Dt - 09.08.2019

-: Electricity :-

Electricity is a form of energy which depends on existance of electric charge both in static and dynamic form.

- The electricity produced by the charges at rest are called as static electricity.
- The electricity produced by the charges at motion are called as current electricity.

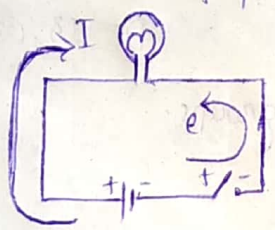
-: Electric Current :-

The rate of flow of charge is called electric current.

- It is represented as I.
- Let q = charge flows through any section of conductor in time 't'.

$$\text{Electric Current } (I) = \frac{q}{t}$$

- Its SI unit is Ampere (A)
-



- Direction of electric current is opposite to the direction of flow of electron.
- Direction of current is from higher potential to lower potential (In external circuit)
- Direction of current within the battery is from lower to higher potential

-: Electric Potential :-

$$V = \frac{W}{+q}$$

$$V = \frac{Kq}{r}$$

Potential determines direction of flow of charge

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Ohm's law :-

According to Ohm's law at constant temprature and other physical quantities the current flow in the conductor is directly propotional to the potential difference.

$$I \propto V$$

$$I = \text{constant} \times V$$

$$I = \frac{1}{R} \times V$$

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

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

$\because$ R = Resistance of the conductor

Resistance (R) :-

$R = \frac{V}{I}$ - It is the obstruction posed by the conductor to flow of electric current.

- It's SI unit is Ohm or Ω.

Basic Elements :-

Dt - 13.08.2019

It is classified into two groups.

(i) Passive Elements

(ii) Active Elements.

(i) Passive Elements :-

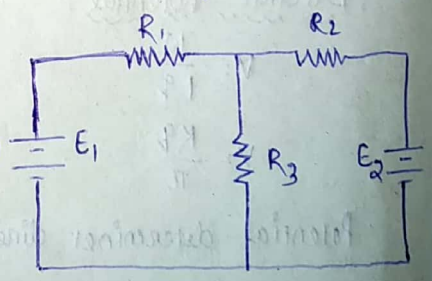
- Passive Elements are those elements which receives electrical energy and converts into heat energy (in case of resistance)
  - magnetic energy (in case of inductance)
  - electrostatic energy (in case of capacitance)

e.g. - R_1, R_2, R_3

(ii) Active Elements :-

Active elements are those elements which supply electric energy.

e.g. - E_1, E_2



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Factors affecting an Resistance :-

$R \propto l$

$\propto \frac{1}{A}$

$R \propto \frac{l}{A}$

$\Rightarrow R = \text{constant} \times \frac{l}{A}$

$\Rightarrow \boxed{R = \rho \times \frac{l}{A}}$ $\because \rho$ = Resistivity of the material of the conductor

$= \frac{m}{\tau e^2 n}$ $\because n$ = number of free electrons per unit volume

e = charge of electron

τ = relaxation time

m = mass of electron.

- Resistance of Conductor $\propto$ Temprature $R_t = R_0(1+\alpha t)$ $\because \alpha$ = Temprature co-efficient of resistance
- The conductors are called ohmic conductors if V-I graph is a straight line
- The conductors are called non-ohmic if V-I graph is a curve
- The devices or circuit elements whose V-I characteristics is not a straight line is said to be non linear resistance

Inductance :- (L)

- $L = \frac{N\phi}{I}$ It opposes the change in current.
  - It is related to magnetic field and depends on current.
- SI unit of inductance Henery (H)

$V_L = -L \cdot \frac{dI}{dt}$

- Energy $= \frac{1}{2} L I^2$

Capacitance :- (C)

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

- Energy $= \frac{1}{2} C V^2$

$= \frac{1}{2} Q V$

$= \frac{1}{2} \frac{Q^2}{C}$

- ~~Current i(t) = $\frac{1}{C}\int$~~

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- Voltage (V) = $\frac{1}{C}\int i\,dt$

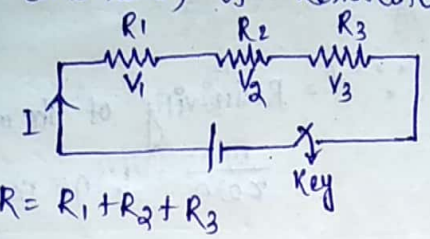
- Current (i) = $C\frac{dV}{dt}$

Dt - 14. 08. 2019

Combination of Resistances:-

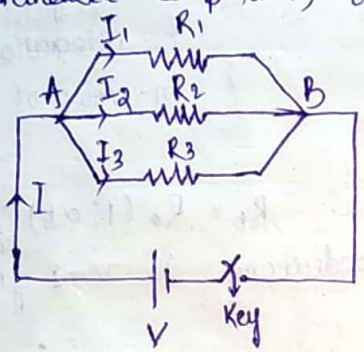
- It is of two types

(i) Series combination of Resistances:-



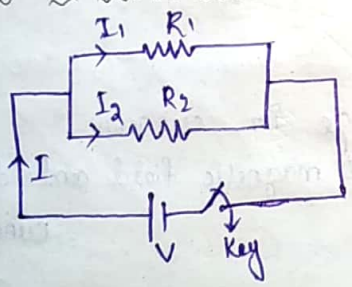
$R = R_1 + R_2 + R_3$

(ii) Parallel Combination of Resistances:-



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

Current division Rule:-



- As $R_1 \parallel R_2$

So $R = \frac{R_1 R_2}{R_1 + R_2}$

Also $V = I_1 R_1$

$\Rightarrow I_1 = \frac{V}{R_1} = \frac{IR}{R_1}$ $\{\because V = IR\}$

$\Rightarrow I_1 = \frac{I\left(\frac{R_1 R_2}{R_1 + R_2}\right)}{R_1}$

$\Rightarrow \boxed{I_1 = I\left(\frac{R_2}{R_1 + R_2}\right)}$ and $\boxed{I_2 = I\left(\frac{R_1}{R_1 + R_2}\right)}$

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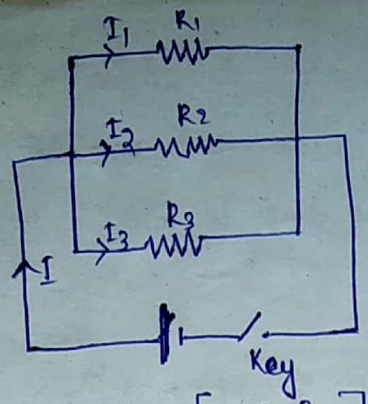


$$I_1 = I\left[\frac{R_2R_3}{R_2R_1+R_2R_3+R_3R_1}\right]$$

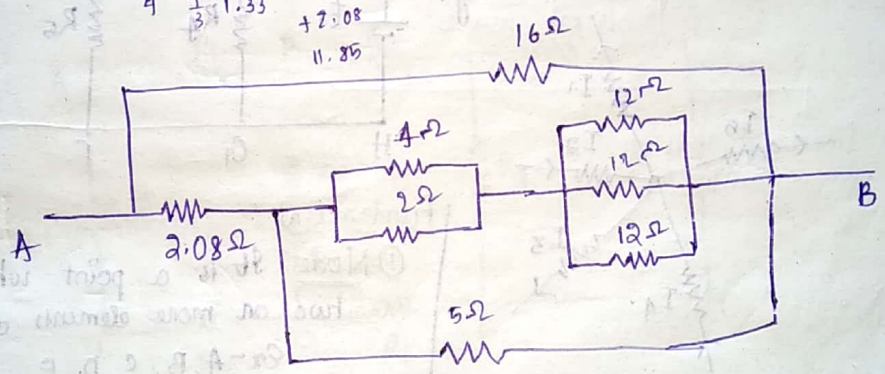
$$I_2 = I\left[\frac{R_1R_3}{R_2R_1+R_2R_3+R_3R_1}\right]$$

$$I_3 = I\left[\frac{R_1R_2}{R_2R_1+R_2R_3+R_3R_1}\right]$$

Problems:

(1)

4 $\frac{4}{3}$ 1.33 9.77 +2.08 11.85



4 1.33

5.33 5

2.6

4.68

$$R = \frac{4.68\times 16}{4.68+16} = 3.62$$

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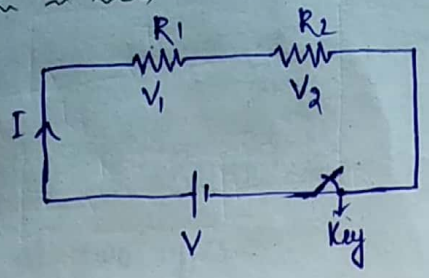
Voltage Division Rule:-



Total resistance $R = R_1 + R_2$

- $V = IR$
- $V_1 = IR_1 = \frac{V}{R} R_1 \quad \left\{ \because I = \frac{V}{R} \right\}$

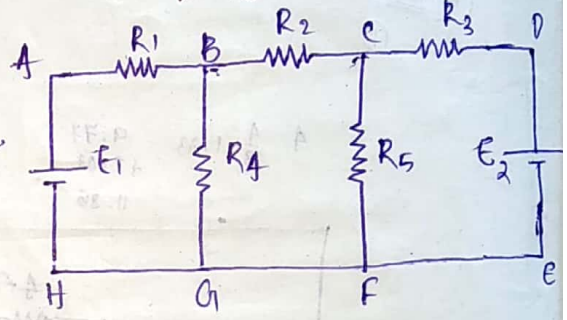
$$\boxed{V_1 = \frac{V R_1}{R_1 + R_2}} \quad \text{and} \quad \boxed{V_2 = \frac{V R_2}{R_1 + R_2}}$$

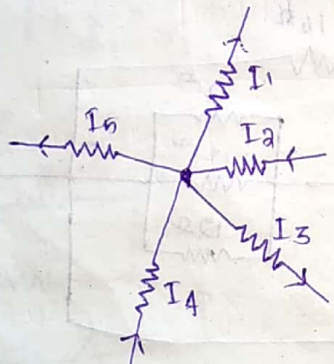
-: Kirchoff's Laws :-

Dt - 16. 08. 2019.

(i) First Law :- (KCL)

This law deals with the law of conservation of electric charge





Mathematically $\Sigma I = 0$

Sign convention :

① Current flows towards the junction = +ve

② Current flows away from the junction = -ve.

Then According to the law,

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

$$\Rightarrow I_1 + I_5 + I_5 = I_2 + I_4$$

Total outgoing current = Total incoming current

Fundamental :-

① Node : It is a point where two or more elements are connected

Ex - A, B, C, D, E

② Junction : Three or more elements are connected.

Ex - B, C, E

③ Branch : The path connected betn two junction is called branch.

Ex - GHAB, BC, GF, CDFE
BG, CF

④ Loop : Any closed electric circuit is called loop.

Ex - ABGHA, CDEFC, BCFGB
ABCDEFGHA

⑤ Mesh : Mesh is a loop which is not further subdivided.

Ex - ABGHA, BCFGB, CDEFC.

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(ii) Second Law (KVL) :-

This law deals with law of conservation of energy.

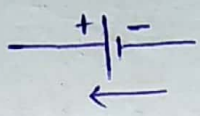
- The algebric sum of emfs and IR drops of any loop is zero.

Mathematically

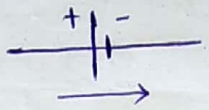
$$\Sigma emfs + \Sigma IR = 0 \rightarrow (1)$$

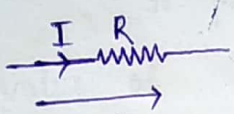
Sign Convention:

① Emf = +ve

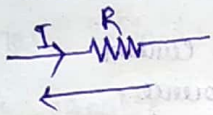


② Emf = -ve



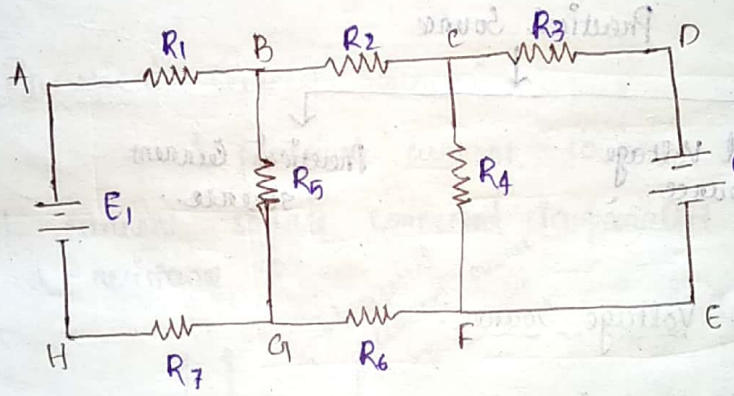
③ 

IR = -ve

④ 

IR = +ve

Q1.



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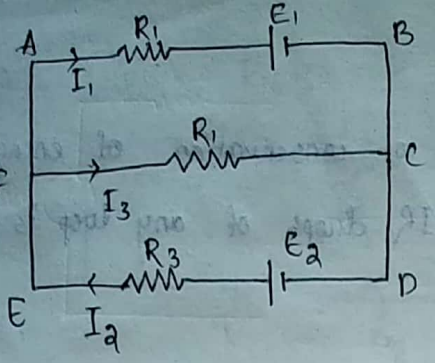
Q2



Sol^n

For loop ABCFA

$$-I_1R_1 - E_1 + I_2R_2 = 0$$

For loop ABCDEFA

$$-I_1R_1 - E_1 + E_2 - I_2R_3 = 0$$

Ideal Source
- Ideal Voltage Source
- Ideal Current Source

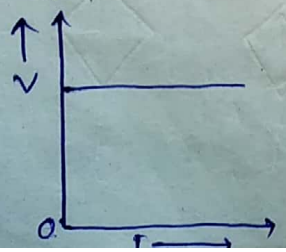
Practical Source
- Practical Voltage Source
- Practical Current Source

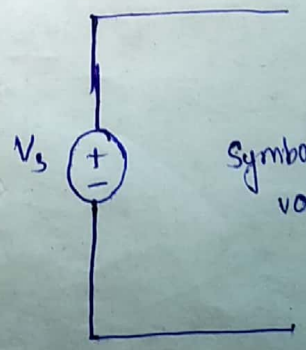
Ideal & Practical Voltage Source:-

(a) Ideal voltage source:-

An ideal voltage source is a source that maintains a constant terminal voltage no matter how much current is drawn from it.

- In ideal voltage source the internal resistance is zero (0), so that voltage droped in the source is zero.
- Power drawn by the source is zero.





Symbol ideal voltage source

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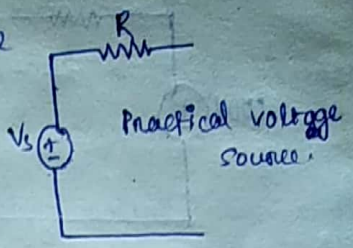
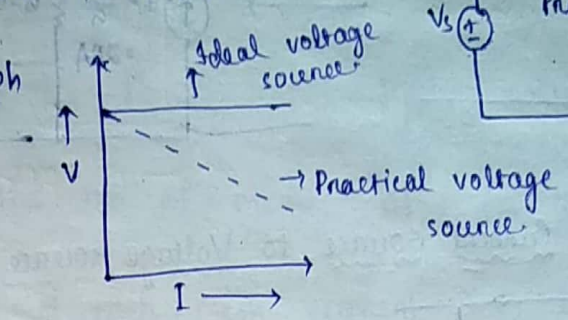
(b) Practical voltage Source :-

It is represented by an ideal voltage source with a resistor in series.



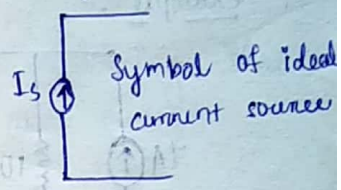
- Voltage-current graph



Ideal and Practical Current Source :-

(a) Ideal current source :-

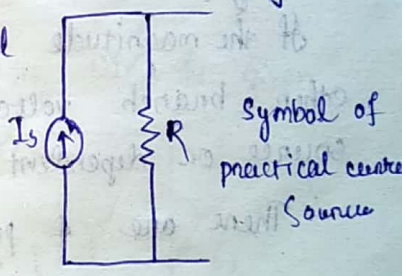
It produces a constant current inspective of the value of the voltage across it.

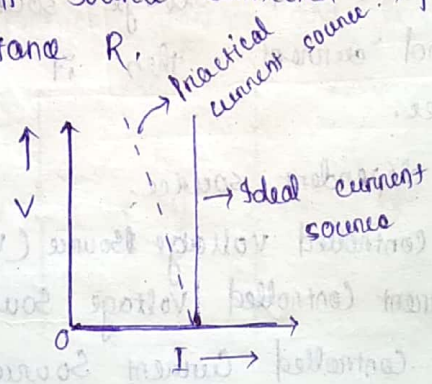


- It has infinite resistance
- It is capable of supplying infinite power

(b) Practical Current Source :-

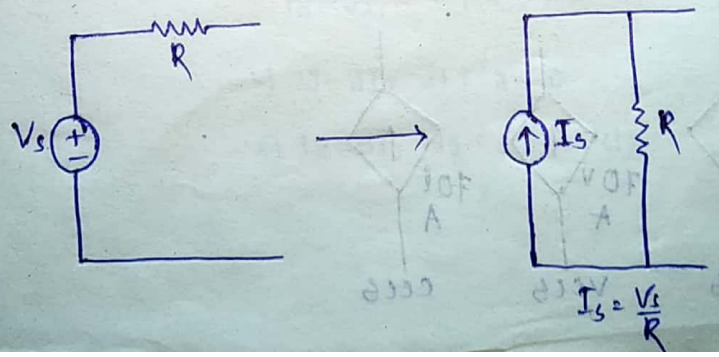
A practical current source represented by an ideal current source connected in parallel with a resistance R.





Source Conversion :-

(1) Convert voltage source to current source :



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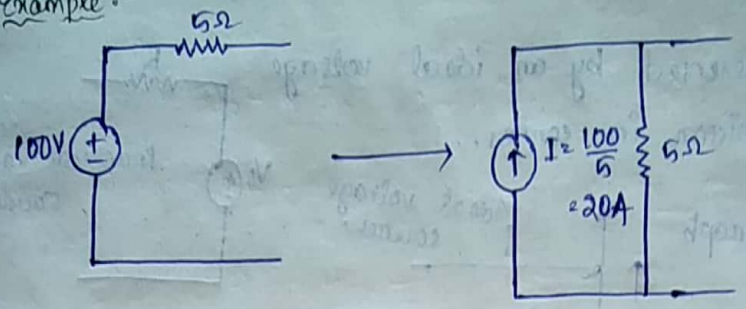
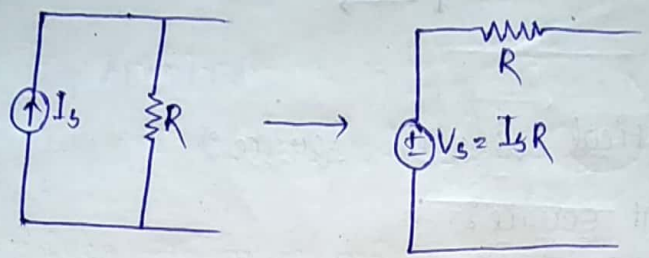
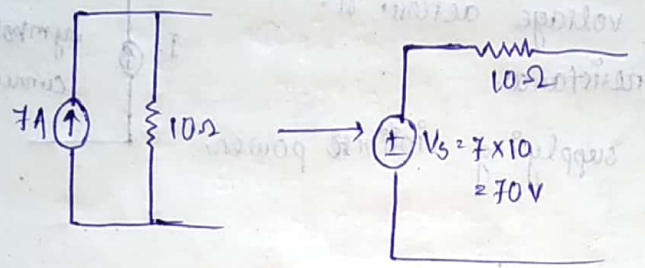
Example :-



(2) Convert Current source to Voltage source :-



Example :-

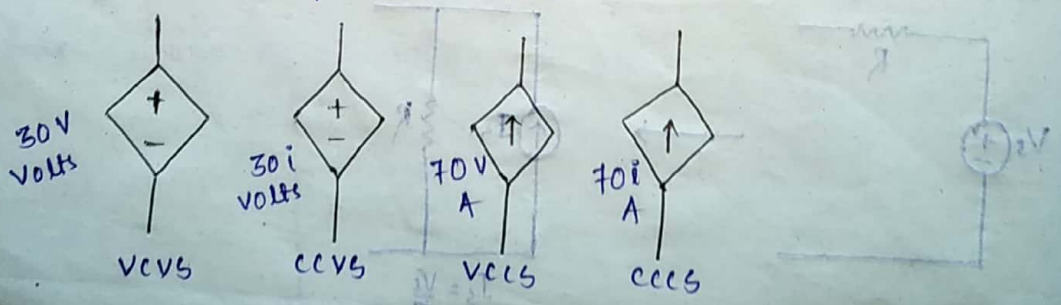


Controlled Source :- (Dependent Source) Dt = 20.08.2019

If the magnitude of current and voltage source depends on other branch voltage and current then it is called controlled source or dependent source.

- There are 4 possible dependent source
  - (i) Voltage controlled voltage Source (VCVS)
  - (ii) ~~Volt~~ Current Controlled Voltage Source (CCVS)
  - (iii) Current Controlled Current Source (CCCS)
  - (iv) Voltage Controlled Current Source (VCCS)

Symbols of dependent sources.



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Mesh Current Analysis :-

This method determines branch current and voltages across the elements of a network.

- These are the following steps to solve mesh analysis.

Step-1

First identify the no. of meshes of the network

Step-2

Assigle a symbol of each mesh current i.e. I_1, I_2.
Also assigle the direction of mesh currents. i.e. clock wise or anti clock wise

Step-3

Apply KVL for each mesh.

Step-4

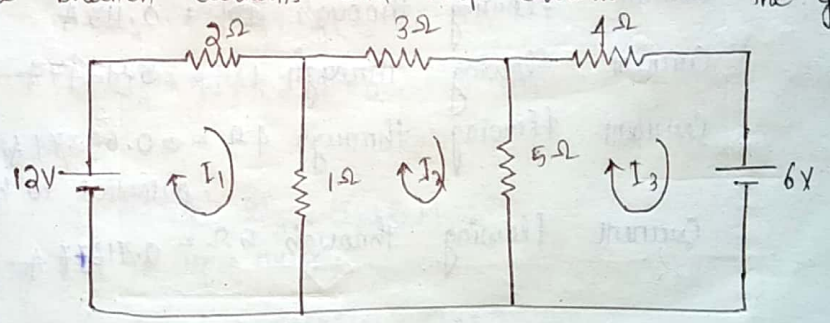
In mesh analysis which mesh we are considering that mesh current should be greater than other mesh current.

Step-5

This method is easier if all the sources are given as voltage sources.

- If there is a current source then convert it into voltage source

Q.) Find the branch currents and loop currents of the given network.



Sol^n

For loop-1

$$12 - 2I_1 - (I_1 - I_2) = 0$$

$$\Rightarrow 12 - 2I_1 - I_1 + I_2 = 0$$

$$\Rightarrow 12 - 3I_1 + I_2 = 0 \quad ---(1)$$

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For loop-2

$$-3I_2 - 5(I_2 - I_3) - 1(I_2 - I_1) = 0$$

$$\Rightarrow -3I_2 - 5I_2 + 5I_3 - I_2 + I_1 = 0$$

$$\Rightarrow -9I_2 + 5I_3 + I_1 = 0 \quad ----(2)$$

For loop-3

$$-4I_3 - 6 - (I_3 - I_2)5 = 0$$

$$\Rightarrow -4I_3 - 6 - 5I_3 + 5I_2 = 0$$

$$\Rightarrow -9I_3 + 5I_2 - 6 = 0 \quad ----(3)$$

Solving eqtn (1), (2) and (3)

$$-3I_1 + I_2 + 0.I_3 = -12$$
$$-I_1 + 9I_2 + 5I_3 = 0$$
$$0I_1 + 5I_2 - 9I_3 = 6$$

Solving $I_1 = 4.0377\,A$

$I_2 = 0.113\,A$

$I_3 = -0.60377\,A$

Current flowing through $2\Omega = 4.0377\,A$

Current flowing through $3\Omega = 0.113\,A$

Current flowing through $1\Omega = 3.9247\,A$

Current flowing through $4\Omega = 0.60377\,A$ from lower potential to higher potential of 6V battery

Current flowing through $5\Omega = 0.71677\,A$

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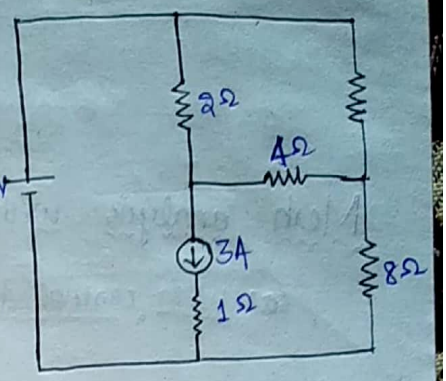
Dt - 21.08.2019

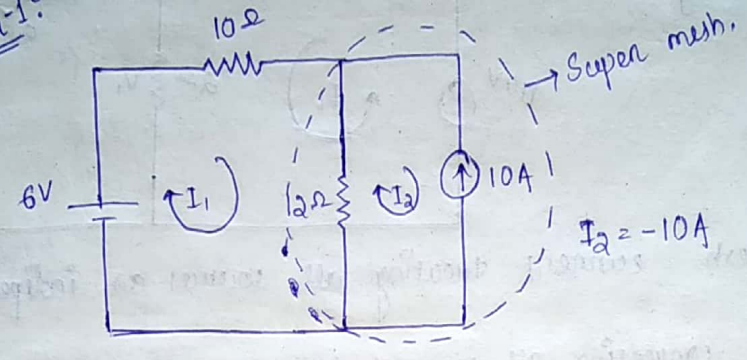
Super mesh :-

- The concept of supermesh is used when a circuit contains current source

- A supermesh is formed by excluding the branch containing a dependent or independent current source connected in common to two meshes and any elements connected in series with it.

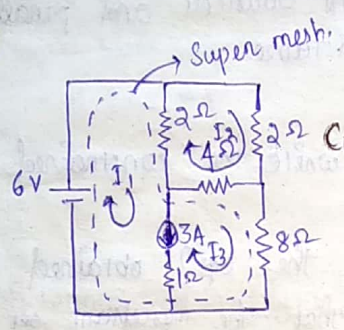


Ex-1:



$I_2 = -10A$

Ex-2



Calculate the branch current through mesh analysis method?

Applying KVL.

$$-2I_2 - 4(I_2 - I_3) - 2(I_2 - I_1) = 0$$

$$-8I_2 + 4I_3 + 2I_1 = 0 \quad ----(1)$$

~~Again~~

~~$-4(I_3 - I_2) - 8I_3 - (I_3 - I_1)$~~

Apply KVL to super mesh.

$$6 - 2(I_1 - I_2) - 4(I_3 - I_2) - 8I_3 = 0$$

$$\Rightarrow -2I_1 + 6I_2 - 12I_3 = -6 \quad ----(2)$$

Apply KCL $3 + I_3 = I_1$

$$\Rightarrow I_1 - I_3 = 3$$

$$\Rightarrow I_1 + 0I_2 - I_3 = 3 \quad ----(3)$$

$I_1 = 3.47A$

$I_2 = 1.1A$

$I_3 = 0.47A$.

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Current flowing through $3\Omega = I_1 - I_2 = 2.32A$

$1\Omega = 0.68A$

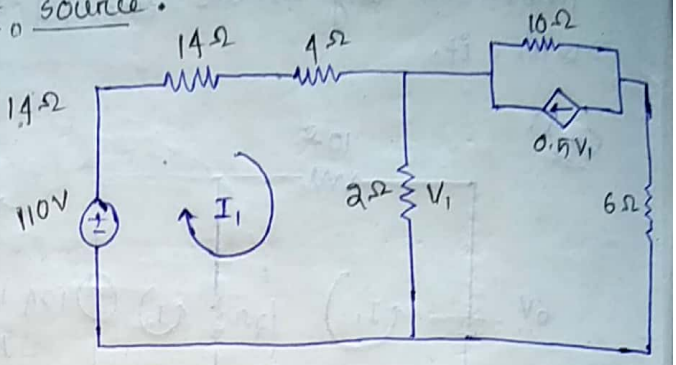
$2\Omega = 1.15A$

Dt - 27.08.2019.

Mesh analysis with controlled source :-

(a) With controlled current source :

(Q) Find current through the 14Ω and 6Ω?



~~Soln~~

Step-1

Write the mesh current treating all sources as independent sources.

- This step includes converting all current sources and parallel resistance to voltage sources and series resistance

Step-2

Identify the controlled sources and write the constrained equation.

Step-3

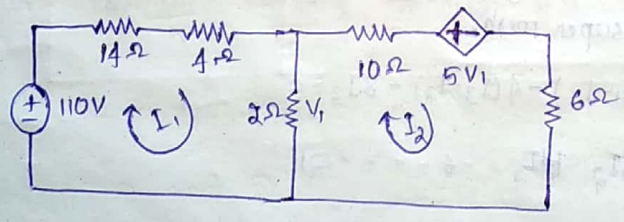
Combine the constrained eqtn with the eqtn obtained in step-1, rearranging terms where necessary, so that the resultant set of equation is in a form convinient for soln.

Step-4

Solve the eqtns and write down the branch currents.

Soln :-

Step-1



Applying KVL

$$110V - 14I_1 - 4I_1 - 2(I_1 - I_2) = 0$$

$$\Rightarrow 110V - 20I_1 + 2I_2 = 0$$

$$\Rightarrow 10I_1 - I_2 = 55 \quad ---- \quad (1)$$

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Again applying KVL

$$-10I_2 - 5V_1 - 6I_2 - 2(I_2 - I_1) = 0$$

$$\Rightarrow -18I_2 + 2I_1 = 5V_1 \quad ---- (2)$$

Step-2

Write constrained eqtn

$$(I_1 - I_2)2 = V_1 \quad --- (3)$$

Step-3

$$2I_1 - 18I_2 = 5(I_1 - I_2)2$$

$$\Rightarrow -8I_1 - 8I_2 = 0$$

$$\Rightarrow I_1 + I_2 = 0 \quad ---- (4)$$

Step-4

Solving eqtn (3) and (4)

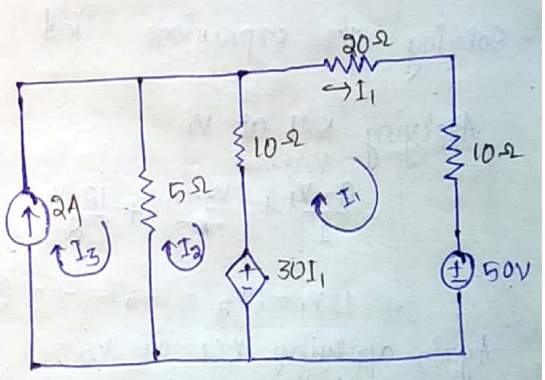
we get

$$11I_1 = 55$$

$$\Rightarrow I_1 = 5A$$

$$\Rightarrow I_2 = -5A.$$

(b) With controlled voltage source :-



$I_3 = 2A$

Q) Find the voltage across 5Ω ?

