Unit- 1

RIPPLE SAHNI

D.C. Circuits

Electricity play an important role in our day to day life.
Electricity is used for
1) Lighting (lamps) 2. Heating (Heaters) 3. Cooling 4. Entertainment (radio & T.V) 5. Transportation (electric traction) 6. Calculations (Calculators)
Now-a-days, all our activities are dependent upon electricity.

Electricity:-

The invisible energy which constitutes the flow of electrons in a closed circuit to do work is called electricity.

Modern Electron theory:-

In past, electricity were developed through experiments & by observing its behaviour.

Modern electron theory says that every matter consists of very small divisible particles called molecules. Molecules is further made up of very small particles called atoms.

An atom consists of following two main parts
1) Nucleus 2) Extra Nucleus.

1) **Nucleus:-** The central part of an atom consists of protons & neutrons

A proton has +ve charge (1.602×10^{-19} coloumbs)
& neutron has no charge

Thus, on the whole nucleus of an atom bears +ve charge

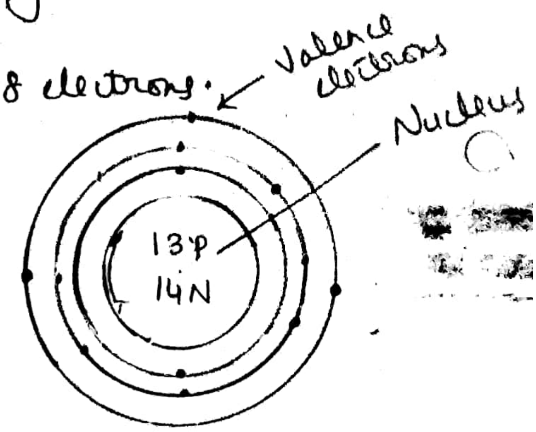
Extra Nucleus :- The outer part of an atom which contains only electrons. An electrons has -ve charge (1.602×10^{-19} coulombs) equal to that of proton.

Atomic Weight = no of protons + no of neutrons in the nucleus

Atomic Number :- no of protons or electrons in an atom

No of electrons in any orbit is given by $= 2n^2$

The one orbit cannot have more than 18 electrons.



eg Aluminium (Al)

Atomic No = 13

Atomic weight = 27

No of protons = 13

No of neutrons = 27 - 13 = 14

At a time, Out of 3 electrons of the Outmost orbit, only one electron is free to move from one atom to the other & is called free electron.

Nature of Electricity :-

Every mater is electrical in nature since it contains charge particles like protons & electrons.

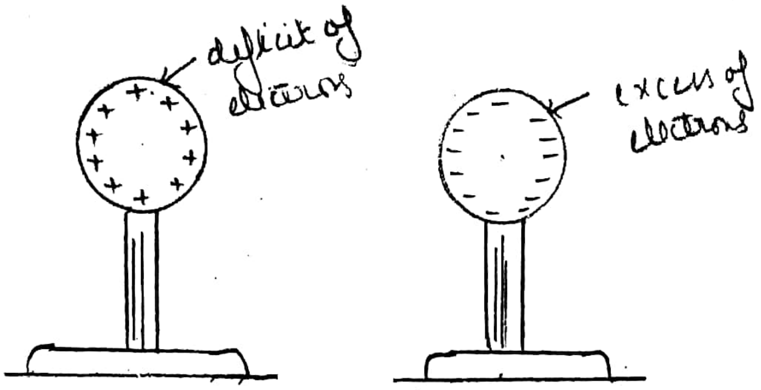
Therefore

1) Ordinarity, a body is neutral as it contains same number of protons & neutrons.

2) If some of electrons are removed from the body, there ②

a deficit of electrons & the body attains a positive charge.

3) If some of electrons are supplied to the body, there occurs excess of electrons & the body attains a negative charge.



A body is said to be charged +vely or -vely if it has deficit or excess of electrons from its normal due share respectively.

Unit of Charge

The practical unit of charge is coulomb.

One coulomb = charge on 6.28×10^{18} electrons.

Free Electrons:-

The valence electrons which are loosely attached to the nucleus of an atom & can be loosely detached are called free electrons.

Electrical potential:-

The capacity of charged body to do work is called electrical potential.

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∴ Electric potential = $\frac{\text{work done}}{\text{charge}} = \frac{W}{Q}$

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

Unit of electrical potential is volts or Joules/coulomb.

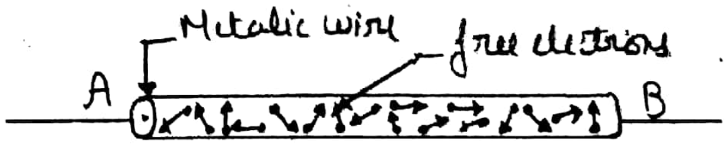
Def:- A body is said to have an electric potential of 1 Volt if 1 Joule of work is done to charge the body to 1 coulomb.

Potential difference:-

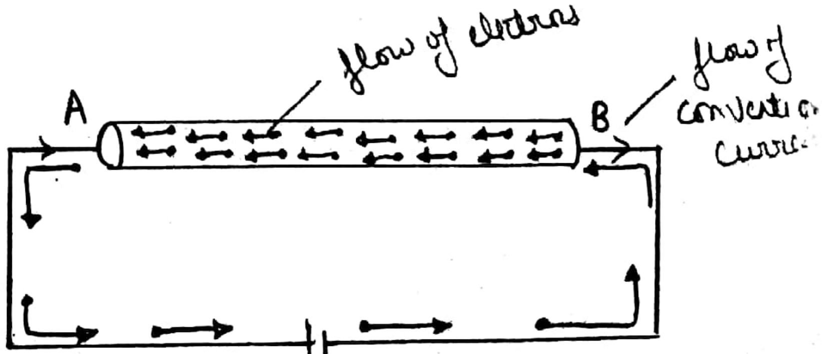
The difference in electric potential of the two charged bodies is called Potential difference.

Unit of potential difference is Volts.

Electric Current:-



In metallic wire, a large number of electrons are available which move from one atom to the other at random.



When an electric potential is applied across the metallic wire, the loosely attached free electrons start moving towards the +ve Terminal of the cell.

Thus, a continous flow of electrons in an electric circuit is called electric current.

Def:-

Current is rate of flow of electrons i.e. charge flowing per second.

$$I = \frac{Q}{t}$$

The unit of current is ampere (A).

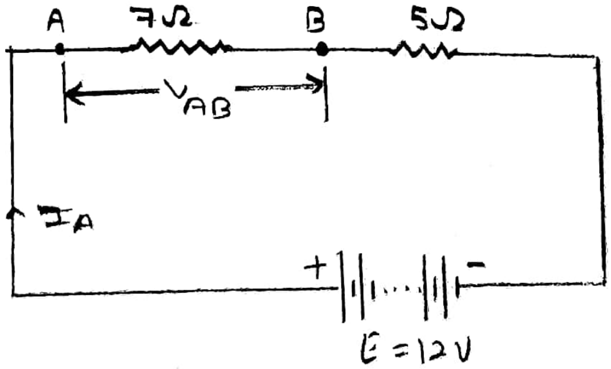
E.m.f (electromotive force) & potential difference:-

E.m.f is the force that causes an electric current to flow in an electric circuit.

In fact it is not a force but it is energy.

E.m.f:- The amount of energy supplied by the source to each coulomb of charge is known as emf

Potential difference:- The amount of energy used by one coulomb of charge in moving from one point to the other is known as potential difference between two points.



In fig as shown on R.H.S.

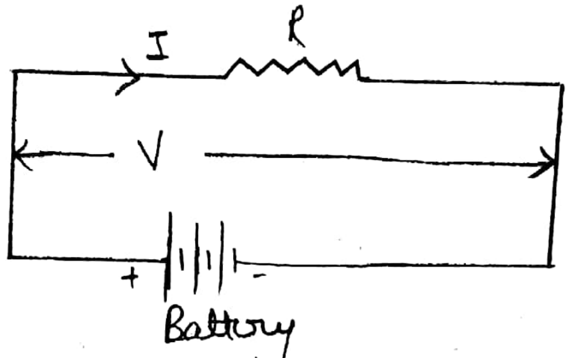
A battery has emf of 12 Volts

The potential diff b/w A & B is 7 Volts

Resistance :- The opposition offered to flow of electric current is called resistance.

Unit of resistance is ohm (Ω)

Ohm's law :-



Ohm law states that current flowing between any two points of conductor is directly proportional to the potential difference across them, provided physical conditions (i.e. temp) do not change.

Mathematically $I \propto V$

or $\frac{V}{I} = \text{constant}$

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

$$V = IR$$

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

Limitations :-

1) Ohm's law cannot applied to the circuit consisting of transistors or electric tubes because such elements are not bilateral i.e. they behave in different way when direction of flow of current is is reversed as in case of diode.

2: Ohm's law cannot applied to the circuits consisting of non-linear elements such as electric arc, powered carbon for silicon carbide, the relationship b/w current & Voltage is given as $V = kI^m$, k & m are constants & m is less than unity.

Law of Resistance:-

The resistance of a wire depends upon

1) It is directly proportional to its length

$$R \propto L \quad \text{—} \ (1)$$

2) It is inversely proportional to its area of cross-section

$$R \propto \frac{1}{A} \quad \text{—} \ (2)$$

3) It depends upon the nature of the material of which the wire is made.

4) It also depends upon the temperature of the wire

Combining (1) & (2)

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

$$R = \rho \frac{L}{A}$$

ρ is called resistivity of the wire

Resistivity depends upon the nature of material of the wire

Resistivity $\quad \rho = \frac{RA}{L}$ $\quad$ 5Ω

Unit of resistivity is Ωm

Specific Resistance -

The specific resistance of a material is defined as the resistance of the material having specific dimensions i.e. one meter length & one square meter as area of cross-section.

Conductance -

The case to the flow of current is called conductance.

The conductance is reciprocal to the resistance

$$G = \frac{1}{R}$$

Unit of conductance is mho

Conductivity -

It is property or nature of material due to which it allows current to flow through it

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

$$\rho = \frac{RA}{l}$$

$$\sigma =$$

Numericals on Ohm's law

Que:-1 A wire of length 1m at a resistance 2Ω. Obtain its resistance if specific resistance double, diameter is doubled length is made three times of first.

Soln:- Given

$l_1 = 1m$, $R_1 = 2\Omega$, $\rho_2 = 2\rho_1$, $d_2 = 2d_2$

& $l_2 = 3l_1$

$$R_1 = \frac{\rho_1 l_1}{A_1} \quad \text{—— (1)} \qquad R_1 = \frac{4\rho_1 l_1}{\pi d_1^2} \quad \text{—— (i)}$$

$$R_2 = \frac{\rho_2 l_2}{A_2} \quad \text{—— (2)} \qquad R_2 = \frac{4\rho_2 l_2}{\pi d_2^2} \quad \text{—— (ii)}$$

Divide (i) by (ii)

$$\frac{R_1}{R_2} = \frac{\cancel{4}\rho_1 l_1}{\cancel{\pi} d_1^2} \times \frac{\cancel{\pi} d_2^2}{\cancel{4}\rho_2 l_2}$$

$$\frac{R_1}{R_2} = \frac{\rho_1 l_1}{d_1^2} \times \frac{(2d_1)^2}{(2\rho_1)(3l_1)}$$

$$\frac{R_1}{R_2} = \frac{\cancel{\rho_1} \cancel{l_1}}{\cancel{d_1^2}} \times \frac{4\cancel{d_1^2}}{2\cancel{\rho_1} \times 3\cancel{l_1}}$$

$$\frac{R_1}{R_2} = \frac{4}{6} = \frac{2}{3}$$

$$R_2 = \frac{3}{2} \times R_1 = \frac{3}{\cancel{2}} \times \cancel{2} = 3\Omega$$

Ques 1.2 There are two wires A & B of same material. A is 20 times longer than B and has one fifth of the cross-section as that of B. If the resistance of A is 1 ohm. What is the resistance of B?

