)$ watts

where $I_a = I - I_{sh}$ amps $(\because I_L = I)$

% Efficiency $= \frac{\text{output}}{\text{input}} \times 100$

$\%\eta = \frac{VI - (W_c + I_a^2 R_a)}{VI} \times 100$ [∵ To. Losses = cons. losses + Varia. losses]

Efficiency of machine as a generator

Let output current supplied by the generator = I Amps

Terminal voltage = V volts

Output of the generator = VI watts

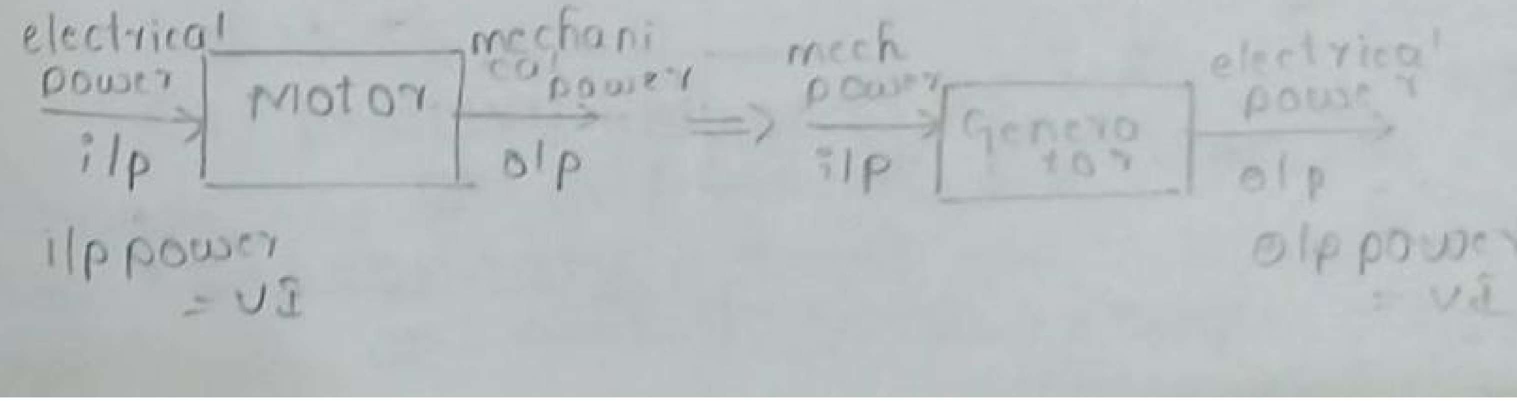
Input = output + Losses

$= VI + (W_c + I_a^2 R_a)$ watts (cons. los, varia. loss (or. cu loss))

$I_a = I + I_{sh}$ $(\because I = I_L)$

% efficiency of generator $= \frac{\text{output}}{\text{input}} \times 100$

$\%\eta = \frac{VI}{VI + (W_c + I_a^2 R_a)} \times 100$



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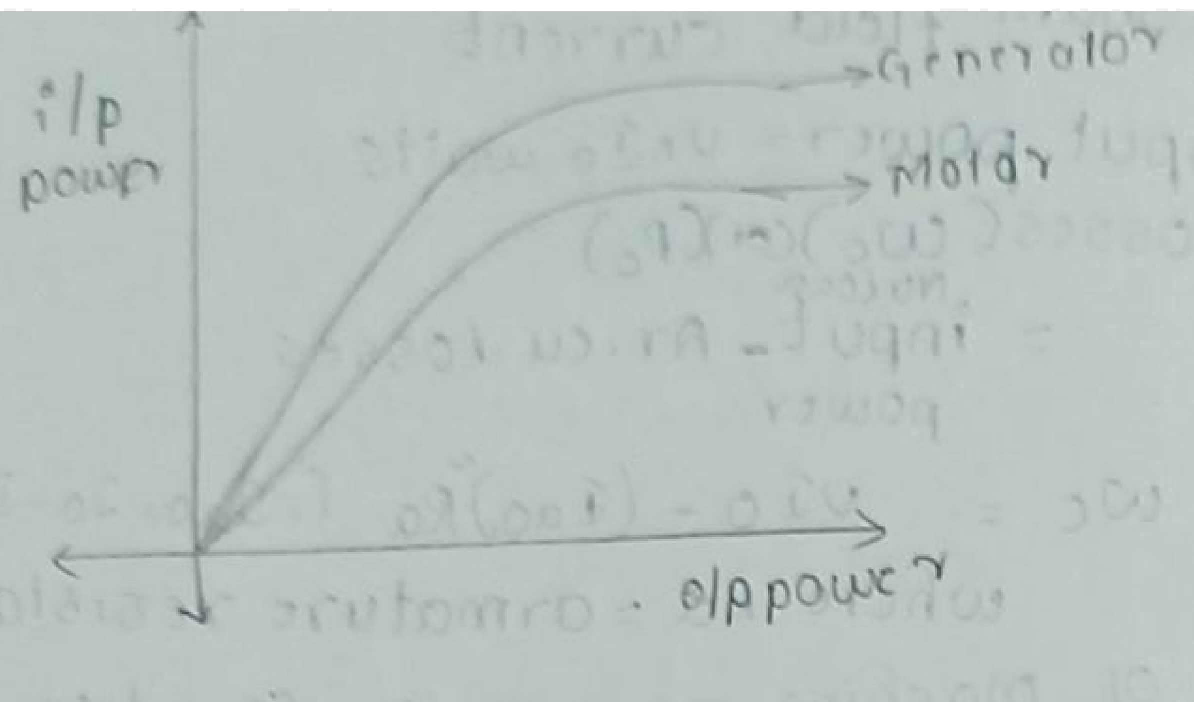


Advantanges:

1. Efficiency and losses at any desired load can be determined due to knowing losses

2. Though the test is carried on dc machines as a motor, the efficiency & losses can be evaluated for motor as well as generator.

3. This test is very simple and is suitable for only shunt and compound motors.

Disadvantages:

1. It is a no-load test so it cannot be applicale for series motor because series motor in absence of load produces high field.

2. Temperature rise in machine on load condition cannot be predicted.

UNIT-III

AC-MACHINES

Transformer -

→ A static device which helps in the transformation of electric power in one circuit to electric power of the same frequency in another circuit.

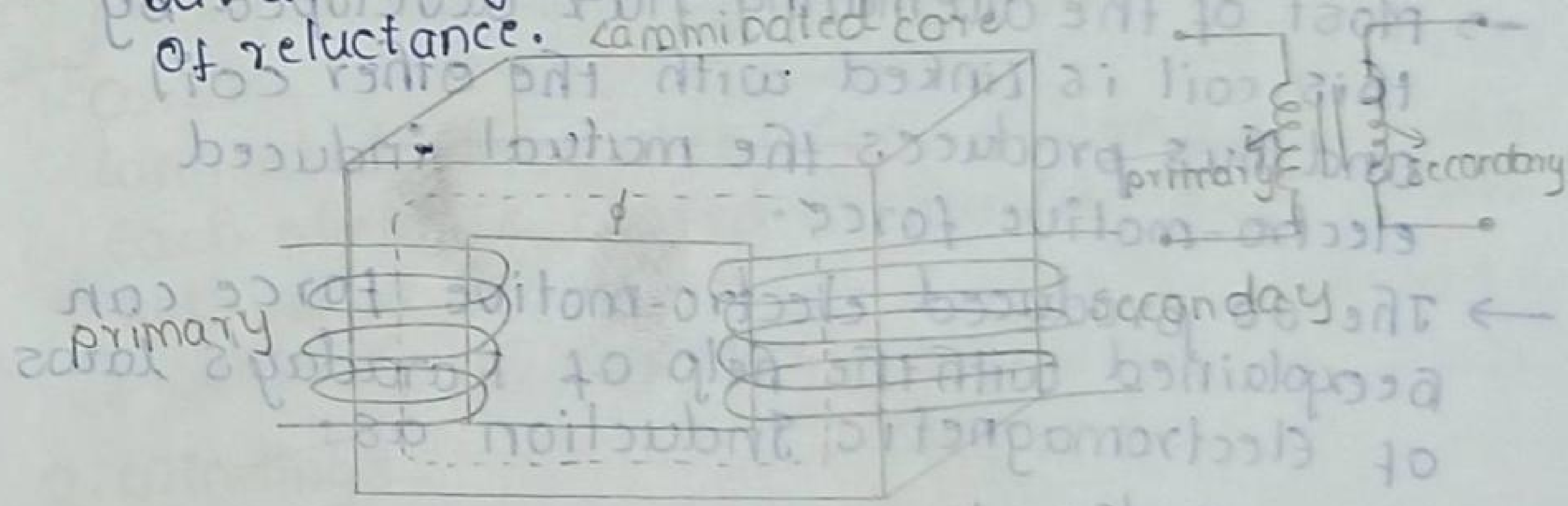
→ The voltage canbe raised or lowered in a circuit, but with a proportional increase or decrease in the current ratings.