Soln

Applying KVL for 2nd loop.

$$-10(I_2 - I_1) + 30I_1 - (I_2 - I_3)5 = 0$$

$$\Rightarrow 8I_1 - 3I_2 = -2 \quad ---- (1)$$

Again applying KVL for 1st loop.

$$-30I_1 - 10(I_1 - I_2) - 20I_1 - 10I_1 - 50 = 0$$

$$\Rightarrow -7I_1 + I_2 = 5 \quad ---- (2)$$

Solving eqtn (1) and (2)

$$8I_1 - 3I_2 = -2$$

eqtn (2) × 3 $\quad -21I_1 + 3I_2 = 15$

$$-13I_1 = 13$$

$$I_1 = -1A$$

$$I_2 = -2A$$

voltage across 5Ω = 20 V

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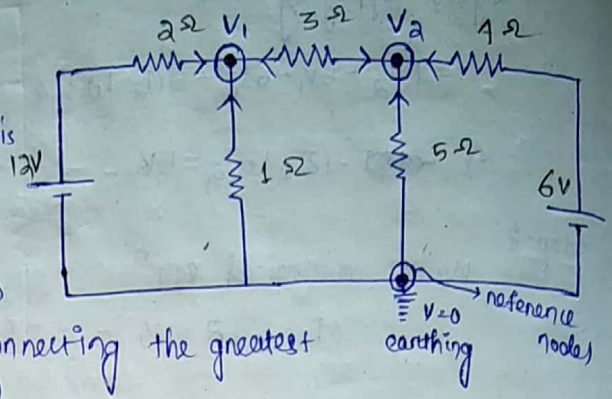
Dt-28.08.2019

Nodal Analysis :-



Step-1

The first step in Nodal Analysis is that we identify all the nodes in the network.

- One of these nodes is taken as reference node (i.e the node connecting the greatest no. of elements)

Step-2

We assume that the reference node is at 0 potential.

Step-3

The node voltages (V_1, V_2, V_3) are measured w.r.t. the reference node

Step-4

We arbitarily assile the current to the branches in which no current is designated. (This method becomes easier if we consider the branch current directed towards the nodes).

Step-5

Apply KCL to find current expressions for each node except the reference node

- Solving the expressions find node voltages and branch current.

Applying KCL at V_1

$$\frac{0-V_1}{1} + \frac{V_2-V_1}{3} + \frac{12-V_1}{2} = 0$$

$$\Rightarrow 11V_1 - 2V_2 = 36 \quad --- (1)$$

Again applying KCL at V_2

$$\frac{V_1-V_2}{3} + \frac{0-V_2}{5} + \frac{6-V_2}{5} = 0$$

$$\Rightarrow 20V_1 - 47V_2 = -90 \quad ---- (2)$$

Solving eqn (1) and (2)

we get $V_1 = 3.92V$

$V_2 = 3.59V$

So current through $2\Omega = 4.01A$

Current through $1\Omega = -3.92A \doteq 3.92A$ (opposite to our assumption)

Current through $3\Omega = 0.11A$ (i.e from 1st to 2nd node)

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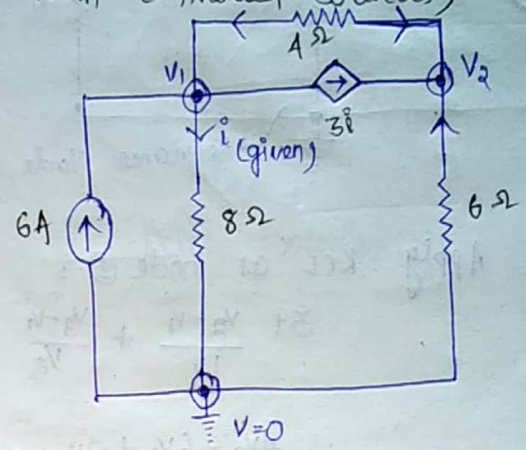
Current through $4\Omega = 0.6025A$

Current through $5\Omega = -0.7164A$

$= 0.7164A$ (opposite to our assumption)

Problem-3 (Nodal Analysis with controlled sources)



Applying KCL at V_1

$$6 - i - 3i + \frac{V_2 - V_1}{4} = 0$$

$$\Rightarrow 6 - \frac{V_1}{8} - \frac{3V_1}{8} + \frac{V_2 - V_1}{4} = 0$$

Applying KCL at V_2

$$3i + \frac{V_1 - V_2}{4} + \frac{0 - V_2}{6} = 0$$

$$\Rightarrow \frac{3V_1}{8} + \frac{V_1 - V_2}{4} + \frac{-V_2}{6} = 0$$

$$i = \frac{V_1 - 0}{8} = \frac{V_1}{8}$$

$$-6V_1 + 2V_2 + 48 = 0 \text{ ---- } (1)$$

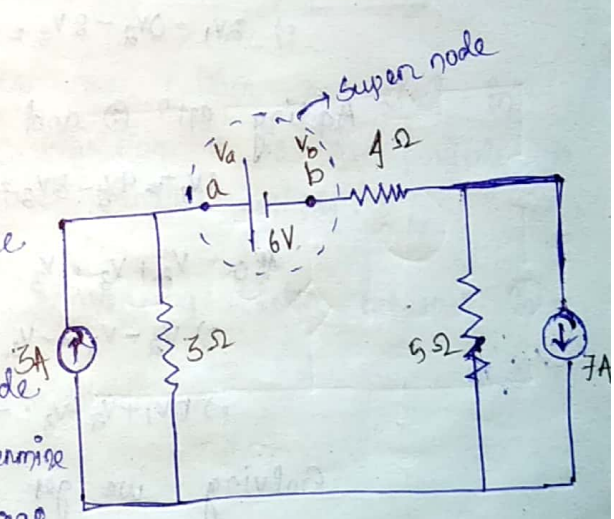
$$15V_1 - 10V_2 = 0 \text{ ------ } (2)$$

Solving eqn (1) and (2) we get

$V_1 = 16$ Volt

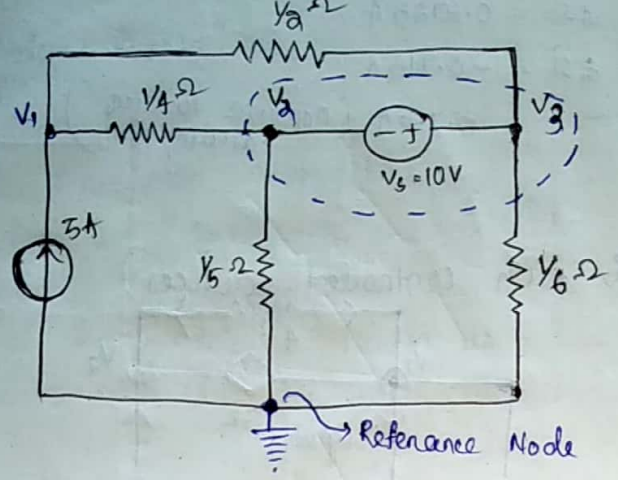
$V_2 = 24$ volt

Supernode :-



- It is related to voltage source
- Two ends of a voltage source cannot make two independent node
- One node voltage can be determine in terms of other node voltage an source voltage, Hence we treat these end nodes and two voltage source together as a super node

(Q)



Determine node voltage by nodal analysis?

Sol^n

Apply KCL at node ①:

$$3 + \frac{V_2 - V_1}{1/4} + \frac{V_3 - V_1}{1/2} = 0$$

$$\Rightarrow 4V_2 - 6V_1 + 2V_3 = -3 \quad ---- (1)$$

Applying KCL at node - ②

$$\frac{0 - V_2}{1/5} + \frac{V_1 - V_2}{1/4} - I_s = 0$$

$$\Rightarrow 4V_1 - 9V_2 = I_s \quad ---- (2)$$

Apply KCL at node ③

$$I_s + \frac{0 - V_3}{1/6} + \frac{V_1 - V_3}{1/2} = 0$$

$$\Rightarrow 2V_1 - 0V_2 - 8V_3 = -I_s \quad ---- (3)$$

Adding eqt^n ② and ③

$$6V_1 - 9V_2 - 8V_3 = 0 \quad ---- (4)$$

Also $V_2 + V_3 = V_s$

$$\Rightarrow V_2 - V_3 = -V_s$$

$$\Rightarrow 0V_1 + V_2 - V_3 = -10 \quad --- (5)$$

Solving we get

$$V_1 = -1.54\,V$$

$$V_2 = -5.18\,V$$

$$V_3 = 4.81\,V$$

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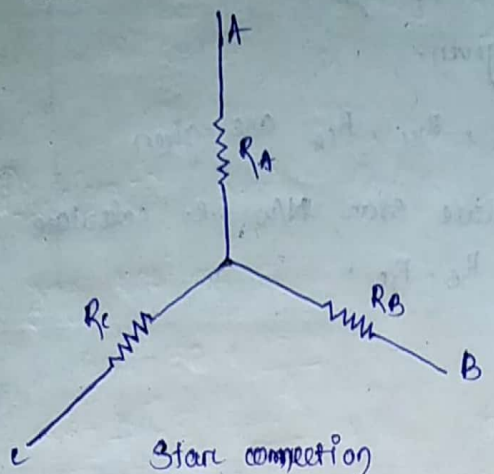
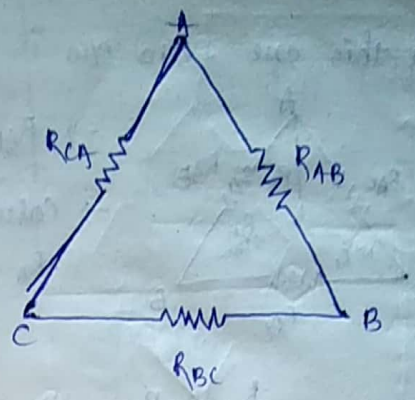
Star and Delta Conversion :-

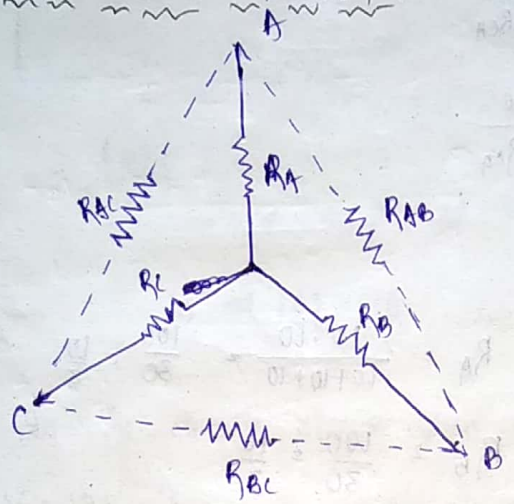


Star connection



Delta connection.

Star - Delta Conversion :-

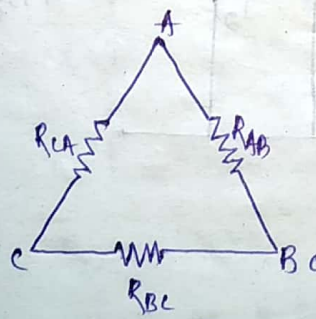


$$R_{AB} = R_A + R_B + \frac{R_A \cdot R_B}{R_C}$$

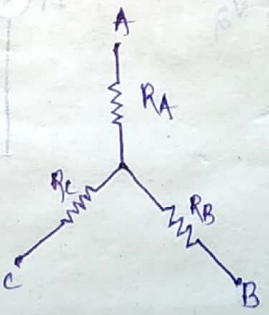
$$R_{BC} = R_B + R_C + \frac{R_B R_C}{R_A}$$

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

- In electric networks resistances are neither connected in series nor in parallel. In this situation it is not possible to simplify the circuit by series and parallel methods.
- The network can be simplified converting delta network into star network and vice versa.



Delta N/W



Star N/W

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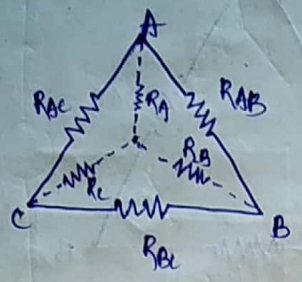
Convert Delta to Star :-

In this case Delta n/w is given.



→ R_{AB}, R_{BC}, R_{CA} are given

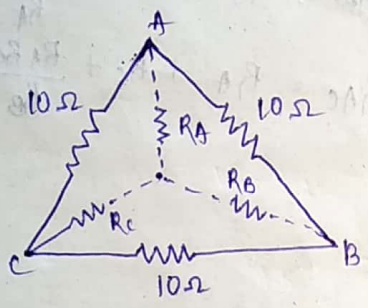
→ Calculate star n/w i.e. calculate R_A, R_B, R_C.

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

$$R_B = \frac{R_{AB} \cdot R_{BC}}{R_{AB} + R_{BC} + R_{CA}}$$

$$R_C = \frac{R_{CA} \cdot R_{BC}}{R_{AB} + R_{BC} + R_{CA}}$$

(Q)

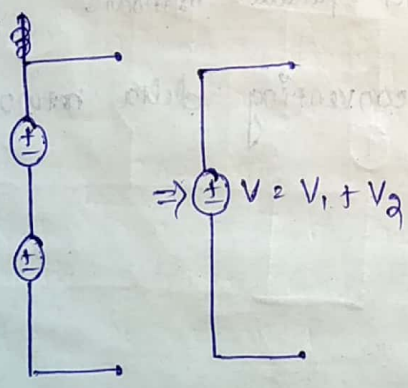


$$R_A = \frac{10 \cdot 10}{10+10+10} = \frac{100}{30} = \frac{10}{3}$$

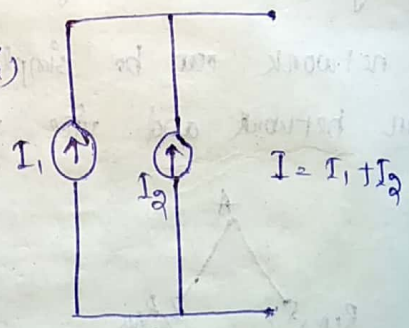
$$R_B = \frac{100}{30} = \frac{10}{3}$$

$$R_C = \frac{100}{30} = \frac{10}{3}$$

(i)



(ii)



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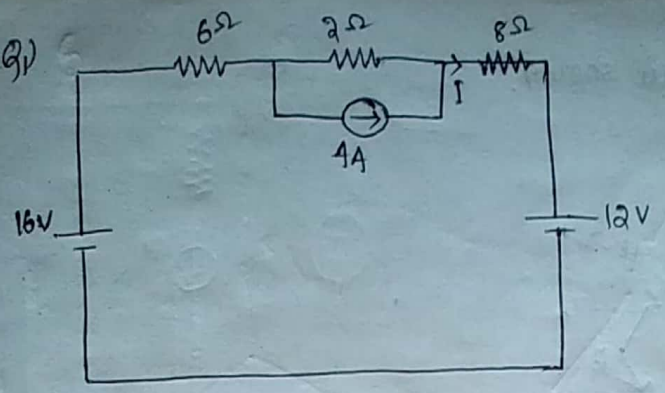
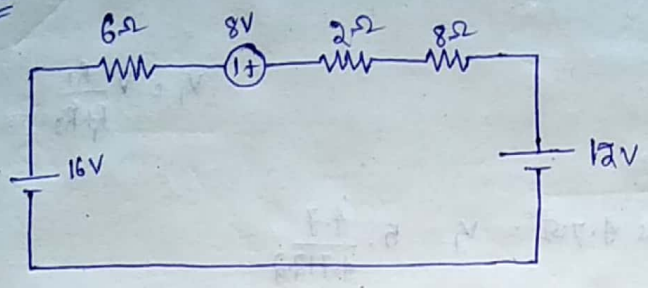
(Q) 

Calculate I ?

Sol^n

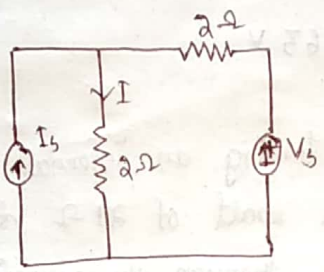


Apply KVL

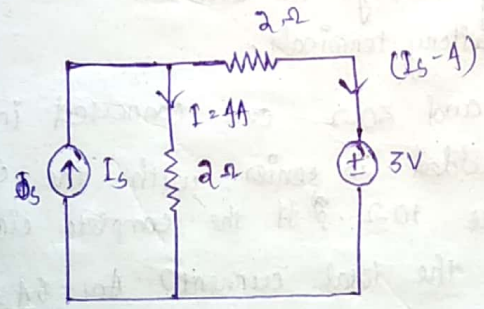
$$16 - 6I + 8 - 2I - 8I - 12 = 0$$

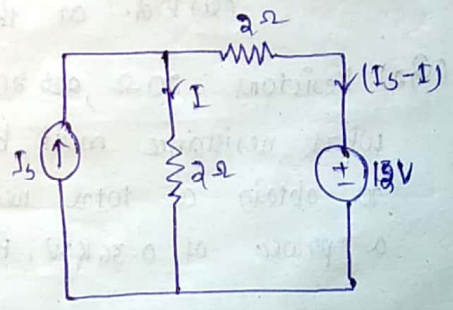
$$\Rightarrow -16I = 12 \quad \Rightarrow I = -\frac{3}{4}$$

(Q) In the circuit shown when $V_s = 3V$, $I = 4A$ calculate I, when $V_s = 12V$?



Sol^n





Apply KVL

$$-3 - 2(I_s - 4) + 8 = 0$$

$$\Rightarrow I_s = \frac{13}{2}$$

Apply KVL

$$-2(I_s - I) - 12 + 2I = 0$$

$$\Rightarrow -13 + 2I - 12 + 2I = 0$$

$$\Rightarrow 4I = 25$$

$$\Rightarrow I = \frac{25}{4} = 6.25\,A$$

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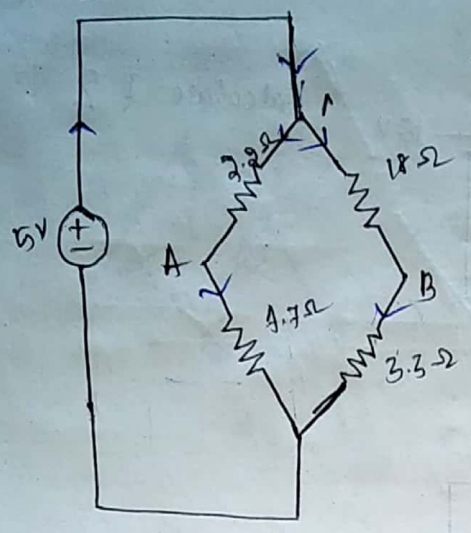
(Q) Find V_{AB} in the circuit shown?



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

Soln

Voltage across $4.7\Omega = V_1 = 5 \cdot \frac{4.7}{4.7+2.2}$

$= 3.4\ V$

voltage across 3.3Ω $V_3 = 5 \cdot \frac{3.3}{3.3+18}$

$= 0.77\ V$

$V_1 - V_{AB} - V_2 = 0$

$V_{AB} = 2.63\ V$

(Q1) Ten 2.2 volt cells, is having an internal resistance 0.1Ω are connected in series to a load of 21Ω determine
(i) Current flowing through the circuit.
(ii) P.d. at the battery terminals.

(Q2) Resistors 20Ω, 20Ω and 30Ω are connected in parallel what resistance must be added in series with the combination to obtain a total resistance 10Ω. If the complete circuit expands a power of 0.36 KW. Find the total current? Ans = 6A.

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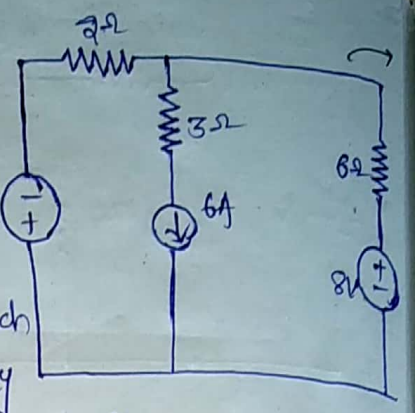
Super position Theorem :-

Statement :-



It states that in a linear bilateral network containing 'n' sources, each branch current (or branch voltage) is the algebric sum of 'n' currents (or branch voltages) each of which is determined by considering one source at a time and removing all other sources.

- In removing the sources, voltage sources an short circuited (or replaced by resistance for non ideal sources) while the ideal current sources are open circuited.

Procedure :-

Step-1

Take only one independent source and deactive the other Independent sources.

- For voltage sources, remove the source and short circuit the respective circuit and for current sources, just delete the source keeping the respective circuit open. Then calculate branch currents

Step-2

Repeat the above step for each of the independent sources.

Step-3

Determine the branch current just add the current obtaining in above steps.

Step-4

If the currents are in same direct' then just add them if the currents are directed opposite substract them.

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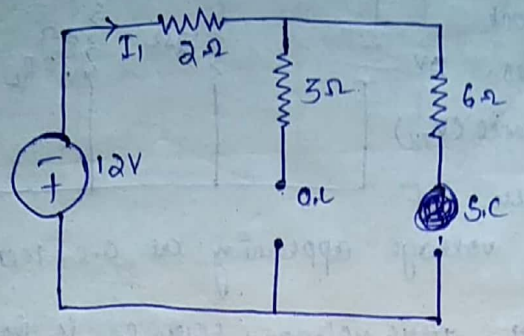
(Q) Find the current through 2Ω ?

Step-1 consider 12V and deactive the other sources.

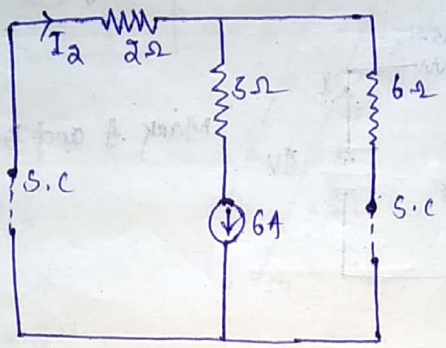


Apply KVL

$-12 - 2I_1 - 6I_1 = 0$

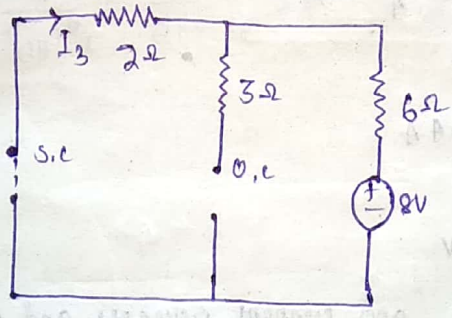
$\Rightarrow I_1 = 1.5A$

Step-2 Consider 6A and deactive the other sources.



$I_2 = 6 \times \frac{6}{2+6} = 4.5A$

Step-3 Consider 8V voltage and deactive the other sources.



Apply KVL

$-2I_3 - 6I_3 - 8 = 0$

$\Rightarrow I_3 = -1A$

Step-4

Current in 2Ω $= I_1 + I_2 + I_3$

$= -1.5 + 4.5 + (-1)$

$= 2A$

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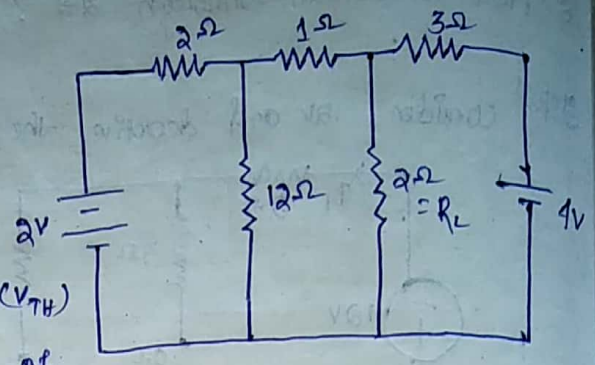
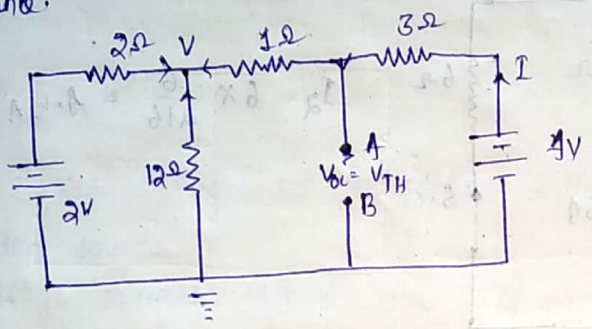
Thevenin's Theorem :-



It states that any two terminals of an active network ~~maybe~~ may be represented by a series combination of a voltage source (V_{TH}) and a resistor (R_{TH}). The value of this equivalent voltage source is the voltage appearing at o.c terminals.

- The value of the equivalent ~~this voltage source is the voltag~~ resistance is equal to the resistance seen looking back into the network with all energy sources replaced by their internal resistance.

Step-1



Mark A and B with V_{TH}

Step-2 Applying Nodal analysis on mesh analysis calculate V_{TH}

So

at V, $\frac{2-V}{2} + \frac{0-V}{12} + \frac{4-V}{4} = 0$

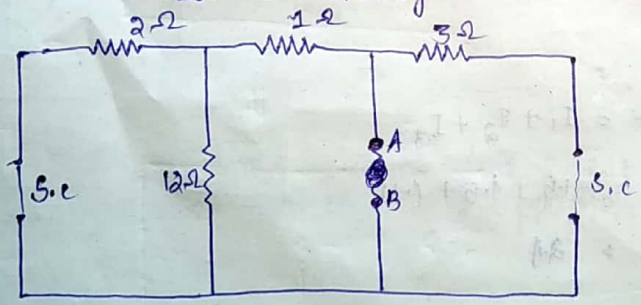
$\Rightarrow V = 2.4V$

$I = \frac{4-2.4}{4} = 0.4A$

$4 - 3I - V_{TH} = 0$

$\Rightarrow V_{TH} = 2.8V$

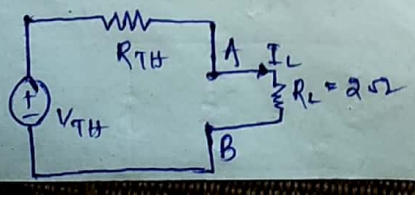
Step-3 Remove all the voltage and current sources and calculate R_{TH}.



$R_{TH} = [(2 \| 12) + 1] \| 3$

$R_{TH} = 1.426\,\Omega$

Step-4 Draw the Thevenin's equivalent diagram and calculate I_L and replace R_L in the circuit.



$I_L = \frac{V_{TH}}{R_{TH} + R_L} = \frac{2.8}{1.426 + 2} = 0.8187A$

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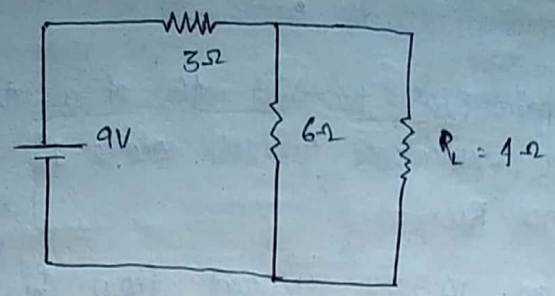
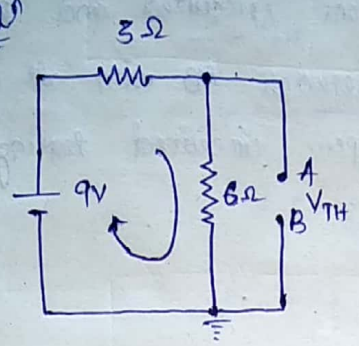
(Q) Calculate the current flowing through load resistance 1Ω as shown in figure?



Soln



$9 - 3I - 6I = 0$

$I = 1\,A$

$6I - V_{TH} = 0$

$\Rightarrow V_{TH} = 6\,V$

$R_{TH} = 2\Omega$

$I_L = \frac{V_{TH}}{R_{TH}+R_L} = \frac{6}{2+1} = 1A$

$\frac{9-V}{3} + \frac{0}{6} = 0$

$\Rightarrow 18 - 3V + V = 0$

$\Rightarrow V = 18\,V$

$I = 3A$

$-V_{TH} - 6I = 0$

$\Rightarrow V_{TH} = -18$

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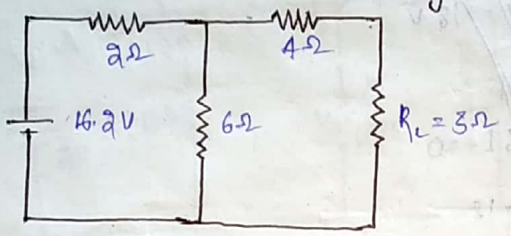
Norton's Theorem :-

Statement :-

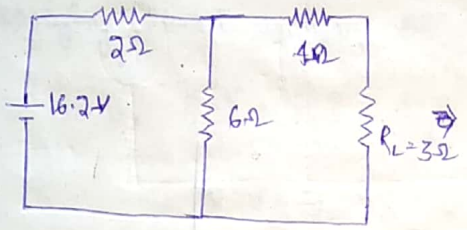
It states that any pair of terminal AB of a network may be replaced by an equivalent current source I_N in parallel with an equivalent resistance R_N.

- The value of I_n is equal to the current flow from A to B when the terminals A and B are short circuited and R_N is the equivalent resistance looking at the network AB with all voltage sources shorted and current sources open circuited leaving their open circuited.