Soln:- $\rho_2 = \rho_1 = \rho$

$L_1 = 20 l_2$

$A_1 = \frac{1}{5} A_2$

$R_1 = 1\,\Omega$

$$R_1 = \frac{\rho_1 L_1}{A_1} \quad \text{— (1)}$$

$$R_2 = \frac{\rho_2 l_2}{A_2} \quad \text{— (2)}$$

Divide (1) by (2)

$$\frac{R_1}{R_2} = \frac{\rho_1 L_1 \times A_2}{A_1 \times \rho_2 l_2}$$

$$= \frac{\cancel{\rho} \times 20 \cancel{l_2} \times \cancel{A_2}}{\frac{1}{5} \cancel{A_2} \times \cancel{\rho} \cancel{l_2}}$$

$$\frac{R_1}{R_2} = \frac{100}{1}$$

$$R_2 = \frac{R_1}{100} = \frac{1}{100}\,\Omega$$

Electric Circuit:-

The path for flow of electric current is called electric circuit. The electric circuit is just an arrangement of electrical energy sources & various circuit elements such as R, L & C are connected in series, parallel or series parallel combinations

Circuit Elements

1) Active & passive elements
2) Unilateral & bilateral elements
3) Linear & Non-element elements
4) Lumped & distributed "

1. Active & passive elements:-

(i) The elements which supplies energy to the circuit or network are called active elements

All energy sources such as batteries or generators are active elements.

(ii) The elements which receives the energy are called passive elements

eg R, L & C

2) Unilateral & Bilateral elements:-

(i) The elements which conducts the current in one direction only are called Unilateral elements

Such as diodes, vacuum tubes, Rectifiers etc.

(ii) Bilateral elements :- The elements which conduct current in both directions are called bilateral elements such as resistors

3) Linear & non linear elements :-

(i) The elements which have V-I characteristics as straight line are called linear elements. eg resistors

(ii) The elements which do not follow V-I characteristics as straight line are non-linear elements eg diodes & transistors.

~~Independe~~

4) Lumped & distributed elements :-

The elements in which action takes place simultaneously are lumped elements such as resistor, inductors & capacitors. These elements are smaller in size.

The elements in which action for a given cause is not occurring simultaneously at the same instant but it is distributed are called distributed elements such as transmission lines which is having distributed resistance along its length.

(ii) Bilateral elements :- The elements which conduct current in both directions are called bilateral elements such as resistors

3) Linear & non linear elements :-

(i) The elements which have V-I characteristics as straight line are called linear elements. eg resistors

(ii) The elements which do not follow V-I characteristics as straight line are non-linear elements eg diodes & transistors.

~~Independe~~

(4) Lumped & distributed elements :-

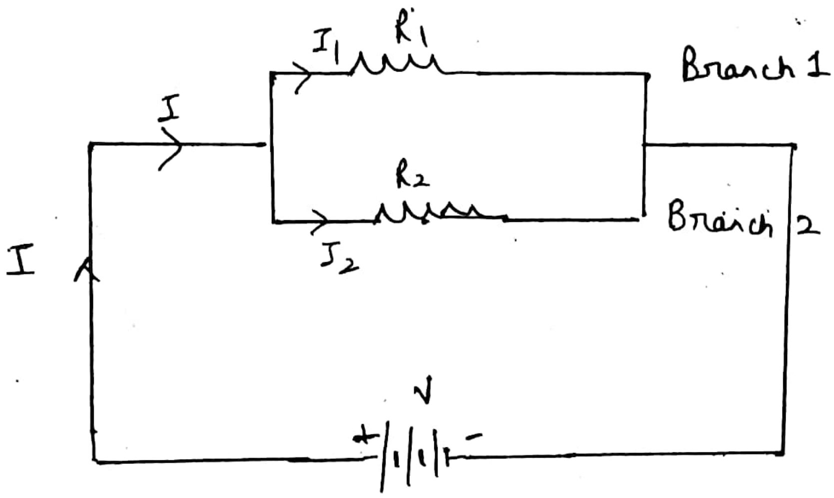
The elements in which action takes place simultaneously are lumped elements such as resistor, inductors & capacitors. These elements are smaller in size.

The elements in which action for a given cause is not occuring simultaneously at the same instant but it is distributed are called distributed elements such as transmission lines which is having distributed resistance along its length.

D.C. circuit :- The closed path for flow of direct current is called d.c. circuit.

- Series circuit
- Parallel circuit

Currents in parallel circuits :-



According to ohm's law

$V = I_1 R_1$ in branch 1

$V = I_2 R_2$ " " 2

$$V = I_1 R_1 = I_2 R_2$$

Total voltage in the circuit is $V = IR$ (ohm's law)

$$IR = I_1 R_1 = I_2 R_2$$

Total resistance in ||el circuit

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

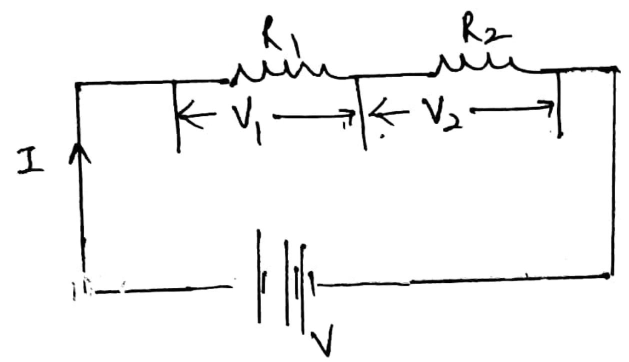
$$I_1 R_1 = I_2 R_2 = I\left(\frac{R_1 R_2}{R_1 + R_2}\right)$$

Then

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

$$I_2 = \frac{R_1}{R_1+R_2}(I)$$

Voltage in Series circuits :-



According to ohm's law

Current in resistance R_1 is

$$I = \frac{V_1}{R_1} \quad \text{— (1)}$$

Current in resistance R_2 is

$$I = \frac{V_2}{R_2} \quad \text{— (2)}$$

$$\frac{V_1}{R_1} = \frac{V_2}{R_2} = I \quad \text{— (3)}$$

Total current in circuit is

$$I = \frac{V}{R} \quad \text{— (4)}$$

Total resistance of circuit is $R = R_1 + R_2$

put value of R in eqn (3) & (4)

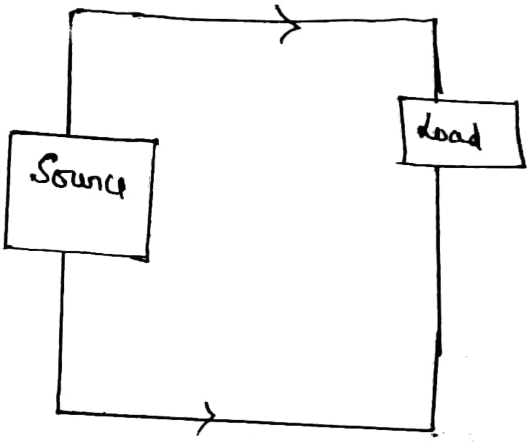
$$\frac{V_1}{R_1} = \frac{V_2}{R_2} = \frac{V}{R_1+R_2}$$

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

$$V_2 = \frac{R_2}{R_1+R_2}(V)$$

Voltage & Current source:-

To deliver electrical energy to the electrical circuits, a source is required & a load is connected to source as shown in fig



The source may be d.c. (direct current) source or an a.c source

D.C. source:- Any source that produces direct voltage continously & has ability to deliver direct current is called d.c. source eg batteries & generators

A.C. source:- Any sourcethat produces alternating voltage continously & has ability to deliver the alternating current is called A.C. source

eg alternators & oscillators & signal generators.

Independent & dependent sources

There are two types of sources — voltage source & current source. Sources can be either independent or dependent upon some other quantities

~~Dependent~~

Independent voltage source :-

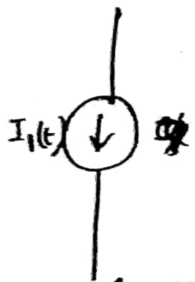
The source ~~which~~ maintains voltage (d.c or a.c) which is not affected by any other quantities.

or

The voltage (a.c or d.c) does not depend on other voltages or current in the circuit.

Symbol for voltage & current source

Independent Voltage Source



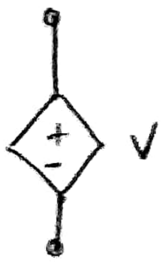
Current source

eg batteries or generators (Voltage source)

eg Semiconductor devices eg diode or transistor Current Source

Dependent Voltage / current source :-

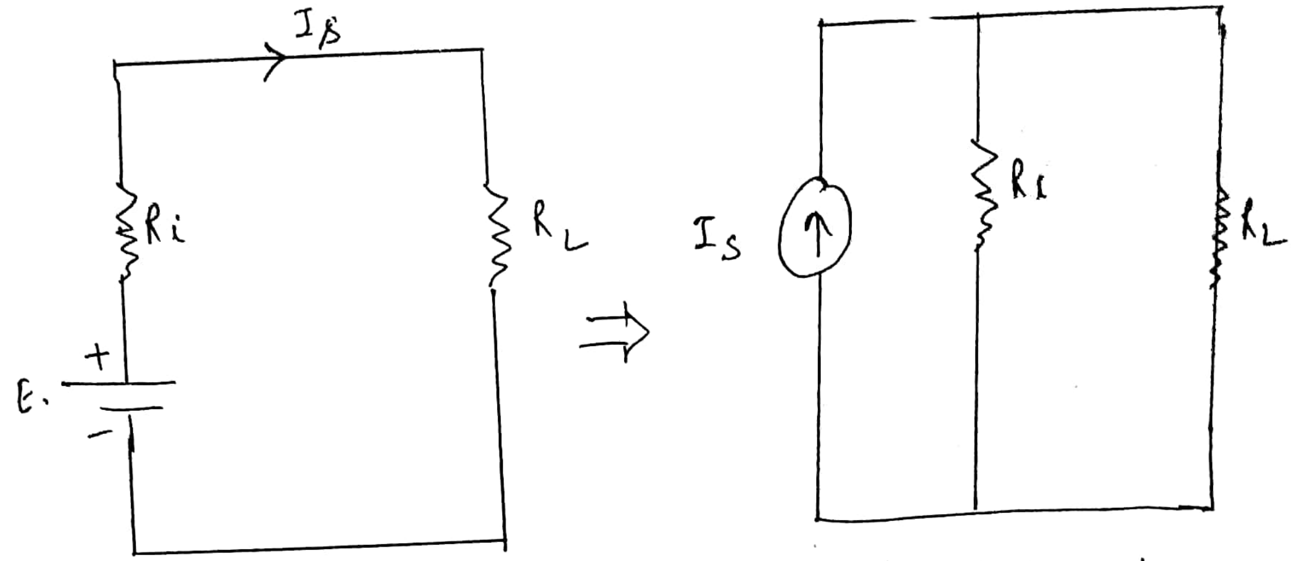
The voltage does depend on another voltage or current in the circuit



Dependent voltage source

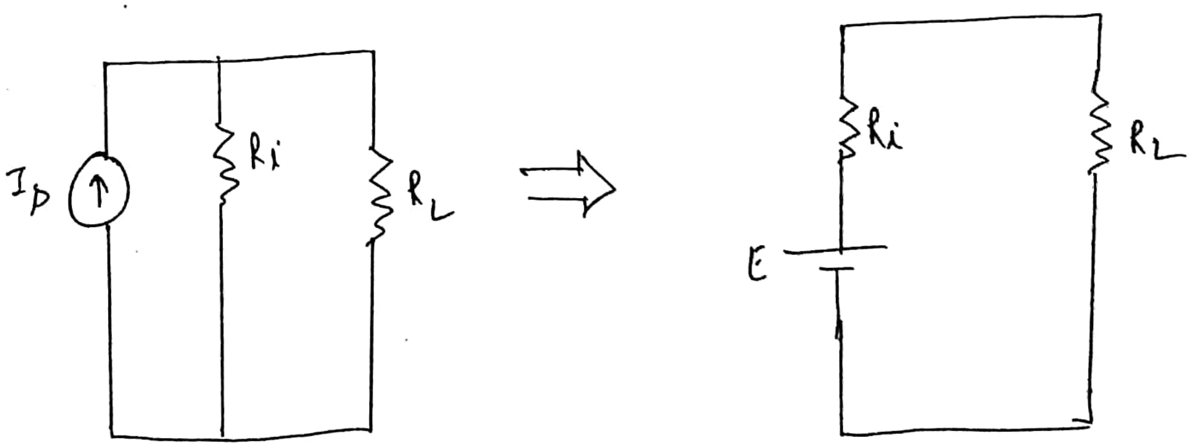
Dependent current source.