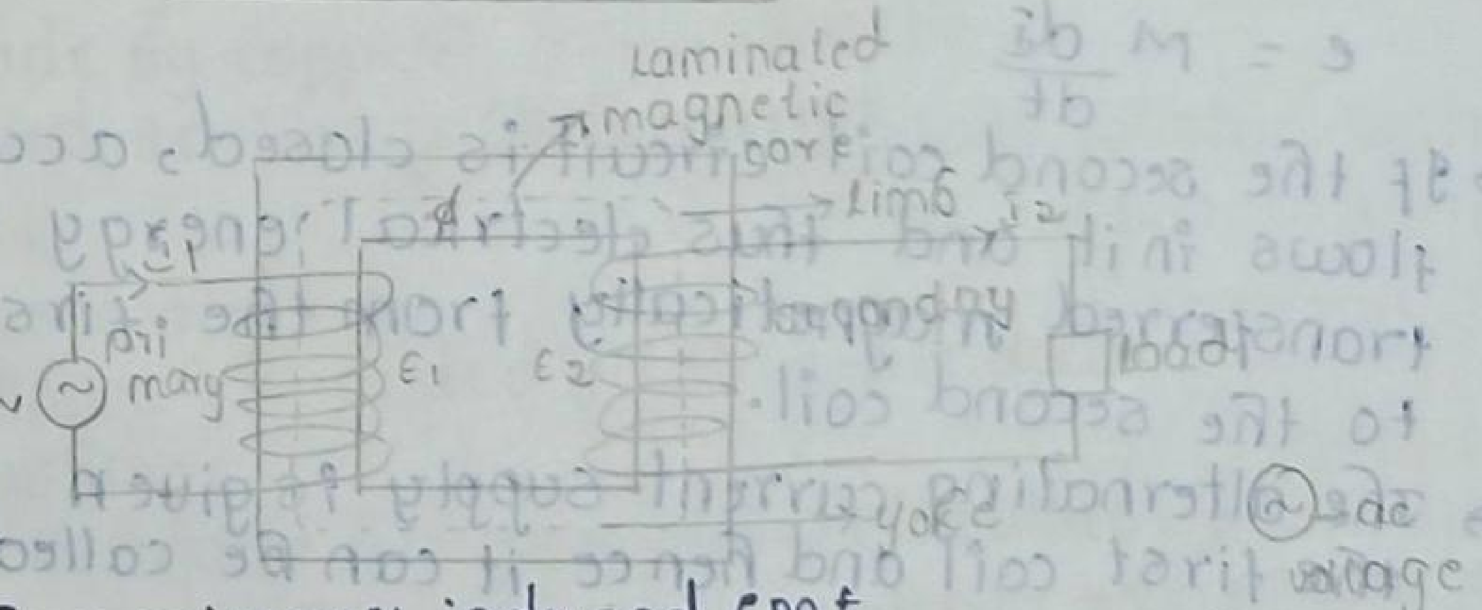
Ex: 11 kV / 33 kV
11 kV / 220 V

Working principle:

→ The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux.

→ A basic transformer consists of two coils that are electrically seperated and inductive, but are magnetically linked through a path of reluctance.

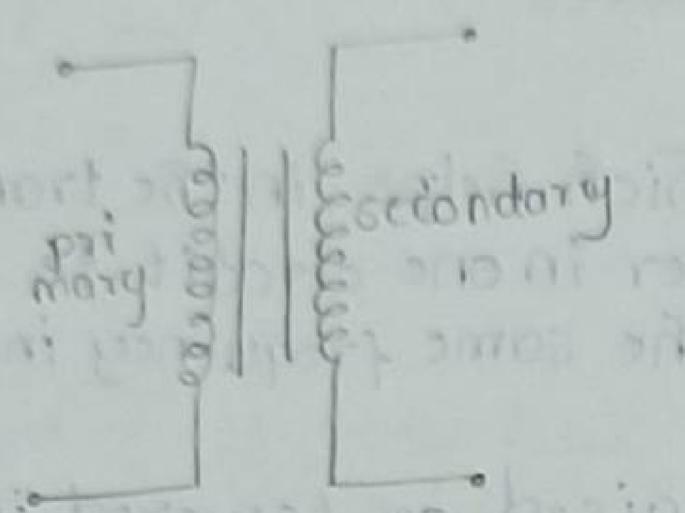




E_1 = primary induced emf
(or) self induced emf

E_2 = secondary induced emf
(or) mutually induced emf

Symbol of Transformer:



$\to v \to i \to \phi \to$ emf

Operation of Transformer:

→ The transformer has primary and secondary windings.

→ The core laminations are joined in the form of strips.

→ A mutual electro-motive force is induced in the transformer from the alternating flux that is set up in the laminated core, due to the coil that is connected to a source of alternating voltage.

→ Most of the alternating flux developed by this coil is linked with the other coil and thus produces the mutual induced electro-motive force.

→ The so produced electro-motive force can be explained with the help of Faraday's laws of Electromagnetic Induction as:

$$e = M\frac{di}{dt}$$

→ If the second coil circuit is closed, a current flows in it and thus electrical energy is transferred magnetically from the first to the second coil.

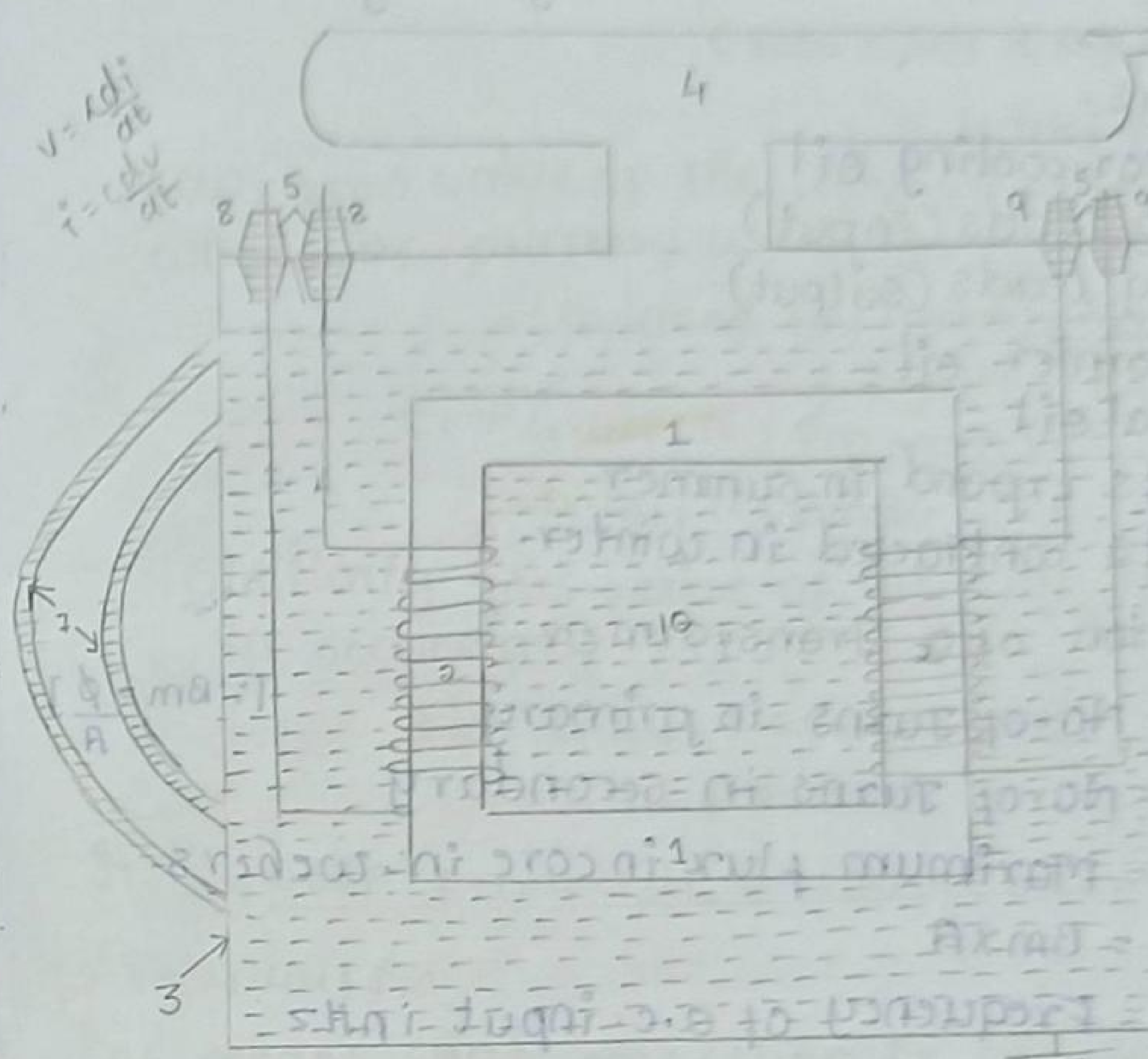
→ The alternating current supply is given to the first coil and hence it can be called as the primary winding.

→ The energy is drawn out from the second coil and thus can be called as the secondary winding.

Construction of Transformer:

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

$i = C\frac{dv}{dt}$



Constructional Details of Transformers

The Important parts of a transformer are

1. Core-
 laminated sheet steel (4% silicon)
 Each sheet is coated with oxide layer
 acts as a insulator
 provides path for flux.

2. Windings -
 made by copper
 used to carry high current

3. Tank

4. Conservator -
 allows expanded oil to settle down

5. Bushings -
 It is made by porcelain (insulator)
 primary & secondary terminals are protected with Bushings.

6. Breather -
 absorbs dust and moisture present in

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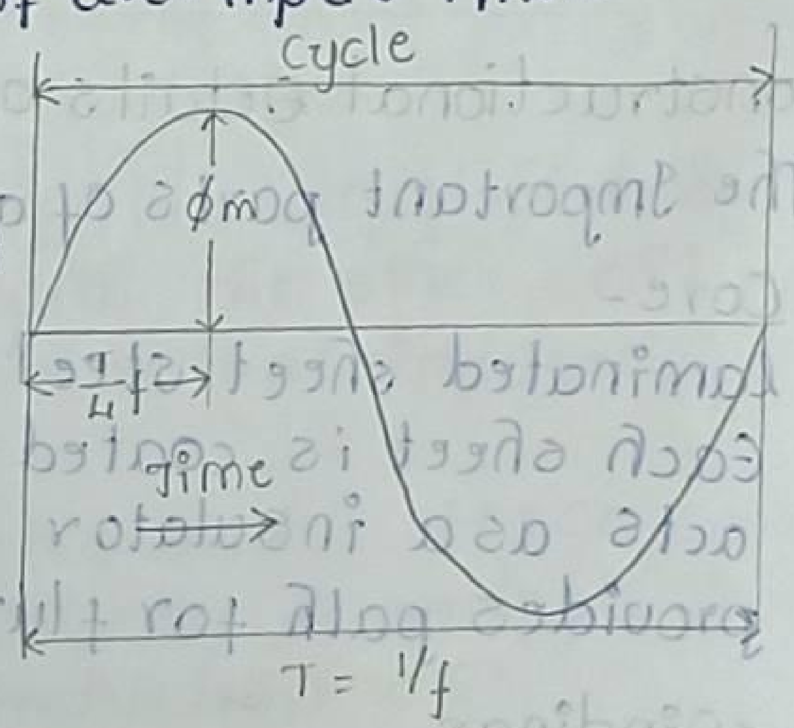
atmosphere and prev...
with oil.