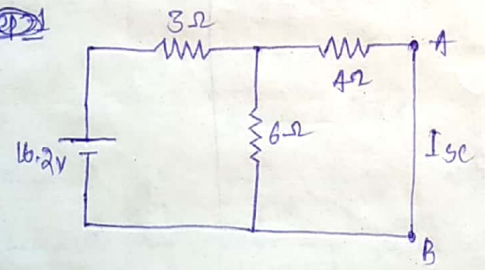
(Q) Find the load current through R_L ?



Soln



Step 1

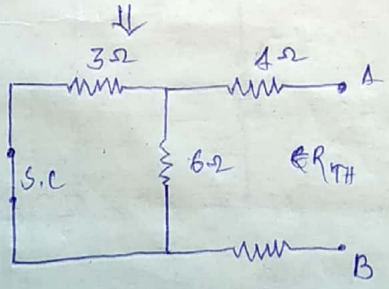


$R = 5.4\Omega$

$I = \frac{16.2}{(6\|4)+3} = 3A$

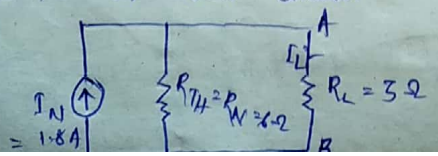
$I_{SC} = 3 \times \frac{6}{6+4} = 1.8A$

(Current division rule)



$R_{TH} = (3\|6) + 4 = 6\Omega$

Norton's equivalent circuit



$I_L = 1.8 \times \frac{6}{(6+3)} = 1.2$

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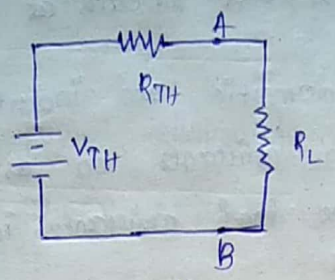
Maximum Power Transfer Theorem :-

Statement :- It states that maximum power is absorved from a network when load resistance (R_L) is equal to the output resistance of the network (R_{TH}) as seen from the terminals of the load.

Proof



$$I = \frac{V_{TH}}{R_{TH}+R_L}$$

$$P = I^2 R_L$$

$$\Rightarrow P = \left(\frac{V_{TH}}{R_{TH}+R_L}\right)^2 R_L = \frac{V_{TH}^2 \cdot R_L}{(R_{TH}+R_L)^2}$$

$$\frac{dP}{dR_L} = \frac{(R_{TH}+R_L)^2 \cdot V_{TH}^2 - V_{TH}^2 R_L \cdot 2(R_{TH}+R_L)}{(R_{TH}+R_L)^4}$$

For maximum power, put $\frac{dP}{dR_L} = 0$

$$\frac{(R_{TH}+R_L)^2 \cdot V_{TH}^2 - V_{TH}^2 R_L \cdot 2(R_{TH}+R_L)}{(R_{TH}+R_L)^4} = 0$$

$$\Rightarrow R_{TH} = R_L$$

Maximum power (P_{max})

We know

$$I = \frac{V_{Th}}{R_{Th}+R_L}$$

For maximum power

$$R_{Th} = R_L$$

$$\text{So } P_{max} = I^2 R_L = \frac{V_{Th}^2}{(R_{Th}+R_L)^2} R_L$$

$$P_{max} = \frac{V_{Th}^2}{4R_L} \quad \text{------(1)}$$

efficiency under max^m power transfer condition

$$\text{efficiency} = \frac{O/P}{I/P} \times 100$$

$$= \frac{\frac{V_{Th}^2}{4R_L}}{\frac{V_{Th}^2}{2R_L}} \times 100 = 50\%$$

$$\text{Power delivered by source} = V_{Th} I = V\left(\frac{V_{Th}}{R_{Th}+R_L}\right) = \frac{V_{Th}^2}{2R_L} \text{ ------}$$

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(Q) From a source of open circuit voltage of 10V & resistance 5Ω. How much max power can be drawn?

$V_{TH} = 10V \quad R_L = 5\Omega$

$$P_{max} = \frac{V_{TH}^2}{R_L \times 4} = \frac{(10)^2}{5 \times 4} = \frac{100}{20} = 5 \text{ Watt}$$

(Q) Is it always possible to operate a circuit at maximum power transfer conditions?

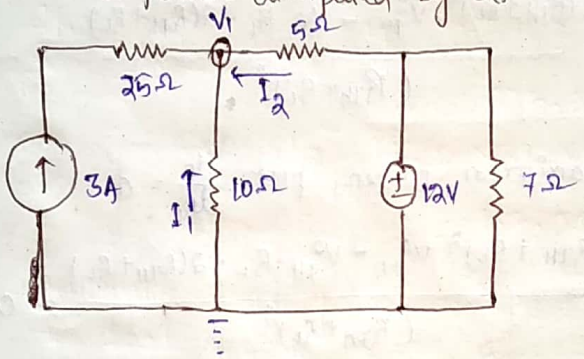
No. For example the domestic and industrial power supplies have very low source resistance so as to provide good voltage regulation. If the load resistance is also low, high current will flow.

(Q1) For the circuit shown find the

(a) Current I_1 and I_2

(b) Power delibered by 3A current source and 12 volt voltage source

(c) Total power dissipated by ckt.



Soln

(i) Apply KCL at 1st node.

$$3 + \frac{0 - V_1}{10} + \frac{12 - V_1}{5} = 0$$

$\Rightarrow V_1 = 18V$

$I_1 = \frac{0 - V_1}{10} = -1.8A$ (i.e. opposite to our assumption.)

$I_2 = \frac{12 - V_1}{5} = -1.2A$ (i.e. opposite to our assumption)

(ii) Voltage across 3A source is

$V_2 = 18 + (3 \times 25) = 93V$

Power delivered by 3A source

$P_1 = V \cdot I = 93 \cdot 3 = 279$ Watt

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Current across 12V source

$= -1.2 + \frac{12}{7} = 0.51A$

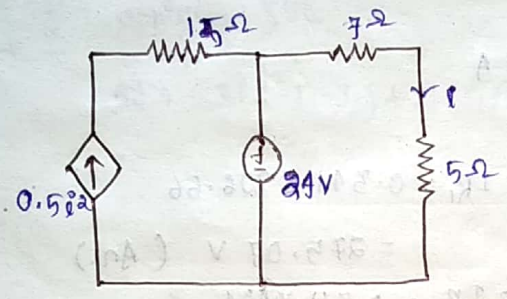
Power supplied 12V source

$P_2 = VI = 12V \times 0.51 = 6.12$

(iii) Total power dissipated

$P = P_1 + P_2 = 285.12$.

(Q) Determine the power delivered by the dependant source as shown in circuit?



Soln

$i = \frac{24}{7+5} = 2A$

Current of dependant source $= 0.5 i_2$

$= 2A$

Let V_D = voltage across the dependant source.

Apply KVL

$V_D - 15 \times 2 - 24 = 0$

$\Rightarrow V_D = 54V$

Power delivered by dependant source $= VI = 54 \cdot 2 = 108$ Watt

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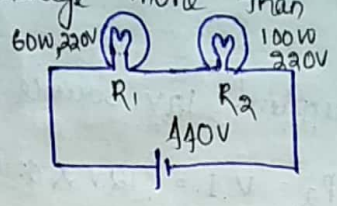
(Q) A 60 watt, 220V lamp is connected in series with a 100 watt, 220 V lamp and a series connection is connected across 440 V supply. Which lamp experiences a voltage more than its rated value?



$$P = \frac{V^2}{R}$$

$$R_1 = \frac{V^2}{P} = \frac{(220)^2}{60} = 806.66\ \Omega$$

$$R_2 = \frac{V^2}{P_2} = \frac{(220)^2}{100} = 484\ \Omega$$

$$R = R_1 + R_2 = 806.66 + 484 = 1290.66\ \Omega$$

$$V = 440V$$

$$I = \frac{V}{R} = \frac{440}{1290.66} = 0.341\ A$$

$$V_1 = IR_1 = 0.341 \times 806.66$$

$$= 275.07\ V \quad (\text{Ans})$$

$$V_2 = IR_2 = 0.341 \times 484$$

$$= 165.044\ V$$

(Q) A 24V automatic battery is connected to two head light such that the load are in parallel. Each of head light is intended to be a 75W load, however a 100W head light is mistakenly installed. What are the resistance of each head light and total resistance seen by the battery?

$$R_1 = \frac{V^2}{P_1} = \frac{(24)^2}{75} = 7.68$$

$$R_2 = \frac{V^2}{P_2} = \frac{(24)^2}{100} = 5.76$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{3.29}\ \Omega$$

$$R_{eq} = 3.29\ \Omega$$

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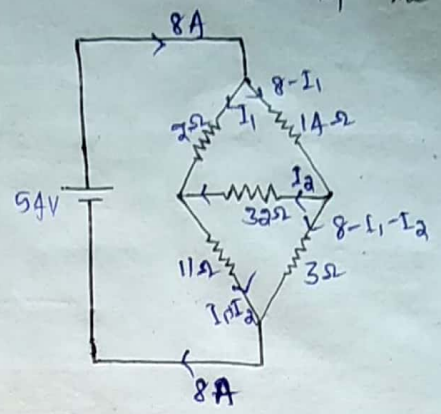
(Q) For the bridge shown in the circuit find the current in each resistor?



Sol^n Apply KVL in 1st Loop

$$-(8-I_1)14 - 32I_2 + 2I_1 = 0$$

Again applying KVL

$$32\Omega - 3(8-I_1-I_2) + 11(I_1+I_2) = 0$$

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Dt - 10.09.2019

-: TRANSIENT :-

When electric circuit containing resistance only is switched on, electric current acquires its max^m value almost in 0 time.

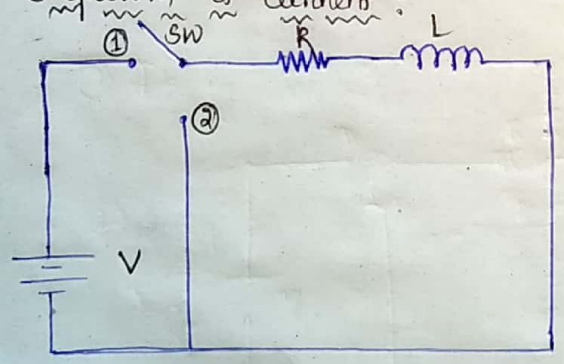
- When electric circuit contains inductor or capacitor, the growth as well as decay of current are opposed by EMF induced.
- Therefore current takes some finite time to reach its max^m value when circuit is switched on. Simillarily when the circuit is switched off the current takes some finite time to decay to 0 value
- Electric current which varies for a small finite time while going from 0 to max^m value or decaying from max^m value to 0 value are called transient current.
- Transient elements are inductor (L) and capacitor (C).
- Inductor and capacitor are energy storing element. Hence they produce transient.

Note :-

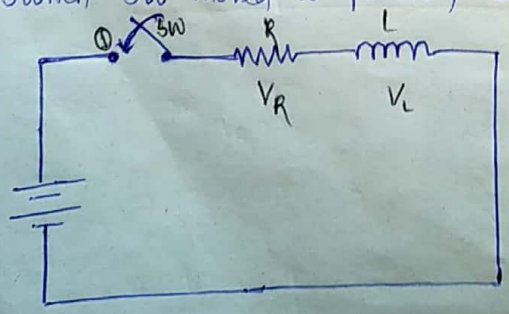
1. If a circuit carries R and L it is called single energy transient. (1st order circuit)
2. If a circuit carries R and C it is called single energy transient.
3. If a circuit carries R, L and C it is called double energy transient. (2nd order circuit)

1. C. Steady State Solutions of R.L Circuit :-

1 Growth of Current :



→ When switch SW moved to position - 1



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When switch SW moves to position ① then current grows in R-L circuit.

- Due to self induction EMF is setup, this EMF opposes the growth of current, so current rises gradually and it takes a definite time to reach its maximum value this time is called transient time

- Let
  I = Instantaneous transient current

Apply KVL,

$$IR + L\cdot\frac{dI}{dt} = V$$

$$\Rightarrow \frac{dI}{dt} + I\frac{R}{L} = \frac{V}{L} \quad \text{------} ①$$

$$I = e^{-\frac{R}{L}t}\int e^{R/L\cdot t}\cdot\frac{V}{L}\,dt + Ke^{-\frac{R}{L}\cdot t}$$

$$\Rightarrow I = e^{-\frac{R}{L}t}\cdot\frac{V}{L}\cdot\frac{e^{R/L\cdot t}}{\frac{R}{L}} + Ke^{-\frac{R}{L}\cdot t}$$

$$\Rightarrow I = e^{-\frac{R}{L}t}\frac{V}{R}e^{\frac{R}{L}t} + Ke^{-\frac{R}{L}t}$$

$$\Rightarrow I = \frac{V}{R} + Ke^{-\frac{R}{L}t} \quad \text{------} ②$$

At $t=0$, Current $I=0$

So

$$0 = \frac{V}{R} + Ke^{0} \quad \Big|\ K = \text{constant}$$

$$\Rightarrow K = \frac{-V}{R}$$

- Eqtn (2) becomes

$$I = \frac{V}{R} - \frac{V}{R}e^{-\frac{R}{L}t}$$

$$\Rightarrow I = \frac{V}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

$V_R = IR$

$V_L = L\cdot\frac{dI}{dt}$

$\frac{dy}{dx} + ay = 0$, → (Homogeneous)

$y = Ke^{-ax}$

$\frac{dy}{dx} + ay = Q$ (Non homogeneous)

$y = e^{-ax}\int e^{ax}Q\cdot dx + Ke^{-ax}$

Dt - 11.09.2019

- When switch moves to position 1 (i.e. at $t=0$) then inductor behaves as open circuit.
- At, $t=0$ (Switch just closed)

  $V_L = V$, $V_R = 0$
- After some time

  V_R = increases & V_L = Decreases.
- After transient period

  $V_L = 0$ $V_R = V$ $\Big|\ \because V_L = L\frac{dI}{dt}$

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$$I = I_0\left(1 - e^{-\frac{t}{\tau}}\right) \quad ----- (3)$$

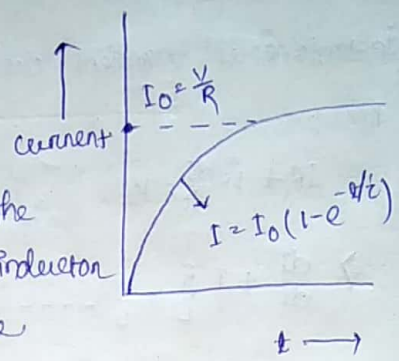
where

$$\tau = \frac{L}{R} = \text{time constant}$$

Definition of 'τ' :-

If $t = \tau$ then

$$I = I_0(1 - e^{-1}) = 0.63 I_0$$



The time constant is defined as the time during which current in a inductor rises 63.2% of its maximum value

- During transient period

$$V_R = IR = I_0\left(1 - e^{-t/\tau}\right) \times R$$

$$= \frac{V}{R}\left(1 - e^{-t/\tau}\right) \times R$$

$$= V\left(1 - e^{-t/\tau}\right)$$

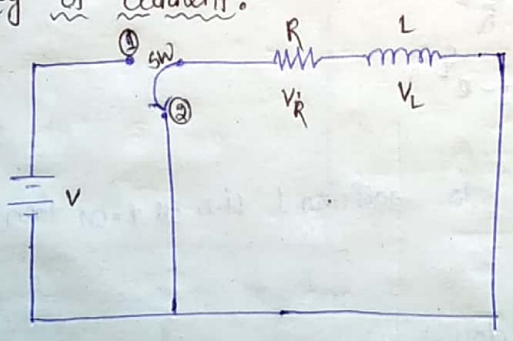
- During transient period

$$V_L = L\frac{dI}{dt} = L\frac{d}{dt}\left[\frac{V}{R}\left(1 - e^{-t/\tau}\right)\right]$$

$$= L \cdot \frac{V}{R}\left(0 + \frac{R}{L} \cdot e^{-\frac{R}{L}t}\right)$$

$$= Ve^{-\frac{Rt}{L}}$$

② **Decay of current:-**



In this case

$$V_R + V_L = 0$$

$$\Rightarrow IR + L\frac{dI}{dt} = 0$$

$$\Rightarrow \frac{dI}{dt} + I\frac{R}{L} = 0 \quad ------ (1)$$

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$$I = Ke^{-\frac{R}{L}t} \quad \text{----} \quad (2)$$

→ At $t=0$ then $I = \frac{V}{R}$

so $\frac{V}{R} = Ke^{0} = K$

→ Eqtn (2) become,

$$I = \frac{V}{R} e^{-\frac{R}{L}t} = I_0 e^{-t/\tau} \quad \text{------} \quad (3)$$

Eqtn (3). represents instantaneous decay of current.

If $t = \tau$ the

$$i = I_0 e^{-1} = 0.37 I_0$$

Deffinition of 'τ':-

The time constant is define as the time during which the current in an inductor falls to 37% of its maximum value

In this case

$$V_R = IR = I_0 e^{-t/\tau} \times R$$

$$= \frac{V}{R} e^{-t/\tau} \times R$$

$$V_R = Ve^{-t/\tau}$$

In this case

$$V_L = L\frac{di}{dt} = L \cdot \frac{d}{dt}\left(\frac{V}{R} e^{-Rt/L}\right)$$

$$= L \cdot \frac{V}{R} - \frac{R}{L} e^{-Rt/L}$$

$$V_L = -Ve^{-t/\tau}$$

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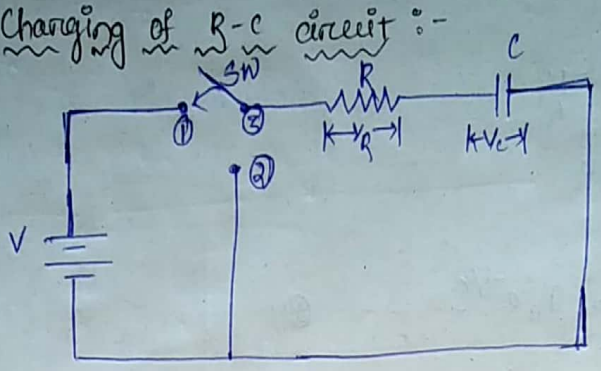
Dt - 13.09.2019

D.C Steady Solution of R-C Circuit :-

(i) Charging of R-C circuit :-



→ When SW moves to position 1 then capacitor behaves as short circuit so maximum current flows through the circuit $(I = \frac{V}{R})$

Here
$V_C = 0$
$V_R = V$

- During transient, let q = charge flows
i = instantaneous current flows = changing current.

→ After transient $V_C = V$ $V_R = 0$

We know that

$V_P = V_R + V_C$

$\Rightarrow V = iR + \frac{1}{C}\int i \cdot dt$ ---- ①

$\because i = \frac{dq}{dt} = \frac{d}{dt}(CV) = C\frac{dV}{dt}$

$\Rightarrow dV = \frac{1}{C} i\, dt$

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

Differenciating the above eqn w.r.t. time t we get

$0 = R\frac{di}{dt} + \frac{i}{C}$

$\Rightarrow \frac{di}{dt} + \frac{1}{RC} i = 0$ ---- ②

Solving eqn ② we get

$i = Ke^{-\frac{t}{RC}}$ --- ③

$\frac{dy}{dx} + ay = 0$

$y = Ke^{-ax}$

$i = y$ $t = x$ $a = \frac{1}{RC}$

$\because K$ is constant whose value can be calculated from initial condition

At $t = 0$,
$i = \frac{V}{R}$

So $\frac{V}{R} = Ke^{-\frac{0}{RC}}$

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

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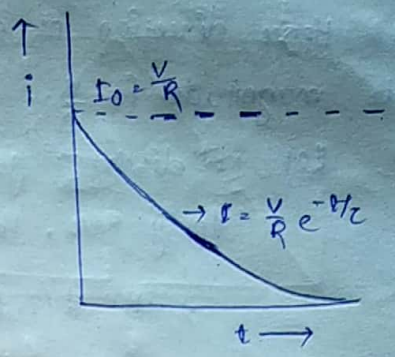
So eqn ③ becomes

$$i = \frac{V}{R} e^{-t/RC}$$

$$\Rightarrow i = \frac{V}{R} e^{-t/\tau} \quad \text{-----} ④$$

$\because \tau = RC$ = time constant.



$$V_R = iR = Ve^{-t/\tau} \quad \text{-----} ⑤$$

$$V_c = \frac{1}{C}\int_0^t i\,dt$$

$$= \frac{1}{C}\int_0^t \frac{V}{R} e^{-t/RC} \cdot dt$$

$$V_c = V(1 - e^{-t/\tau}) \quad \text{-----} ⑥$$

Time constant (τ) =

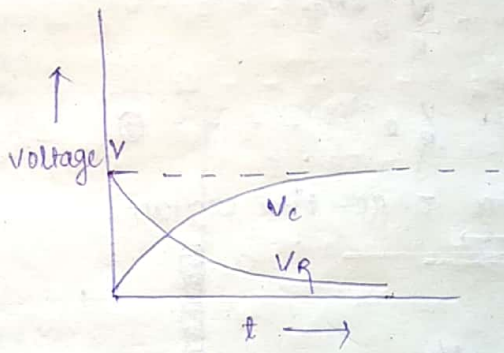
If $t = \tau$ then V_c

$$V_c = V(1 - e^{-1})$$

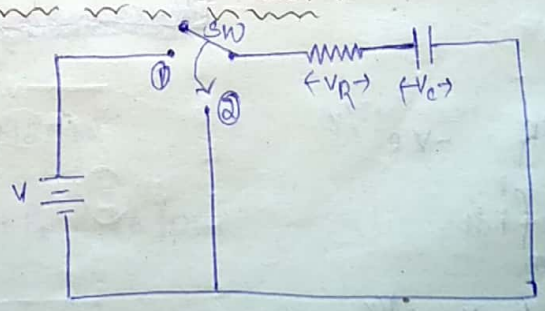
$$= V \times 0.632$$

$$V_c = 0.632\,V$$

Thus time constant is defined as the time required for the voltage of capacitor to attain 63.2% of its steady state value



(ii) Discharging of R-C Circuit :-



When SW moves to the position two then the battery gets disconnected from the circuit.

- The voltage across the capacitor was start discharging current through the resistor in opposite to the original current direct^n.

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Hence direction of current during discharge is negative and its magnitude is $\frac{V}{R}$.

Let i = discharging current.

Apply KVL, $V_R + V_C = 0$

$$\Rightarrow iR + \frac{1}{C}\int i \cdot dt = 0$$

$$\Rightarrow R\frac{di}{dt} + \frac{i}{C} = 0$$

$$\Rightarrow \frac{di}{dt} + \frac{i}{RC} = 0 \quad \text{-----} \quad (1)$$

Solving eqtn (1) we get

$$i = Ke^{-t/RC} \quad \text{-----} \quad (2)$$

where K = constant whose value can be calculated from initial condition.

At $t = 0$, $i = -\frac{V}{R}$

$$-\frac{V}{R} = Ke^{0}$$

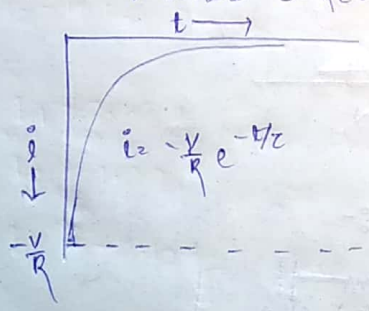
$$\Rightarrow K = -\frac{V}{R}$$

eqtn (2) becomes

$$i = -\frac{V}{R}e^{-t/RC}$$

$$\Rightarrow i = -\frac{V}{R}e^{-t/\tau} \quad \text{-----} \quad (3)$$

$\because$ where $\tau = RC$ = time constant



$$V_R = iR = -Ve^{-t/\tau}$$

$$V_C = \frac{1}{C}\int_0^t i\,dt$$

$$= \frac{1}{C}\int -\frac{V}{R}e^{-t/\tau}\,dt$$

$$V_C = Ve^{-t/\tau}$$

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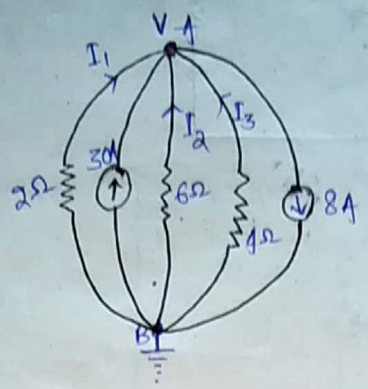
(Q) Calculate the current flowing through 3 resistances 2Ω, 4Ω and 6Ω



Soln

$$\frac{0-V}{2} + 30 + \frac{0-V}{6} + \frac{0-V}{4} - 8 = 0$$

$\Rightarrow V = 24V$

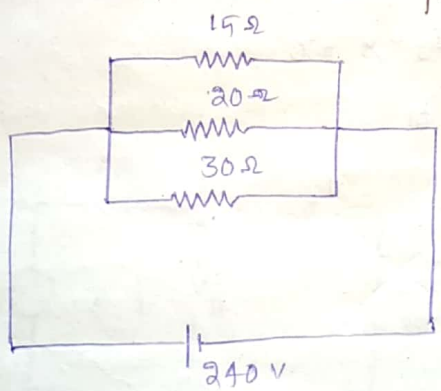
$I_1 = -12A$ (Opposite to our assumption)

$I_2 = -4A$ (" " " ")

$I_3 = -6A$ (" " " ")

(Q) 3 resistors 15Ω, 20Ω & 30Ω are connected in parallel across 240V DC source compute the power dissipated in each resistance and the total power drawn from the source?

Soln



$P_1 = \frac{V^2}{R} = 3840W$

$P_2 = \frac{V^2}{R} = 2880W$

$P_3 = \frac{V^2}{R} = 1920W$

$P = P_1 + P_2 + P_3 = 8640W$

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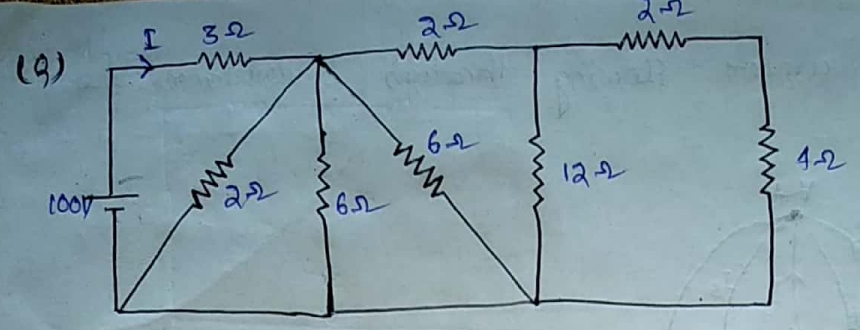
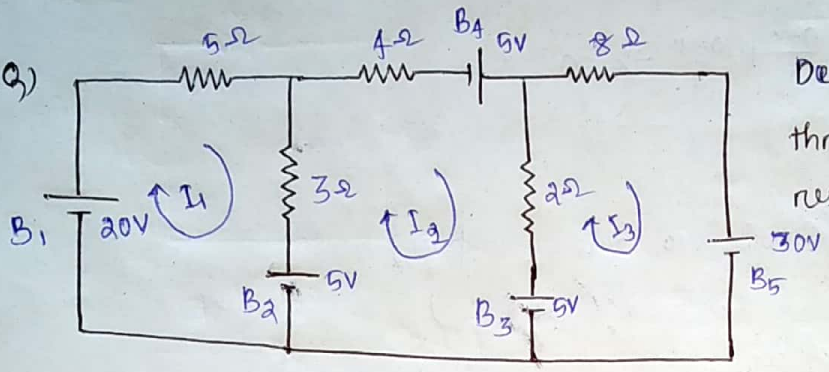
(9)



$R_{eq} = 4\Omega$

$I = \frac{V}{R} = \frac{100V}{4\Omega} = 25A$

(Q)



Determine current flowing through 5Ω, 8Ω, 25Ω resistor in the circuit?

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

$\Rightarrow 8I_1 - 3I_2 = 15$ ---- (1)

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

$\Rightarrow 9I_2 - 3I_1 + 2I_3 = 5$ ---- (2)

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

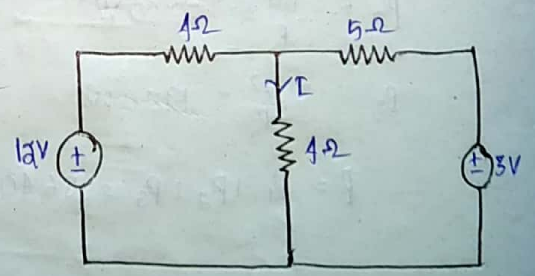
$\Rightarrow 2I_2 - 10I_3 = 25$ ---- (3)

$I_1 = 2.58\ A$

$I_2 = 1.89\ A$

$I_3 = -2.12\ A.$

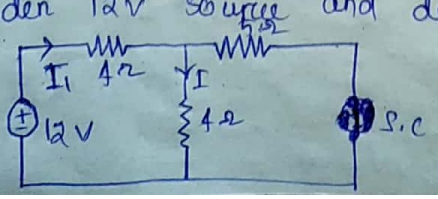
(9) Find 'I' by superposition principle



Soln

Step-1

Consider 12V source and deactive others.



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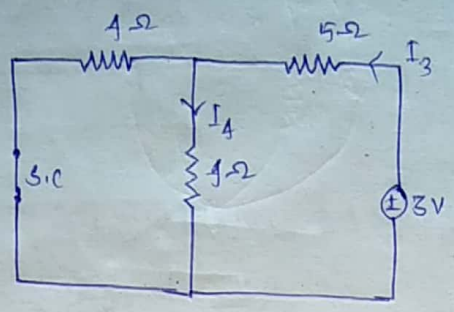
$$I_1 = \frac{12}{4+\left(\frac{5\times4}{5+4}\right)} = 1.93A$$

$$I_2 = 1.93 \times \left(\frac{5}{4+5}\right) =$$

Step-2



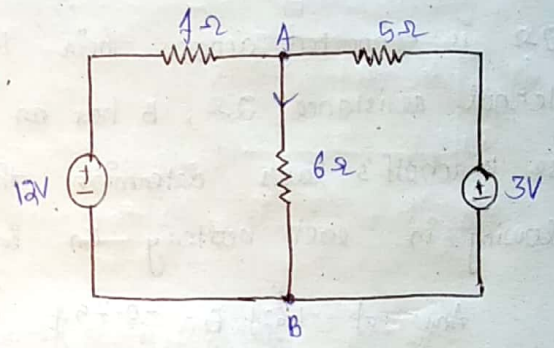
$$I_3 = \frac{3}{5+\left(\frac{4\times4}{4+4}\right)} = 0.43A$$

$$I_4 = 0.43 \times \left(\frac{4}{4+4}\right) = 0.215A$$

Step-3

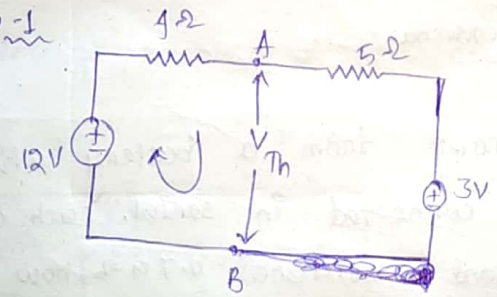
Total current = 1.285 A

(Q) Find 'I' by Thevenin's Theorem.