Source transformation



Voltage source

source current

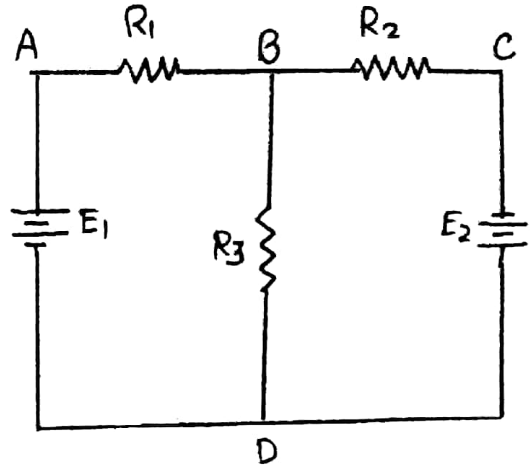


Current source

Voltage source

Network Terminology:-

1) Electric Network:- is inter connection of electric components (eg batteries, resistors, inductors & capacitors)



2) Electric circuit:- is network consisting of closed conducting path through which an electric current either flow or intended to flow.

3) Active Elements:- The elements which supplies energy to the circuit. In fig E_1 & E_2 are active elements

4) Passive Elements:- The elements which receives the energy
In fig on R.H.S R_1, R_2 & R_3 are passive elements

5) Passive Network:- An electric network which do not contain any source of emf.

6) Active Network:- An electric network which contains one or more than one source of emf.

7) Node:- is a point where two or more circuit elements are joined
In fig A, B, C and D are nodes.

8) Junction:- is a point in the network where three or more circuit elements are joined. It is a point where current is divided
In fig B & D are junctions

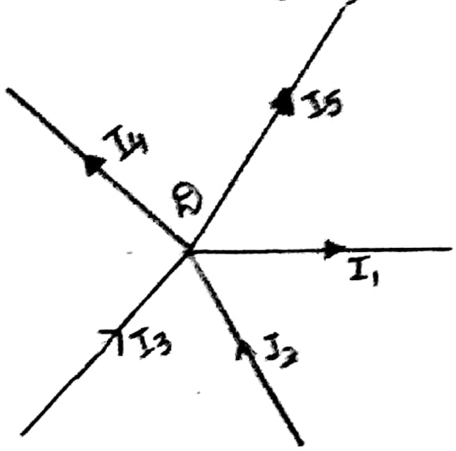
9) Loop:- The closed path of a network. eg ABDA, BCDB and ABCDA

10) Mesh:- The elementary form of loop which cannot be further divided is called mesh. eg ABDA and BCDB

11) Branch:- Part of a network which lies between two junction points
In fig DAB, BCD and BD are the three branches.

Kirchoff's law:-

Kirchoff's first law:- This law relates the currents flowing through the circuit, it is known as Kirchoff's current law (KCL)



Kirchoff's Current law (KCL):- states that the algebric sum of current meeting at a point on junction is zero.

Mathematically $\Sigma I = 0$

Incoming currents as +ve

Outgoing currents as -ve

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

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

sum of incoming currents = sum of outgoing currents.

Kirchoff's Second law:- This law relates to voltage in a closed circuit of an electric network. It is known as Kirchoff's voltage law.

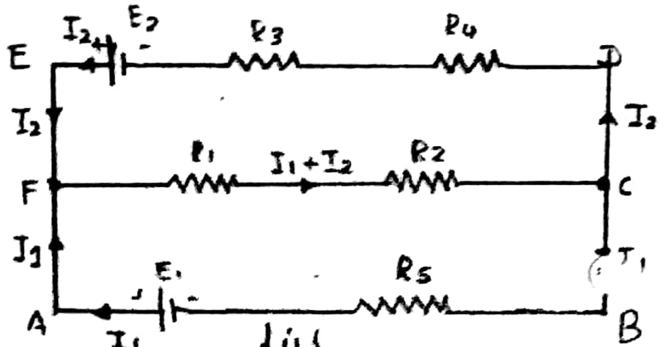


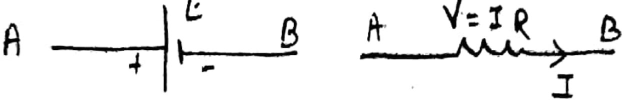
fig 1

Kirchoff's Voltage law (KVL):-

In a closed circuit, the algebric sum of all emfs plus the algebric sum of all the voltage drops is zero.

Mathematically $\Sigma E + \Sigma V = 0$

Sign Convention:-



Tracing branch A to B, E is -ve]
Tracing branch B to A, E is +ve]

If we are moving in same direction as that of current — fall in voltage drop.

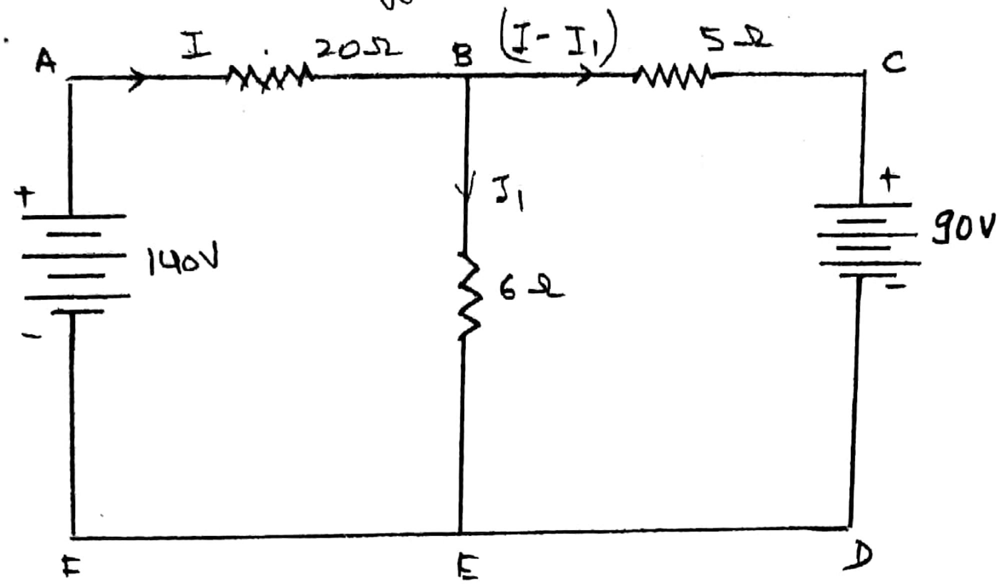
Now apply KVL in fig 1 on R.H.S

In loop AFCBA $\quad -R_1(I_1+I_2) - R_2(I_1+I_2) - I_1R_5 + E_1 = 0$

or $\quad E_1 = R_1(I_1+I_2) + R_2(I_1+I_2) + I_1R_5$ ——— (1)

Ques:-1

In the circuit, as shown in fig. Calculate current & power in the 6 Ω resistance.



Solution:-

In closed loop ABEFA

$$-20I - 6I_1 + 140 = 0$$

$$20I + 6I_1 = 140$$

$$10I + 3I_1 = 70 \quad \text{—— (i)}$$

In closed loop BCDEB

$$-5(I-I_1) - 90 + 6I_1 = 0$$

$$-5I + 5I_1 + 6I_1 = 90$$

$$-5I + 11I_1 = 90 \quad \text{—— (ii)}$$

Multiply (ii) by (2)

$$\cancel{10I} + 3I_1 = 70$$

$$-\cancel{10I} + 22I_1 = 180$$

$$25I_1 = 250$$

$$I_1 = \frac{250}{25} = 10A$$

Power in 6Ω resistor $= I_1^2 R$

$$= (10)^2 \times 6$$

$$= 600 \text{ watts}$$

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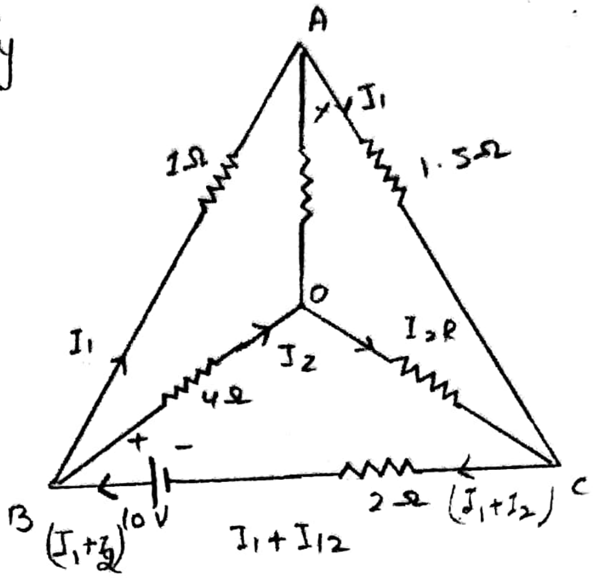
Ques:- Find the value of R and the current through it in the circuit shown in fig when the current is zero in branch OA.