7. Radiators -
used for cooling oil
8. winding leads (input)
9. winding leads (output)
10. Transformer oil -
mineral oil
oil gets expand in summer
oil gets contracted in winter.

EMF Equation of a Transformer

$[\because B_m = \frac{\phi}{A}]$

Let N_1 = No. of Turns in primary
N_2 = No. of Turns in secondary
ϕ_m = Maximum flux in core in webers
$= B_m \times A$
f = Frequency of a.c. input in Hz



As shown in fig. flux increases from its zero value to maximum value ϕ_m in one quarter of the cycle i.e in $1/4f$ sec.

$\therefore$ Average rate of change of flux $= \frac{\phi_m}{1/4f}$

$= 4f\phi_m$ wb/s or volt

Now, rate of change of flux per turn means induced emf in volts

Average emf/turn $= 4f\phi_m$ volt

If flux ϕ varies sinusoidally, then r.m.s value of induced emf is obtained by multiplying the average value with form factor.

$$\text{Form Factor} = \frac{\text{rms value}}{\text{average value}} = 1.11$$

$\therefore$ rms value of emf/turn $= 1.11 \times E_{avg}$

$E_{rms} = 1.11 \times 4f\phi_m$
$= 4.44 f\phi_m$ volt

Now, rms value of the induced emf in the whole of primary winding
= (induced emf/turn) x No. of primary turns (N_1)

$E_1 = 4.44 f N_1 \phi_m \longrightarrow ①$
$= 4.44 f N_1 B_m A$

Similarly rms value of the emf induced in secondary is

$E_2 = 4.44 f N_2 \phi_m \longrightarrow ②$
$= 4.44 f N_2 B_m A$

It is seen from ① & ② that $E_1/N_1 = E_2/N_2$
$= 4.44 f\phi_m$.

It means that emf/turn is the same in both the primary and secondary windings.
In an ideal transformer on no-load, $V_1 = E_1$ and $E_2 = V_2$ where V_2 is the terminal voltage

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 f\phi_m$$

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

Voltage transformation Ratio (K) (Not necessary for exam)
From equations ① & ②

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{1}{K} \Big/ \frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

This constant K is known as voltage transformation ratio.
(i) If $N_2 > N_1$ i.e $K > 1$, then transformer is called step-up transformer.
(ii) If $N_2 < N_1$ i.e $K < 1$ then transformer is known as step-down transformer

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Again, for an ideal transformer input VA = output VA

$$V_1 I_1 = V_2 I_2$$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{1}{K}$$

$$\boxed{\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{1}{K}}$$

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

Hence, currents are in the inverse ratio of the voltage transformation ratio.

Step-up transformer:
If the primary coil has 3 loops and the secondary coil has 30, the voltage is stepped up 10 times.

Step-down transformer:
If the primary coil has 30 loops and the secondary coil has 3, the voltage is stepped down 10 times.

Ex: 33kV/11kV

Losses in a Transformer
→ Losses appear in the form of heat and produce
(i) an increase in temperature
(ii) a drop in efficiency

B = Magnetic flux density
K_h = hysteresis constant
f = frequency
K_e = eddy current constant
t = thickness of laminator sheet

1. Core (or) Iron losses (P_i): (constant losses)
Hysteris loss $= K_h f B_m^{1.6} v$ watts/m^3
eddy current loss $= K_e f^2 B_m^2 t^2$ watts/m^3

2. Copper losses $[\because P = I^2 R]$
Total Cu losses, $P_c = I_1^2 R_1 + I_2^2 R_2$
$= I_1^2 R_1$ (or) $I_2^2 R_2$

Total losses in a transformer $= P_i + P_c$
= constant losses + variable losses

Losses in a Transformer
→ The losses that occur in transformers have to be accounted for in any accurate model of transformer behaviour.

1. Copper (I^2R) losses:
Copper losses are the resistive heating losses in the primary and secondary windings of the transformer. They are proportional to the square of the current in the windings.

2. Eddy current losses:
Eddy current losses are resistive heating losses in the core of the transformer. They are proportional to the square of the voltage applied to the transformer.

3. Hysteresis losses:
Hy sterisis losses are associated with the rearrangement of the magnetic domains in the core during each half-cycle. They are a complex, nonlinear function of the voltage applied to the transformer.

4. Leakage flux: (not necessary for exam)
The fluxes which escape the core and pass through only one of the transformer windings are leakage fluxes. These escaped

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fluxes produce a self-inductance in the prima[ry] and secondary coils and the effects of this inductance must be accounted for.

Efficiency of a Transformer

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} = \frac{\text{output}}{\text{output} + \text{losses}}$$

$$= VI\cos\phi$$

$\cos\phi$ = power factor

$p.f = \cos\phi$

Efficiency from Transformer tests:

Full Load Iron Loss $= P_i \longrightarrow$ from open-circuit test

Full Load Cu loss $= P_C \longrightarrow$ from short-circuit test

Total Full load losses $= P_i + P_C$

We can now find the full-load efficiency of the transformer at any power factor without actually loading the transformer.

$$\text{F.L. efficiency}, \eta_{F.L} = \frac{\text{Full load VA} \times p.f}{(\text{Full Load VA} \times p.f) + P_i + P_C}$$

Also for any load equal to $x *$ full load

corresponding total losses $= P_i + x^2 P_C$

$$\text{corresponding } \eta_x = \frac{(x * \text{full load VA}) \times p.f}{(x * \text{full load VA} \times p.f) + P_i + x^2 P_C}$$

Note that iron loss remains the same at all loads.

i/p → [sys] → o/p + losses

$\xrightarrow{I}$ $\phi = 0$ $\cos\phi = \cos 0 = 1$

Resistivity load → p.f = 1 → unity

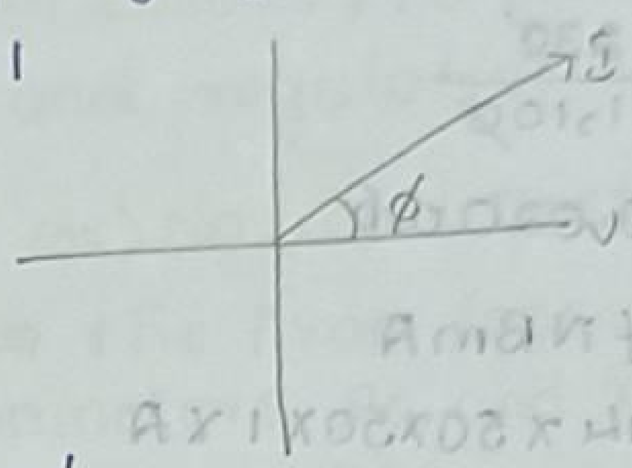
Inductive load → p.f → lagging p.f

Capacitive load → p.f → leading p.f

Inductive load

$\overrightarrow{\text{lagging}}$ p.f (lying behind I lags V)

p.f < 1

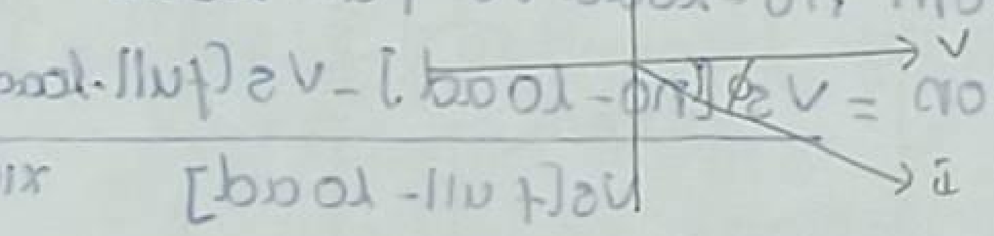


Resistive load

p.f = unity

Capacitive load → leading p.f (lying ahead)

I leads V



VA = Rating of Transformer

$$\%\eta = \frac{x \times \text{KVA rating of T/F} \times \cos\phi}{(x \times \text{KVA rating of T/F} \times \cos\phi) + (P_i + x^2 P_{Cu})} \times 100$$

$x = 1$ at full load

$$\%\eta = \frac{1 \times \text{KVA rating of T/F} \times \cos\phi}{(1 \times \text{KVA rating of T/F} \times \cos\phi) + (P_i + (1)^2 P_{Cu})} \times 100$$

1. Calculate the emf/turn, if the flux is 0.015 wb at a frequency of 50Hz single turn

sol: $\boxed{E = 4.44 f N_1 \phi_m}$ $N = 1$

$= 4.44 \times 50 \times 1 \times 0.015$

$= 3.33$ volts

2. Calculate the flux in the core of a single phase transformer having a primary voltage of 230V at 50Hz and 50 turns if the flux density in the core is 1 Tesla. Calculate the net cross sectional area of the core

$E_1 = 4.44 f N_1 \phi m$

$230 = 4.44 \times 50 \times 50 \times \phi m$

$\phi m = \frac{230}{11{,}100}$

$\phi m = 0.020 wb$

$E = 4.44 f N B m A$

$230 = 4.44 \times 50 \times 50 \times 1 \times A$

$\phi m = B m A$

$0.020 = (1) A$

$A = 0.0207 m^2$

Transformer voltage regulation

The voltage regulation of a transformer is the change in the magnitude of the secondary terminal voltage from no-load to full load

$$\% \text{ voltage Regulation} = \frac{V_s[\text{no-load}] - V_s[\text{full-load}]}{V_s[\text{full-load}]}$$

$$(\text{or})\ \% R = \frac{V_{02} - V_{2FL}}{V_{2FL}} \times 100$$

$$\approx \frac{V_p[\text{no-load}] - V_p[\text{full-load}]}{V_p[\text{full-load}]} \times 100$$

referred to primary side

V_{02} = No-load secondary voltage $= kV_1$

V_2 = secondary voltage no load

$$\boxed{V_{02} - V_2 = I_2 R_{02} \cos\phi_2 \pm I_2 X_{02} \sin\phi_2}$$

→ The +ve sign is for lagging p.f and -ve sign for leading p.f.