$R_L = 6\Omega$

Step-1



$12 - 4I - 5I - 3 = 0$

$\Rightarrow 9I = 9$

$\Rightarrow I = 1A$

$12 - V_{Th} - 4I = 0$

$\Rightarrow V_{Th} = 8V$

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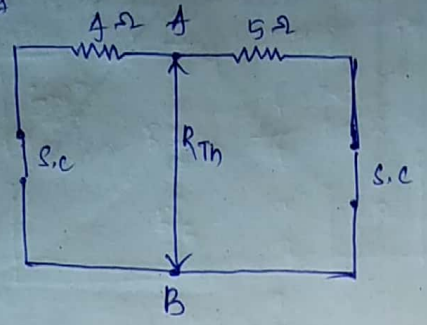
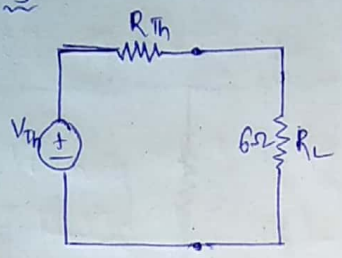
Step-2



$$R_{Th} = \frac{5 \times 4}{5+4} = 2.222\,\Omega$$

Step-3



$$I_L = \frac{V_{Th}}{R_{Th}+R_L} = 0.97\,A$$

(Q1) Two batteries A and B are connected in parallel and load of 10Ω is connected across their terminal. A has an emf 12V and internal resistance 2Ω, B has an emf 8V and internal resistance 1Ω. Use Kirchoff's laws determine the values and directn of current flowing in each battery an in external resistance 10Ω?

Ans- A = -1.62A B = -0.75A external -

(Q2) A stereo sound system is operated from a battery which is made from eight dry cells connected in series. each cell has an emf of 1.5V and internal resistance 0.75Ω how much is the available power from this battery? Ans - 6W

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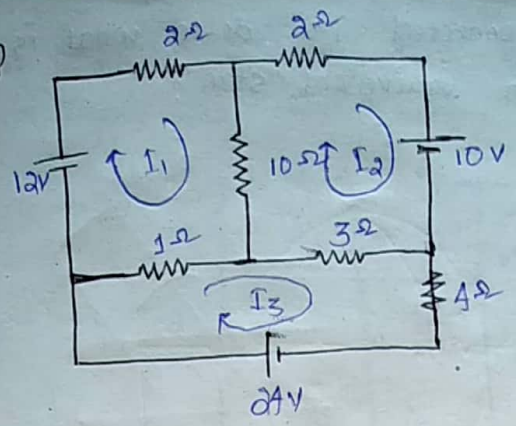
(Q1)



Find current through all resistors and voltage drop across 10Ω using mesh analysis method?

$12 - 2I_1 - 10I_1 + 10I_2 - 1I_1 + 1I_3 = 0$

$\Rightarrow 12 - 13I_1 + 10I_2 + I_3 = 0$

$\Rightarrow 13I_1 - 10I_2 - I_3 = 12$ ---- (1)

$-10I_2 + 10I_1 - 2I_2 - 10 - 3I_2 + 3I_3 = 0$

$\Rightarrow 10I_1 - 15I_2 + 3I_3 = 10$ ---- (2)

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

$\Rightarrow I_1 + 3I_2 - 8I_3 = -24$ ---- (3)

$I_1 = 2.785$ A

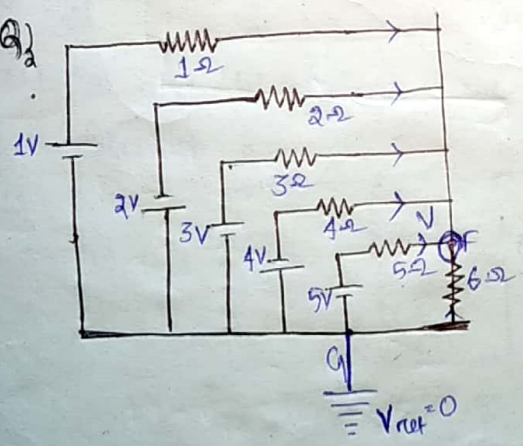
$I_2 = 2.01$ A

$I_3 = 4.10$ A

Voltage drop across 10Ω resistor $= (I_1 - I_2)10$

$= 7.7$ Volts.

(Q2)



Find the potential of node F w.r.t. G?

$\frac{1-V}{1} + \left(\frac{-2-V}{2}\right) + \left(\frac{3-V}{4}\right) + \left(\frac{-4-V}{4}\right) + \left(\frac{5-V}{5}\right) + \left(\frac{0-V}{6}\right) = 0$

$\Rightarrow \frac{60 - 60V - 60 - 30V + 45 - 15V - 60 - 15V + 60 - 12V - 10V}{60} = 0$

$\Rightarrow -142V = -75 \quad \Rightarrow V = 0.53$

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(Q) Three resistances of 3Ω are connected in delta what is the value of resistance is in equivalent star?

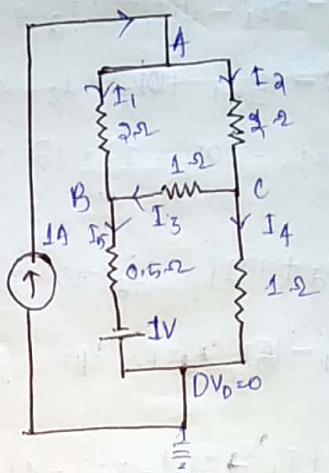
Soln

$$R_A = \frac{9}{9} = 1\,\Omega$$

$$R_B = \frac{9}{9} = 1\,\Omega$$

$$R_3 = \frac{9}{9} = 1\,\Omega$$

(Q) Find the voltages at A, B & C using node voltage equation.



Soln

At node A

$$I_1 + I_2 = 1$$

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

$$\Rightarrow 2V_A - V_B - V_C = 2$$

$$\Rightarrow V_A - 0.5V_B - 0.5V_C = 1 \quad \text{------} \; (1)$$

At node B

$$I_1 + I_3 = I_5$$

$$\Rightarrow \frac{V_A - V_B}{2} + \frac{V_C - V_B}{1} = \frac{V_B + 1 + 0}{0.5}$$

$$\Rightarrow 3V_B - V_A - 2V_C = 4V_B - 4V_D + 4$$

$$\Rightarrow V_A + V_B + 2V_C = 4V_D + 4$$

$$\Rightarrow 0.5V_A + 0.5V_B + V_C = 2V_D + 2$$

$$\Rightarrow V_A - 3V_B + 2V_C = 4V_B + 4$$

$$\Rightarrow -0.5A + 3.5V_B - V_C = -2 \quad \text{---} \; (2)$$

At node C $\quad I_2 = I_3 + I_4$

$$\left(\frac{V_A - V_C}{2}\right) = \left(\frac{V_C - V_B}{1}\right) + \left(\frac{V_C - 0}{1}\right)$$

$$\Rightarrow V_A - V_C = 4V_C - 2V_B$$

$$\Rightarrow V_A - 5V_C + 2V_B = 0$$

$$\Rightarrow 0.5V_A + V_B - 2.5V_C = 0 \quad \text{---} \; (3)$$

Solving eqn (1), (2) & (3)

$$V_A = 0.739V$$

$$V_B = -0.478V$$

$$V_C = -0.043V$$

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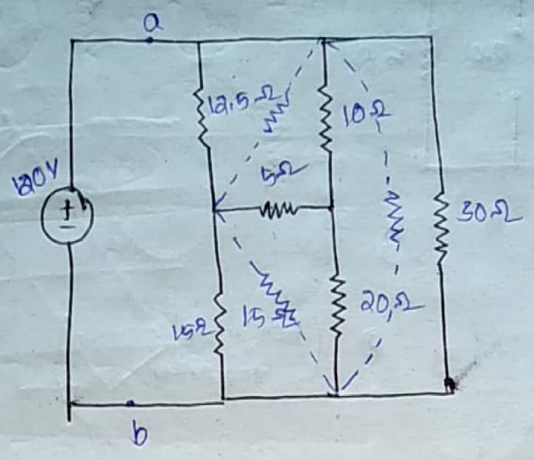
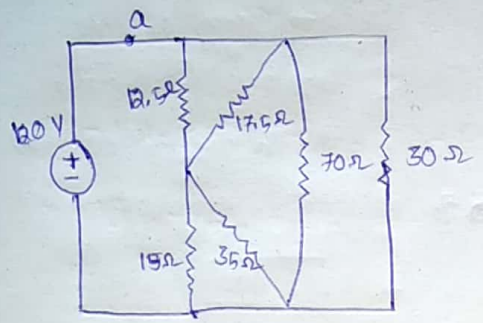
(Q5) Obtain the equivalent resistance R_{ab} for the circuit shown in figure and find current 'i'.





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

$= 17.5\,\Omega$

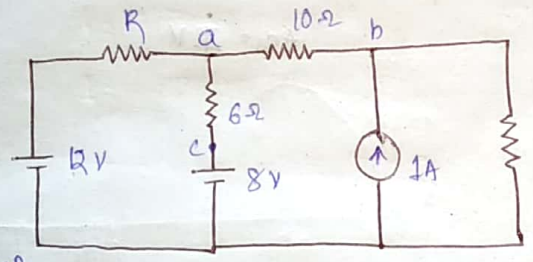
$R_{BC} = 70\,\Omega$

$R_{CA} = 35\,\Omega$

$R_{ab} = 9.756\,\Omega$

$I = \frac{V}{R} = \frac{120}{9.756} = 12.45\,A$

(Q6)

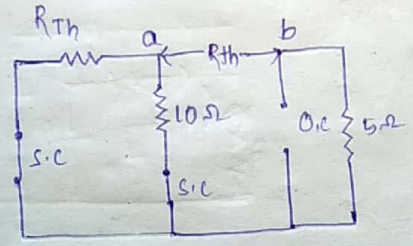


Calculate R that results maximum power transfer to the 10Ω connected between
(i) 'a' and 'b' terminals
(ii) 'a' and 'c' terminals.

Soln

(i) 'a' and 'b' terminals are open

calculate R_{Th}



$$R_{Th} = \left(\frac{10R}{10+R}\right) + 5 \quad \text{---} \; (1)$$

But $R_{Th} = R_L = 10\,\Omega$ --- (2) (For maximum power transfer)

From eqn (1) and (2) we get

$R = 10\,\Omega$

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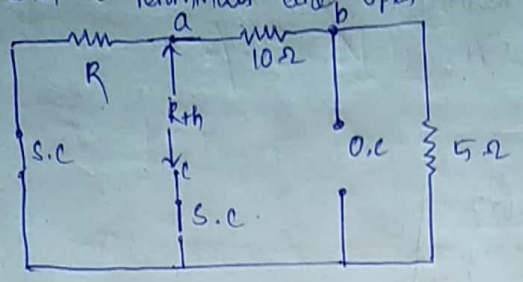
(ii) 'a' and 'c' terminals are open.



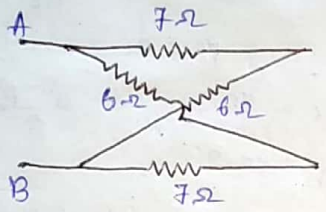
$$R_{Th} = \left(\frac{15R}{15+R}\right) \quad --- \quad (1)$$

But $R_{Th} = R_L = 10\Omega$ --- (2) (For max^m power transfer)

From eqt^n (1) and 2 we get

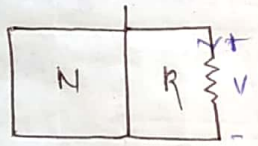
$R = 30\Omega$

(Q6)



$R_{ab} = 6.5\Omega$

(Q6) In the N/W shown



(i) when $R = 10\Omega$ then $V = 20V$

(ii) when $R = 20\Omega$ then $V = 30V$

(iii) when $R = 80\Omega$ then $V = ?$

Ans = 48V

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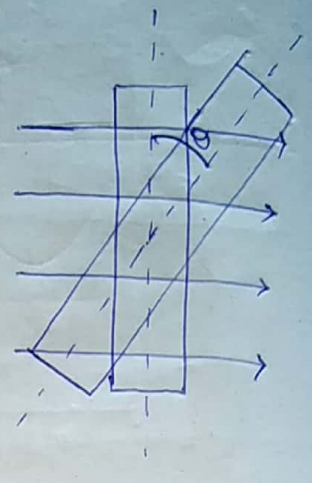
Dt- 17.09.2019

:A.C. Network:-

Generation of A.C:



→ When coil rotates in uniform magnetic field then flux linkages through the coil changes. So emf is induced in the coil It is given by

$$e = -N \cdot \frac{d\phi}{dt}$$

$$\Rightarrow e = -N \cdot \frac{d}{dt}(\vec{B} \cdot \vec{A})$$

($\vec{B}$ → flux density, $\vec{A}$ → Area vector)

$$\Rightarrow e = -N \frac{d}{dt}(BA\cos\theta)$$

$$\Rightarrow e = -N \frac{d}{dt}(BA\cos\omega t)$$

$$\Rightarrow e = NBA\,\omega \sin\omega t \quad \text{-----} (1)$$

l → length of coil

b → breadth of coil

$A = lb$ → Area of coil

$\omega = \frac{\theta}{t}$ = angular velocity of coil

$\boxed{\theta = \omega t}$

emf e = maximum = E_m

when $\sin\omega t$ = maximum = 1

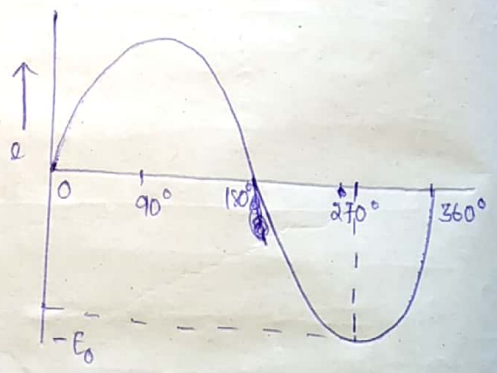
So

$$\boxed{E_m = NBA\omega} \quad \text{-----} (2)$$

Eqn (1) becomes

$$\boxed{e = E_m \sin\omega t}$$

$$\Rightarrow \boxed{e = E_m \sin\theta}$$



→ Current flows through the coil

$$i = \frac{emf}{R} = \frac{E_m \sin\theta}{R}$$

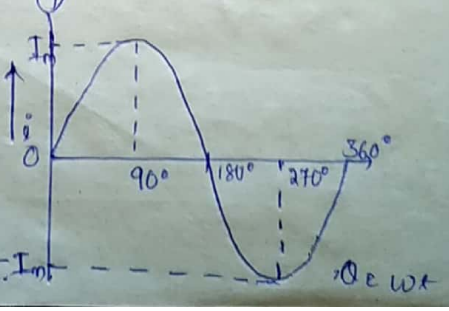
$$\boxed{i = I_m \sin\theta} \quad \text{-----} (3)$$

$$\Rightarrow \boxed{i = I_m \sin\omega t} \quad \text{-----} (4)$$

$$\because I_m = \frac{E_m}{R}$$

↓

max value of c = peak value of A.C.



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Fundamental Terms :-

1. Instanteneous Value :-

The value of alternating quantity at a given instant is called instanteneous value. It is represented by ~~small~~ small letters.

- Instanteneous current

$$i = I_m \sin \omega t$$

- Instanteneous emf

$$e = E_m \sin \omega t$$

2. Amplitude :-

It is the maximum value of an alternating quantity attend by it in a cycle. It is represented by I_m or E_m.

3. Cycle :-

One complete set of positive and negative values of an alternating quantity is K/A a cycle.

4. Time period :-

It is the time taken by an alternating quantity to complete one cycle. It is represented by T.

5. Frequency :-

Number of cycles per second is called as frequency. It is represented by f.

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

Average value of A.C :

① For symmetrical wave,

$$\text{Average value} = \frac{\text{Area of one alternation}}{\text{Base length of one alternation}}$$

∵ one alternation → Half cycle

② For unsymmetrical wave,

$$\text{Average value} = \frac{\text{Area of one cycle}}{\text{Base length of one cycle}}$$

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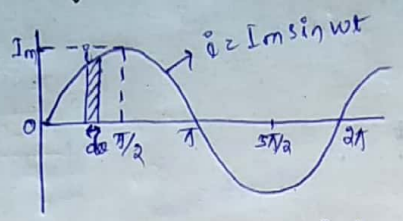
③ Average value of A.C $(I_{av}) = \frac{1}{T}\int i.dt$.

④ Average value of alternating emf $(E_{av}) = \frac{1}{T}\int e.dt$.

(Q) Calculate average value of sinusoidal wave of A.C.



Area of strip = $i.d\theta$

$$\int_0^{\pi} i.d\theta = \int_0^{\pi} I_m \sin\theta d\theta = I_m [-\cos\theta]_0^{\pi}$$

$$= I_m(-\cos\pi + \cos 0)$$

$$= 2I_m = \text{area of half cycle.}$$

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

R.M.S. Value :- (Effective Value or Virtual Value)

Effective value of A.C is that value of A.C which produces same heating effect ~~through~~ in same time through a resistance as produced by A.C

- It is represented by I_{rms} or I_{eff} or I_{ven}.

Expression for I_{rms} or I_{eff} :-

Analytical Method :-

- Let us consider a resistance is 'R'.
  When A.C flows through 'R' then heat energy will be developed.
- dH = small amount of heat developed in time dt.

$$\therefore dH = (I_m \sin \omega t)^2 R.dt$$

- In time time 'T' total heat developed through 'R' is

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$$\int_0^H dH = \int_0^T (I_m \sin \omega t)^2 R \cdot dt.$$

$$\Rightarrow H = I_m^2 R \int_0^T \sin^2 \omega t \cdot dt$$

$$\Rightarrow H = I_m^2 R \int_0^T \left(\frac{1-\cos 2\omega t}{2}\right) dt$$

$$\Rightarrow H = I_m^2 R \left[\int_0^T \frac{1}{2} dt - \cancel{\int_0^T \frac{\cos 2\omega t}{2} \cdot dt}^{\,0}\right]$$

$$\Rightarrow H = I_m^2 R \left[\tfrac{1}{2} T\right] = \frac{I_m^2 R T}{2} \text{ ----- } (1)$$

- Now D.C flows through the same resistance 'R' in same time. It is found that same amount of heat will be developed through 'R'. So D.C is called effective value of A.C.

Here $dH = I_{dc}^2 R \cdot dt = I_{eff}^2 R \cdot dt.$

- In time 'T' the amount of heat developed

$$\int_0^H dH = \int_0^T I_{eff}^2 \cdot R \cdot dt$$

$$\Rightarrow H = I_{eff}^2 R T \text{ ------ } (2)$$

From eqtn (1) and (2) we get

$$I_{eff}^2 \cancel{R} \cancel{T} = \frac{I_m^2 \cancel{R} \cancel{T}}{2}$$

$$\Rightarrow \boxed{I_{eff} = \frac{I_m}{\sqrt{2}}}$$

or

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

Graphical Method :-

$$\text{RMS value} = \sqrt{\frac{\text{Area of } \tfrac{1}{2} \text{ cycle square wave}}{\text{base length of } \tfrac{1}{2} \text{ cycle}}}$$

↓

For symmetrical wave

$$\text{RMS value} = \sqrt{\frac{\text{Area of one cycle squared wave}}{\text{base length of one cycle}}}$$

↓

For unsymmetrical wave

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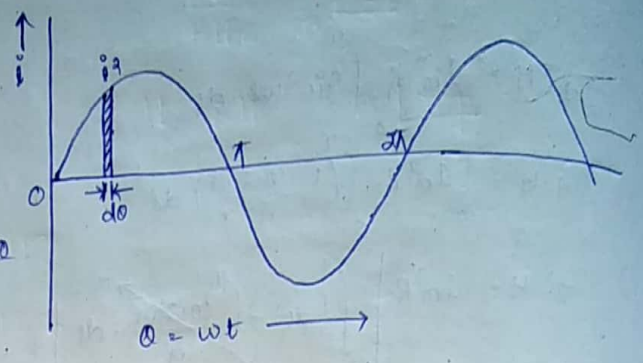
(Q) Find the R.M.S value of sinusoidal ~~wave~~ current?

Ans:-



Area of strip = $i \cdot d\theta$

Total area of half cycle

$$= \int_0^{\pi} i^2 d\theta = \int_0^{\pi} I_m^2 \sin^2\theta \cdot d\theta$$

$$= \frac{I_m^2 \pi}{2}$$

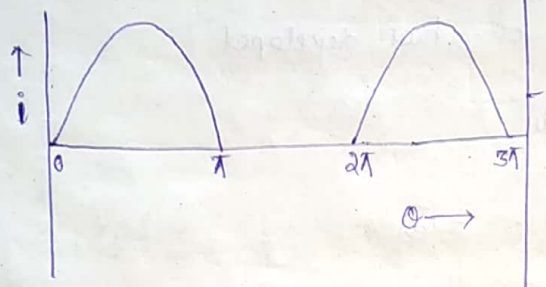
$$I_{rms} = \sqrt{\frac{I_m^2 \pi/2}{\pi}} = \frac{I_m}{\sqrt{2}}$$

(Q) Calculate R.M.S value, Average value and form factor of wave shown.

① ½ wave rectifier ② Full wave rectifier

Ans:-

①



Form factor:-

It is represented by K_f.

It is defined as the ratio of R.M.S value to average value

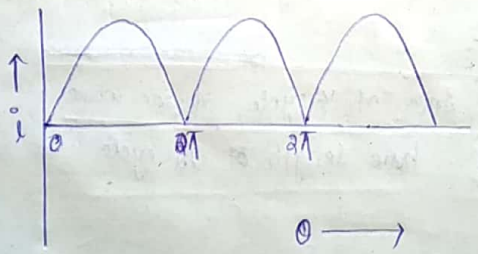
$$K_f = \frac{\text{R.M.S value}}{\text{Average value}}$$

$$I_{rms} = \sqrt{\frac{I_m^2 \pi/2 + 0}{2\pi}} = I_m/2$$

$$I_{av} = \frac{2I_m + 0}{2\pi} = \frac{I_m}{\pi}$$

$$K_f = \frac{I_m/2}{I_m/\pi} = 1.57$$

②



$$I_{rms} = \sqrt{\frac{I_m^2 \pi/2}{\pi}} = \frac{I_m}{\sqrt{2}}$$

$$I_{av} = \frac{2I_m}{\pi}$$

$$K_f = \frac{I_m/\sqrt{2}}{2I_m/\pi} = 1.11$$

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Sinusoids :

The quantities obeying sine law are called as sinusoids.

The quantities are alternating current, alternating voltage etc

Phasor :-

Phasor is a rotating vector

- We know that $e^{j\theta} = \cos\theta + j\sin\theta$

$$e^{j\omega t} = \cos\omega t + j\sin\omega t$$

$$Ve^{j\omega t} = V\cos\omega t + jV\sin\omega t$$

→ $V\sin\omega t$ = imaginary part of $Ve^{j\omega t}$

$$= \text{Im}\, Ve^{j\omega t} = \text{Im}\, Ve^{j\omega t} \cdot e^{j0} \quad \text{------} \; ①$$

$V\sin(\omega t + \theta)$ = Imaginary part of $Ve^{j(\omega t+\theta)}$

$$= \text{Im}\, Ve^{j(\omega t+\theta)} \cdot e^{j\theta} \quad \text{------} \; ②$$

From eqn ① and ② the factor $e^{j\omega t}$ is common to both and it contains the information about angular frequency ω.

- Once the sinusoids of the same frequency are involved this information is redundant.
- The representation of $V\sin\omega t$ and $V\sin(\omega t+\theta)$ are simplified by droping the term $e^{j\omega t}$. So we can write

$$V\sin\omega t = Ve^{j0}$$

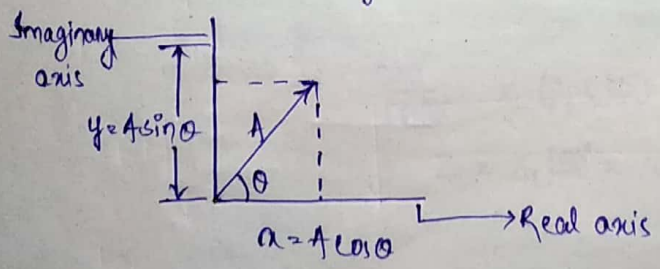
$$V\sin(\omega t+\theta) = Ve^{j\theta}$$

Dt - 21.09.2019

Polar ⇒ $\underset{\text{Magnitude}}{A}\angle\theta$ → Phase (direction)

$$\boxed{A\angle\theta} = \boxed{A\cos\theta + jA\sin\theta}$$

↓ Polar ↓ Rectangular



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$A = x + jy$

$|A| = \sqrt{x^2+y^2}$

$e^{j\theta} = \cos\theta + j\sin\theta$

$Ae^{j\theta} = A\cos\theta + j\sin\theta = A\angle\theta$

$\rightarrow V\sin(\omega t+\phi) = V^{e^{j\phi}} = V\angle\phi$

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

$A\angle\alpha \cdot B\angle\beta = A\cdot B\angle\alpha+\beta$

(Q) Find the sum of five currents given $I_1 = 10\sin\omega t$, $I_2 = 20\sin(\omega t+\pi/6)$, $I_3 = 5\cos\omega t$, $i_4 = 20\sin(\omega t - \frac{\pi}{4})$, $i_5 = 30\cos(\omega t + \frac{2\pi}{3})$. Express the resultant in the form of $i = A\sin(\omega t+\phi)$

Soln

$i_1 = \sin\omega t = 10\angle 0^\circ$

$i_2 = 20\sin(\omega t + \pi/6) = 20\angle 30^\circ$

$i_3 = 5\cos\omega t = 5\sin(\omega t + 90^\circ) = 5\angle 90^\circ$

$i_4 = 20\sin(\omega t - \pi/4) = 20\angle -45^\circ$

$i_5 = 30\cos(\omega t + \frac{2\pi}{3}) = 30\sin(\omega t + \frac{2\pi}{3} + 90) = 50\angle 210^\circ$

$i = i_1 + i_2 + i_3 + i_4 + i_5$

$= 10\angle 0 + 20\angle 30 + 5\angle 90 + 20\angle -45 + 50\angle 210$

$= (10 + j0) + (17.32 + j10) + (0 + j5) + (14.14 - j14.14) + (-25.98 - j15)$

$= (15.48 - j14.14)$

$= 20.96\angle -42.41$ A

$i = 20.96\sin(\omega t - 42.41)$ A

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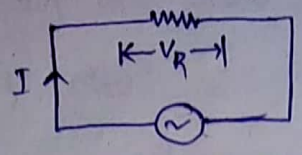
A.C circuit containing R-only :-

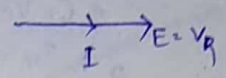


$e = E_m \sin(\omega t)$ → Angle

Apply KVL,

$e - V_R = 0$

$\Rightarrow e = V_R$ $\quad \left\{ \because I_m = \frac{E_m}{R} \right\}$



$\Rightarrow E_m \sin \omega t = IR$

$\Rightarrow I = \frac{E_m}{R} \sin \omega t$

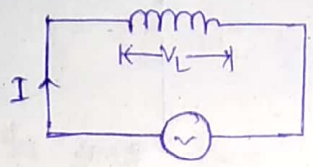
$\Rightarrow \boxed{I = I_m \sin \omega t}$

Impedance

$Z = \frac{E \angle 0^\circ}{I \angle 0^\circ}$

$\boxed{Z = R \angle 0^\circ}$

A.C circuit containing I-only :-



$E = E_m \sin \omega t$

Apply KVL

$E - V_L = 0$

$\Rightarrow E = V_L$

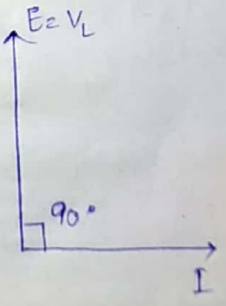
$\Rightarrow E_m \sin \omega t = L \frac{dI}{dt}$

$\Rightarrow \int dI = \frac{E_m}{L} \int \sin \omega t \, dt$

$\Rightarrow I = \frac{E_m}{\omega L} (-\cos \omega t) = \frac{E_m}{\omega L} \sin(\omega t - 90^\circ)$

$\boxed{I = I_m \sin(\omega t - 90^\circ)}$

$\because \boxed{I_m = \frac{E}{\omega L}} = \frac{E}{X_L}$



Impedance

$Z = \frac{E \angle 0^\circ}{I \angle -90^\circ} = X_L \angle 0 - (-90^\circ)$

$Z = X_L \angle 90^\circ = X_L \cos 90^\circ + j X_L \sin 90^\circ$

$Z = j X_L = j \omega L$

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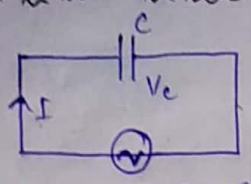
A.C. Circuit containing 'C' Only :-



$E = E_m \sin \omega t$

Apply KVL

$E - V_c = 0$

$\Rightarrow E = V_c$

$\Rightarrow E_m \sin \omega t = \frac{q}{C}$

$\Rightarrow q = C E_m \sin \omega t$

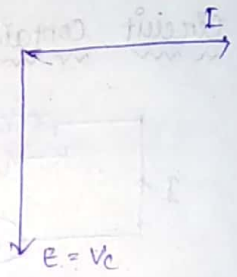
$\Rightarrow \frac{d}{dt}(q) = \frac{d}{dt}(C E_m \sin \omega t)$

$\Rightarrow I = \omega C E_m \cos \omega t$

$$\boxed{I = \omega C E_m \sin(\omega t + \pi/2)}$$

$$\boxed{I = I_m \sin(\omega t + \pi/2)}$$

$\because I_m = \frac{E_m}{1/\omega C} = \frac{E_m}{X_c}$



Impedance

$Z = \frac{E\angle 0^\circ}{I\angle 90^\circ} = X_c \angle -90^\circ$

$= X_c \cos(-90^\circ) + j X_c \sin(-90^\circ)$

$Z = -jX_c = -\frac{j}{\omega C} = \frac{-j \times j}{j\omega C} = \frac{1}{j\omega C}$ $\quad \because j = \sqrt{-1}$

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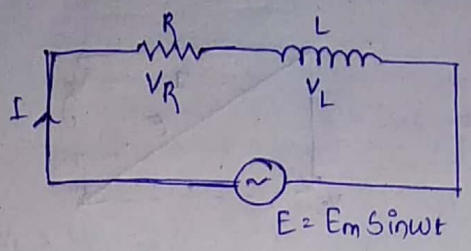
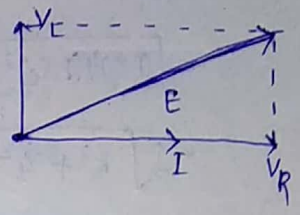
(Q) Calculate expression for impedance and current in R-L, R-C and R-L-C circuit also draw the phasor diagrams?