Solution:-

Apply KVL in loop AOBA

$$-4I_2 + 1I_1 = 0$$

$$I_1 = +4I_2 \quad \text{——} \quad (1)$$

In loop ABCA

$$I_1 - 10 + 2(I_1+I_2) + 1.5I_1 = 0$$

$$I_1 + 2I_1 + 1.5I_1 + 2I_2 = 10$$

$$4.5I_1 + 2I_2 = 10 \quad \text{——} \quad (2)$$

$$4.5I_1 + 2I_2 = 10 \quad \text{——} \quad (2)$$

$$4.5(4I_2) + 2I_2 = 10$$

$$18I_2 + 2I_2 = 10$$

$$20I_2 = 10$$

$$I_2 = \frac{10}{20} = \frac{1}{2} = 0.5\text{ A}$$

$$I_1 = 2\text{ A}$$

In loop BOCB

$$-4I_2 - I_2R - 2(I_1+I_2) + 10 = 0$$

$$-4(0.5) - 0.5(R) - 2(2.5) + 10 = 0$$

$$-2 - 0.5R - 5 + 10 = 0$$

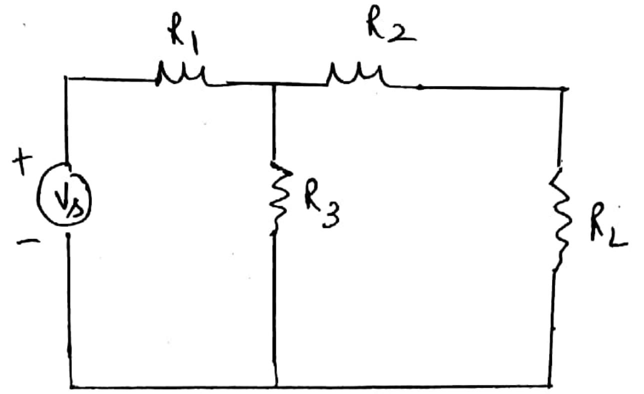
$$0.5R = 3$$

$$R = \frac{3}{0.5} = \frac{30}{5} = 6\Omega$$

Norton's Theorem! -

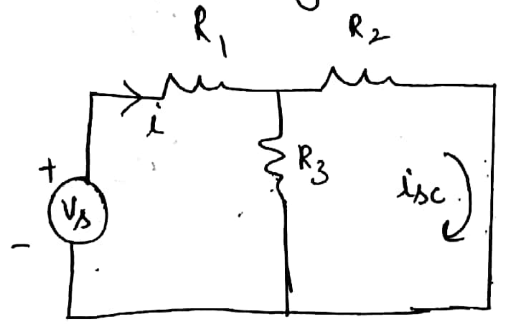
Any two terminal bilateral linear d.c. circuit can by replaced by equivalent circuit consisting of current source in a parallel with a resistance

Explanation:-



To find the current in load resistance R_L

. Let replaced R_L by short circuit



Calculate short circuit i_{sc}

$$i = \frac{V_s}{R_1 + R_2 \| R_3} = \frac{V_s}{R_1 + \frac{R_2 R_3}{R_2 + R_3}}$$

$$i_{sc} = \frac{R_3}{R_2 + R_3} \cdot i = \frac{R_3}{R_2 + R_3} \cdot \frac{V_s}{R_1 + \frac{R_2 R_3}{R_2 + R_3}}$$

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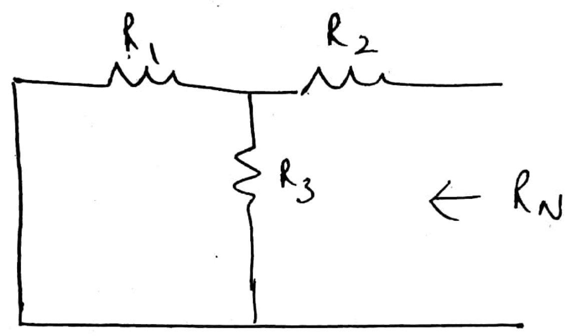
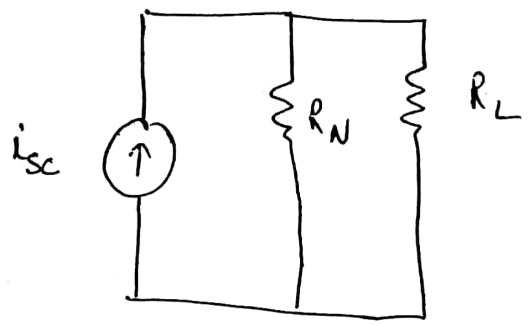
Now calculate equivalent resistance (Norton Resistance)



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

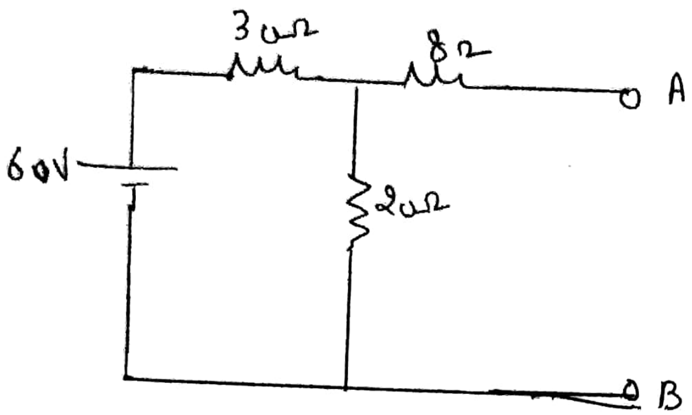
Now Norton's equivalent circuit is



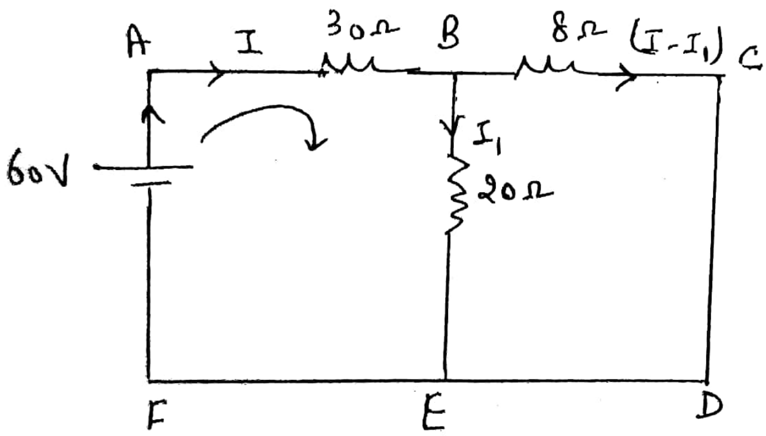
$$I_L = i_{sc} \cdot \frac{R_N}{R_N + R_L}$$

mple 1 :-

btain the Norton current & equivalent resistance from 'AB'