→ It may be noted that %age voltage regulation of the transformer will be the same whether primary or secondary side is considered.

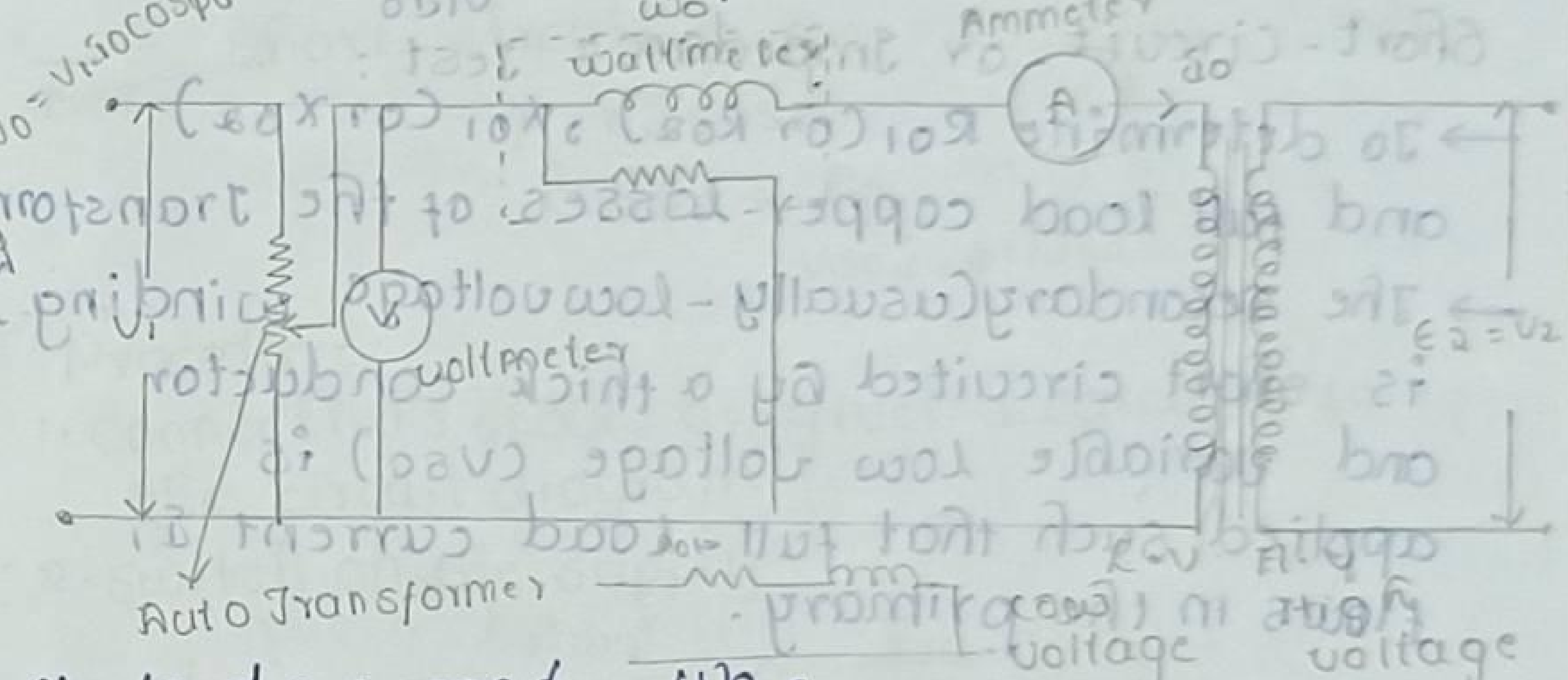
Transformer Tests:

These tests are conducted to determine the Iron & copper losses, to determine the efficiency and regulation at any load.

Open-circuit (or) No-Load Test:

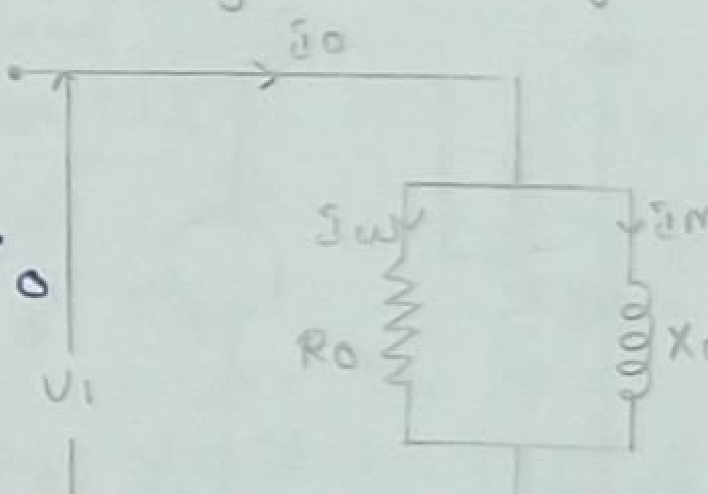
→ To determine the iron losses of transformer and also parameters R_0 and X_0 of the transformer.

→ Rated voltage (115V) is applied to the primary (usually low-voltage winding) while the secondary is left open circuited.



No-load p.f. $\cos\phi_0 = \frac{W_0}{V_1 I_0}$

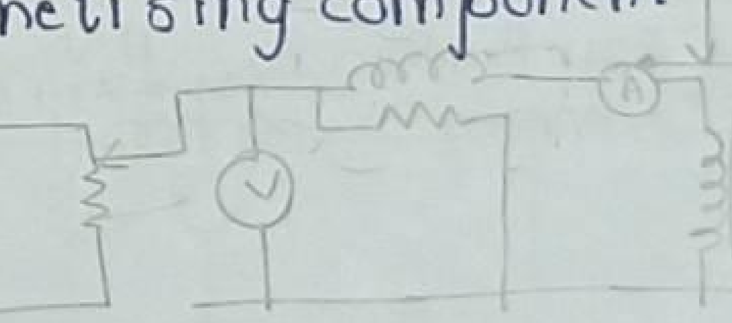
I_w = working component current



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

$R_0 = \frac{V_1}{I_w}$ and $X_0 = \frac{V_1}{I_m}$

I_m = magnetising component current



OC-Test:

Procedure

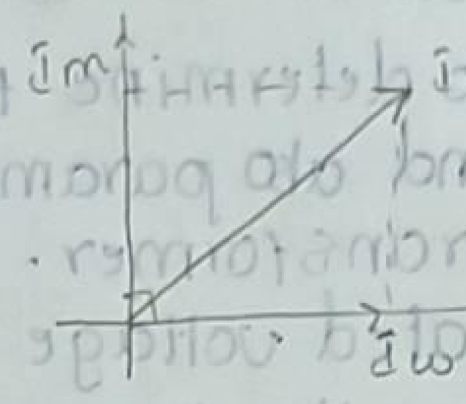
1. Connections should be given according to the circuit diagram
2. Switch on the supply
3. Vary the Auto transformer till rated voltage