(i) R - L Circuit





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

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

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

$$\tan\phi = \frac{V_L}{V_R} = \frac{IX_L}{IR} = \frac{X_L}{R} = \frac{\omega L}{R}$$

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

In polar form

$$E = V_R + V_L$$

$$\Rightarrow E = I(R + j0) + I(0 + jX_L)$$

$$\Rightarrow E = I(R + jX_L)$$

$$\Rightarrow E = IZ$$

$$\because Z = R + jX_L$$

= impedance R-L circuit.

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

$$\because I_m = \frac{E_m}{Z}$$

Let voltage as referance phasor.

$$Z = \frac{\text{voltage}}{\text{current}} = \frac{E\angle 0}{I\angle\phi} = \frac{E}{I}\angle\phi =$$

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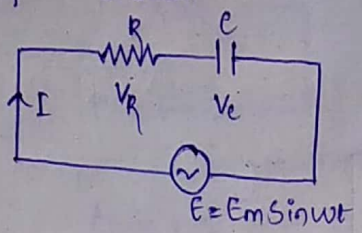
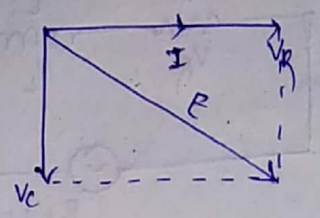
(ii) R-C circuit.





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

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

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

$$\Rightarrow Z = \sqrt{R^2 + X_C^2}$$

$$\tan\theta = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{1}{\omega CR}$$

$$\theta = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

In polar form :

$$E = V_R + V_C$$

$$= I(R + j0) + I(0 + jX_C)$$

$$\Rightarrow E = I(R + jX_C)$$

$$\Rightarrow E = IZ$$

$$\because Z = R + jX_C$$

= impedance R-C circuit

$$\Rightarrow I = I_m \sin(\omega t + \theta)$$

$$\because I_m = \frac{E_m}{Z}$$

Let voltage as reference phasor

$$Z = \frac{\text{voltage}}{\text{current}} = \frac{E\angle 0}{I\angle\theta} = \frac{E}{I}\angle -\theta$$

Note For Problem :-

R-L ckt	R-C ckt
~~Note for Problem~~	
Inductive circuit	Capacitive circuit
Lagging	Leading
$\rightarrow Z\angle\theta$	$\rightarrow Z\angle\theta$
$\rightarrow I\angle -\theta$	$\rightarrow I\angle\theta$

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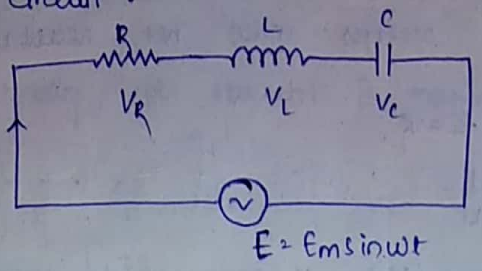
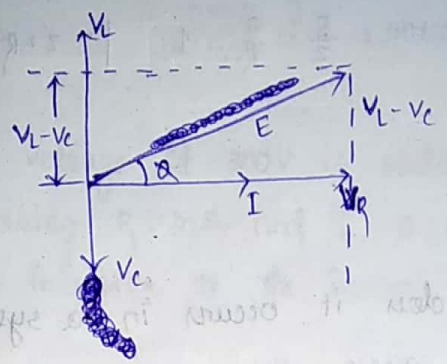
(iii) R-L-C Circuit :-



(i) $V_L > V_C$



$E = V_R + V_L + V_C$

$\Rightarrow E = I(R + j0) + I(0 + jX_L) + I(0 - jX_C)$

$\Rightarrow E = I[R + j(X_L - X_C)]$

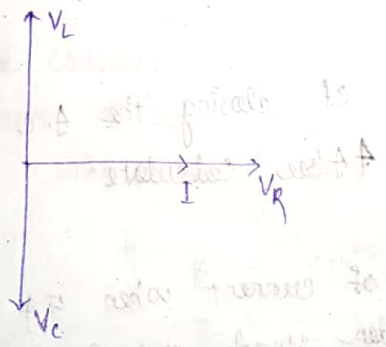
$\Rightarrow E = IZ$

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

Similarily for $V_C > V_L$

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

(ii) $V_L = V_C$



In this case net drop $V_L - V_C = 0$ So $E = V_R$

- In this case impedance of R-L-C circuit $Z = R$
- In this case $I = \frac{V}{R}$
- In this case $V_L = V_C \Rightarrow \cancel{I} X_L = \cancel{I} X_C$

$\Rightarrow X_L = X_C$

$\Rightarrow \omega L = \frac{1}{\omega C}$

$\Rightarrow \omega^2 LC = 1$

$\Rightarrow \omega = \frac{1}{\sqrt{LC}}$

$\Rightarrow 2\pi f = \frac{1}{\sqrt{LC}}$

$\Rightarrow f = \frac{1}{2\pi\sqrt{LC}}$

This is the expression for resonant frequency.

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Series Resonance :-

Series resonance occurs when net reactance is, $X_L - X_C = 0$

In series resonance $Z = R$.

- Resonant frequency $f = \frac{1}{2\pi\sqrt{LC}}$
- Voltage across inductor (V_L), Voltage across capacitor (V_C).
- Current $I = \frac{V}{R}$
- In series resonance power factor $= \frac{R}{Z} = \frac{R}{R} = 1$ $\quad | \because Z = R$

Power Factor :-

(Q.) What is transient ? why does it occurs in a system?

If we switch off the source or switch over the network to another source, the circuit starts attaining another steady state.

- The time taken by the circuit to change over from one steady state to another steady state is called transient time.
- Inductance will not allow sudden change in current and capacitance will not allow sudden change in voltage. Hence transient occurs in inductive and capacitive circuits.

(Q) $R = 5\Omega$, $L = 20H$ at the instant of closing the A.C supply the current increases at the rate 4A/sec. Calculate

(i) Applied voltage

(ii) The rate of growth of current when 5A flows

(iii) The stored energy under steady state?

$R = 5\Omega$

$L = 20H$

$\frac{di}{dt} = 4 A/sec$

(i) $V_L = L \cdot \frac{di}{dt} = 20 \cdot 4 = 80\ V$

(ii) $V = V_R + V_L$ = applied voltage

$\Rightarrow V = V_R + L \cdot \frac{di}{dt}$

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$\Rightarrow \frac{di}{dt} = \frac{V - V_R}{L} = \frac{80 - (IR)}{L} = \frac{80 - (5 \times 5)}{20} = 2.75\ A/sec$

(iii) Under steady state current is maximum

So

$I_0 = \frac{V}{R} = \frac{80}{5} = 16\ A$

$\text{Energy} = \frac{1}{2} L I^2$

$= \frac{1}{2} \times 20 \times 16 \times 16$

$= 2560\ J$

(Q2) A direct voltage of 200V is suddenly applied to a R-L series circuit having $R = 20\Omega$ and $L = 0.2H$. Determine the voltage drop across the inductor at the instant of switching on and 0.2 sec later?

Given

$V = 200V$

$R = 20\Omega$

$L = 0.2H$

$\tau = \frac{L}{R} = \frac{0.2}{20} = 0.01\ sec$

(i) $V_L = V = 200V$

(ii) $V_L = V e^{-t/\tau} = 200 \times e^{-0.2/0.01}$

$= 4.1 \times 10^{-7} V$

(Q3) The time constant of a coil was found to be 2.5 milisec. With a resistance of 100Ω added in series, a new time constant 0.5 milisec was obtained find R and L of the coil?

$\tau_1 = \frac{L}{R} = 2.5 \times 10^{-3}\ sec$

$\tau_2 = \frac{L}{R+100} = 0.5 \times 10^{-3}\ sec$

$\frac{\tau_1}{\tau_2} = \frac{2.5}{0.5} = \frac{L/R}{L/R+100}$

$\Rightarrow$

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(Q) What is meant by the term (i) Short circuit (ii) Open circuit?

Short Circuit :-

When two points of a circuit are connected together by a thick material metallic wire they they are called short circuited.

- S.C. has practically 0 resistance
- The current through S.C is very large
- The voltage across S.C is zero.

Open Circuit :-

Two points are said to be open circuited when there is no direct connection between them.

- Open circuit has infinite resistance so no current flows betn two points.
- Open circuit has voltage.

(Q) If 1000 Ω resistance and capacitance 40 μF then calculate the time constant?

$R = 1000\,\Omega$

$C = 4\,\mu F$

Time constant $\tau = RC$

$= 1000 \times 40 \times 10^{-6}$

$= 4 \times 10^{-2}\,s$

(Q) A 25 V DC supply is connected to a coil of inductance 1H and resistance 5 Ω. Determine the value of the current flowing 100 m sec after being connected to supply?

$V = 25V$

$L = 1H$

$R = 5\Omega$

$\tau = \frac{L}{R} = \frac{1}{5} = 0.2\,s$

$i = I_0 (1 - e^{-t/\tau})$.

$I_0 = \frac{V}{R} = \frac{25}{5} = 5A$

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$$i = 5(1 - e^{-0.1/0.2})$$

$$= 5(1 - e^{-0.5})$$

$$= 5(1 - 0.605)$$

$$= 5 \times 0.395$$

$$= 1.975$$

(Q) A capacitor C charged from DC supply of 100 V through a resistance of 100Ω if the time constant is 15 milisec calculate the value of C? Also the time requirement for the capacitor to acquire 90% of steady state charge assuming 0 initial charge in capacitor?

$R = 100\,\Omega$

$\tau = 15 \times 10^{-3}\,s$

$V = 100\,V$

$\tau = RC = s$

$\Rightarrow C = \frac{\tau}{R} = \frac{15 \times 10^{-3}}{100} = 1.5 \times 10^{-4}\,F$

We know

$q = Q_0(1 - e^{-t/\tau})$

$Q_0 = CV = 1.5 \times 10^{-4} \times 100$

$= 1.5 \times 10^{-2}$

$0.9 = 1.5 \times 10^{-2}(1 - e^{-t/15 \times 10^{-3}})$

$\Rightarrow 0.9 Q_0 = Q_0(1 - e^{-t/\tau})$

$\Rightarrow 0.9 = (1 - e^{-t/\tau})$

$\Rightarrow e^{-t/\tau} = 0.1$

$\Rightarrow -t/\tau = \ln 0.1$

$\Rightarrow t = -2.30 \times 1.5 \times 10^{-3}$

$= -3.45 \times 10^{-3}$

(Q) A coil has an inductance of 1.2H and resistance 10Ω and is connected to a 200V, DC supply. Draw the current time characteristics and hence determine the value of the current flowing 60 milisec after connecting the coil to supply?

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$L = 1.2H$

$R = 40\Omega$

$V = 200V$

$\tau = \frac{L}{R} = \frac{1.2}{40} = 0.03$

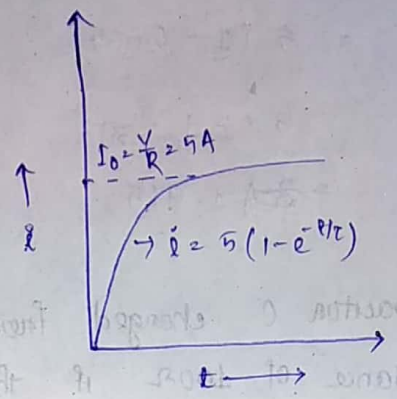
$i = I_0 (1 - e^{-t/\tau})$

$= \frac{V}{R} (1 - e^{-t/\tau})$

$= 5 \left(1 - e^{-\frac{60\times10^{-3}}{0.03}}\right)$

$= 5 (1 - 0.135)$

$= 4.325 A$



(Q) A resistance R and 5 μF connected in series across 100V DC. Calculate R such that the voltage across capacitor becomes 50V in 5 sec after switched on?

$C = 5 \mu F$

$V_1 = 100V \quad V_C = 50V$

$t = 5$

$V_c = V(1 - e^{-t/\tau})$

Here $\tau = RC =$

$V = 100V$

$V_c = 50V$

$50 = 100(1 - e^{-t/\tau})$

$\Rightarrow 1 - e^{-t/\tau} = 0.5$

$\Rightarrow e^{-t/\tau} = 0.5$

$\Rightarrow -t/\tau = -0.693$

$\Rightarrow \frac{t}{RC} = 0.693$

$\Rightarrow R = \frac{5}{0.693 \times 5 \times 10^{-6}}$

$\Rightarrow R = 1.44 \times 10^{6} \Omega$

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(Q) A resistance R and 3.5 μF capacitor are connected in series across a 230V DC source. A voltmeter is connected across the capacitor (i) Find R, so that voltmeter reads 165 V at 5.65 s

(ii) Initial charging current

(iii) Energy stored in the capacitor

(iv) Current at 5.65 s.

$C = 3.5\,\mu F$

$V = 230V$

(i) $V_c = 165\ V$

$t = 5.65$

$V_c = V_0(1 - e^{-t/\tau})$

$\Rightarrow 165 = 230(1 - e^{-t/\tau})$

$\Rightarrow 1 - e^{-t/\tau} = \frac{165}{230} = 0.717$

$\Rightarrow e^{-t/\tau} = 0.283$

$\Rightarrow -t/\tau = -1.26$

$\Rightarrow \tau = \frac{5.65}{-1.26} = -4.47$ $\Rightarrow R = \frac{-4.47}{3.5\times10^{-6}} = 1.27\times10^{6}\ \Omega$

(ii) $I = \frac{V}{R} = \frac{230}{1.27\times10^{6}} = 1.811\times10^{-6}\ A$

(iii) $E = \frac{1}{2}CV^2 = \frac{1}{2}\times3.5\times10^{-6}\times(230)^2 = 0.0925$ Joule

(iv) $i = I_0(1 - e^{-t/\tau})$

$= \frac{V}{R}(1 - e^{-t/\tau})$

$= 1.811\times10^{-6}\left(1 - e^{\frac{-5.65}{-4.47}}\right) = 181.1\times10^{-6}(-2.539)$

$= -4.596\times10^{-4}$

(Q) Determine the current in R-L circuit having $R = 3\Omega$ and $L = 12H$ at $t = 6$ sec. after a DC supply of 120 V connected to it.?

$R = 3\Omega$

$L = 12H$

$t = 6$

$V = 120V$

$i = I_0(1 - e^{-t/\tau}) = \frac{V}{R}(1 - e^{-t/L/R}) = \frac{120}{3}(1 - e^{-6\times3/12})$

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$= 40 \times (1 - e^{-24})$

$= 40 \times 0.776$

$= 31.07\ A$

(9) A 8 μF capacitor is connected with series with 500 kΩ resistor across 200V D.C supply. Calculate

(i) time constant

(ii) Initial charging current

(iii) time taken for capacitor to reach 160V.

(iv) Current and P.D across capacitor 4s after the switching ON.

(v) Current after transient period.

(i) $\tau = RC = 8 \times 10^{-6} \times 500 \times 10^{3}$

$= 4\ s$

(ii) $I = \frac{V}{R} = \frac{200}{500 \times 10^{3}} = 0.4 \times 10^{-3}$

(iii) $V_c = V(1 - e^{-t/\tau})$

$160 = 200(1 - e^{-t/\tau})$

$\Rightarrow 1 - e^{-t/\tau} = 0.8$

$\Rightarrow e^{-t/\tau} = 0.2$

$\Rightarrow -t/\tau = -1.609$

$\Rightarrow t = 1.609 \times 4$

$= 6.437\ s$

(iv) $i = I_0(1 - e^{-t/\tau})$

$= 0.4 \times 10^{-3}(1 - e^{-6.437/4})$

$= 0.4 \times 10^{-3}(1 - 0.2)$

$= 0.4 \times 10^{-3} \times 0.8$

$= 0.32 \times 10^{-3}$

~~$P = i^2R = \frac{0.08 \times 10^{-3}}{500 \times 10^{3}} = 1.6 \times 10^{-10}$~~

$V = iR = 0.32 \times 10^{-3} \times 500 \times 10^{3} = 160V$

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(v) $i = 0$

(Q) A coil has an inductance of 5H and resistance 15Ω when it is connected to 120 V

(i) Steady state value of current in coil.

(ii) Time constant

(iii) Induced EMF after 0.1 s.

(iv) Time for the current to rise to 85% of its final value

(v) Current after 0.3 sec.

$L = 5H$

$R = 15\Omega$

$V = 120V$

(i) $I_0 = \frac{V}{R} = \frac{120}{15} = 8A$

(ii) $\tau = \frac{L}{R} = \frac{5}{15} = 0.25$

(iii) $V_L = Ve^{-t/\tau}$

$= 120 \times e^{-0.1/0.2}$

$= 120 \times 0.606$

$= 72.783\ V$

(iv) $0.85 I_0 = I_0 (1 - e^{-t/\tau})$

$\Rightarrow e^{-t/\tau} = 1 - 0.85$

$\Rightarrow -t/\tau = \ln(0.15)$

$= -1.897$

$\Rightarrow t = 1.897 \times 0.2$

$= 0.379\ s$

(v) $i = i_0(1 - e^{-t/\tau})$

$= 8(1 - e^{-0.3/0.2})$

$= 8(1 - 0.223)$

$= 8 \times 0.776 = 6.214\ A$

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(Q) Explain how a capacitor behaves in a DC ckt when switch is closed?

(Q) Explain how a inductor behaves in a d.c ckt. when switch is closed?

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Dt - 24.09.2019

A.C. Circuit :-

(Q) Calculate power dissipated by 10Ω resistance connected to an AC supply $V = 100 \sin(314t + 37°)$ V ?

Sol^n Given

$$V = 100 \sin(314t + 37°) \text{ V}$$

$$V_{Max} = 100 \text{ V}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{100}{\sqrt{2}} = 70.71 \text{ V}$$

$$P = \frac{V_{rms}^2}{R} = \frac{(70.71)^2}{10} = 499.9 \simeq 500 \text{ W}$$

(Q) A series RC circuit having $R = 4\Omega$ and $C = 120\,\mu F$ is connected across 230V 50Hz supply. Calculate

(i) The reactance
(ii) The impedance
(iii) Current drawn by the circuit.
(iv) Power factor of the circuit.

$R = 4\Omega$

$C = 120\,\mu F$

(i) $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 120 \times 10^{-6}} = 26.52\,\Omega$

(ii) Impedance $= Z = Z_1 + Z_2$

$$Z = (R + j0) + (0 - jX_C)$$

$$\Rightarrow Z = R - jX_C$$

$$\Rightarrow Z = 4 - j26.5$$

$$\Rightarrow Z = 26.8 \angle -81.41° \,\Omega$$

$$\therefore \theta = 81.41° \text{ (leading)}$$

$$\cos\theta = 0.149 \text{ (lead)}$$

$$I = \frac{V}{Z} = \frac{230\angle 0°}{26.8\angle -81.41°} = 8.58 \angle 81.41°$$

lagging = inductance
leading = capacitance

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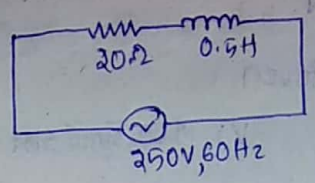
(Q) A resistor of 20Ω is series with 0.5 H inductor is connected across 250V, 60Hz. Find the current through the inductor?

$R = 20\Omega$

$I = 0.5H$

$V = 250V$

$f = 60Hz$



(i) $X_L = \omega L = 2\pi f L = 2\pi \times 60 \times 0.5 = 188.4\,\Omega$

$Z_1 = (R + j0) + (0 + jX_L)$

$= R + jX_L$

$= 20 + j188.4$

$= 189.46\angle 83.94^\circ$

$\theta = 83.94^\circ$ (lagg)

$\cos\theta = 0.105^\circ$

$I = \dfrac{V\angle 0^\circ}{Z\angle 83.94} = 1.32\angle -83.94^\circ$ (lagg)

(Q) A circuit contains an inductance of 1H in series with a resistance of 100Ω. A voltage of $e = 100\sqrt{2}\sin(314t)$ V is applied across the circuit? Express the rms value of current in polar form, complex form. Give the expression for instantaneous current?

$e = 100\sqrt{2}\sin(314t)$

$V_{max} = 100\sqrt{2}$

$V_{rms} = \dfrac{V_m}{\sqrt{2}} = 100V$

$\omega = 314$

$f = \dfrac{\omega}{2\pi} = 49.97$

$X_L = \omega L = 314 \times 1 = 314\,\Omega$

$R = 100\,\Omega$

$Z = (R + j0) + (0 + jX_L)$

$= R + jX_L$

$= 100 + j314$

$= 329.54\angle 72.33$

$I = \dfrac{V}{Z} = \dfrac{100}{329.54\angle 72.33} = 0.303\angle -72.33$ (Lagg)

$I = 0.092 - j0.29$

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Instantaneous current $= I = I_m \sin(\omega t - \theta)$

$= 0.428 \sin(314t - 72.35)\ A$

(Q) Two impedances $15\angle 60^\circ\ \Omega$ and $10\angle -30^\circ\ \Omega$ are connected in series and their series combination is connected in parallel with another impedance $30\angle 45^\circ\ \Omega$ find out the equivalent impedance in polar and complex form?

$Z_1 = 15\angle 60 \qquad Z_2 = 10\angle -30$

$Z_3 = 7.5 + j12.99 + 8.66 - j5$

$= 16.16 + j7.99$

$Z_3 = 18.02\angle 26.31\ \Omega$

$Z_4 = 30\angle 45^\circ$

$Z_4 = 21.21 + j21.21$

$$Z_{eq} = \frac{Z_3 Z_4}{Z_3 + Z_4} = \frac{18.02\angle 26.31^\circ \times 30\angle 45^\circ}{16.16 + j7.99 + 21.21 + j21.21}$$

$$= \frac{540.6\angle 71.31}{37.37 + j29.2}$$

$$= \frac{540.6\angle 71.31}{47.42\angle 38}$$

$= 11.4\angle 33.31$

$= 9.52 + j6.26$

(Q) Determine the RMS value of $V(t) = 50 + 70.7\cos(377t)$

$$V_{rms} = \sqrt{(50)^2 + \left(\frac{70.7}{\sqrt{2}}\right)^2}$$

$= 70.705\ V$

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(Q) Find the RMS value of $x(t) = 2\cos\omega t + 2.5$

$$X_{rms} = \sqrt{\left(\frac{2}{\sqrt{2}}\right)^2 + (2.5)^2}$$

$$= \sqrt{2 + 6.25}$$

$$= \sqrt{8.25}$$

$$= 2.872$$

(Q) Calculate the combined impedance and admitance in polar form when 3 impedances of value $5\angle 30^\circ\ \Omega$, $3 + j6\ \Omega$ and $4 - j8\ \Omega$ are connected in series?

$$Z_1 = 5\angle 30$$

$$= 4.33 + j2.5$$

$$Z_2 = 3 + j6$$

$$Z_3 = 4 - j8$$

$$Z = 11.33 + j0.5$$

$$Z = 11.34\angle 2.52\ \Omega$$

Admitance $(Y) = \frac{1}{Z} = \cancel{0.088\angle -2.52}\ 0.088\angle -2.52\ \mho$

(Q) Two impedances $25\angle -50^\circ\ \Omega$ and $15\angle 45^\circ\ \Omega$ are connected in parallel find out resultant impedance in rectangular and polar form?

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A.C. Power :-

Average power in AC (P) $= \frac{1}{2\pi}\int_0^{2\pi} P.d\theta$

or

$$P = \frac{1}{T}\int_0^{T} P.dt$$

The power that gives rise to energy dissipation in a resistor is called active power or true power.

- The energy delivered to the load (inductive or capacitive load) and then that energy return to the source the power describing the rate of energy moving in and out of a reactance is called reactive power
- AC power

AC Power
- Apparent power
- Real power or True power
- Reactive power

Average power in a circuit containing R only :-

Here

$V = V_m \sin\omega t = V_m \sin\theta \quad (\because \theta = \omega t)$

$i = I_m \sin\omega t = I_m \sin\theta$

- Average power

(P_{av}) = Real power

$= \frac{1}{2\pi}\int_0^{2\pi} P.d\theta$

$= \frac{1}{2\pi}\int_0^{2\pi} V_m I_m \sin^2\theta \, d\theta$

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

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

$= \frac{V_m I_m}{2} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = V_{rms} \cdot I_{rms}$.

$\because P$ = instantaneous power

$= vi$

$= (V_m \sin\theta)(I_m \sin\theta)$

$= V_m I_m \sin^2\theta$

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Average power in a circuit containing L-only :-

Here

$$V = V_m \sin\omega t = V_m \sin\theta$$

but $i = I_m \sin(\omega t - \pi/2) = I_m \sin(\theta - \pi/2)$

$$P = \frac{1}{2\pi}\int_0^{2\pi} P \cdot d\theta = \frac{1}{2\pi}\int_0^{2\pi} vi \cdot d\theta$$

$$\Rightarrow P = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\theta \cdot I_m \sin(\theta - \pi/2)\, d\theta$$

$$\Rightarrow P = \frac{1}{2\pi}\int_0^{2\pi} V_m I_m \sin\theta\,(-\cos\theta)\, d\theta$$

$$\Rightarrow P = \frac{-V_m I_m}{2\pi}\int_0^{2\pi} \sin\theta \cos\theta\, d\theta$$

$$\Rightarrow P = \frac{-V_m I_m}{2\pi}\int_0^{2\pi} \frac{\sin 2\theta}{2} \cdot d\theta$$

$$\Rightarrow P = 0$$

Average power in a circuit containing C-only :-

Here

$$V = V_m \sin\omega t = V_m \sin\theta$$

but $i = I_m \sin(\omega t + \pi/2) = I_m \sin(\theta + \pi/2)$

Simillarily as power in L circuit

$$P = 0$$

Average power in a circuit containing R-L only :-

Here

$$V = V_m \sin\omega t = V_m \sin\theta$$

$$i = I_m \sin(\omega t + \alpha) = I_m \sin(\theta - \alpha)$$

$$P = \frac{1}{2\pi}\int_0^{2\pi} P \cdot d\theta$$

$$P = \frac{V_m I_m}{R} \cos\alpha$$

$$= \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\alpha$$

$$P = V_{rms} I_{rms} \cos\alpha$$

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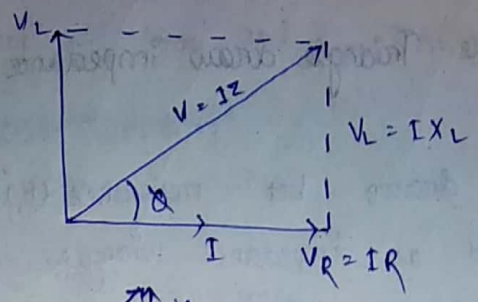
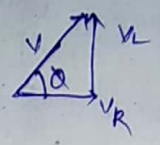
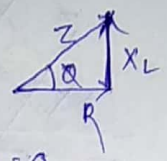


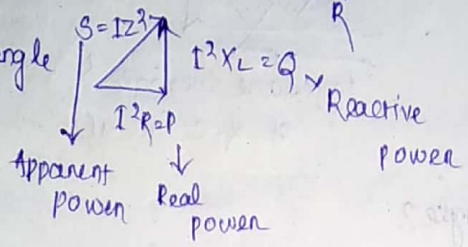
Voltage Triangle



Impedance Triangle



Power triangle



Reactive power generates from reactive element.

- The product of RMS value of voltage and current with a sign of the angle betn them is called reactive power. It is represented by Q.

$$\boxed{Q = V_{rms} \cdot I_{rms} \sin\theta} \quad \text{--- (1)}$$

$$\Rightarrow Q = V_{rms} I_{rms} \cdot \frac{X_L}{Z}$$

$$= I_{rms} I_{rms} X_L$$

$$= I^2 X_L$$

- The reactive power of inductance is +ve where reactive power of capacitance is -ve.
- Inductance absorves reactive power while capacitance injects reactive power.
- In Inductance reactive power develops the flux but in capacitance reactive power stores the charge.
- The unit of reactive power is VAR or KVAR

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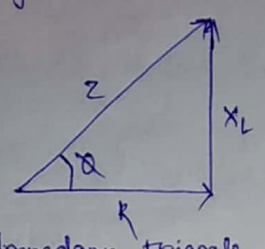
Dt - 25.09.2019

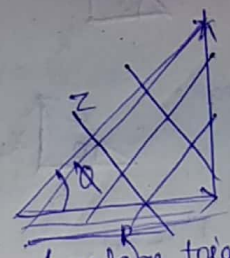
(Q) Explain Impedance Triangle draw impedance triangle of R-L and R-C circuit?