- Now calculate short circuit current



Now we have to calculate $(I - I_1) = ?$

Now apply KVL at ABEFA

$$+60 - 30I - 20I_1 = 0$$

$$-30I - 20I_1 = -60$$

$$3I + 2I_1 = 6 \quad \text{——} \quad (1)$$

- apply KVL at BCDEB

$$-8(I - I_1) + 20I_1 = 0$$

$$-8I + 8I_1 + 20I_1 = 0 \qquad -8I + 28I_1 = 0$$

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=

$4I - 14I_1 = 0$ —— 2

Solving equation 1 & 2

$3I + 2I_1 = 6 \quad \times 7$

$4I - 14I_1 = 0$

$21I + 14I_1 = 42$

$4I - 14I_1 = 0$

$25I = 42$

$I = \frac{42}{25}$

Now put the value of I in 2

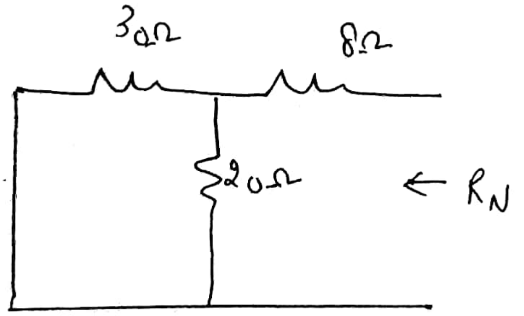
$4\left(\frac{42}{25}\right) = 14I_1$

$I_1 = \frac{4 \times 42}{25 \times 14} = \frac{12}{25}$

Now I_{sc} is $I + I_1 = \frac{42}{25} + \frac{12}{25}$

$= \frac{30}{25} = \frac{6}{5} = 1.2\,A$

Now Calculate equivalent resistance

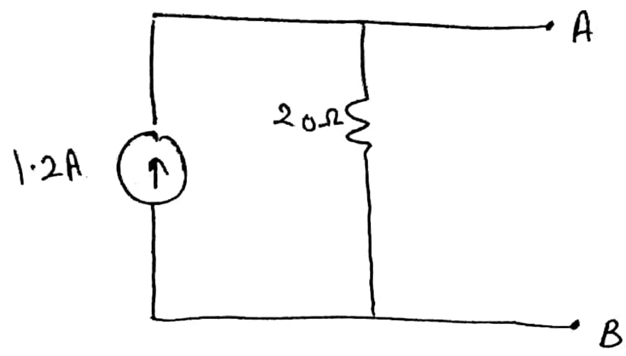


$R_N = 8 + \frac{30 \times 20}{50}$

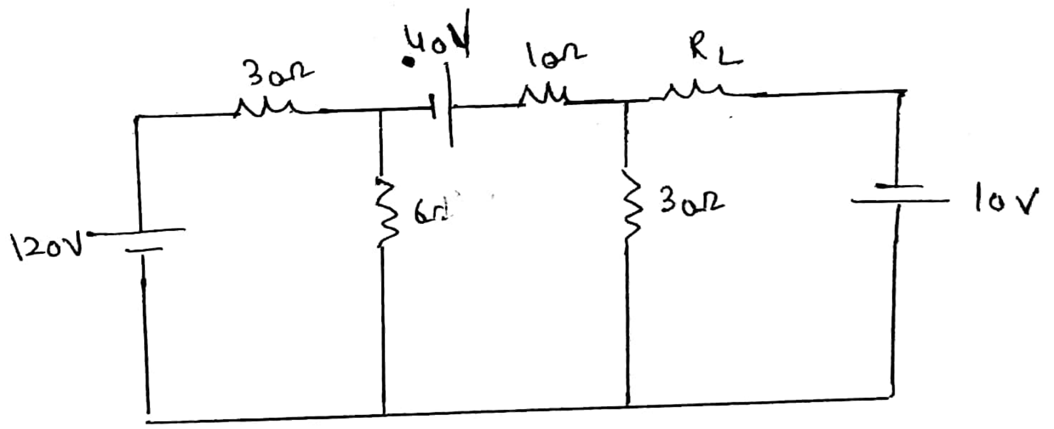
$= 8 + \frac{60}{5} = 8 + 12$

$= 20\Omega$

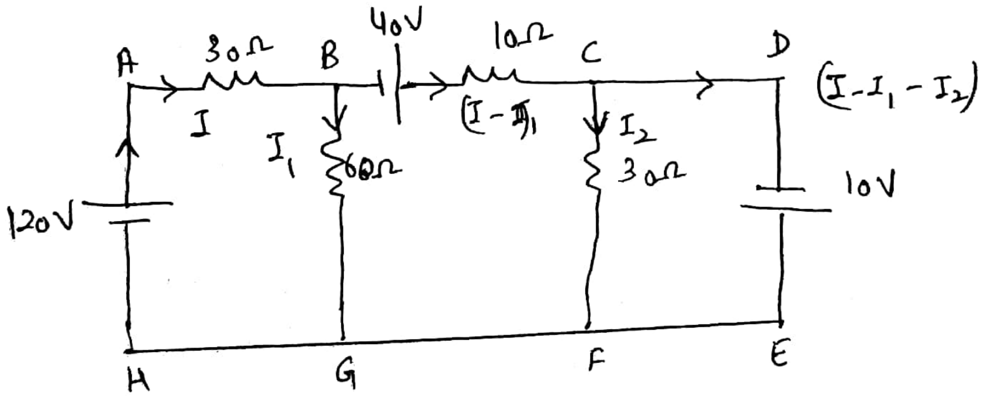
...w equivalent circuit is



(2) Find the Norton's equivalent circuit as seen by R_L



- Replace load resistance by short circuit & calculate I_{sc}



Now Calculate $I_{sc} = (I - I_1 - I_2)$

Apply KVL at ABGHA

$$-30I - 60I_1 + 120 = 0$$

③

$30I + 60I_1 = 120$

$5I + 10I_1 = 20$ —— ①

$I + 2I_1 = 4$ —— ①

Apply KVL at BCFGB

$+40 - 10(I - I_1) - 30I_2 + 60I_1 = 0$

$-10I + 10I_1 + 60I_1 - 30I_2 = -40$

$-10I + 70I_1 - 30I_2 = -40$

$5I - 8I_1 + 15I_2 = +90$ ⇒ $I - 7I_1 + 3I_2 = 4$ —— ②

$5I - 8I_1 + 15I_2 = 90$

Apply KVL at CDEFC

$+10 + 30I_2 = 0$

$30I_2 = -10$

$I_2 = -\frac{1}{3}A$ —— ③

put value of I_2 in ②

$I - 7I_1 - 1 = 4$

$I - 7I_1 = 5$ —— ④

$I + 2I_1 = 4$

$-9I_1 = 1$

$I_1 = -\frac{1}{9}$

then I is $I + 2I_1 = 4$

$I = 4 + \frac{2}{9}$

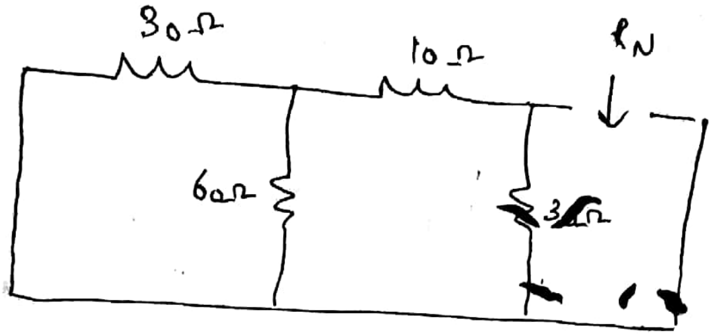
$I = \frac{38}{9}$

$$I_{sc} = I - I_1 - I_2$$

$$= \frac{38}{9} + \frac{1}{9} + \frac{1}{3}$$

$$= \frac{38+1+3}{9} = \frac{42}{9} = \frac{14}{3} A$$

Now calculate equivalent resistance R_N

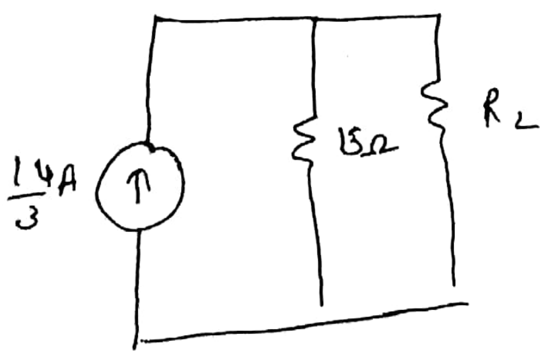


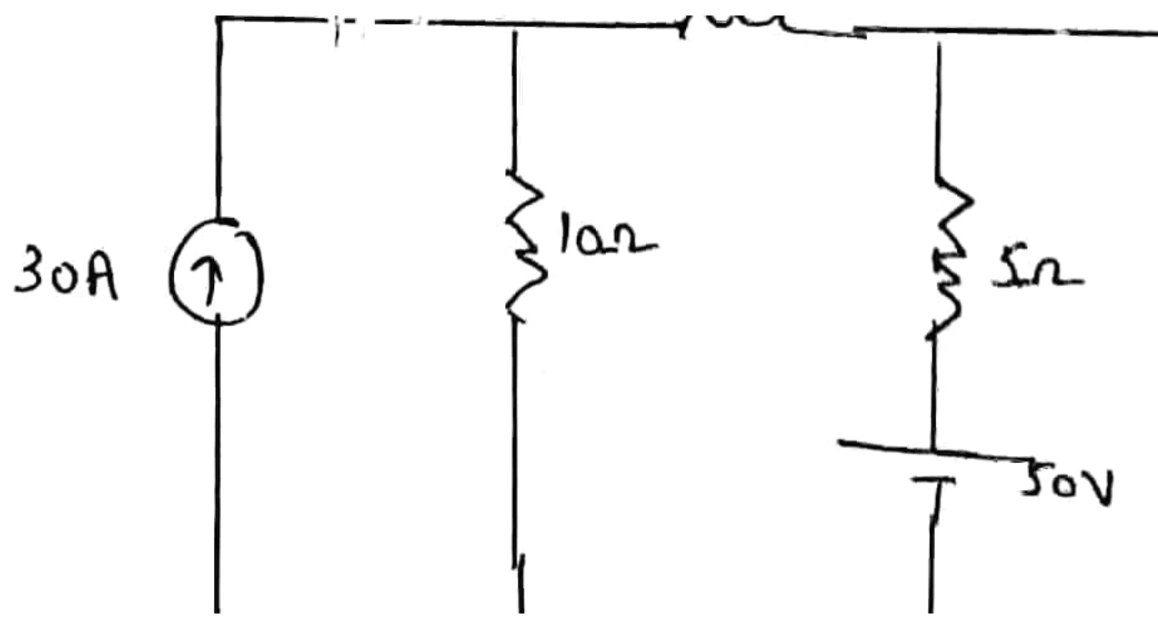
$$R_N = \frac{\cancel{30}^{20} \times \cancel{60}}{\cancel{90}_{3}} + 10$$

$$= 30 \parallel 30$$

$$= \frac{30 \times \cancel{30}}{\cancel{60}_{2}} = 15\Omega$$

equivalent circuit is




30A
10Ω
5Ω
50V

By KVL at closed loop FCDEF

16

$-5I - 5I_1 - 50 + 300 - 10I = 0$

$-15I - 5I_1 = -250$

Eqn $3I + I_1 = +50$ —— (1)

→ at closed loop CABDC

$+50 + 5I_1 = 0$

$5I_1 = -50$

$I_1 = -10A$

Put value of I_1 in eqn (1)

$3I - 10 = 50$

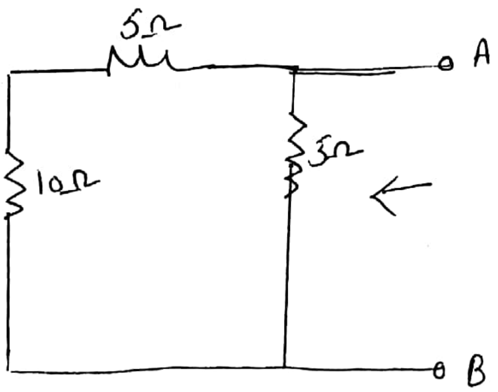
$3I = 60$

$I = 20A$

Then I_{sc} (current in branch AB) is $= I - I_1$

$= 20 + 10 = 30A$

Now calculate equivalent resistance R_N



$R_N = 5 + \frac{5\times 10}{15}$

$= 5 + \frac{10}{3} = \frac{25}{3}$

$= 5 \parallel 15$

$= \frac{5\times 15}{20} = \frac{15}{4} = 3.75$

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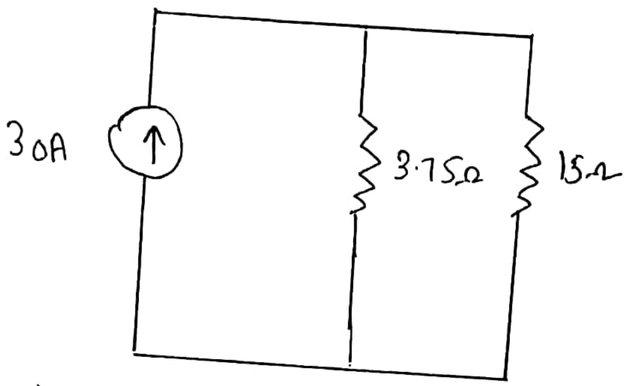
Now Norton's equivalent circuit

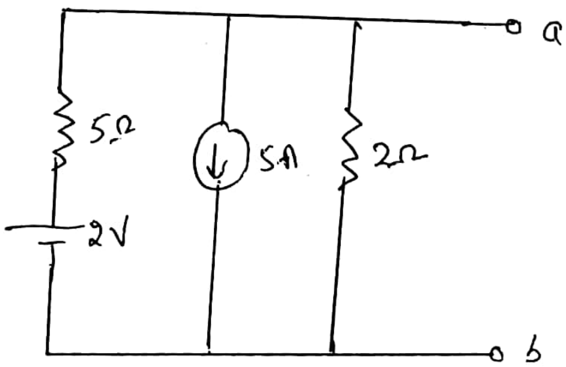


Current in 15Ω

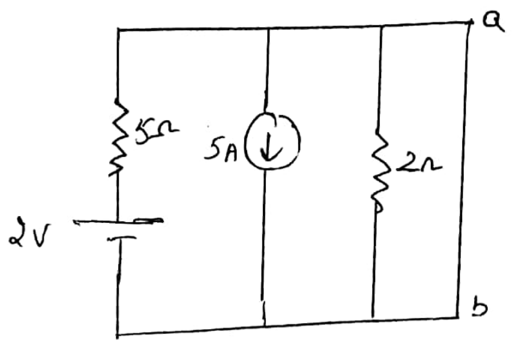
$$I = \frac{3.75}{3.75+15} \times 30$$

$$I = \frac{3.75}{18.75} \times 30 = 6A$$

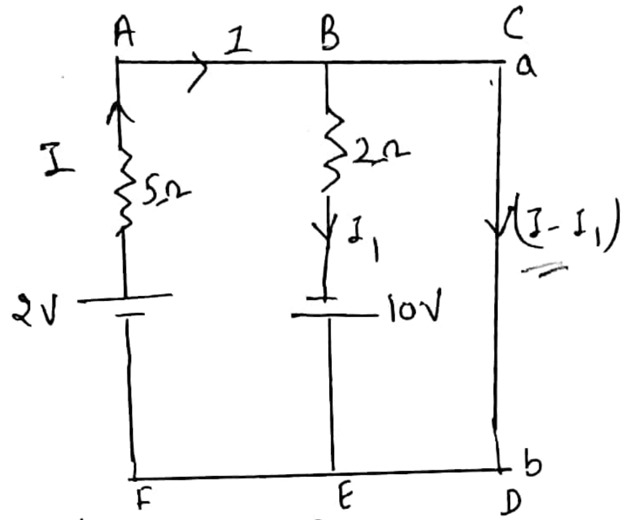
Ques:-4 Find the Norton's equivalent circuit across a-b for network shown in fig