is applied to LV winding

4. Note down the readings (voltmeter, Ammeter, wattmeter) V_1, I_0, W_0

5. Bring back to zero position of autotransformer

6. Then switch of the supply



$$P = V_0 I_0 \cos\phi_0$$

$$W_0 = V_1 I_0 \cos\phi_0$$

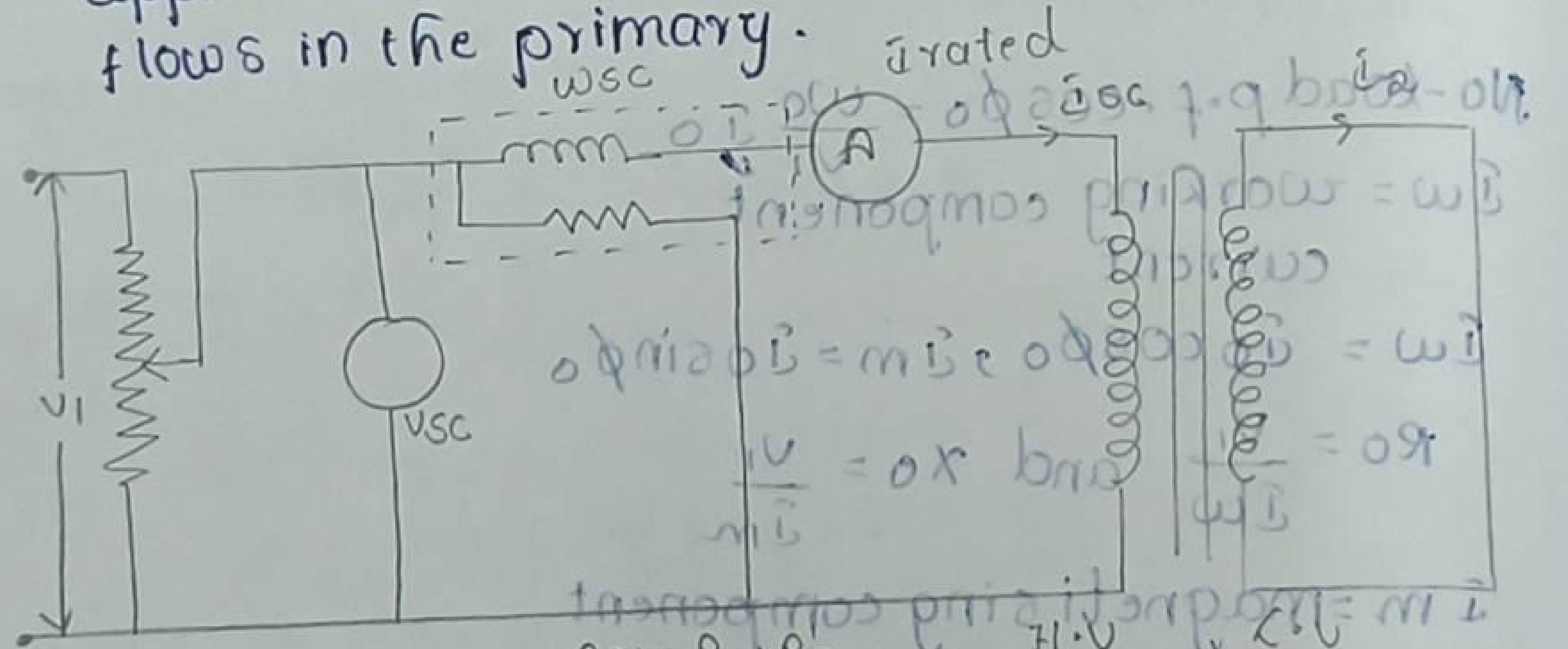
$$\cos\phi_0 = \frac{W_0}{V_1 I_0}$$

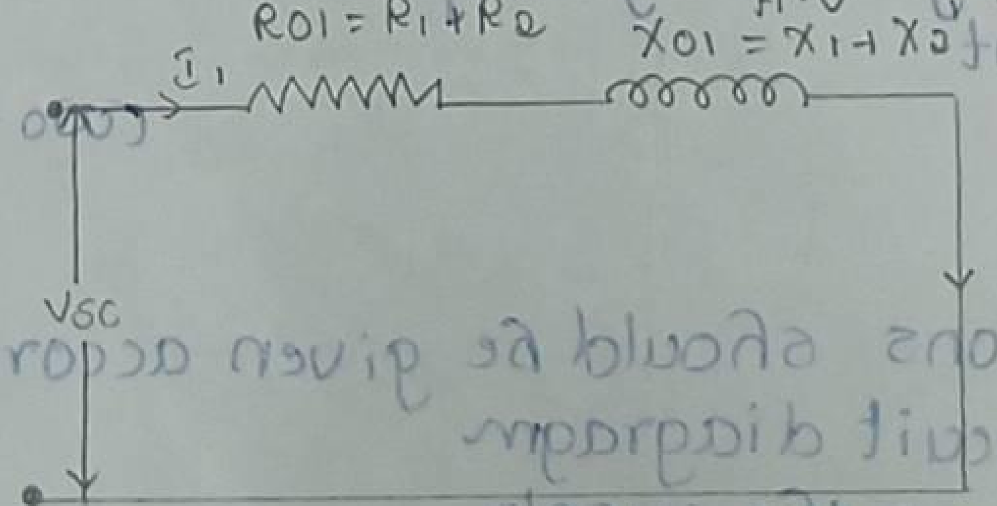
No-load p.f $\rightarrow \cos\phi_0 = \frac{W_0}{V_1 I_0}$

Short-circuit or Impedance Test:

→ To determine R_{01} (or R_{02}), X_{01} (or X_{02}) and full load copper losses of the Transformer

→ The secondary (usually - low voltage winding) is short circuited by a thick conductor and variable low voltage (V_{SC}) is applied such that full-load current I_1 flows in the primary.





$$P_c = I_1^2 R_1 + I_1^2 R_2' = I_1^2 R_{01}$$

$$R_{01} = \frac{P_c}{I_1^2 \text{ (or) } I_{sc}^2} \quad [\because P_{cu} = I^2 R_{01}]$$

where R_{01} is the total resistance of transformer referred to primary.

Total impedence referred to primary

$$Z_{01} = \frac{V_{SC}}{I_1 \text{ (or) } I_{sc}} \quad [\because Z = \frac{V}{I}]$$

Total Leakage reactance referred to primary

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2} \quad [Z^2 = R^2 + X^2]$$

$$X = \sqrt{Z^2 - R^2}$$

Short-circuit p.f

$$P = VI\cos\phi$$

$$\cos\phi_2 = \frac{P_c}{V_{SC} I_1 \text{ (or) } I_{sc}}$$

Procedure:

1. Connections should be given according to the circuit diagram
2. Switch on the supply

3-ϕ Induction Motors

→ An electric motor is adevice which converts an electrical energy into a mechanical energy. This mechanical energy then can be supplied to various types of loads. The motors can operate on DC as well as 1-ϕ and 3-ϕ AC supply.

→ The motors operating on DC supply are called DC-motors, while motors operating on AC supply are called AC-motors.

→ The AC motors are classified as 1-ϕ and 3ϕ Induction motors. Synchronous motors and some special purpose motors. Out of all these types, 3-ϕ induction motors are widely used for various industrial applications.

Advantages:

(i) It has simple and rugged construction.
(ii) It is relatively cheap.
(iii) It requires little maintainance.
(iv) It has high efficiency and reasonably good power factor.
(v) It has self starting torque.

Disadvantages:

(i) It is essentially a constant speed motor and its speed cannot be changed easily.
(ii) Its starting torque is inferior to DC shunt motor.

Rotating Magnetic field (RMF)

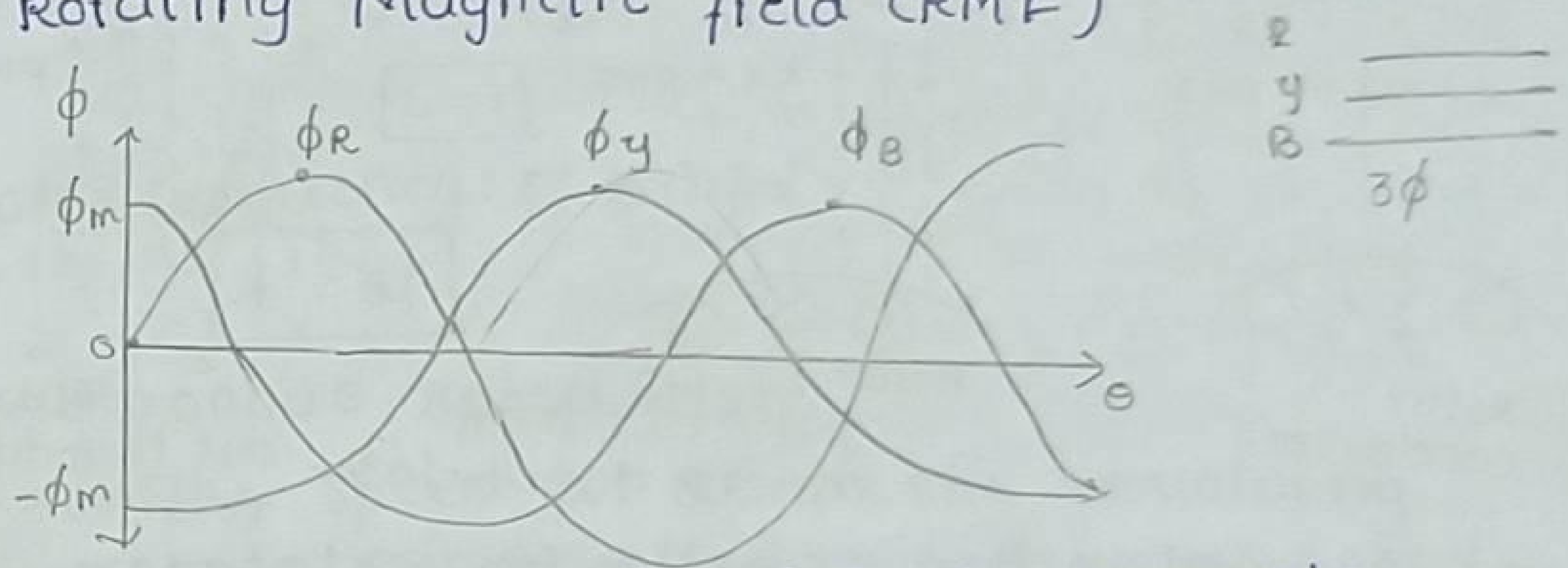
→ The working of 3-ϕ induction motor is based on the production of Rotating magnetic field. (RMF)

→ The Rotating magnetic field can be defined as the field or flux having constant amplitude but whose axis is continuously rotating in a plane with a certain speed called synchronous speed N_s.

→ In 3-ϕ Induction motors, such a rotating magnetic field is produced by supplying currents to a set of stationary windings, with the help of 3-ϕ AC supply.

→ The current carrying windings produce the magnetic field or flux & due to interaction of three fluxes produced due to 3-ϕ supply, resultant flux has a constant magnitude and its axis rotating in space, without physically rotating three windings.

→ This type of field is nothing but Rotating Magnetic field (RMF)



Fluxes produced by line currents

Principle of operation of 3-ϕ Induction Motor

→ Induction motor works on a principle of Electromagnetic induction.