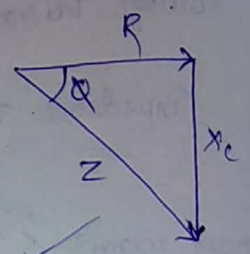
The triangle drawn betn resistance (R), reactance (X_L) and impedance (Z) called as impedance triangle

→ Impedance triangle of R-L circuit



Impedance triangle of R-L circuit

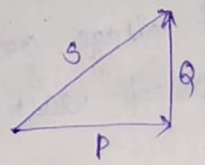




Impedance triangle of R-C circuit.

(Q) What is ~~the~~ Power Triangle?

The triangle drawn betn real power (P), reactive power (Q) and apparent power (S) is called power triangle.



$S = P + jQ$

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

(Q) What do you mean by apparent power?

It is defined as the product of rms values of voltage and current in a circuit. It is represented by S.

$S = V_{rms} I_{rms} = I^2 Z$

- In complex form apparent power

$S = P + jQ$

∵ P = real power or active power

Q = Reactive power or imaginary power

- Complex power of apparent power S can be calculated as

$S = V I^*$

where, I^* = conjugate of I

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(Q) In an AC circuit $v = 220 \sin(\omega t + 45°)$ $i = 2\sin(\omega t - 45°)$ calculate the value of V_{rms} and i_{rms}? Also calculate P and Q?

$V = 220\sin(\omega t + 45°)$

$i = 2\sin(\omega t - 45°)$

$V_{rms} = V = \frac{V_m}{\sqrt{2}} = \frac{220}{\sqrt{2}} = 155.5$ volt

$I_{rms} = I = \frac{I_m}{\sqrt{2}} = \frac{2}{\sqrt{2}} = \sqrt{2} = 1.414$ A

In polar form

$V = 155.5 \angle 45°$

$I = 1.414 \angle -45°$

conjugate of $I = I^* = 1.414 \angle 45°$

Complex power $(S) = VI^* = 155 \angle 45° \times 1.414 \angle 45°$

$= 219.87 \angle 90°$

$= 0 + j219.87$ --- ①

But we know,

$S = P + jQ \longrightarrow$ ②

From eqn ① & ②

$P = 0$ watt

$Q = 219.87$ VAR

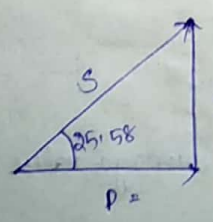
(Q) An impedance $2 + j3$ is connected in parallel with another impedance $1 - j2\,\Omega$ if the input reactive power is 100 VAR what is the total active power?

$Z_1 = 2 + j3\,\Omega$ $Z_2 = 1 - j2\,\Omega$

$= 3.6 \angle 56.3$ $= 2.23 \angle -63.43$

$Z_{eq} = \frac{Z_1 Z_2}{Z_1 + Z_2} = \frac{8.03 \angle -7.15}{3 + j} = \frac{8.03 \angle -7.15}{3.16 \angle 18.43} = 2.54 \angle -25.58$

$\theta = 25.58$



$\tan\theta = \frac{Q}{P}$

$\Rightarrow P = \frac{100}{\tan(25.58)} = 208.9$ Watt

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(Q) What is power factor?

It is the ratio of the real power to apparent power.

- It is defined as the ratio of resistance to impedance.
- Power factor = $\cos\theta = \frac{R}{Z} = \frac{P}{S}$
- Maximum value of power factor $\cos\theta$ 1.
- Minimum value of power factor $\cos\theta$ 0.

(Q) In an A.C circuit V = 10V, I = 2A, P = 10 watt find power factor?

P = 10 watt

I = 2A V = 10 V

$\cos\theta = \frac{P}{VI} = 0.5$

(Q) If active power is equal to apparent power what is the value of power factor of the circuit?

$P.f = \cos\theta = 1$

(Q) How is that a purely inductive circuit although the current flows but the active power is zero?

Ans- In purely inductive AC circuit current lags by 90° in phase with voltage so $\cos\theta = \cos 90° = 0$.

Power $P = VI\cos\theta = 0$

(Q) In an A.C circuit can apparent power is equal to real power?

In series resonance of R-L-C circuit $\cos\theta = 1$

So, there power is equal to $VI\cos\theta = VI$ = Apparent power.

(Q) In an AC circuit which power has higher value apparent power or real power?

Apparent power.

(Q) What is form factor?

It is the ratio of rms value to average value

(Q) What does the form factor of an AC circuit indicates?

It indicates how fare the AC wave departs from sinusoidal wave. The form factor of sinusoidal wave is 1.11. If the form factor of the given wave is less than 1.11 then

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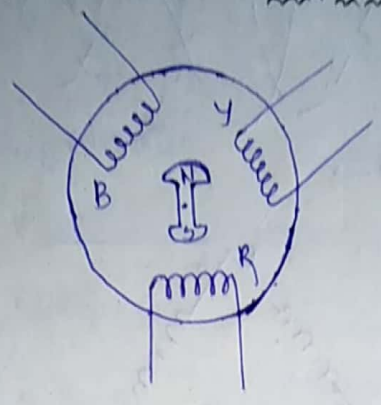
It is said to be flat topped. On the other hand if it is more than 1.11 the wave is said to peaky.

Three Phase A.C :- (3-φ A.C)



Coil = phase

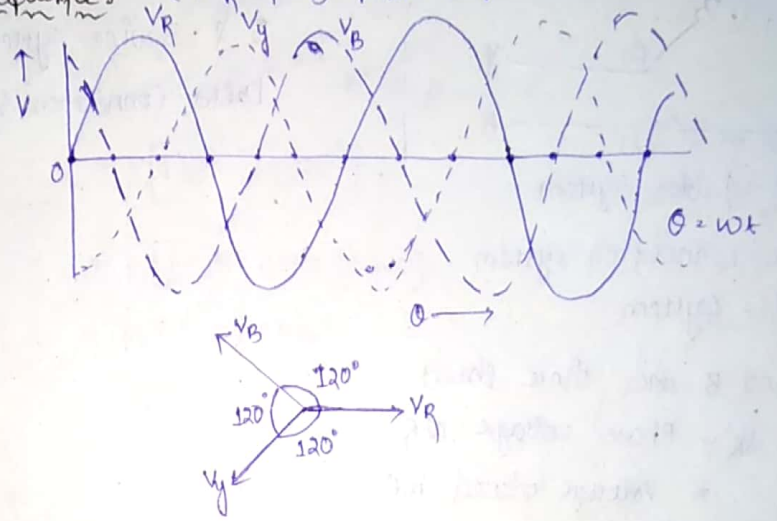
$V_R = V_m \sin \omega t$

$V_Y = V_m \sin(\omega t - 120°)$

$V_B = V_m \sin(\omega t - 240°)$

$= V_m \sin(\omega t + 120°)$

Phase sequence :- (i) R-Y-B phase sequence



The order in which the voltages in 3 phases reach their maximum positive values is called phase sequence

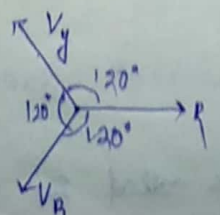
- It is of two types (i) R-Y-B phase sequence
  (ii) R-B-Y phase sequence

(i) R-~~B~~-~~B~~Y Phase sequence

The voltage in coil R attains maximum +ve value first, next coil Y and then coil B hence the phase sequence is called R-Y-B.

(ii) R-B-Y phase sequence

. The voltage in coil R attains maximum +ve value first, next coil B and then coil Y hence the phase sequence is called R-B-Y.



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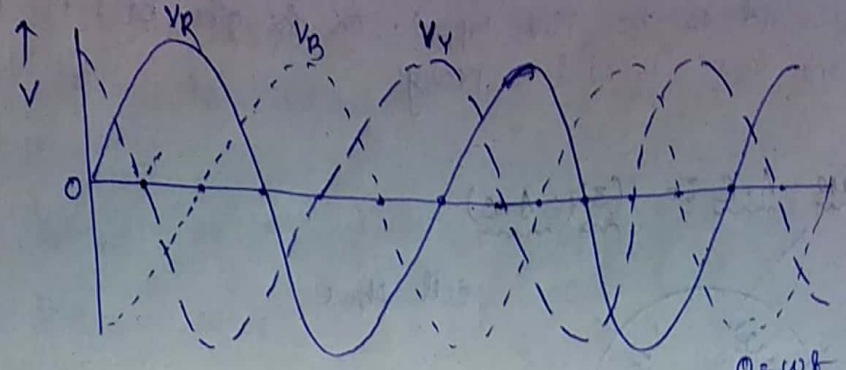
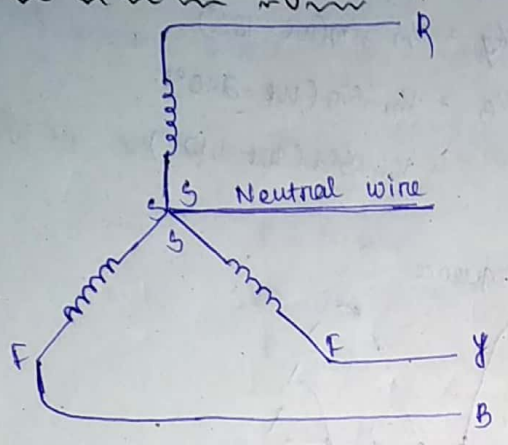


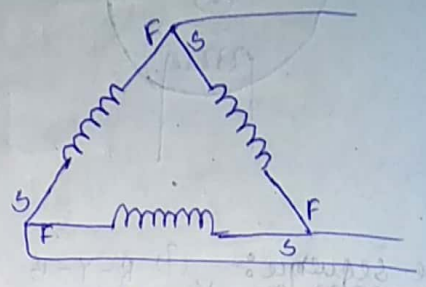
Star Connection System:-



3-φ 4 wire system

Star connection system

Y - System



3-φ · 3 wire system

Delta Connection System.

→ R, Y and B are three phases

V_R = Phase voltage of R

= Voltage Induced in R

= V_{ph}

= V (say)

V_Y = Phase voltage of Y

= voltage induced in Y

= V_{ph}

= V (say)

V_B = Phase voltage of B

= Voltag induced in B

= V_{ph}

= V (say)

V_{RY} = Line voltage = V_L

V_{YB} = line voltage = V_L

V_{BR} = line voltage = V_L

Voltage betn any two line is called line voltage.

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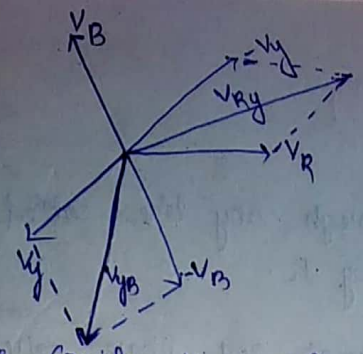

$V_R = V\angle 0^\circ$ Consider V_R as reference.

$V_Y = V\angle -120^\circ$

$V_B = V\angle -240^\circ$

$V_{RY} = V_R - V_Y = V\angle 0^\circ - V\angle -120^\circ$

$\cancel{= (V\cos 0 + jV\sin 0) - [V\cos(-120^\circ) + jV\sin(-120^\circ)]}$

$\cancel{= V - [-\frac{1}{2}V - jV\frac{\sqrt{3}}{2}]}$

$= V[1\angle 0^\circ - 1\angle -120^\circ]$

$1\angle 0^\circ = 1 + j0$

$1\angle -120^\circ = -0.5 - j0.866$

$= V[1 + j0 + 0.5 + j0.866]$

$= V[1.5 + j0.866]$

$= V\, 1.732\angle 30^\circ$

$= \sqrt{3}\, V\angle 30^\circ$

→ Line voltage = $\sqrt{3}$ × Phase Voltage

→ $\boxed{V_L = \sqrt{3}\, V_{ph}}$

$V_{YB} = V_Y - V_B = V\angle -120^\circ - V\angle -240^\circ$

$= V[1\angle -120 - 1\angle -240^\circ]$

$= V[-0.5 - j0.866 + 0.5 - j0.866]$

$= V[0 - j1.732]$

$= V\, 1.732\angle -90^\circ$

$= \sqrt{3}\, V\angle -90^\circ$

Line voltage = $\sqrt{3}$ × Phase voltage.

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Simillarily for V_{BR}

→ Line current : Current flows through any line called as Line current
It is represented by I_L.

→ Phase current : Current flow through any phase called as phase current.
It is represented by I_{ph}

In star connection line current is equal to phase current

$$\Rightarrow I_L = I_{ph}$$

But line voltage = $\sqrt{3}$ × phase voltage

$$\Rightarrow V_L = \sqrt{3} \times V_{ph}$$

→ Power in star connection

Power $P = 3 V_{ph} I_{ph} \cos\theta$

$$= 3\left(\frac{V_L}{\sqrt{3}}\right) I_L \cos\theta$$

$$= \sqrt{3}\, V_L I_L \cos\theta$$

where as,
θ is the angle betn V_{ph} and I_{ph}.

Similarily reactive power

$$Q = 3 V_{ph} I_{ph} \sin\theta$$

$$= \sqrt{3}\, V_L I_L \sin\theta$$

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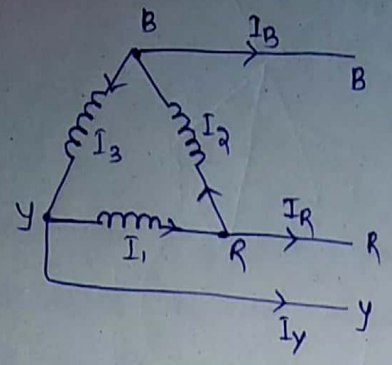
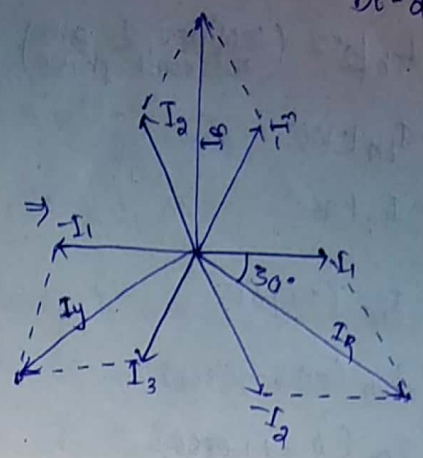
Delta Connection :-

Dt - 26.09.2019





→ let $I_1 = I_{YR}$ = Phase current = I_{Ph}.

$I_2 = I_{RB}$ = Phase Current = I_{Ph}

$I_3 = I_{BY}$ = Phase Current = I_{Ph}

The current flowing through each phase is called phase current.

→ I_R = Line Current = I_L

I_Y = Line current = I_L

I_B = Line Current = I_L

The current flows through a line is called as line current.

→ V_{RL} = Line Voltage = V_L

V_{YB} = Line voltage = V_L

V_{BR} = Line voltage = V_L

The voltage between any two line is called as line voltage

→ Phase voltage = V_{Ph}

Here in delta connection line voltage is equal to phase voltage

* $\boxed{V_L = V_{Ph}}$

- At node 'R' :-

Apply KCL,

$I_1 = I_2 + I_R$

$\Rightarrow I_R = I_1 - I_2$

$= I_{Ph}(1 + j0) - I_{Ph}(-0.5 - j0.866)$

$\Rightarrow I_R = I_{Ph}(1.5 + j0.866) = I_{Ph}\, 1.732 \angle 30° = \sqrt{3}\, I_{Ph} \angle 30°$

So * $\boxed{I_R \text{ is the line current} = \sqrt{3} \times \text{Phase current}}$

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- $I_1 = I_{ph} \angle 0^\circ$ (consider I_1 as reference phasor)

$I_2 = I_{ph} \angle -120^\circ$

$I_3 = I_{ph} \angle -240^\circ$

- $I_1 = I_{ph}(1 + j0)$

$I_2 = I_{ph}(-0.5 - j0.866)$

$I_3 = I_{ph}(-0.5 + j.0866)$

- <u>At node 'y'</u>

Simillarily

Apply KCL

$I_3 = I_1 + I_y$

$\Rightarrow I_y = I_3 - I_1$

$= I_{ph}(-0.5 + j0.866) - I_{ph}(1 + j0)$

$= I_{ph}(-1.5 + j0.866)$

$= I_{ph}\, 1.732 \angle 150^\circ$

$I_y = \sqrt{3}\, I_{ph} \angle 150^\circ$

At node 'B'

Apply KCL

$I_2 = I_3 + I_B$

$\Rightarrow I_B = I_2 - I_3$

$= I_{ph}(-0.5 - j0.866) - (-0.5 + j0.866)$

$= I_{ph}(0 - j1.732)$

$= I_{ph}\, 1.732 \angle 90^\circ$

$I_B = \sqrt{3}\, I_{ph} \angle 90^\circ$

→ In delta connection active power

$P = 3 V_{ph} \cdot I_{ph} \cos\theta$

$= 3 V_L \cdot \frac{I_L}{\sqrt{3}} \cos\theta$

$= \sqrt{3}\, V_L I_L \cos\theta$

where θ is the angle betn V_{ph} and I_{ph}

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Reactive power $Q = 3 V_{ph} I_{ph} \sin\theta$

$= 3 V_L \frac{I_L}{\sqrt{3}} \sin\theta$

$= \sqrt{3} V_L I_L \sin\theta$

(Q) When you say that the AC supply is 220 V, what does it mean?

It means the rms value of AC supply is 220V. Its amplitude will be $\sqrt{2}$ times its value i.e. $V_m = \sqrt{2}\, 220$

(Q) 3 coils each having resistance 30Ω and impedance 50Ω are connected in Δ across 400V, 50 Hz 3 phase supply find

(i) Line current

(ii) Power factor

(iii) Active power absorved.

Sol^n

$R_{ph} = 30\Omega$ $Z_{ph} = 50\Omega$ $V_{ph} = 400V$

$I_{ph} = \frac{V}{Z} = 8A$

(i) $I_L = \sqrt{3} \times I_{ph} = 13.85 A$

(ii) $\cos\theta = \frac{R_{ph}}{Z_{ph}} = \frac{30}{50} = 0.66$

(iii) $P = \sqrt{3} V_L I_L \cos\theta$

$= \sqrt{3} \times 400 \times 13.85 \times 0.66$

$= 5757.336 W$

(Q) A star connected 3 phase load has resistance 8Ω and capacitive reactance 10Ω in each phase. The load is fade from a 3phase 400 V, 50Hz balanced supply. Calculate line current, active and reactive power?

$R = 8\Omega$ $X_C = 10\Omega$

$V_L = 400V$

$V_{ph} = \frac{400}{\sqrt{3}} = 230.94 V$

$Z_{ph} = \sqrt{R^2 + X_C^2}$ $(8 - j10)$

$= \sqrt{64 + 100} = 12.8 \angle -51.34$

$= 12.8\Omega$

$\theta = 51.34$

$I_{ph} = \frac{230.94}{12.8} = 18.04 A$

$P = 3 V_{ph} I_{ph} \cos\theta$ $\cos\theta = \frac{R_{ph}}{Z_{ph}} = 0.624$ $\sin\theta = 0.78$

$= 3 \times 230.94 \times 18.04 \times 0.625$

$= 7804.54 W$

$\sin\theta = \sqrt{1 - \cos^2\theta} = 0.78$

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$$Q = 3 V_{ph} I_{ph} \sin\theta$$

$$= 3 \times 230.94 \times 18.04 \times 0.78$$

$$= 9748.8 \text{ W}$$

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MODULE - 3

10 mrks ques
2 short ques
1 prob

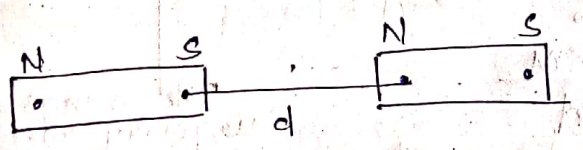
Magnet :-

Properties :-

- A magnet has 2 poles i.e north and south pole and the pole strengths of 2 poles are same.
- The 2 poles of a magnet cannot be isolated.
- Between magnets, like poles repel and unlike poles attract
- Magnet always attract ~~on~~ iron and its alloys.
- Magnetic field exerts force on moving charge and current carrying conductor.
- Magnet can be magnetically saturated.
- Magnet can be demagnetised by heating, mechanical jerks and with lapse of time.
- It produces magnetism in other materials by induction.
- The magnetism of materials mainly due to spin motion of electrons.
- On bending a magnet, its pole strength remains unchanged, ~~by~~ but its magnetic moment changes.

$\boxed{\text{magnetic moment} = (m)(2l)}$

Coulomb's law :-



$F \propto m_1 m_2$

$\propto \frac{1}{d^2}$

$F \propto \frac{m_1 m_2}{d^2}$

$F = K \frac{m_1 m_2}{d^2}$

$F = \frac{1}{4\pi\mu_0} \frac{m_1 m_2}{d^2} = \frac{1}{4\pi\mu_0\mu_r} \frac{m_1 m_2}{d^2}$

μ = Permeability of the med.

$\mu = \mu_0 \mu_r$

μ_0 = absolute permeability $= 4\pi \times 10^{-7}$

μ_r = relative permeability

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Magnetic Field :-

Magnetic flux (ϕ) :-

It is the no. of magnetic lines of force come out of the north pole or enter south pole of a magnet.
It is represented by ϕ.

SI unit = weber = 10^8 maxwell

Magnet flux density :-

$$B = \frac{\phi}{A}$$

It is defined as the flux passing per unit area through a plane at right angles to the flux.

→ It is presented by B.

$$B = \phi / A$$

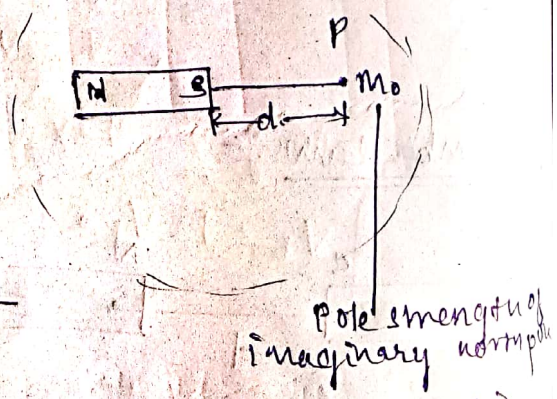
→ SI unit = weber / m^2
or
= tesla

$$\boxed{1 \text{ Tesla} = 10^4 \text{ gauss}}$$

Magnetising force :- (or Magnetic Intensity)

Force acting on 'm_0' is

$$F = \frac{k M m_0}{d^2}$$



Mangnetising force (H) $= \frac{F}{m_0}$

$$= \frac{kM}{d^2}$$

Magnetic intensity at any point in a magnetic field is defined as the force acting on a unit north pole placed at that point.

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16.10.19

Relation between 'B' and 'H' :-

→ B = magnetic flux density
H = magnetising force (or magnetic intensity)

→ $B \propto H$

$B = \text{const.} \times H$

$B = \mu H$

μ = permeability of the material

μ_0 = absolute permeability.
= permeability of air or vaccum
= $4\pi \times 10^{-7}$ H/m

μ_r = relative permeability

Permeability :-

→ $\mu = B/H$

It is the ratio of magnetic flux density to magnetising force.

→ Permeability of a material is defined as its conducting power for magnetic lines of force. Greater the permeability, greater is the conducting power for magnetic lines of force.

→ Permeability of soft iron (pure iron) is high i.e $\mu_r = 8000$.
Due to high μ_r of soft iron, it is used for electrical equipment.

→ μ_r is not const. for a given magnetic material. It varies with flux density in the material.

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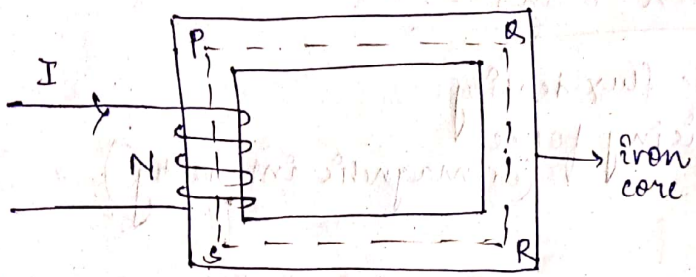
Magnetic circuit –

pole strength (magnetic ckt)
analogue
current (magnetic ...)



→ The closed path follow by magnetic flux is called magnetic ckt.

→ Let us consider a coil of N turns wound on an iron core as shown. when current I passes through the coil, magnetic flux ϕ is setup in the core. The flux follow the close path PQRS, this path is called magnetic ckt.

Magneto-motive force :- (mmf)

work done / pole strength

→ The amount of workdone required to carry a unit magnetic pole once through the entire magnetic field called mmf.

→ It drives magnetic flux through magnetic ckt.

good magnetic material
s ↑
μ ↓

→ It is the product of current and no. of turns of the coil.

$$mmf = NI$$

→ unit – Ampere turn (AT)

Analysis of magnetic ckt –

Let us consider a magnetic ckt of area of cross section 'a' and mean length 'l'.
A coil of N turns wound on the core as shown.

We know that –

$$B = \frac{\phi}{a}$$

$$B = \mu H \Rightarrow H = \frac{B}{\mu} \rightarrow (1)$$

$$H = NI/l \rightarrow (2)$$

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From eqn ① and ②

$$\frac{B}{\mu} = \frac{NI}{l}$$

$$\Rightarrow \frac{\phi/a}{\mu} = \frac{NI}{l}$$

$$\Rightarrow \frac{\phi}{a\mu} = \frac{NI}{l}$$

$$\Rightarrow \phi l = NIa\mu$$

$$\Rightarrow \phi = \frac{NI}{l/a\mu}$$

$$\Rightarrow \boxed{\phi = \frac{NI}{S}}$$

$$\therefore S = \frac{l}{a\mu} = \frac{l}{a\mu_0\mu_r}$$ = reluctance of magnetic ckt.

R = emf/current

$$S = \frac{NI}{\phi} = \frac{mmf}{flux}$$

$$\boxed{S = \frac{AT}{Wb}}$$

18.10.19

Reluctance :-

→ It is the opposition posseed by the magnetic ckt to the flow of magnetic flux.

→ It is represented by 'S'

→ $S = \frac{l}{a\mu_0\mu_r}$

Its unit is AT/Wb

$$S = \frac{NI}{\phi} = \frac{mmf}{\text{magnetic flux}}$$

Factors affecting on reluctance :-

It depends -

- directly length of the magnetic ckt
- inversely area of cross section of magnetic ckt.
- inversely permeability of the medium.

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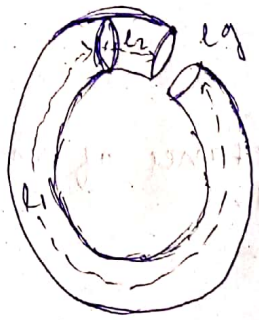
Permeance (1)

→ Reciprocal of reluctance is called permeance.

Permeance $= \frac{1}{S} = \frac{a\mu_0\mu_r}{l}$

Its unit is $\frac{Wb}{AT}$

Series magnetic field -



→ In series magnetic ckt, magnetic flux through each part is same.

→ Total reluctance, $(S = S_1 + S_2 + S_g)$

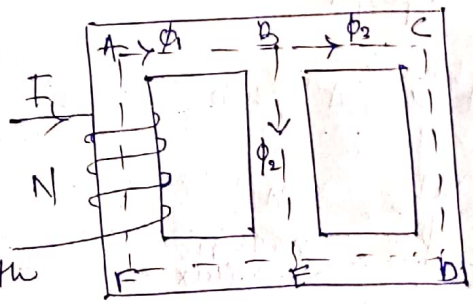
$$S_g = \frac{l_1}{a_1\mu_0\mu_{r_1}} + \frac{l_2}{a_2\mu_0\mu_{r_2}} + \frac{l_g}{a_g\mu_0}$$

{∵ a_1 = area of cross section of l_1
a_2 = area of cross section of l_2
a_3 = area of cross section of gap}

Parallel magnetic ckt -

→ In parallel magnetic ckt, mmf across each path is same.

→ a magnetic ckt, which has more than one path for flux is called parallel magnetic ckt.



→ From fig, I produces magnetic flux ϕ_1. This flux ϕ_1 is divided into 2 parts ϕ_2 and ϕ_3 along two magnetic paths BE and BCDE.

→ The two paths BE and BCDE are parallel, so mmf of BE = mmf of BCDE.

Total mmf = mmf of EFAB + mmf of BE (or mmf of BCDE)

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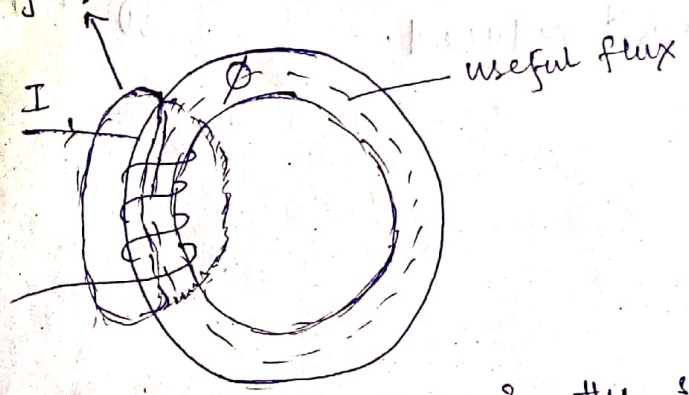
Total mmf = $NI = \phi_1 S_1 + \phi_2 S_2$

Leakage flux :-



→ The total magnetic flux is the sum of useful flux and leakage flux.

→ The part of total flux which has its path within magnetic ckt, called as useful flux.

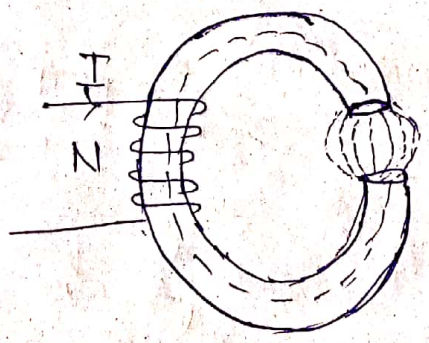
→ The part of total flux having its path partly in magnetic ckt and partly in air is called as leakage flux.

→ The ratio of total flux to useful flux is called leakage factor or leakage coefficient (λ)

$$\text{leakage coefficient } (\lambda) = \frac{\text{Total flux}}{\text{useful flux}}$$

→ Value of $\lambda > 1$ always.

Magnetic fringing :-



→ Consider a ring provided with an air gap. When flux lines cross the gap, they tend to bulge out across the edges of air gap. This effect is called fringing.