First apply short circuit across a-b



...t current source into voltage source



Now Calculate $(I-I_1) = ?$

Apply KVL (ABEFA)

$$-2I_1 + 10 + 2 - 5I = 0$$

$$-5I - 2I_1 = -12$$

$$5I + 2I_1 = 12 \quad \text{——} \quad (1)$$

Apply KVL at BCDEB

$$-10 + 2I_1 = 0$$

$$2I_1 = 10$$

$$I_1 = 5\,A$$

Put value of I_1 in eqn (1)

$$5I + 10 = 12$$

$$5I = 2$$

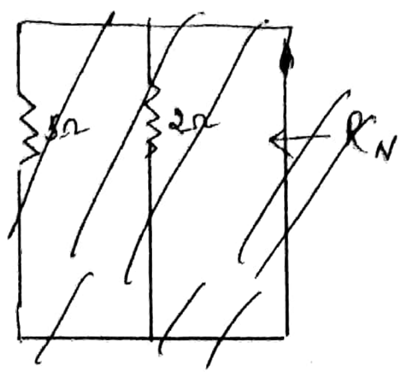
$$I = \frac{2}{5} = 0.4\,A$$

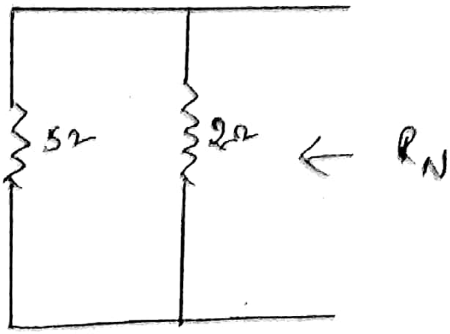
Current in branch (ab)

$$I_{SC} = I - I_1 = 0.4 - 5$$

$$= -4.6\,A$$

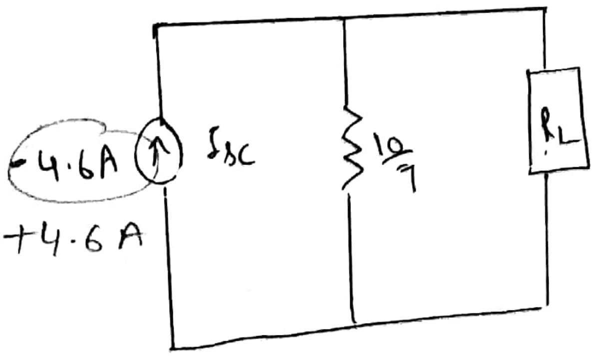
Now Calculate equivalent resistance (R_N or R_{eq})





$$R_N = \frac{2\times5}{7} = \frac{10}{7}$$

Equivalent circuit is

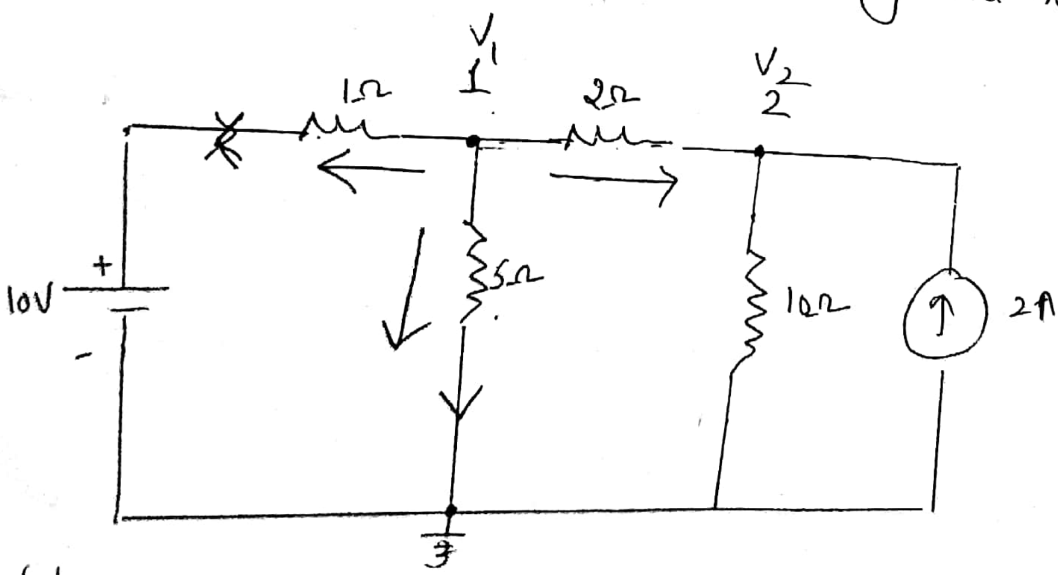


Nodal Analysis:- Nodal analysis provide a general procedure for analysing circuits using node voltage as the circuit variable. In the **node voltage method**, we can solve for the unknown voltages in a circuit using KCL.

Steps:-

1. The first step is to select an essential nodes (is a node joining three or more elements). Then to select an essential nodes as a reference arbitrary, the node with the most nodes attached is a good choice.

- Then the node voltage can be defined as voltage at a given node wrt reference node.
- Finally KCL is applied to all non-reference nodes.



Node '3' is selected as reference node

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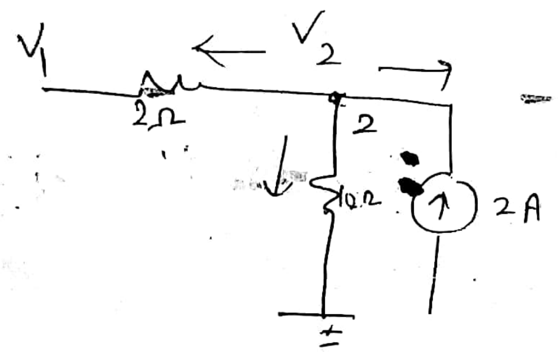
Apply KCL at node '1'

$$\frac{V_1 - 10}{1} + \frac{V_1 - 0}{5} + \frac{V_1 - V_2}{2} = 0$$

$$10V_1 - 100 + 2V_1 + 5V_1 - 5V_2 = 0$$

$$17V_1 - 5V_2 = 100 \quad \text{—— (1)}$$

Apply KCL at node '2'



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

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

$$-5V_1 + 6V_2 = 20 \quad \text{—— (2)}$$

Solve the eqn '1' & '2'

$$17V_1 - 5V_2 = 100 \quad \times 6$$

$$-5V_1 + 6V_2 = 20 \quad \times 5$$

$$102V_1 - 30V_2 = 600$$

$$-25V_1 + \cancel{30}V_2 = 100$$

$$77V_1 = 700$$

$$V_1 = \frac{700}{77} = \frac{100}{11} = 9.09\,V$$

Put value of V_1 in eqn '1'

$$17\left(\frac{100}{11}\right) - 5V_2 = 100$$

$$V_2 = 10.91\,V$$

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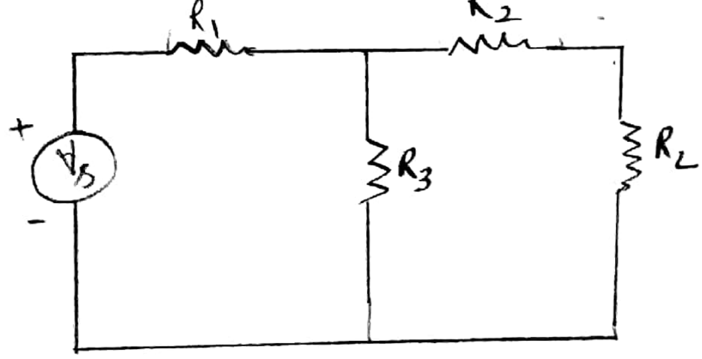
Thevenin's theorem:-

Statement:- Any two terminal bilateral linear d.c. circuit can be replaced by an equivalent circuit consisting of a voltage source & a series resistor.

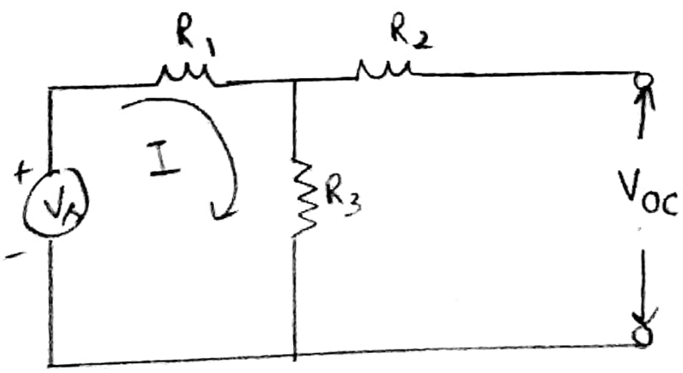
- It is applicable where it is desired to determine current through or voltage across any one element in a network without going through the rigorous method of solving of a network equations

Explanation:-

Simple d.c. circuit as shown in fig. We have to find the current in load resistance (R_L)

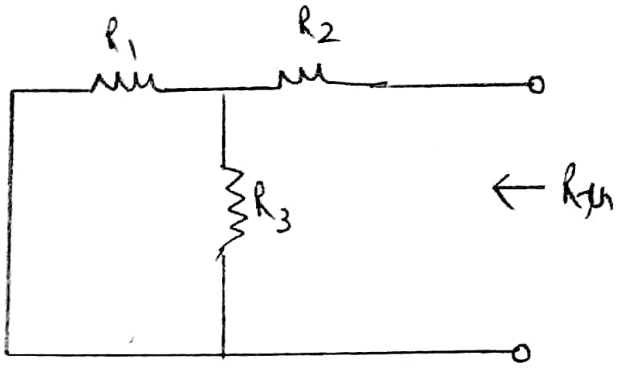


- Remove the load resistance & find open circuit voltage V_{oc} across the open circuited load terminals

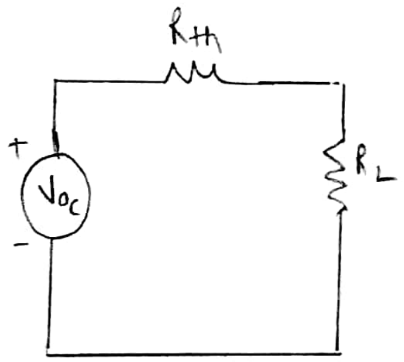


$$V_{oc} = \frac{R_3 V_s}{R_1 + R_3}$$

- To find the thevenin resistance (Voltage source is removed by a short circuit.



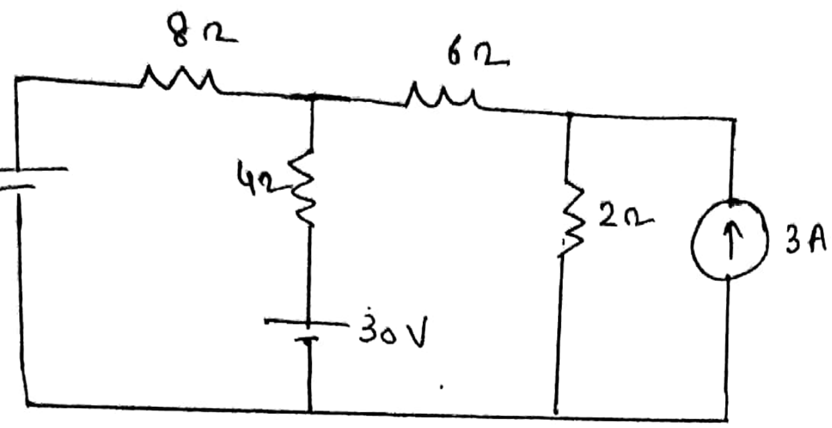
$$R_{th} = R_2 + \frac{R_1 R_3}{R_1 + R_3}$$



Thevenin's Equivalent circuit

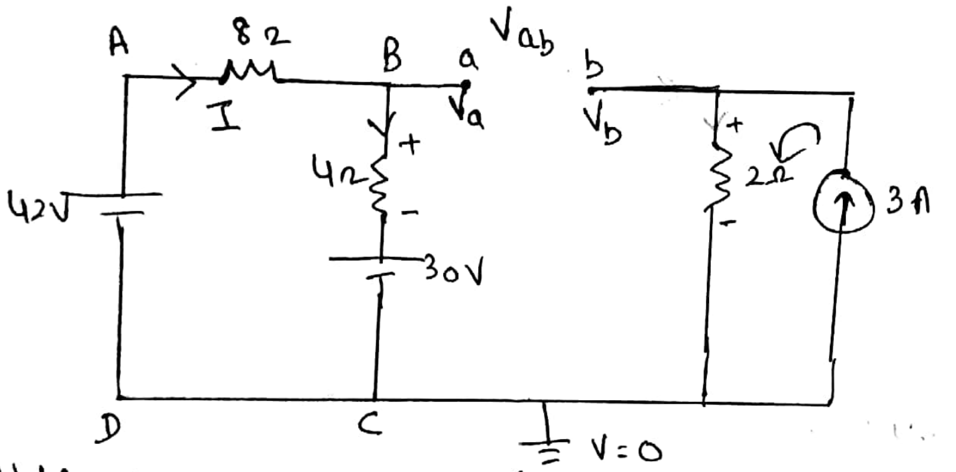
$$\boxed{I_L = \frac{V_{oc}}{R_{th} + R_L}}$$