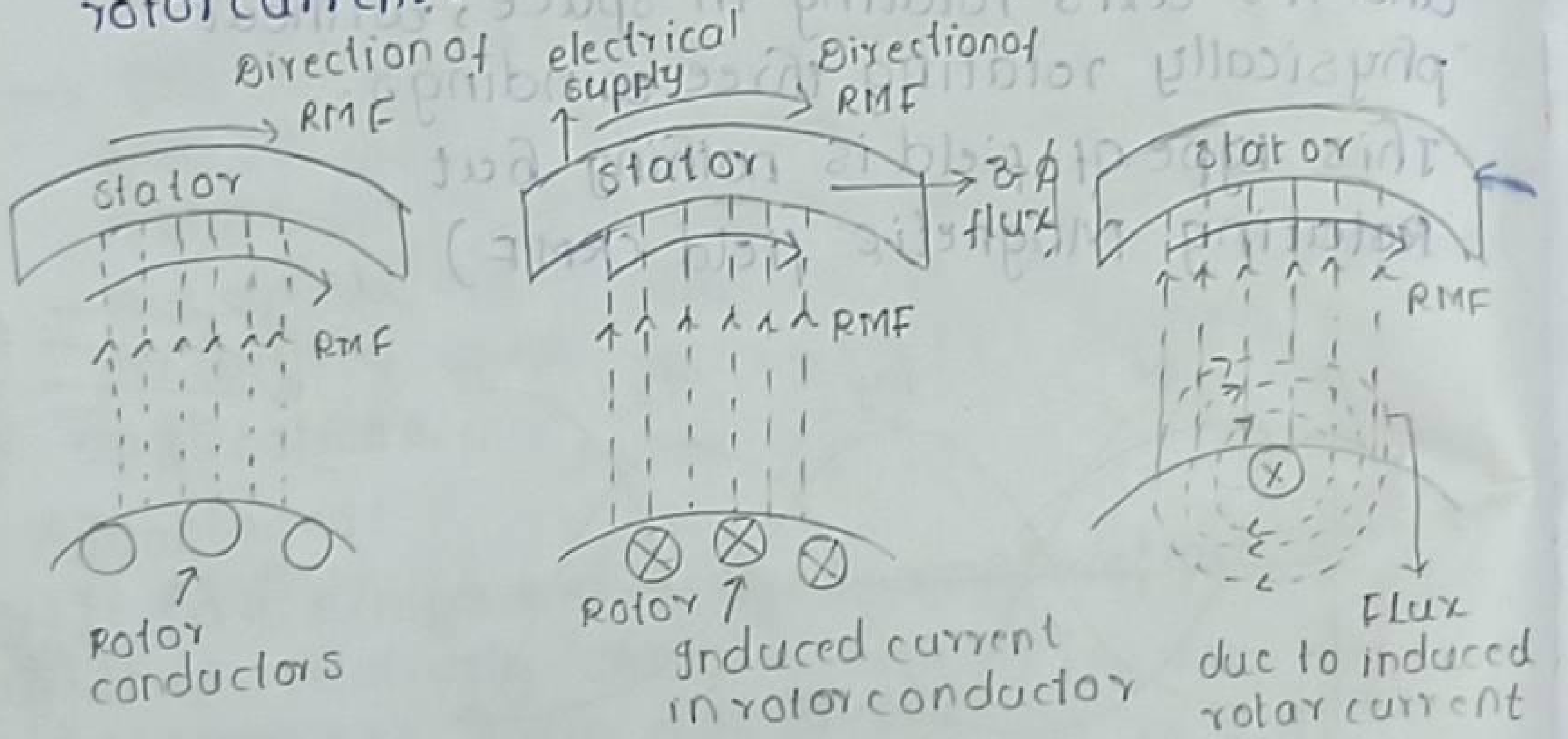
→ When a 3-ϕ supply is given to the 3-ϕ stator winding, a rotating magnetic field of constant magnitude ($1.5\phi_m$) is produced. The speed of this rotating magnetic field is synchronous speed, $N_s = 120f/P$ rpm

→ This rotating field produces an effect of rotating poles around a rotor. Let direction of rotation of this rotating magnetic field is clockwise

→ Now at this instant rotor is stationary and stator flux RMF is rotating so its obvious that there exists a relative motion b/w the RMF and rotor conductors.

→ Now RMF gets cut by the rotor conductors as RMF sweeps over rotor conductors. whenever conductor cuts the flux, EMF gets induced init called Rotor induced EMF.

→ As rotor forms closed circuit, induced EMF circulates current through rotor called rotor current.



emf → current → flux → Force → Torque → rotor conductors rotate

mechanical energy ←

Slip of 3-ϕ Induction Motor

Slip:

It is defined as the ratio of difference between synchronous speed and rotor speed to the synchronous speed

$$S = \frac{N_S - N}{N_S}$$

$$S\% = \frac{N_S - N}{N_S} \times 100$$

where N_S = speed of rotating magnetic field in rpm (or) synchronous speed

N = speed of rotor i.e motor in rpm

$N_S - N$ = Relative speed b/w the two speed is called slip speed.

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

$$\boxed{f = \frac{N_S P}{120}}$$

supply frequency

→ In practical rotor continues to rotate with a speed slightly less than the synchronous speed of the rotating magnetic field ($N < N_S$) Asynchronous speed

→ At starting, actual speed N is zero, so $S = 1$

$$S = \frac{N_S - N}{N_S}$$

$$S = \frac{N_S - 0}{N_S}$$

$$\boxed{S = 1}$$

Rotor frequency: f' (or) f_r

$$\boxed{f' = Sf}$$

Synchronous speed (N_S):

The speed at which the revolving flux rotates is called synchronous speed. Its value depends upon the no. of poles and the supply frequency which is given by

$$f = \frac{NP}{120}$$

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

synchronous speed $\boxed{N_S = \frac{120f}{P} \text{rpm}}$

P = no. of poles on the stator

f = supply frequency in Hz

Ex: For 6-pole, 50Hz motor, what is N_S

$$N_S = \frac{120f}{P} = \frac{\cancel{120}^{20} \times 50}{\cancel{6}} = 1000 \text{rpm}$$

It means that the flux rotates around the stator at a speed of 1000 rpm.

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Rotor speed (or) Motor speed:

$$S = \frac{N_S - N}{N_S}$$

$$SN_S = N_S - N$$

$$N = N_S - SN_S$$

$$\boxed{N = N_S(1-S)}$$

Rotor frequency (or) Frequency of rotor emf (or) Frequency of rotor current:

$$f' \text{ (or) } f_r = fS$$

$$\boxed{S = \frac{f_r}{f}}$$

→ If the induced emf is in the stator of an 50 Hz 8 pole induction motor has a frequency of 50 Hz and that in the rotor is 1.5 Hz, at what speed is the motor running and what is the slip.

$f = 50\,Hz$, $f_r = 1.5\,Hz$, $P = 8$

$$N_S = \frac{120f}{P} = \frac{120 \times 50}{8} = 750\,rpm$$

$$S = \frac{f_r}{f} = \frac{1.5}{50} = 0.03$$

$$N = (1-S)N_S$$

$$= (1-0.03)750$$

$$= 727.5\,rpm$$

→ A three phase, 20hp, 208V, 60Hz, six pole, wye (Y) connected induction motor delivers 15kW at a slip of 5%.

calculate

a. Synchronous speed

b. Rotor speed

c. Frequency of rotor current

Synchronous speed

$$N_S = \frac{120f}{P} = \frac{120 \times 60}{6} = 1200\,rpm$$

Rotor speed

$$N = N_S(1-S)$$

$$= 1200(1-0.05)$$

$$= 1140\,rpm$$

Frequency of rotor current

$$f = S \cdot f$$

$$= 0.05 \times 60$$

$$= 3\,Hz$$

→ A three phase, 460V, 100hp, 60Hz four-pole induction machine delivers rated output power at a slip of 0.05. Determine the

a. synchronous speed

b. motor speed

c. frequency of the rotor circuit

d. slip speed.

Synchronous speed

$$N_S = \frac{120f}{P} = \frac{\overset{30}{\cancel{120}} \times 60}{\cancel{4}} = 1800\,rpm$$

motor speed

$$N = N_S(1-S)$$

$$= 1800(1-0.05) = 1710\,rpm$$

frequency of the rotor circuit

$$f' = Sf$$

$$= 0.05 \times 60$$

$$= 3\,Hz$$

slip speed

$$N_S - N = 1800 - 1710$$

$$= 90\,rpm$$

Torque Equation of 3-ϕ Induction Motor

Rotor Torque:

The torque T developed by the rotor is directly proportional to

(i) rotor current (I_2)

(ii) rotor emf (E_2)

(iii) power factor of the rotor circuit ($\cos\phi_2$)

$T \propto E_2 I_2 \cos\phi_2$

$T = k E_2 I_2 \cos\phi_2$

where I_2 = rotor current at standstill

E_2 = rotor emf at standstill

$\cos\phi_2$ = rotor power factor at stand still

Starting Torque: (T_{st})

Let E_2 = rotor emf per phase at stand still

X_2 = rotor reactance per phase at stand still

R_2 = rotor resistance per phase

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

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

Rotor impedance /phase, $Z_2 = \sqrt{R_2^2 + X_2^2}$

Rotor current /phase,

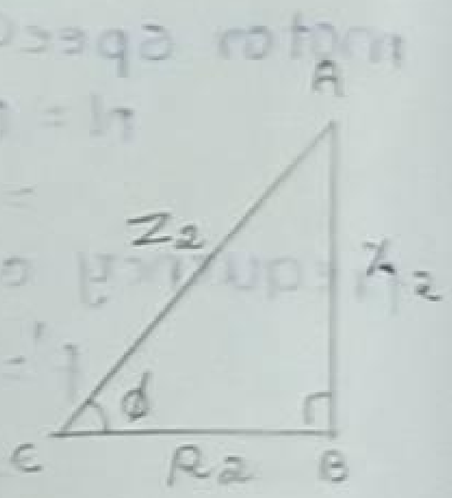
$$R = \frac{V}{I}$$

$$Z = \frac{V}{I} \Rightarrow I = \frac{V}{Z} = \frac{E}{Z}$$

$$I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{R_2^2 + X_2^2}}$$

Rotor power factor

$$\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$$



$\therefore$ starting torque

$$T_{st} = k E_2 I_2 \cos\phi_2$$

$$= k E_2 \times \frac{E_2}{\sqrt{R_2^2 + X_2^2}} \times \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$$

$$T_{st} = \frac{k E_2^2 R_2}{R_2^2 + X_2^2}$$

Running Torque: (T_r)

→ The torque produced in an induction motor depends on the following factors:

(i) The part of Rotating magnetic field (ϕ) which reacts with rotor and is responsible to produce induced emf in the rotor.