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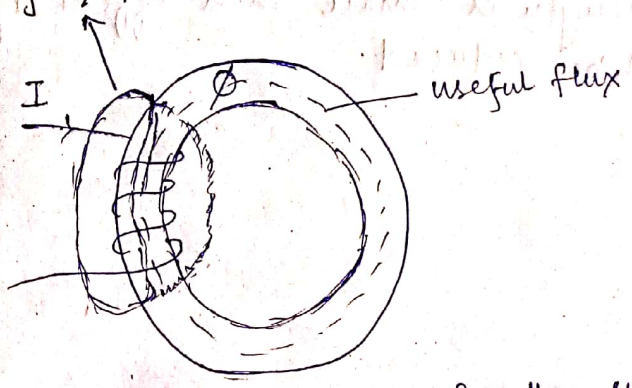
Total mmf = $NI = \phi_1 S_1 + \phi_2 S_2$

Leakage flux :-



→ The total magnetic flux is the sum of useful flux and leakage flux.

→ The part of total flux which has its path within magnetic ckt, called as useful flux.

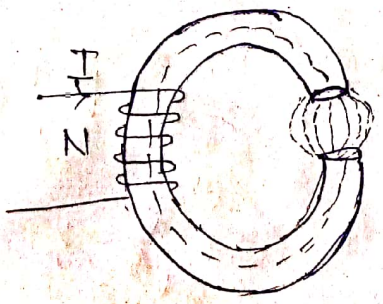
→ The part of total flux having its path partly in magnetic ckt and partly in air is called as leakage flux.

→ The ratio of total flux to useful flux is called leakage factor or leakage coefficient (λ)

$$\text{leakage coefficient } (\lambda) = \frac{\text{Total flux}}{\text{useful flux}}$$

→ Value of $\lambda > 1$ always.

Magnetic fringing :-



→ Consider a ring provided with an air when flux lines cross the gap, they out across the edges of air gap. called fringing.

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→ Fringing increases the gap area of the ring
→ so flux density in the gap decreases.
→ If the gap length is small then effect of fringing will be reduced.

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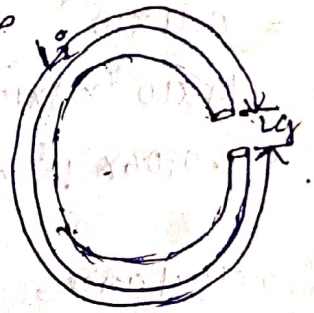
A ring has cross sectional area $3cm^2$ and mean diameter 25cm. An air gap 0.4mm has been cut across the ring. The ring wound with a coil of 200 turns through which current of 2A flows. If flux is 0.24mWb. Calculate μ.



$D = 25\,cm = 25\times10^{-2}\,m$, $\phi = 0.24\times10^{-3}\,Wb$
$N = 200$, $I = 2A$

Length of ring $= \pi D$
$= \pi \times 25\times10^{-2}\,m$
$= 78.5\times10^{-2}$

Length of airgap $= 0.4\,mm$
$= 0.4\times10^{-3}\,m$

length of iron $= L_i = \pi D - L_g$
$= 78.5\times10^{-2} \times 0.4\times10^{-3}$
$= 78.46\times10^{-2}\,m$

Area of cross section $= (a) = 3\,cm^2$
$= 3\times10^{-4}\,m^2$

Total reluctance $(S) = S_i + S_g$

$$= \frac{L_i}{a\mu_0\mu_r} + \frac{L_g}{\mu_0 a}$$

$$\Rightarrow S = \frac{78.46\times10^{-2}}{3\times10^{-4}\times4\pi\times10^{-7}\times\mu_r} + \frac{0.4\times10^{-3}\,m}{3\times10^{-4}\times4\pi\times10^{-7}}$$

$$\Rightarrow S = \frac{2.08\times10^{9}}{\mu_r} + 0.0106\times10^{8} \quad \text{--- (1)}$$

But we know, $\phi = \frac{NI}{S}$

$$S = \frac{NI}{\phi} = \frac{200\times2}{0.24\times10^{-3}} = 1.6\times10^{6}\,\frac{AT}{Wb} \quad \text{--- (2)}$$

From eqn (1) and (2), we get

$$1.6\times10^{6} - 0.0106\times10^{8} = \frac{2.08\times10^{9}}{\mu_r}$$

$$\mu_r = \frac{2.08\times10^{9}}{1.6\times10^{6} - 0.0106\times10^{8}} = 34666 \times 10$$

$$\simeq 3467$$

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Alternative method.

In series magnetic ckt, magnetic flux ~~as~~ remains same.

$$S_g = \frac{l_g}{\mu_0 a}$$

$$= \frac{0.4 \times 10^{-3}}{4\pi \times 10^{-7} \times 3 \times 10^{-4}}$$

$$= 0.0106 \times 10^{8} \text{ AT/Wb}$$

Total reluctance, $S = \frac{NI}{\phi} = \frac{200}{0.24 \times 10^{-3}} \times 2$

$= 1666.6 \times 10^{3}$

$= 1$

$$S_i = S - S_g$$

$$= 0.60 \times 10^{6}$$

606666.667 2.544×10^5

$$S_i = \frac{L_i}{\mu_0 \mu_r a}$$

$$0.60 \times 10^{6} = \frac{78.46 \times 10^{-2}}{4\pi \times 10^{-7} \times \mu_r \times 3 \times 10^{-4}}$$

3.768×10^10

$$\mu_r = \frac{2.08 \times 10^{9}}{0.60 \times 10^{6}}$$

254.7

Total mmf = AT = 400

1666666.667
1060000

mmf of gap = $AT_g = \phi S_g$

$= 0.24 \times 10^{-3} \times 5$

$= 2.547 \times 10^{2}$

$= 254.7$

mmf of iron = $AT_i = AT - AT_g$

$= 145.3$

$$\phi = \frac{mmf}{S_i} = \frac{AT_i}{S_i}$$

$$S_i = \frac{AT_i}{\phi} = \frac{145.3}{0.24 \times 10^{-3}} = 605416.666 \text{ AT/Wb}$$

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$$\frac{L_i}{\mu_0 \mu_r a} = 60541667.666$$

$$\mu_r = \frac{78.46 \times 10^{-2}}{37.68 \times 60541667.666}$$

$$= 3439$$

2.812079.93

Q. A iron ~~beam~~ ring of Diameter 15cm and area of cross section 10 cm² is wound with 200 turns. There is a gap of 2mm cut in the ring. For $B = 1\ wb/m^2$ and $\mu_r = 500$, Find exciting current.

$D = 15cm = 0.15m$

$A = 10cm^2 = 10 \times 10^{-4} m^2 = 10^{-3} m^2$

$N = 200$

$L_g = 2 \times 10^{-3} m$

$B = 1\ wb/m^2$

$\mu_r = 500$

Length of ring $= \pi D = 3.14 \times 0.15 = 0.471\ m$

~~length of~~ $L_i = \pi D - L_g$

$= 0.471 - 0.002$

$= 0.469\ m$

$$\frac{NI}{\phi} = S$$

$$I = \frac{S\phi}{N}$$

$$B = \frac{\phi}{a}$$

$$\phi = Ba = 1 \times 10^{-3}$$

$$S = S_i + S_g$$

$$= \frac{0.469}{4\pi \times 10^{-7} \times 10^{-3} \times 500} + \frac{2 \times 10^{-3}}{4\pi \times 10^{-7} \times 10^{-3}}$$

$$= \frac{0.0469}{6280 \times 10^{-10}} + \frac{2 \times 10^{-3}}{12.56 \times 10^{-10}}$$

$$= \frac{5.89 \times 10^{-10} + 12.58 \times 10^{-10}}{78876.8 \times 10^{-10}}$$

$$= \frac{18.45 \times 10^{-10}}{78876.8 \times 10^{-10}}$$

$$= 2.33$$

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Q The inductance of a coil is 0.15H. The coil has 100 turns, Find —

(a) Flux through the coil when current is 4A.

(b) Energy stored in the magnetic field

(c) Voltage induced in the coil when current reduced to zero in 0.01 sec.

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

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

$$\text{energy stored} = \frac{1}{2}LI^2$$

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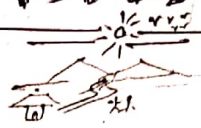
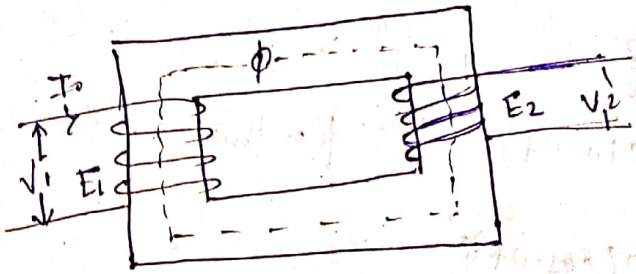
22.10.19

15 MKS

TRANSFORMER





→ Transformer is a static device which consists of two or more stationary electric ckts. interlinked by common magnetic ckt, for transferring electric energy from one ckt to another at same frequency but with changed voltage (or current)

$V = V_m \sin \omega t$

→ In transformer, frequency (or f) and apparent power is always const.

→ Principle —
It is based on the principle of mutual induction i.e whenever magnetic flux linkages with a coil changes an emf is induced in the coil.

Working —
→ When alt. voltage V_1 is applied to primary of a transformer then a current I_0 flows through it. This I_0 is called exciting current which produces alt. magnetic flux (ϕ) in the core. This flux links both primary and secondary windings. So emf (E_1) induced in primary and emf (E_2) induced in secondary.

→ Acc. to Lenz's law, Emf E_1 will oppose V_1 so we can write $\boxed{E_1 = -V_1}$.

→ When load is connected to secondary then current will start flowing in sec. winding. The voltage induced in secondary winding is responsible to deliver power to the load connected to it.

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→ If 2ndary is open then 2ndary current is zero and $\boxed{E_2 = V_2}$

Emf eqn –

We know that,

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

$$\Rightarrow e = -N\frac{d(\phi_m \sin\omega t)}{dt} \quad \{\because \phi = \phi_m \sin\omega t\}$$

$$= -N\phi_m \omega(\cos\omega t)$$

$$= -N\phi_m\omega[\sin(90-\omega t)]$$

$$= N\phi_m\omega[\sin(\omega t - 90)]$$

$$= E_m[\sin(\omega t - 90^\circ)]$$

$$\therefore E_m = N\phi_m\omega = \text{max}^m \text{ emf}$$

RMS value of emf –

$$E_{rms} = \frac{E_m}{\sqrt{2}} = \frac{N\phi_m\omega}{\sqrt{2}}$$

$$= \frac{N\phi_m(2\pi f)}{\sqrt{2}}$$

1.414×3.14

$$= 4.44 N\phi_m f$$

This is the exp. of emf eqn

→ For primary coil emf induced,

$$E_1 = 4.44 N_1\phi_m f$$

similarly, for 2ndary coil emf induced,

$$E_2 = 4.44 N_2\phi_m f$$

Voltage transformation ratio –

It is defined as the ratio of secondary voltage to primary voltage. It is represented by K. so, $K = \frac{E_2}{E_1} = \frac{N_2}{N_1}$

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Also, it is defined as the ratio of 2ndary turns to primary turns.

V. Imp

Turn ratio — The ratio of primary to 2ndary turns called as turn ratio.

$$\text{Turn ratio} = \frac{N_1}{N_2}$$

NOTE - (i) If $N_2 > N_1$ then $E_2 > E_1$. It is the condn for step-up transformer.

(ii) If $N_2 < N_1$ then $E_2 < E_1$. It is the condn for step down transformer.

Ideal transformer :-

→ Primary and secondary winding resistance are negligible ~~hav~~ hence there is no resistive voltage drop and no resistive heat loss.

→ The leakage flux and inductances are zero, so there is no reactive voltage drop in the winding.

→ The efficiency is 100% i.e there are no high hysteresis loss and heat losses due to resistance

→ The permeability of the core is infinity.

The power (VA) in primary = the secondary (power in VA)

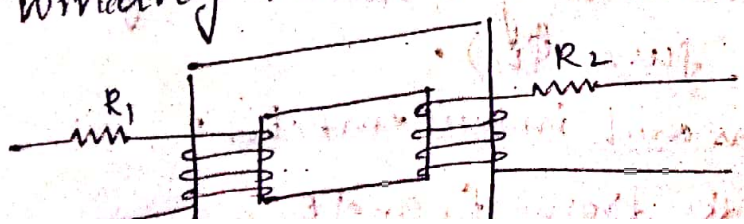
$V_2/V_1 = I_1/I_2 \rightarrow (1)$ Also $E_1 I_1 = E_2 I_2$

$\rightarrow E_2/E_1 = I_1/I_2 \longrightarrow (2)$

Thus, $E_2/E_1 = K = V_2/V_1 = I_1/I_2$

Practical transformer :-

(1) Winding resistances —



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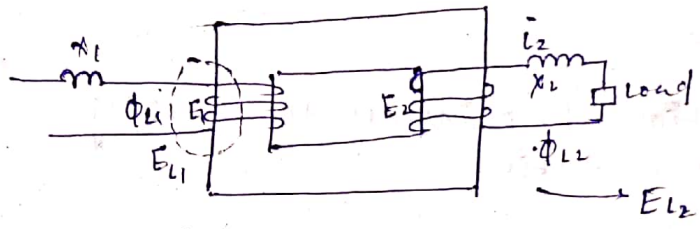
(ii) Leakage Reactance —



(iii) Iron loss :- (core loss)

- Eddy current loss
- Hysteresis loss

P.T → Practical transformer are far diff. from ideal transformer. It has winding resistance, leakage reactance and iron losses.

→ In practical transformer 1° and 2° winding consists of copper conductors so it posses resistance.

$R_1 \rightarrow$ 1° resistance
$R_2 \rightarrow$ 2° resistance
} → connected in series as shown in fig.

L.R → In ideal transformer all flux produced by 1° links in both 1° and 2° winding. but in practical transformer a portion of this flux ~~oriented~~ diverted to the surroundings. It is because surrounding (air) has a permeability. This small portion of flux called as leakage flux (ϕ_{L1}). This ϕ_{L1} links only in 1° and induces emf E_{L1} in 1°

→ The 2° current I_2 produces flux ϕ_2. A portion of ϕ_2 diverted to the surrounding. This leakage flux is called 2° leakage flux (ϕ_{L2}).

It links in 2° turns and induces emf E_{L2}.

E_{L1} and E_{L2} are diff. from E_1 and E_2.

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→ As the leakage flux linking with each winding produces self induced emf in that winding hence the effect of leakage flux equivalent to an inductance in series with each winding.

$X_1 \rightarrow 1^a$ reactance

$X_2 \rightarrow 2^a$ "

I.L → As core of the transformer subjected to alternating flux, there occurs AD current and hysteresis loss. These 2 losses are called <u>iron losses</u>.

→ Its value is less in practical transformer.

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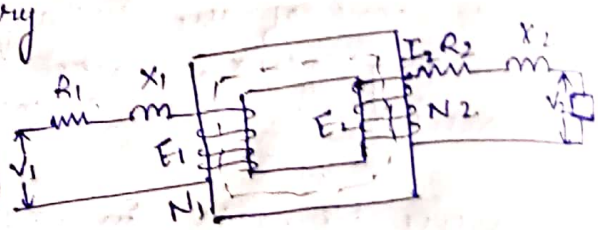
Impedence Reflection and Power transform :-

→ To make transformer calculation simpler, it is preferrable to transfer voltage, current and impedence either to primary or 2 secondary.

→ Equivalent values reflected to primary :-

Let R_2 = Resistance of secondary

R_2' = Resistance of 2ndary reflected to primary



The resistance R_2' should produce same effect in 1° as it produces in 2°.

So, $(I_2')^2 R_2' = I_2^2 R_2 \longrightarrow (1)$

where, I_2' = current of 2° winding reflected to 1° winding. This I_2' is used to counteract the demagnetizing effect of 2° current I_2. Therefore -

$$N_1 I_2' = N_2 I_2$$

$$\Rightarrow I_2' = \frac{N_2}{N_1} I_2$$

$$\Rightarrow I_2' = K I_2$$

eqn (1) becomes

$$(I_2')^2 R_2' = I_2^2 R_2$$

$$\Rightarrow R_2' = \frac{I_2^2 R_2}{(I_2')^2}$$

$$= \frac{I_2^2 R_2}{K^2 I_2^2}$$

$$\Rightarrow R_2' = \frac{R_2}{K^2}$$

similarly -

$$X_2' = \frac{X_2}{K^2}$$

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where X_2 = reactance of 2° winding
X_2' = reactance of 2° winding reflected to 1°.

Let R_{01} = Effective resistance of the whole transformer referred to 1°.

$= R_1 + R_2'$

$= R_1 + \frac{R_2}{K^2}$

X_{01} = Effective reactance of the whole transformer referred to 1°

$= X_1 + X_2'$

$= X_1 + \frac{X_2}{K^2}$

Z_{01} = Effective impedence of whole transformer referred to 1°

$= R_{01} + j X_{01}$

$|Z_{01}| = \sqrt{R_{01}^2 + X_{01}^2}$

→ Equivalent values reflected to secondary :-

Let R_{02} = Effective resistance of the whole transformer. referred to 2°.

$= R_2 + R_1'$

$= R_2 + K^2 R_1$

Let X_{02} = Effective reactance of the whole transformer referred to 2°

$= X_2 + X_1'$

$= X_2 + K^2 X_1$

Let Z_{02} = Effective impedence of the whole transformer referred to 2°

$= R_{02} + j X_{02}$ ⇒ $|Z_{02}| = \sqrt{R_{02}^2 + X_{02}^2}$

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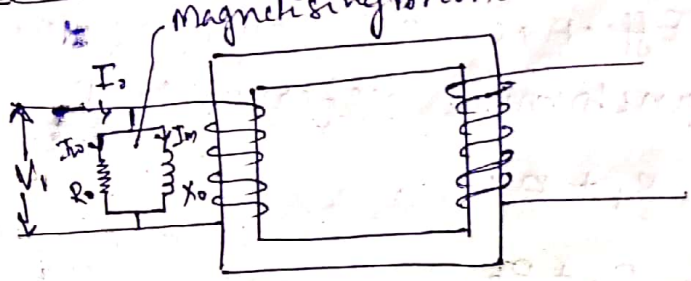
Practical transformer :-

(1) Practical transformer on no load :-

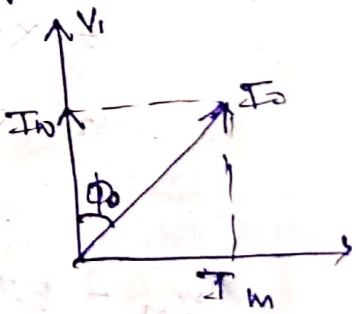


→ I_0 = no load current

I_0 resolves into two components.

I_m = magnetising current (Wattless current)

I_w = current flows through the coil



→ $I_w = I_0 \cos\phi_0$

$I_m = I_0 \sin\phi_0$

$\therefore \phi_0 = \tan^{-1}\left(\frac{I_m}{I_w}\right)$

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

→ No load primary input power is equal to iron loss of the core $= V_1 I_0 \cos\phi_0$

Q A distribution transformer X no load primary current one ampere at 0.24 power factor lagging. Find magnetising current.

$I_0 = 1$ Amp $\quad \cos\phi_0 = 0.24$

$I_m = I_0 \sin\phi_0 \quad \phi_0 = \cos^{-1}(0.24)$

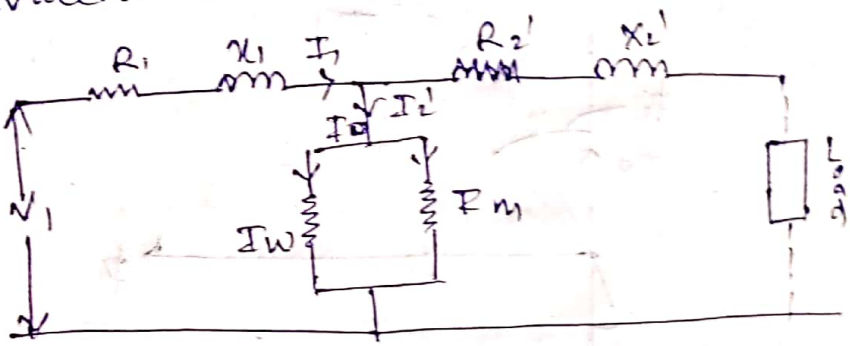
$= 1 \times 0.97$ Amp $\quad = 76.11$

or

$I_m = I$

(ii) Practical transformer on Load :-

Imp Equivalent circuit :-



→ When 2ndary is loaded, 2°dry current I_2 is setup.

→ The secondary current setup its own mmf $N_2 I_2$ and hence its own flux ϕ_2. This ϕ_2 opposes main primary flux ϕ_1 which is due to I_0.

→ The secondary ampere turns $N_2 I_2$ are called demagnetising ampere turns.

→ The secondary flux ϕ_2 ~~oppo~~ weakens the primary flux ϕ_1 momentarily. Hence primary emf E_1 ~~ex~~decreases. For a moment, V_1 increases over E_1 and hence ~~increase~~ causes more current to flow primary. Let the additional primary current be I_2'.

→ The additional primary mmf $N_1 I_2'$ balances $N_2 I_2$. As a result magnetic effects of secondary current I_2 are immediately neutralised by current I_2'.

→ So we can write -

$$N_1 I_2' = N_2 I_2$$

$$\Rightarrow I_2' = \frac{N_2 I_2}{N_1}$$

$$\Rightarrow I_2' = K I_2$$

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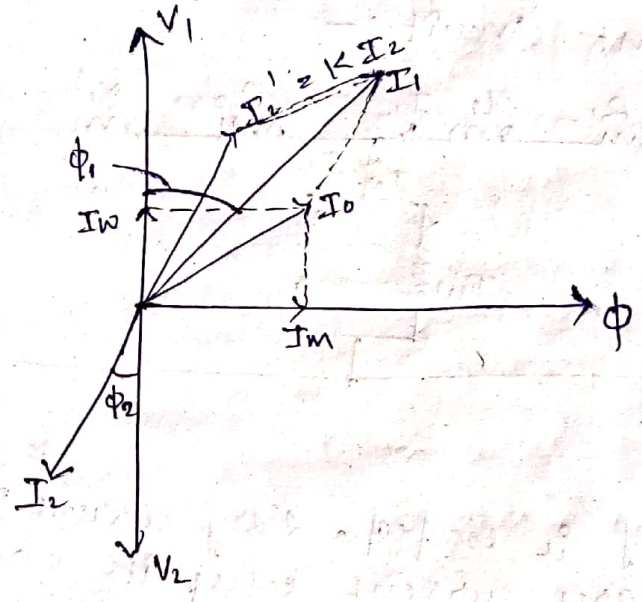
Draw the phasor diagram of practical transformer under inductive load.



30.10.19 :-

Losses of Transformers :-

There are the following losses of a transformer:-

(i) Cu loss

(ii) Iron loss (or core loss)

Cu loss :-

- These losses occur due to resistance of the windings.
- If I_1 and I_2 are primary and secondary currents respectively and R_1 and R_2 are the respective resistances of 2 windings then copper losses occuring in 2 windings are - $I_1^2 R_1$ and $I_2^2 R_2$ respectively.
- Total copper loss of the transformer -

$$I_1^2 R_1 + I_2^2 R_2$$

- The Cu loss vary with square of load current.

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Iron loss -

It is of 2 types -

1) hysteresis loss

2) Eddy current loss

~~Hysteresis loss~~ -

Voltage regulation -

$$\text{Voltage reg.} = \frac{\text{2ndary no load voltage} - \text{2ndary full load voltage}}{\text{2ndary no load voltage}}$$

$$= \frac{E_2 - V_2}{E_2} \times 100$$

Efficiency of the transformer:-

It is defined as the ratio of output power to input power.

It is represented by $\% \eta = \frac{\text{output power in KW}}{\text{input power in KW}} \times 100$

$$= \frac{\text{output power}}{\text{output power + losses}} \times 100$$

Condition for max^m efficiency of transformer?

When variable Cu loss is equal to constant iron loss then efficiency will be max^m.

Why transformer will not work on DC?

If we feed DC supply to the 1° winding of a transformer then the magnetic flux produce will not vary but remains const in magnitude. Therefore no emf will be induced in the secondary winding except at the moment of switching on.

Thus the transformer cannot be employed for rising or lowering the DC voltage

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Also there ~~are~~ will be no back induced emf in the P° windings and therefore a heavy current will be drawn from the supply mains. which may result in the burning out ~~of~~ in the transformer windings.

Q. Why transformer related to KVA?

The size of a transformer determined by KVA of the load the current that passes through the windings ~~which~~ will determine cu losses. whereas iron losses, induction losses depends on voltage that's why the transformer rating may be expressed in KVA.

Isolation transformer —

→ When the transformer receives energy at 1V and delivery it at the same voltage then the transformer is called one to one transformer.

→ For one to one transformer, $N_1 = N_2$ and $E_1 = E_2$. Such a transformer is used to isolate ~~to 2 currents~~ the ckt. and is known as isolation transformer.

→ Frequency and Apparent power constant in transformer.

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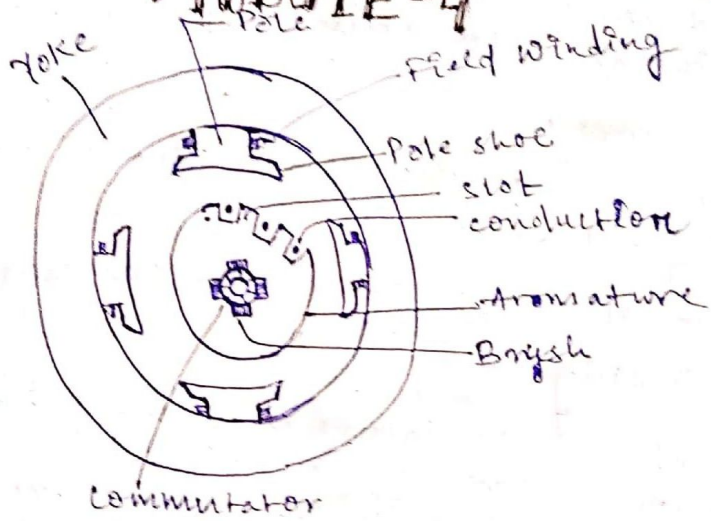
21.11.19

MODULE-4



D.C Machines

- D.C generator
- D.C motors

D.C Generator :-

It converts mechanical energy into electrical energy which D.C in character.

PRINCIPLE :-

When magnetic flux linkages through a conductor changes then an emf is induced which will cause a current flow through the conductor.

CONSTRUCTION :-

~~Whole~~ All DC machines have 5 imp. components :-

1- Field system
2- Armature core
3- Armature winding
4- Commutator
5- Brush

Field system — The func is to produce uniform magnetic field within which armature rotates.

- It consists of poles bolted to a circular frame (yoke). The yoke is made of solid cast steel. which carry magnetic flux.
- The field coils are mounted on the poles and carry DC exciting current.

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The field coils are connected in such a way that adjacent poles have opposite polarity.

Armature core :-

- It is keyed to the machine shaft and rotates b/w the field poles.
- It consists of soft iron laminations.

Armature winding :-

The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as armature winding. This is the winding in which working emf is induced.

Commutator :-

- It is a mechanical rectifier which converts alternating voltage generated in the armature winding into direct voltage across the ~~posit~~ brushes. It is made of copper segments insulated from each other by mica sheets.

Brush :-

The purpose of brushes is to ensure electrical connections b/w commutator and external load circuit. It is made of carbon.

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ϕ ϕ

Armature Winding :-

It is of two types -

i) Lap winding

ii) Wave winding

Lap winding :- In lap winding, no. of parallel path equal to no. of poles.

→ No. of brushes are equal to ~~to~~ no. of parallel path.

→ $A = P$

Wave winding :- In wave winding, no. of parallel path (A) are two.

→ In this winding total no. of brushes are two.

→ $A = 2$

EMF Eqn of DC generator -

ϕ = Magnetic flux per Pole

P = no. of Poles

ϕ_P = total flux

N = revolution per min i.e r.p.m

So $\frac{N}{60}$ = revolution per sec. i.e r.p.s

= frequency in Hz

$\frac{60}{N}$ = time

Z = Total no. of conductors.

A = Total no. of parallel path.

$\frac{Z}{A}$ = no. of conductors in one path

Emf induced in one conductor $= \frac{d\phi}{dt}$

$= \frac{\phi P}{60/N} = \frac{\phi P N}{60}$

Emf induced in one path $= \frac{\phi P N}{60} \times$ no. of cond. in one path

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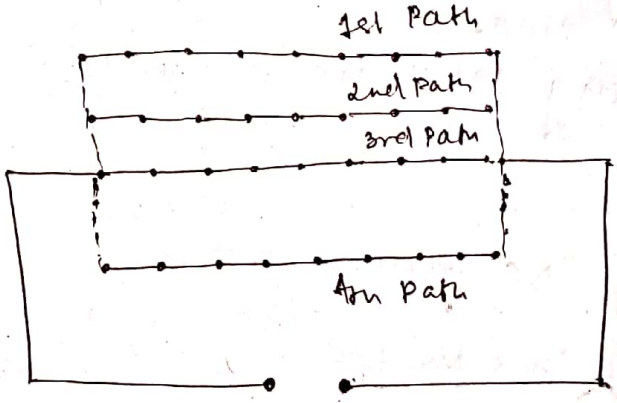
$$= \frac{\phi PN}{60} \times \frac{Z}{A}$$

$$= \frac{\phi PNZ}{60A}$$

~~Total~~ As all paths are connected in parallel, so total emf is -

$$E_g = \frac{\phi Z N P}{60A}$$



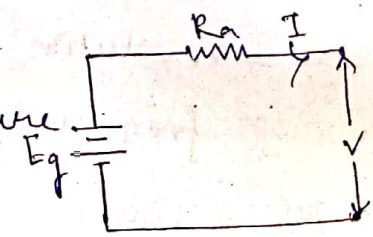
Generator Voltage and Power Eqn -

R_a = Armature resistance

E_g = Generated voltage in armature

I = current flows

V = terminal velocity



Apply KVL,

$$E_g - IR_a - V = 0$$

$$E_g - IR_a = V \longrightarrow (1)$$

multiply I on both sides of eqn (1) - we get,

$$E_g I - I^2 R_a = VI$$

$$\Rightarrow E_g I - I^2 R_a = P \longrightarrow (2)$$

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where $P = VI$ = terminal output power

$E_g I$ = generated electric power in the armature

$I^2 R_a$ = copper loss in the armature

Eqn ② is the power eqn of D.C generator.