Example 1



Calculate the current in 6Ω

- Remove the load resistance & calculate open circuit voltage across the open circuited load terminals



$$\frac{V_a-30}{4}+\frac{V_a-42}{8}=0$$

$$2V_a-60+V_a-42=0$$

$$3V_a=102$$

$$V_a=34V$$

$$\frac{V_b}{2}=3$$

$$V_b=6V$$

Apply KVL at ABCD (closed loop)

$$42-8I-4I-30=0$$

$$12=12I$$

$$I=1A$$

Now Calculate voltage at terminal 'a'

$$+30+4I=V_a$$

$$30+4=V_a$$

$$V_a=34V$$

Now Calculate V_b

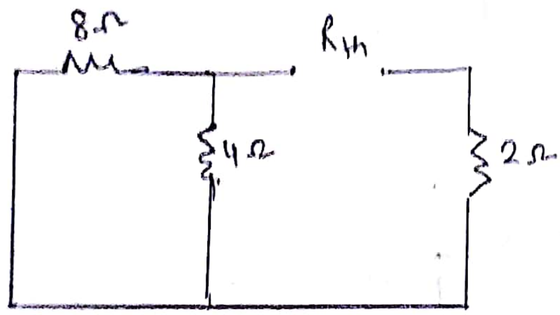
$$0 + 2\times3 = V_b$$

$$V_b = 6V$$

Then $V_{ab} = V_a - V_b = 34 - 6 = 28V$

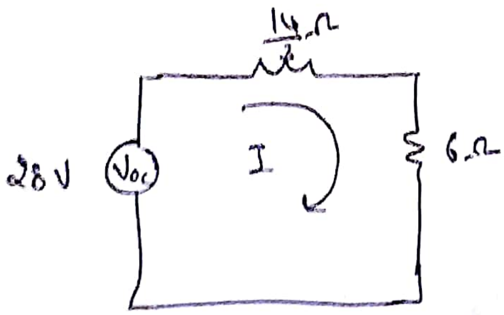
Now Calculate R_{th}

All the voltage sources are short circuited & circuit source is open circuit.



$$R_{th} = \frac{8\times\cancel{4}}{\cancel{12}_{3}} + 2$$

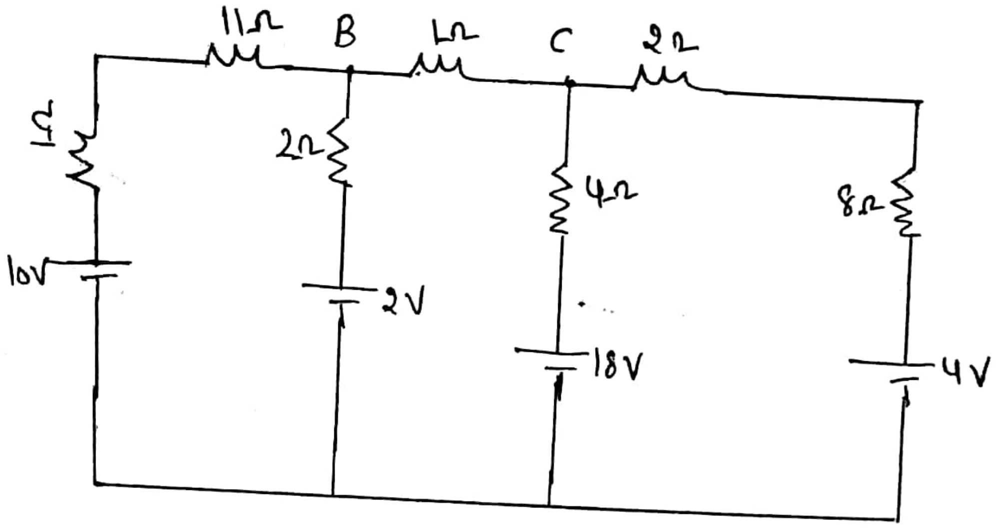
$$= \frac{8}{3} + 2 = \frac{8+6}{3} = \frac{14}{3} \text{ ohm}$$



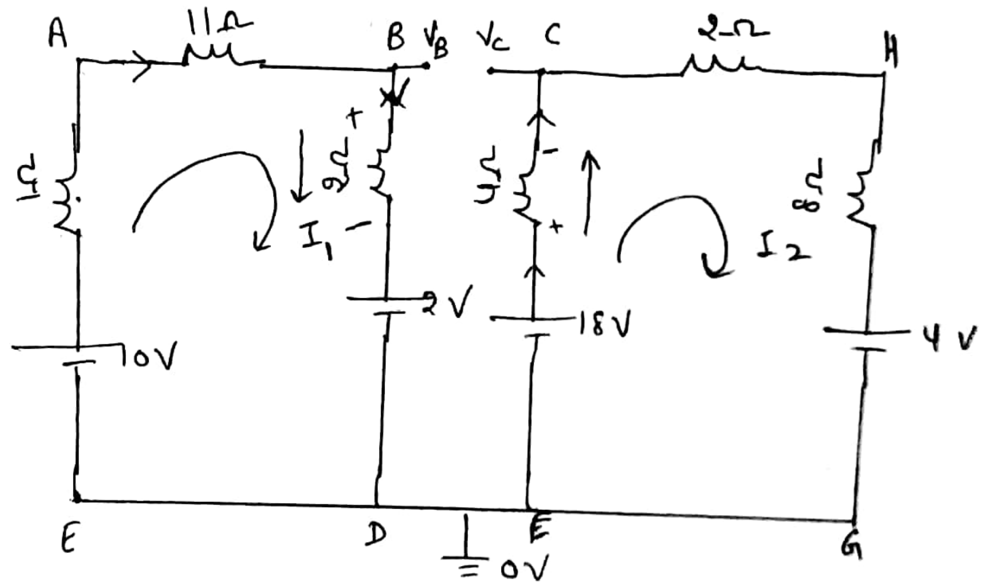
$$I = \frac{28}{6+\frac{14}{3}}$$

$$= \frac{\cancel{28}^{7}\times3}{\cancel{32}_{\cancel{16}_{8}}} = \frac{21}{8} = 2.625Ω$$

Example 2



Find the Thevenin's equivalent circuit at terminal BC. Determine the current through 1Ω



Apply KVL at closed loop ABDEA

$$10 - I_1 - 11 I_1 - 2I_1 - 2 = 0$$

$$\cancel{-} 14 I_1 = \cancel{-} 8$$

$$I_1 = \frac{8}{14} = \frac{4}{7} \text{ A}$$

Now V_B is

$$+2 + 2I_1 = V_B \quad V_B = 2 + 2\left(\frac{4}{7}\right) = 2 + \frac{8}{7} = \frac{22}{7} \text{ V}$$

Now Apply KVL at CFGHC

$$+18 - 4I_2 - 2I_2 - 8I_2 - 4 = 0$$

$$14 = 14 I_2$$

$$I_2 = 1A$$

V_c is

$$+18 - 4I_2 = V_c$$

$$18 - 4(1) = V_c$$

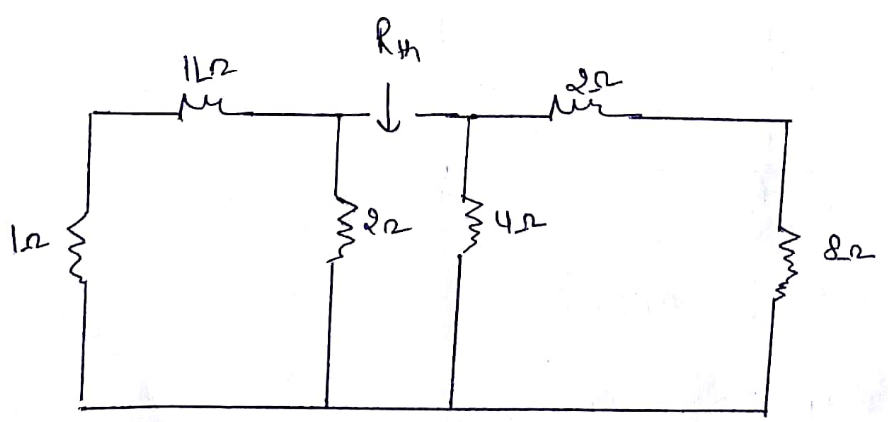
$$V_c = 14\ V$$

V_{th} voltage at terminal $V_{BB} = V_B - V_B$

$$= V_B - V_B$$

$$= \frac{14}{7} - \frac{22}{7} = 14 - 3.14 = 10.86\ V$$

Now calculate R_{th}



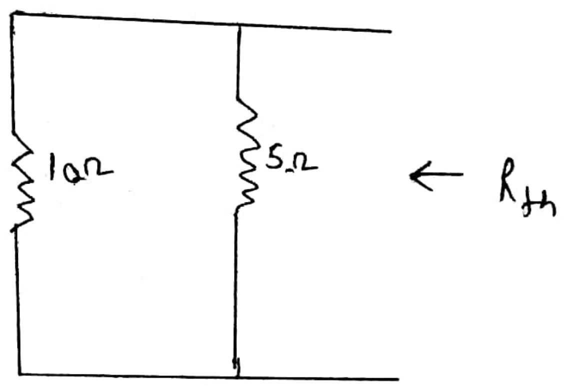
$$[2 \parallel (12)] \parallel [4 \parallel 10\Omega] = \left[\frac{12}{7} \parallel \frac{20}{7}\right]$$

$$\left[\frac{2\times12}{14} \parallel \frac{4\times10}{14}\right] = \frac{\frac{12}{7}\times\frac{20}{7}}{\frac{12}{7}+\frac{20}{7}} = \frac{240\times7}{49\times32}$$

$$\left[\frac{24}{14} \parallel \frac{40}{14}\right]$$

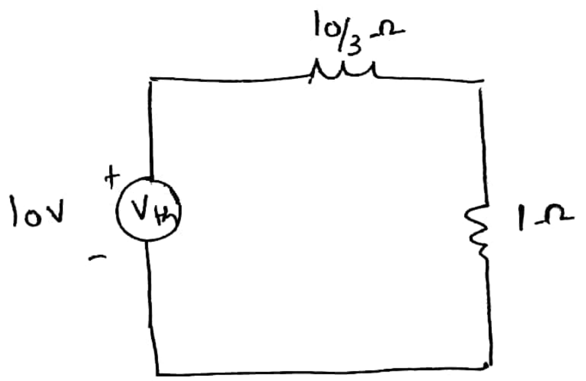
$$= 1.0714\Omega$$

Now Calculate R_{th}



$$R_{th} = \frac{10 \times \cancel{5}}{\cancel{15}_{3}} = \frac{10}{3}\,\Omega$$

Now thevenin's equivalent circuit is



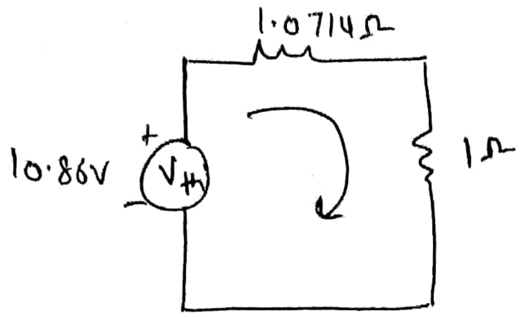
$$I_{th} = \frac{10}{\frac{10}{3}+1} = \frac{10}{3.33+1} = 2.31\,A$$