(ii) The magnitude of rotor current in running condition (I_2)

(iii) The power factor of the rotor circuit in running condition ($\cos\phi_2$)

$$T_r \propto \phi I_{2r} \cos\phi_{2r}$$

(iv) The flux produced by stator is proportional to stator voltage E_1 and rotor voltage E_2

$$\phi \propto E_{2r}$$

$$I_2 = \frac{SE_2}{Z_2} = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

$$\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

$$T_r = k E_{2r} I_{2r} \cos\phi_{2r}$$

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

$$T_r = \frac{k \cdot S E_2^2 \cdot R_2}{R_2^2 + (SX_2)^2}, \text{ where } k = \frac{180}{2\pi N_s}$$

Torque slip characteristics of Three phase induction motor.

→ As the induction motor is loaded from no load to full load, its speed decreases hence slip increases

→ The curve obtained by plotting torque against slip from $S = 1$ (starting) $N = 0$ to $S = 0$ (at synchronous speed) $N \uparrow$ is called Torque-slip characteristics.

→ At constant supply voltage, E_2 is also constant, so we write torque equation

$$T_r \propto \frac{SR_2}{R_2^2 + (SX_2)^2}$$

→ Now to judge the nature of torque-slip characteristics, let us divide the slip range ($S = 0$ to $S = 1$) into two parts and analyze them independently.

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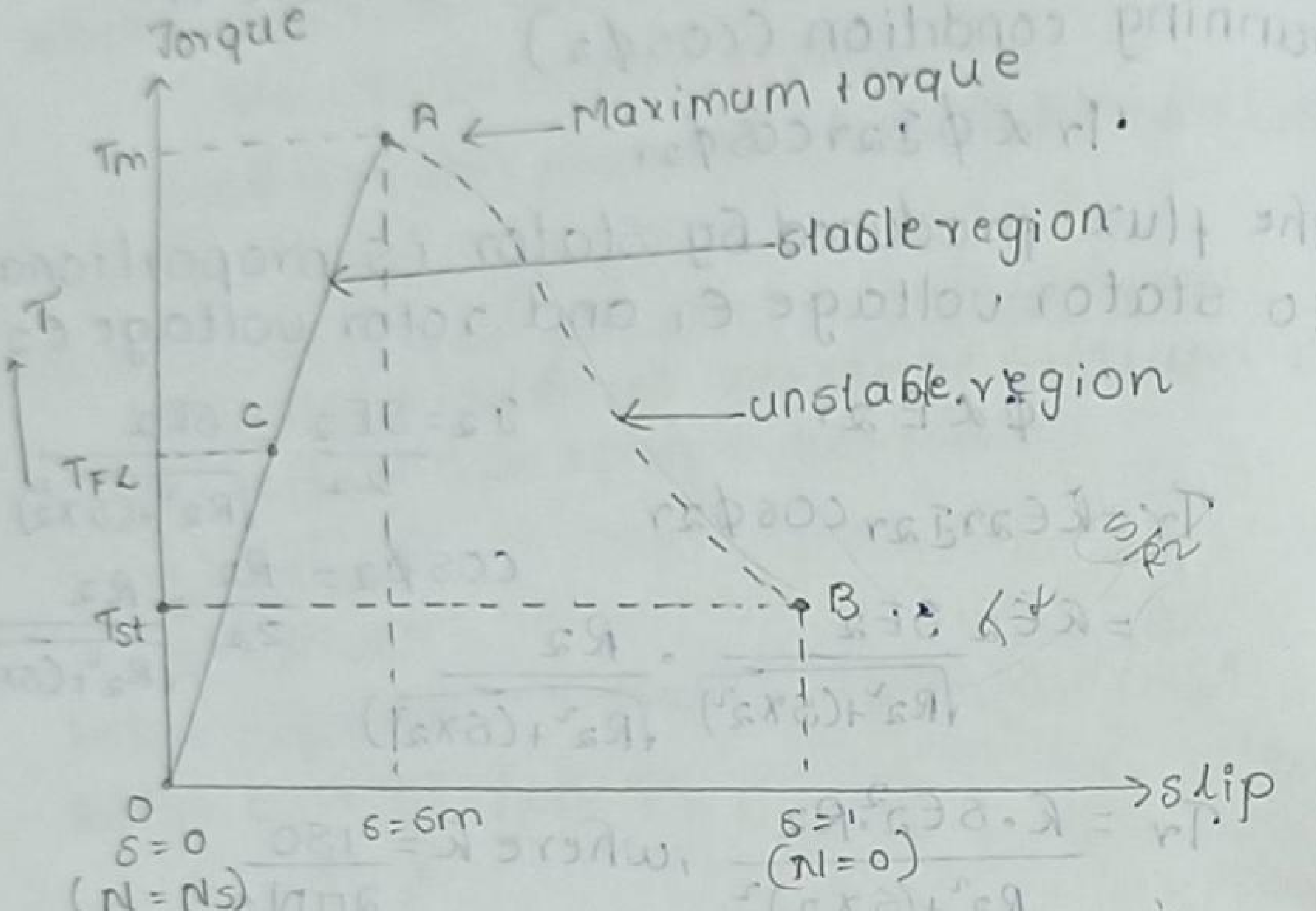
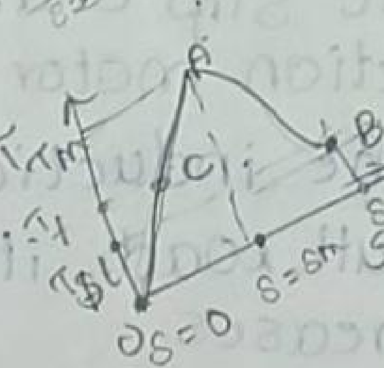
(i) Low slip region ($s=0$ to $s=s_m$)
(ii) High slip region ($s=s_m$ to $s=1$)



OA = stable region
AB = unstable region
Point A = Maximum torque
point B = starting torque
point C = Full load torque



(i) Low slip region:
In low slip region, s is very very small. Due to this, the term $(sX_2)^2$ is so small as compared to R_2^2, that it can be neglected.

$$T \propto \frac{sR_2}{R_2^2 + \underbrace{(sX_2)^2}_{\text{neglect}}}$$

$$T \propto \frac{s\cancel{R_2}}{R_2^{\cancel{2}}} \Rightarrow T \propto \frac{s}{R_2} \text{ as } R_2 \text{ is constant}$$

$$\boxed{T \propto s}$$

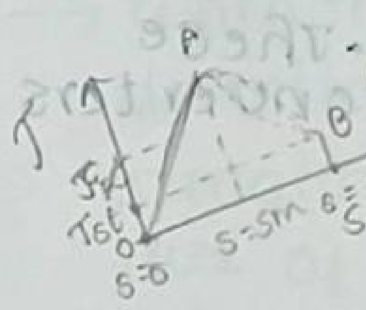
→ Hence, in low slip region torque is directly proportional to slip. So as load increases, speed decreases, increasing the slip. This increase the torque which satisfies the load demand. Hence the graph is straight line in nature.

→ So range $s=0$ to $s=s_m$ is called low slip region, known as a stable region of operation.

(ii) High slip region:

→ In this region slip is very high i.e. slip value is approaching 1. Here it can be assumed that the term R_2^2 is very very small as compared to $(sX_2)^2$. Hence neglecting R_2^2 from the denominator

$$T \propto \frac{sR_2}{\underbrace{R_2^2}_{\text{neglect}} + (sX_2)^2}$$



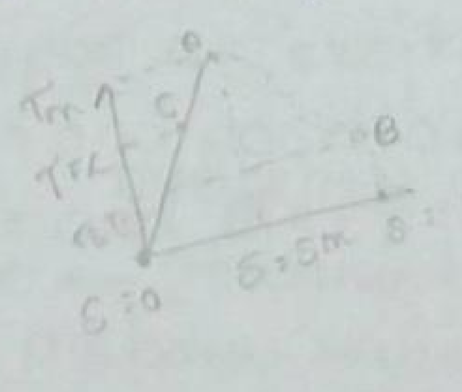
$$T \propto \frac{\cancel{s}R_2}{s^{\cancel{2}}X_2^2} \Rightarrow T \propto \frac{R_2}{sX_2^2} \text{ as } X_2 \text{ \& } R_2 \text{ are constants}$$

$$\boxed{T \propto \frac{1}{s}}$$

→ So in high slip region torque is inversely proportional to the slip. Hence it is like rectangular hyperbola.

→ Now when load increases, load demand increases but speed decreases. As speed decreases, slip increases. In high slip region as $T \propto \frac{1}{s}$, torque decreases as slip increases.
Hence this region is called unstable region of operation.

→ So range $s=s_m$ to $s=1$ is called high slip region, known as unstable region of operation.



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3-ϕ Altern...