To get the condn for maxm power output,

Differential eqn ② w.r.t I. and equated to 0,

$$\frac{dP}{dI} = E_g - 2IR_a$$

$$E_g - 2IR_a = 0$$

$$\Rightarrow E_g = 2IR_a$$

$$\Rightarrow IR_a = \frac{E_g}{2}$$

Putting this value of IR_a in eqn ① we get.

$$E_g - IR_a = V$$

$$E_g - \frac{E_g}{2} = V$$

$$\Rightarrow \frac{E_g}{2} = V$$

Thus, the output power will be maxm when the terminal voltage will have half of generated emf.

Types of DC generator :-

It is of 2 types

- separately excited DC generator
- self excited DC generator

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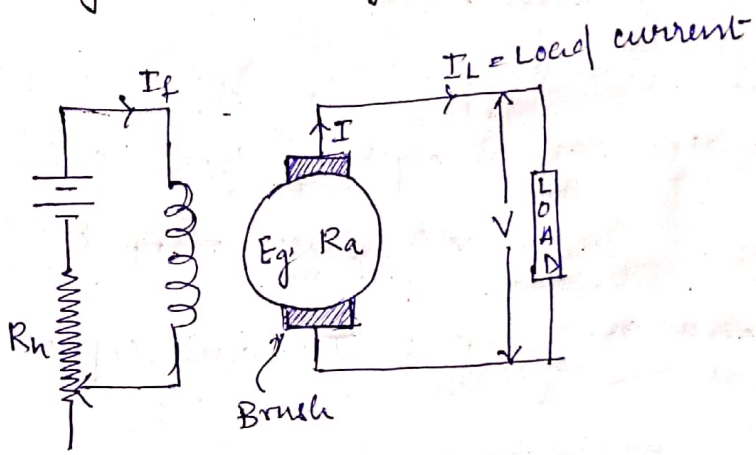
06.11.19

(1) Separately excited DC generators :-



→ A DC generator whose field magnetic winding is supplied from an independent external d.c source is called separately excited D.C generator.

I_a = armature current

E_g = Generated emf

R_a = Armature resistance

I_L = Load current

I_f = Field current

→ $I_a = I_L$

$V = E_g - I_a R_a$

= terminal voltage

Power generated = $E_g \times I_a$

Power delivered to load = $E_g I_a - I_a^2 R_a$

$= I_a (E_g - I_a R_a)$

$= I_a V$

(2) Self excited DC generator :-

It is of 3 types :-

- shunt DC generator
- series DC generator
- compound DC generator.

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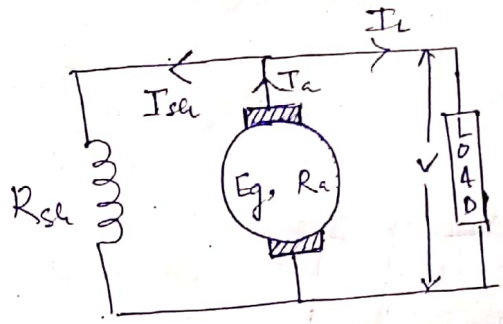
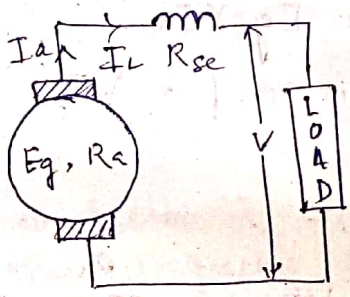
Shunt DC gen. –



- In a shunt gen., the field winding is connected in parallel with armature winding.
- The shunt field winding has many turns.
- shunt field has a high resistance.
- Armature current, $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a R_a$
- shunt current, $I_{sh} = \frac{V}{R_{sh}}$
- Power generated, $E_g \times I_a$
  Power delivered to the load $= V I_L$

Series DC gen. –



- In series ~~wound~~ DC gen., the field winding is connected in series with armature winding.
- series field winding has less no. of turns
- series field winding has low resistance.

R_{se} = series field resistance

→ Armature current, $I_a = I_L$

→ Terminal voltage, $V = E_g - I(R_a + R_{se})$

→ Power generated $= E_g \times I_a$

→ Power delivered to load $= E_g I_a - I_a^2 (R_a + R_{se})$

$= I_a [E_g - I_a (R_a + R_{se})]$

$= I_a V = V I_a$

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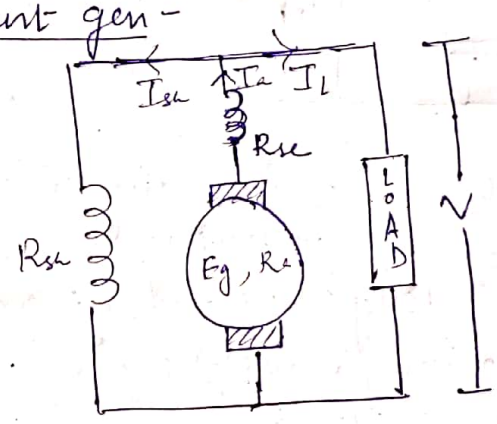
Compound DC generator :-

It is of two types-

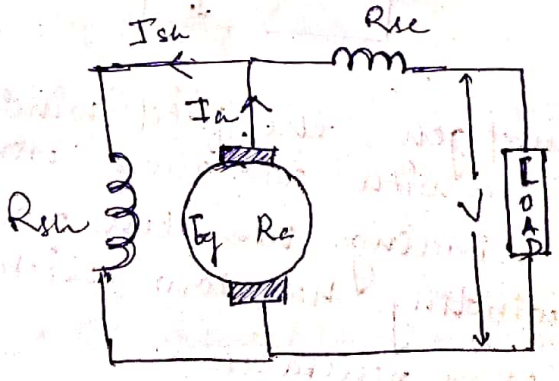
- Long shunt DC gen.
- Short shunt DC gen.

Long shunt gen -



- In this gen, shunt field winding is in parallel with series field and armature winding.
- Armature current. $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a(R_a + R_{se})$
- shunt field current, $I_{sh} = \frac{V}{R_{sh}}$
- Power generated = $E_g \times I_a$
- Power delivered to load = $V I_L$

Short shunt gen. -



- In this gen, shunt field winding is parallel with armature winding.
- Armature current, $I_a = I_L + I_{sh}$
- Terminal voltage, $V = E_g - I_a R_a - I_L R_{se}$

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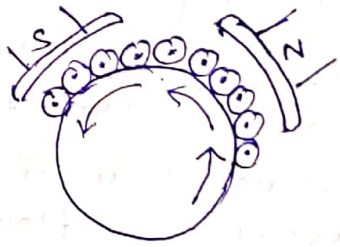
- shunt current, $I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$

- Power generated $= E_g I_a$

- Power delivered to load $= V I_L$

07.11.19

D.C MOTOR :-



It is a machine which converts DC power to mechanical power.

Principle - It states that when a current carrying conductor is placed in a magnetic field then conductor experiences a mechanical force.

Its value is - $\vec{F} = I(\vec{l} \times \vec{B})$

The direction of a vector can be determined by flemmings left hand rule.

$$|\vec{F}| = IlB \sin\theta$$

If $\theta = 90°$, $F = BIl$

Working -

→ Each armature conductor is carrying current and is placed in the magnetic field. A mechanical force acts on it.

→ Force on each conductor is tending to rotate the armature in anticlockwise direction.
All these forces add together to produce a driving torque which sets the armature rotating.

* Back emf / ~~current~~ counter emf in DC motor -

When ~~DC~~ ~~mo~~ armature of DC motor rotates under the influence of driving torque then the armature conductors move through the magnetic field and hence emf is induced in them.

→ The induced emf acts in opp. direction to the applied voltage V. Hence known as back emf.

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$E_b = \frac{\phi Z N P}{60A}$, A = no. of parallel path
P = no. of poles
N = speed in rpm
ϕ = flux per pole
Z = total armature conductors

→ The value of E_b is smaller than terminal voltage V.
→ As the armature rotates back emf E_b is induced which opposes applied voltage V.
→ The applied voltage V has to force current through armature against E_b.
The workdone in overcoming and causing the current to flow against E_b is converted to mechanical energy developed in the armature.

→ Energy conversion in DC motor is only possible due to the production of E_b.

Voltage eqn of DC motor :-
Let I_a = Armature current
R_a = Armature resistance
V = Applied voltage
E_b = Back emf induced.

$$I_a = \frac{V - E_b}{R_a}$$

$\Rightarrow I_a R_a = V - E_b$

$\Rightarrow \boxed{V = I_a R_a + E_b}$

Power eqn of DC motor :-
we know that, $V = E_b + I_a R_a$

$$\boxed{V I_a = E_b I_a + I_a^2 R_a} \longrightarrow (2)$$

where $V I_a$ = Power supply to armature (Input armature)
$E_b I_a$ = Power developed (Armature output)
$I_a^2 R_a$ = copper loss
↳ Electrical power wasted in armature

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condition for max^m power :-

We know that power eq^n is -

$$VI_a = I_a^2 R_a + E_b I_a$$

$$\Rightarrow E_b I_a = VI_a - I_a^2 R_a$$

$$\Rightarrow P = VI_a - I_a^2 R_a$$ ($P = E_b I_a$ - Power developed in armature)

$$\frac{dP}{dI_a} = V - 2I_a R_a$$

for max^m power,

$$\frac{dP}{dI_a} = 0$$

$$\Rightarrow V - 2I_a R_a = 0$$

$$\Rightarrow V = 2I_a R_a$$

$$\Rightarrow I_a R_a = \frac{V}{2}$$

Putting this value in voltage eq^n -

$$V = \frac{V}{2} + E_b$$

$$\Rightarrow E_b = V - \frac{V}{2}$$

$$\Rightarrow E_b = \frac{V}{2}$$

Mechanical power developed by the motor in max^m when back emf = $\frac{1}{2}$ x applied voltage.

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12.11.19

Armature Torque in DC motor :-

Let r = radius of armature

l = length of armature

A = no. of parallel path

B = magnetic flux density

Z = total no. of armature conductors.

I_a = armature current flows

$\frac{I_a}{A}$ = ~~total~~ current in each conductor

ϕ = flux per pole

P = total no. of poles

→ Force acting on ~~each~~ one conductor,

$$F = B\left(\frac{I_a}{A}\right) l$$

→ Torque due to one conductor.

$$T = F \times r$$

$$= B\left(\frac{I_a}{A}\right) l r$$

→ Total armature torque,

$$T_a = Z B\left(\frac{I_a}{A}\right) l r$$

$$T_a = Z\left(\frac{\phi}{a}\right)\left(\frac{I_a}{A}\right) l r \quad \left\{ \because B = \frac{\text{flux}}{\text{area}} = \frac{\phi}{a} \right\}$$

$$\because a = \frac{2\pi r l}{P}$$

We know that,

$$T_a = Z\left(\frac{\phi}{\frac{2\pi r l}{P}}\right)\left(\frac{I_a}{A}\right) l r$$

$$\boxed{T_a = \frac{Z \phi I_a P}{2\pi A}} \quad \text{———— (1)}$$

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But we know that -

Back emf $E_b = \frac{\phi Z N P}{60 A}$

$$\frac{Z \phi P}{A} = \frac{E_b \times 60}{N}$$

Eqn ① becomes

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

$$\Rightarrow T_a = \frac{9.55 E_b I_a}{N} \text{ Nm}$$

From eqn ①, $T_a \propto \phi I_a$ $\left\{ \because Z, P \& A \text{ are constant} \right\}$

→ For shunt machine, flux ϕ = const

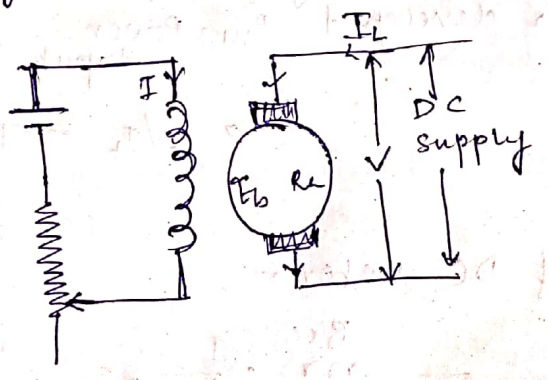
So $\boxed{T_a \propto I_a}$

→ For series machine, flux $\phi \propto I_a$

So $\boxed{T_a \propto I_a^2}$

Types of DC motor :-

(i) Separately excited DC motor



→ Let I_a = Armature current

= line current

= I_L

E_b = back emf produced

= $V - I_a R_a$

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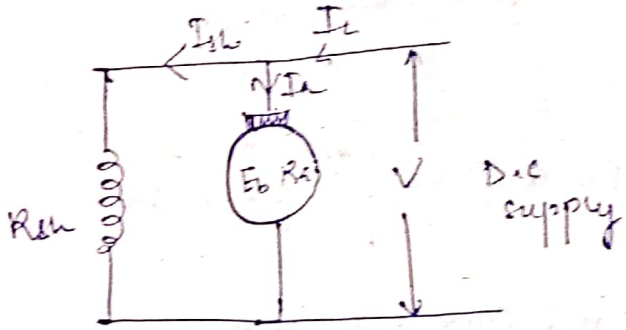
Power drawn from the supply = VI_L

Mechanical power developed = P_m

= Power input to armature − Power loss

$= VI_L - I_a^2 R_a$

(ii) Shunt type DC motor −



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

V = supply voltage

Back emf developed, $E_b = V - I_a R_a$

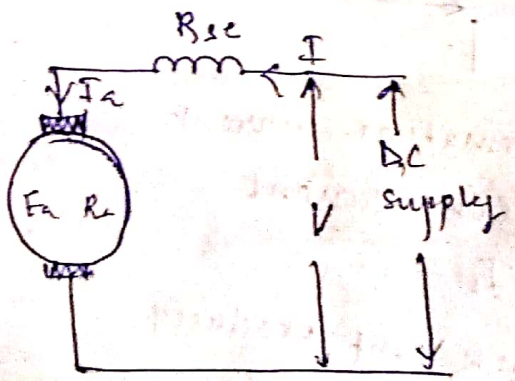
Shunt resistance $R_{sh} = \frac{V}{I_{sh}}$

Power drawn from the supply = $V \times I_L$

Mechanical power developed P_m = Power input − Power loss

$= VI_L - I_a^2 R_a - I_{sh} R_{sh}$

(iii) Series type of DC motor −



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Line current I_L = Armature current I_a

V = supply voltage.

Back emf induced in the motor. $E_b = V - I_a(R_a + R_{se})$

power drawn from main supply = VI_L

mechanical power developed, $P_m = VI_L - I_a^2(R_a + R_{se})$

$= E_b I_a$

Losses of DC machine -

These are the following losses of DC machine

(i) cu loss

(ii) Fe loss

(iii) mechanical loss / Friction loss

13.11.19

Cu loss - It is of 3 types - Armature cu loss
- shunt field cu loss
- series field cu loss

Armature cu loss $= I_a^2 R_a$

shunt field cu loss $= I_{sh}^2 R_{sh}$

series field cu loss $= I_{se}^2 R_{se}$

Fe loss - It is of 2 types - Hysteresis loss
- Eddy current loss

Hysteresis loss - It occurs in the armature of DC machine since armature is subjected to magnetic field ~~of~~ reversals as it passes under successive poles.

- Hysteresis loss, $P_h = \eta B_m^{1.6} f V$ watt ~~volt~~

Eddy current loss - when armature rotates in the magnetic field of the poles an emf is induced in it which circulates eddy current in the armature pole. $P_E = K_e B_m^2 f^2 t^2 V$ watt

Mechanical loss -

These loss are due to friction and winding.

Friction loss i.e bearing friction, &

Windage loss i.e air friction or rotating armature

What do you mean by stray loss?

Iron loss and mechanical loss together combine to form stray loss.

Speed control of DC motor :-

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

$$\Rightarrow N = \frac{60 A \times E_b}{\phi Z P}$$

clearly $N \propto \frac{E_b}{\phi}$

$N \propto \frac{V - I_a R_a}{\phi}$ → shunt motor $\{\because E_b = V - I_a R_a\}$

For series motor, $E_b = V - I_a R_{se} - I_a R_a$

$$N = \frac{V - I_a R_{se} - I_a R_a}{\phi}$$

→ ~~It is of~~ Speed ~~control~~ of DC motor depends on -

- Magnetic flux per pole (ϕ)
- Resistance of the armature ckt

→ It is of 2 types → Flux controlled method
→ Armature controlled method.

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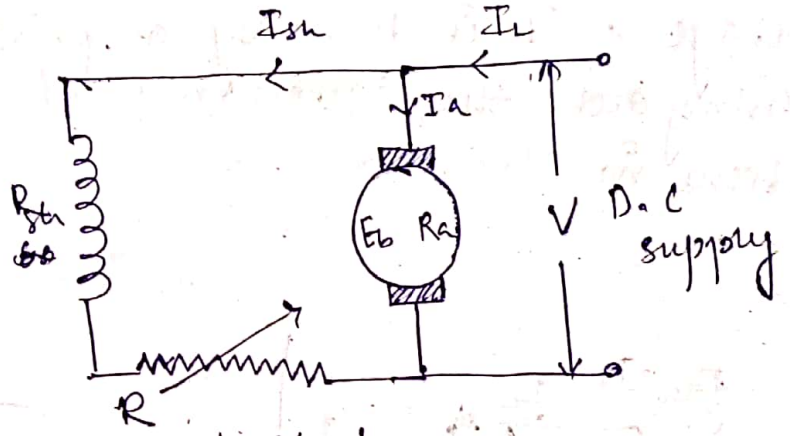
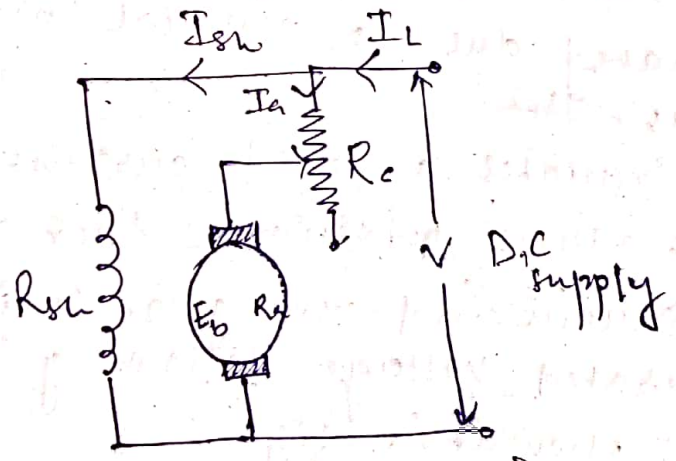
Flux controlled method -



we know, $N \propto \frac{1}{\phi}$

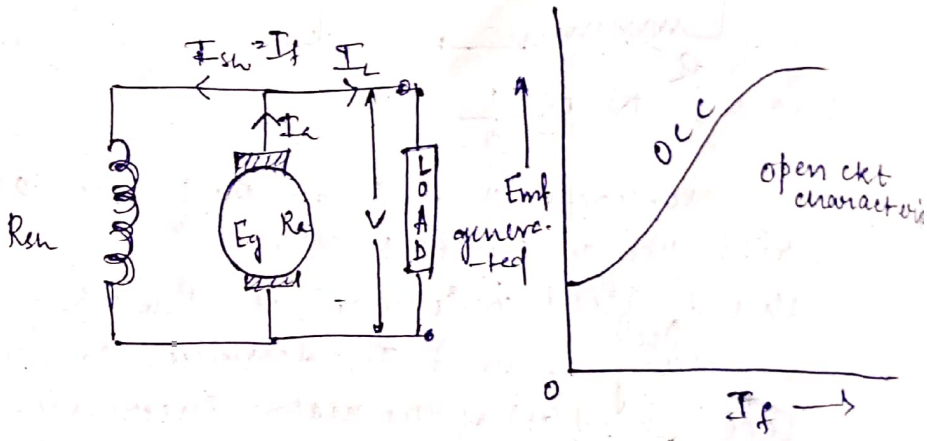
- In this method, A variable Resistance (R) is connected in series with shunt field.
- The shunt field resistance is $R_{sh} + R$
- If we ~~vary~~ ↑se R then I_{sh} decreases. so flux ϕ decreases therefore speed (N) of the motor increases.

Armature controlled method -



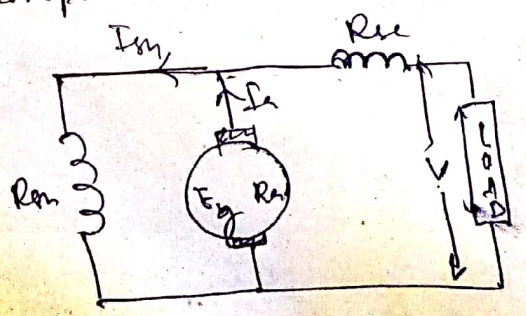
- In this method a ~~value~~ variable resistance of Re is connected in series with armature.
- Due to voltage drop in Re the back emf (E_b) decreases, ~~so~~ but $N \propto E_b$. so speed of the motor decreases

Q Describe the self excited D.C shunt generator building its terminal voltage as it is run by a prime mover. clearly bring out the importance of residual magnetism in the core



Let us consider a shunt generator as shown in fig.
If the generator is run at a const speed, some emf will be generated due to residual magnetism in the main poles. ~~The~~
This small emf circulates a field current (I_f) which in turn produces additional flux ~~This~~
This process continuous and the gen. builds up the normal generated voltage following the open ckt characteristics shown in fig.

Q A 50 KW, 250 V short shunt compound generator has the following data, $R_a = 0.06\,\Omega$
$R_{se} = 0.04\,\Omega$
$R_{sh} = 125\,\Omega$
Calculate the induced armature voltage at rated load and terminal voltage. Take 2 volt as gross drop.



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given, $V = 250$ volt

O/P power $= 50 \times 10^3$ watt

$$I_L = \frac{\text{Power}}{\text{voltage}} = \frac{50 \times 10^3}{250} = 200 \text{ Amp.}$$

$$I_{sh} = \frac{V - I_L R_{se}}{R_{sh}} = \frac{250 + 200 \times 0.04}{125}$$

$$= \frac{258}{125}$$

$$= 2.064 \text{ Amp}$$

$$I_a = I_L + I_{sh} = 200 + 2.064$$

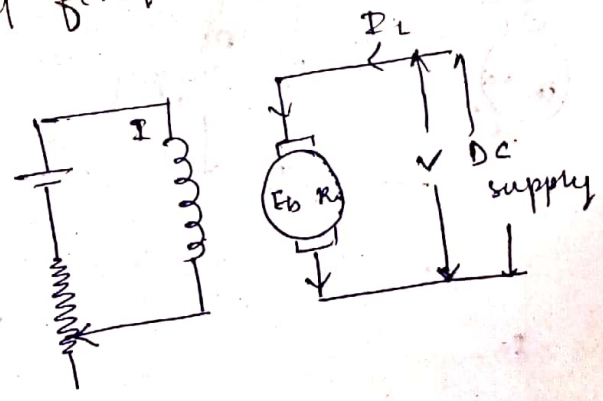
$$= 202.064 \text{ Amp}$$

$$E_g = V + I_L R_{se} + I_a R_a + \text{gross drop}$$

$$= 250 + 200 \times 0.04 + 202.064 \times 0.06 + 2$$

$$= 272.12$$

Q A 20KW, 230 V separately excited generator has armature resistance 0.2 Ω and load current 100 Amp. find generated voltage when terminal voltage is 230 V and find output power.



$V = 230$ V

$R_a = 0.2\ \Omega$

$I_L = 100$ Amp. $= I_a$

$$E_g = V + I_a R_a$$

$$= 230 + 100 \times 0.2$$

$$= 250 \text{ V}$$

O/P power = O/P voltage × O/P current

$$= 230 \times 100$$

$$= 23 \text{ KW}$$

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Q-A 120V, 10 Amp, DC shunt generator has $R_a = 0.6\Omega$ $I_{sh} = 2$ Amp. Calculate the generated emf in the generator.

$V = 120V$

$I_L = 10$

$R_a = 0.6\Omega$

$I_{sh} = 2$ Amp

$I_a = I_L + I_{sh}$

$= 10 + 2$

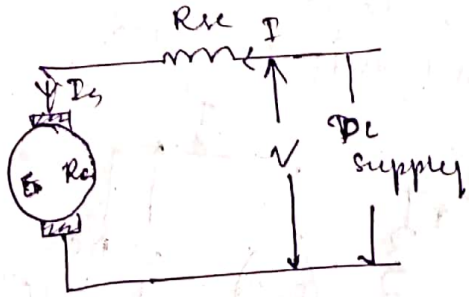
$= 12$

$E_g = V + I_a R_a$

$= 120 + 12 \times 0.6$

$= 127.2$

Q-A DC series motor operates at 800 rpm with line current 100 Amp from 230V mains. Given $R_a = 0.15\Omega$, $R_{se} = 0.1\Omega$, Find the speed at which more runs at a line current of 25 Amp. Assuming flux at this current (25) 45% of flux at 100 A.



we know,

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

$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{\phi_2}{\phi_1} \quad \text{——— (1)}$$

$E_{b1} = V - I_a [R_a + R_{se}]$

$= 230 - 100 [0.15 + 0.1]$

$= 205$ V

$E_{b2} = 230 - 25 [0.15 + 0.1]$

$= 223.75$ V.

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$N_1 = 800$

$\phi_2 = 0.45\,\phi_1$

$$\frac{800}{N_2} = \frac{205}{223.75} \times \frac{0.45}{1}$$

$$\frac{800 \times 223.75}{205 \times 0.45} = N_2$$

$$N_2 = \frac{179000}{92.25}$$

$= 1940.37$ rpm.

A 4 pole 500 v DC shunt motor has total conductors 720 which are wave connected. The full load armature current 60 Amp. and flux per pole 0.03 Wb ~~and~~ $R_a = 0.2\,\Omega$, voltage per ~~gross~~ brush is 1 volt. Calculate the full load speed.

$E_b = V - I_a R_a - \text{gross drop}$

$= 500 - 60 \times 0.2 - 2$

$= 486$

wave connected $= 2$

lap connected $= 1$

$$N = \frac{E_b \times 60A}{\phi Z P}$$

$$= \frac{480 \times 60 \times 2}{0.03 \times 720 \times 4}$$

$= 675$

Q Will a DC shunt motor operate on AC supply?

Shunt has large turns, it has inductance ~~were~~ when AC applied large inductive reactance X_L of shunt winding generates which reduces shunt current (I_{sh}) so motor will not run usually on AC supply.

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15.11.19

Q A dc motor runs on a 200V supply and has negligible armature resistance. What happens to its speed if the armature voltage is reduced by 20% and the field current increased by 30%.

$V = 200$ volt

$R_a = 0$

$I_a R_a = 0$

$I_{f_1} = 1.3 I_{f_2}$

$E_{b_2} = 0.8 E_{b_1}$

$E_{b_1} = 100$

$E_{b_2} = 100 - 20$

$= \frac{100}{100} - \frac{20}{100}$

$\frac{130}{100}$

flux $\phi \propto I_f$

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

$$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$$

$$= \frac{0.8 E_{b_1}}{E_{b_1}} \times \frac{\phi_1}{1.3 \phi_2}$$

$$= \frac{0.8}{1.3}$$

$N_2 = 0.61 N_1$

$= (1 - 0.39) N_1$

So, speed decreased by 39%.

Q A dc shunt generator generates an emf of 520 V. ~~At~~ at a speed of 1200 rpm. It has 2000 armature conductors and the flux per pole is 0.013 wb. The armature winding has 4 parallel paths.

(i) Determine the no. of poles.

(ii) Find the generated voltage if the armatu

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winding is wave connected.

Ans $V = 520\,V$

$Z = 2000$

$\phi = 0.013\,Wb$

$A = 4$

$N = 1200$

(i) $E_g = \frac{P\phi Z N}{60A}$

$520 = \frac{P \times 0.013 \times 2000 \times 1200}{60 \times 4}$

$\Rightarrow \frac{124800}{31200} = P$

$\Rightarrow P = 4$

(ii) $E_g = 2E_g = 1040\,V$ (parallel path ↓ voltage ↑ inversely prop.)

Q A D.C shunt motor rotating at 1500 rpm ~~of~~ is fed by 120 V AC source. The line current run by the motor is 51 Amp. The shunt field resistance is 120 ohm. Find —

(i) the back emf E_b.

(ii) the mechanical power and torque developed the motor. assume the armature 0.1 Ω.

$I_L = 51\,Amp$ $R_{sh} = 120\,\Omega$ $R_a = 0.1\,\Omega$

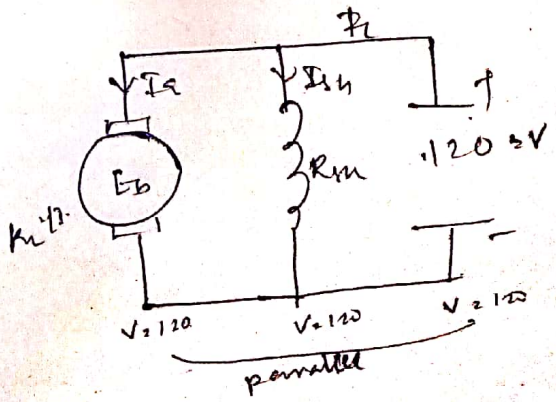
$E_b = V - I_a R_a$

$I_{sh} = \frac{V}{R_{sh}} = \frac{120}{120} = 1\,A$

$I_a = 51 - 1 = 50\,A$

$E_b = 120 - 50 \times 0.1$

$= 115$



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mechanical power = $E_b I_a$

$= 115 \times 50$

$= 5.75$ KW

mechanical Torque $= \frac{P}{\omega} = \frac{5750}{2\pi f}$

$= \frac{5750}{2\pi \frac{N}{60}} = \frac{5750}{\frac{2 \times 3.14 \times 1500}{60}}$

$= 36.6$

$\simeq 37$

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