(or)

AC generators

Introduction:

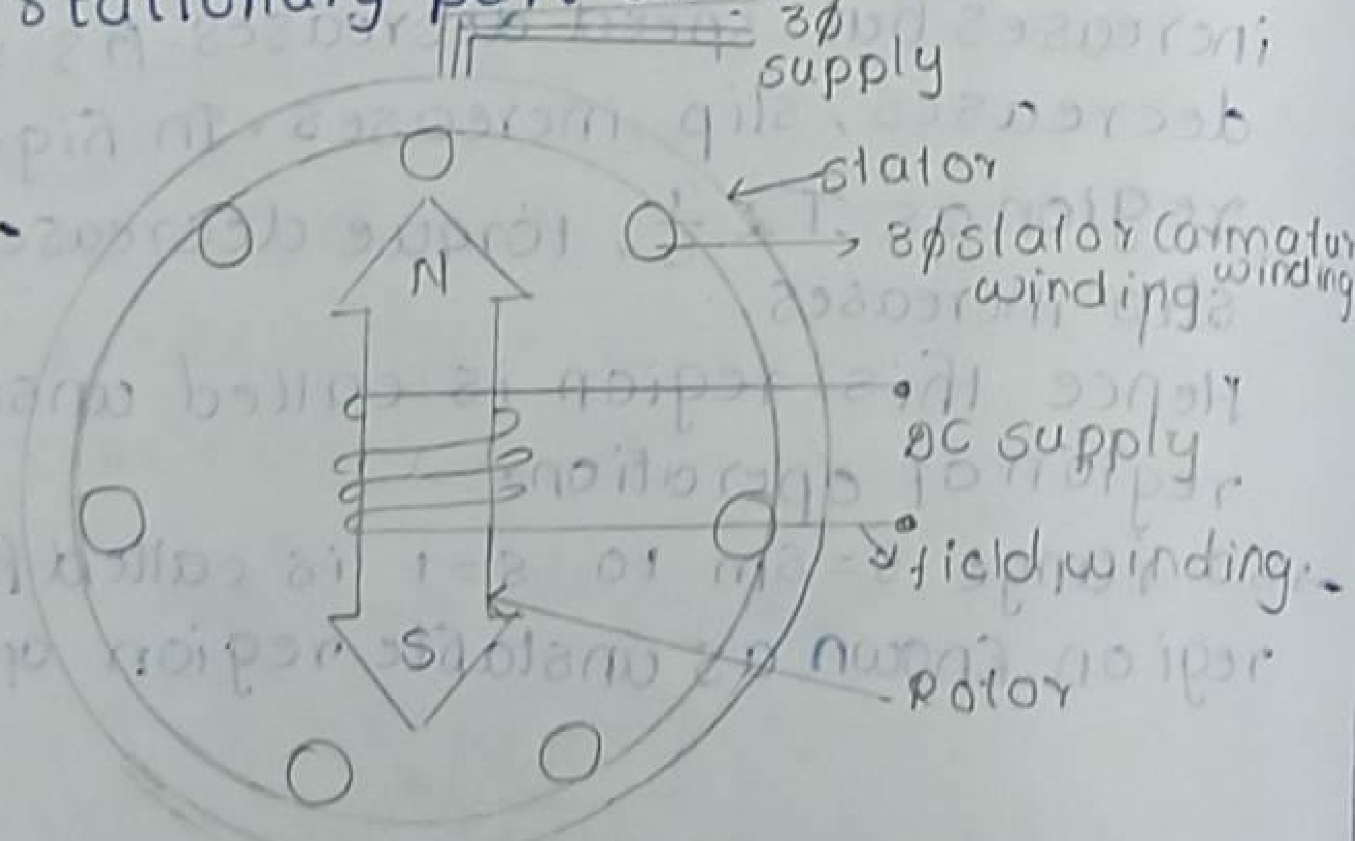
→ A.C system has number of advantages over D.C. system.

→ These day 3-phase AC system is being exclusively used for generation, transmission and distribution of power.

→ The machine which produces 3-phase power from mechanical energy is called an alternator or synchronous generator.

→ Alternators are the primary source of all the electrical energy we consume. These machines are the largest energy converters found in the world.

→ Since no commutator is required in an alternator, it is usually more convenient and advantageous to place the field winding on the rotating part and armature winding on the stationary part as shown below.

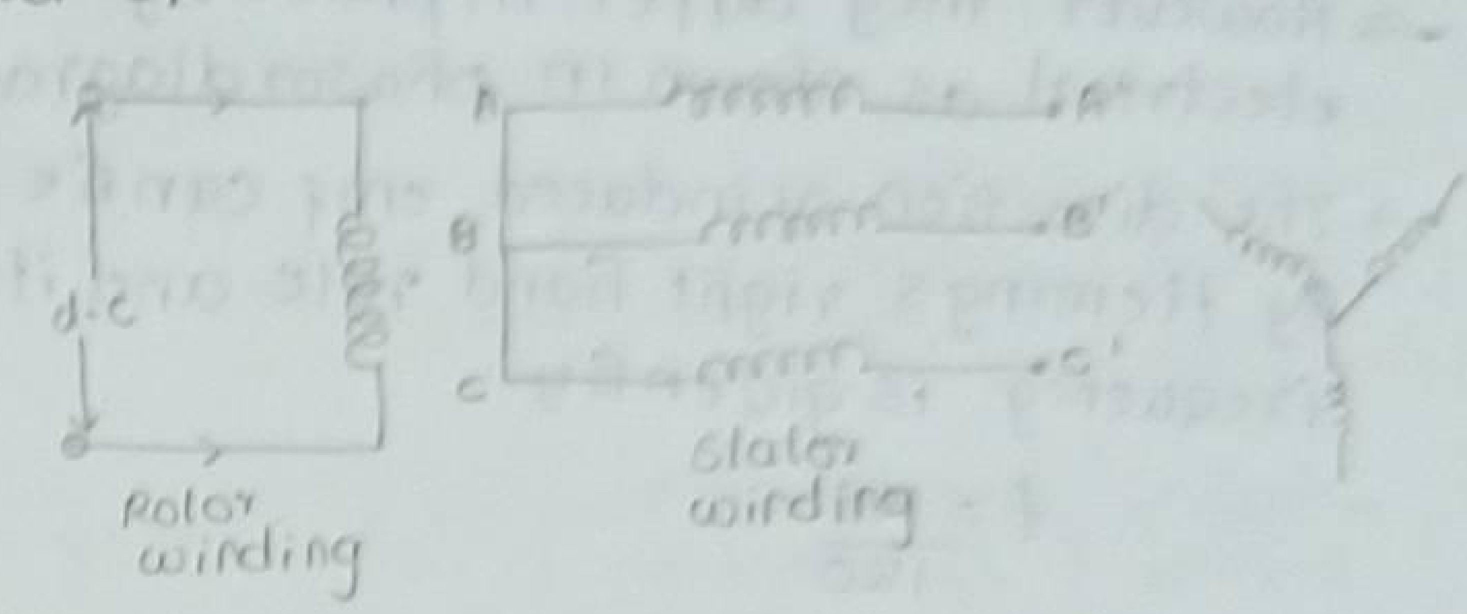


AC - Generator

field winding → rotor (magnetic poles)

armature winding → Stator

Operation of alternator:

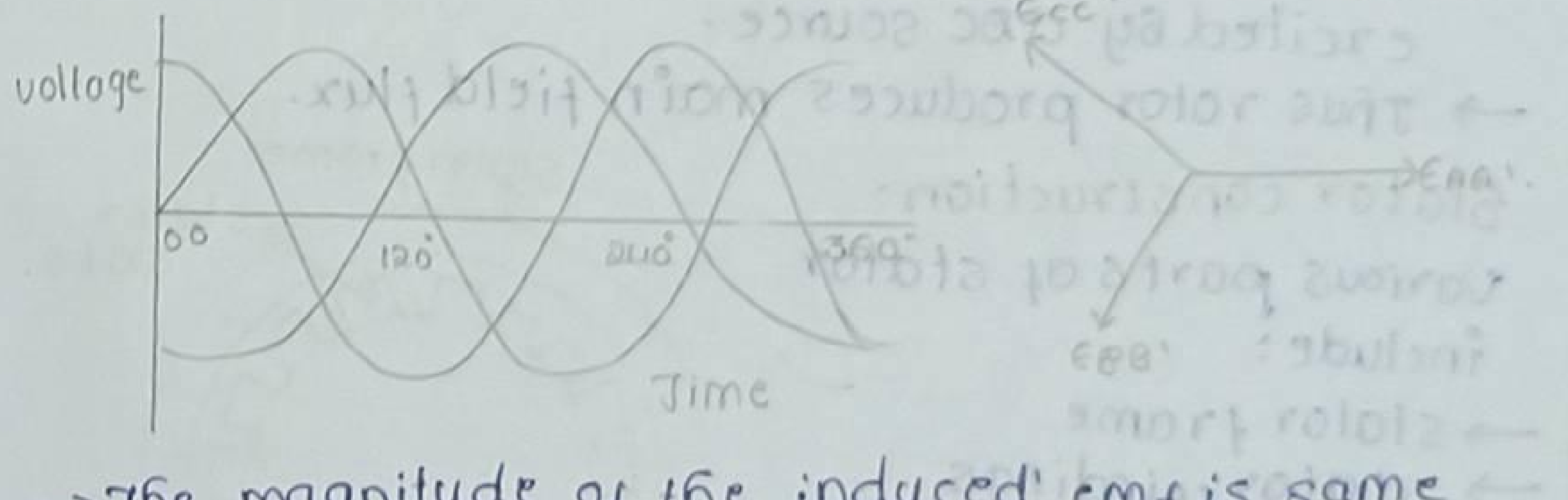


→ Above figure shows a star-connected armature winding and DC field winding.

→ The rotor winding is energized from the DC exciter and alternate N and S poles are developed on the rotor.

→ When the rotor is rotated in anti-clockwise direction by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles.

→ Consequently emf is induced in the armature conductors due to electromagnetic induction. The induced emf is alternating since N and S poles of rotor alternately pass the armature conductors.



→ The magnitude of the induced emf is same in each phase and depends upon DC exciting current, rotor flux, the number and position of the conducts in the phase and the speed of the rotor.

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→ However [illegible] phasor diagram electrical as shown in phasor diagram

→ The direction of induced emf can be found by flemings right hand rule and its frequency is given by

$$f = \frac{NP}{120}$$

N = speed of rotor in r.p.m

P = number of rotor poles.

Construction of alternator / synchronous generator

→ Basic parts of a synchronous generator are

→ Satator - Stationary part of the machine

→ It carries armature winding in which voltage is generated.

→ It has a three phase winding excited by AC supply.

→ The output of the machine is taking from the stator

→ Rotor - It is the rotating part of the machine.

→ It carries the field winding which is excited by a DC source.

→ Thus rotor produces main field flux.

Stator construction:

Various parts of stator include:

→ stator frame

→ stator windings

→ stator core

→ stator frame is made up of cast iron for small sized machines.