Now Power loss in 1Ω resistor is $= I^2R$

$= (2.31)^2 \times 1$

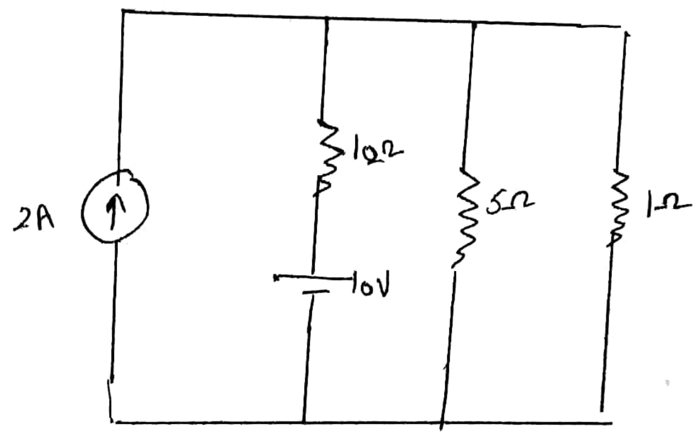
$= 5.33\,W$

Now thevenin's Equivalent circuit is

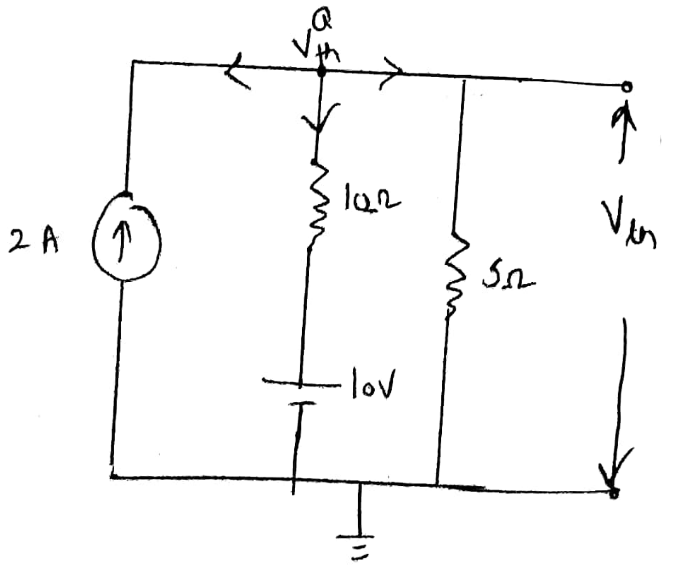


$$I = \frac{10.86}{2.0714} = 5.24A$$

(3)



Find the power loss in 1Ω resistor



Apply KCL at node a

$$\frac{V_{th} - 10}{10} + \frac{V_{th}}{5} = 2$$

$$V_{th} - 10 + 2V_{th} = 20$$

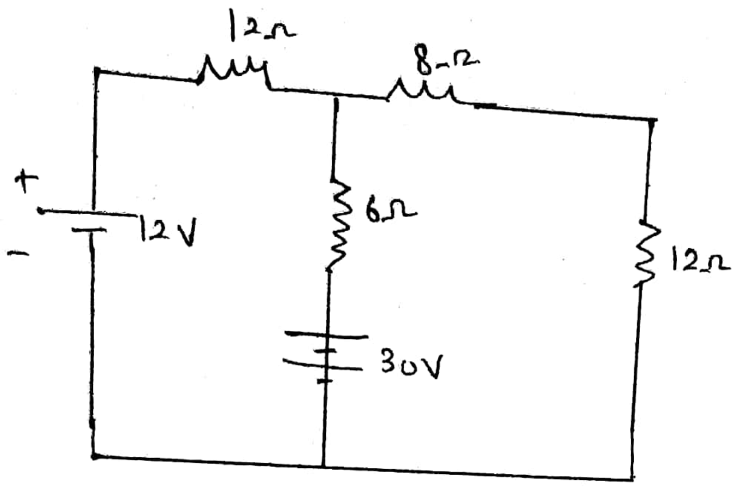
$$3V_{th} = 30$$

$$V_{th} = 10V$$

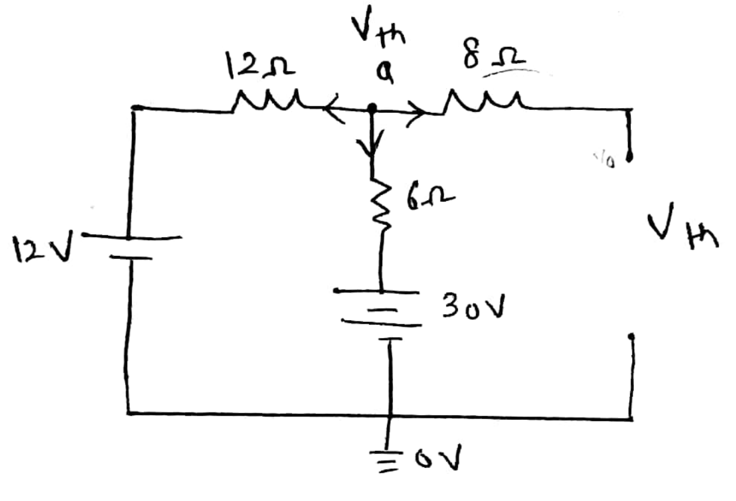
ull - 4

(5)

Determine the current 12Ω resistor connected across the terminal A - B



(1) Remove the load resistance & calculate open circuit voltage (V_{th})



Apply KCL at node 'a'

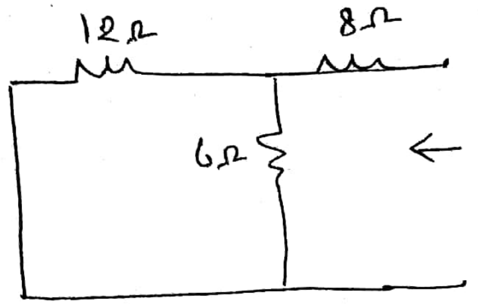
$$\frac{V_{th} - 12}{12} + \frac{V_{th} - 30}{6} = 0$$

$$V_{th} - 12 + 2V_{th} - 60 = 0$$

$$3V_{th} = 72$$

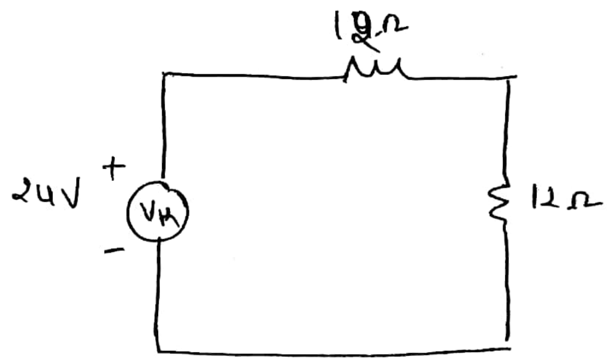
$$V_{th} = 24V$$

Now calculate R_{th}



$$R_{th} = \frac{12 \times \cancel{6}}{\cancel{18}_{3}} = 4\Omega + 8\Omega = 12\Omega$$

Thevenin's Equivalent circuit is



$$I = \frac{24}{24}$$

$1\,A$

Nodal Analysis:- Nodal analysis provide a general procedure for analysing circuits using node voltage as the circuit variables.

Nodal Analysis is also called node voltage method. In the node voltage method, we can solve for the unknown voltages in a circuit using KCL.

Steps:-

1. The first step is to select an essential nodes. (is a node joining three or more elements) Then to select an essential nodes as a reference nodes. The choice is arbitrary, the node with the most branches attached is a good choice.

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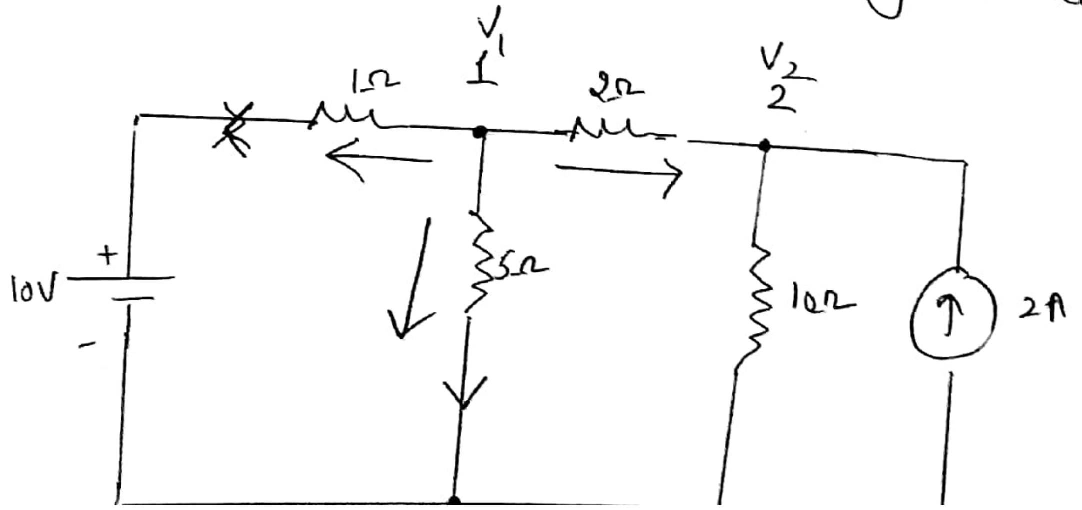

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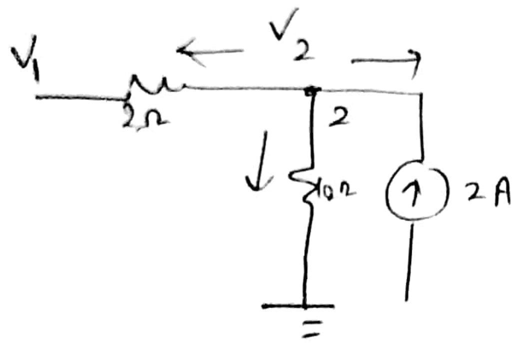
Apply KCL at node '1'

$$\frac{V_1 - 10}{1} + \frac{V_1 - 0}{5} + \frac{V_1 - V_2}{2} = 0$$

$$10V_1 - 100 + 2V_1 + 5V_1 - 5V_2 = 0$$

$$17V_1 - 5V_2 = 100 \quad \text{—— (1)}$$

Apply KCL at node '2'



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

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

$$-5V_1 + 6V_2 = 20 \quad \text{—— (2)}$$

Solve the eqn '1' & '2'

$$17V_1 - 5V_2 = 100 \quad \times 6$$

$$-5V_1 + 6V_2 = 20 \quad \times 5$$

$$102V_1 - 30V_2 = 600$$

$$-25V_1 + \cancel{30}V_2 = 100$$

$$77V_1 = 700$$

$$V_1 = \frac{700}{77} = \frac{100}{11} = 9.09V$$

Put value of V_1 in eqn '1'

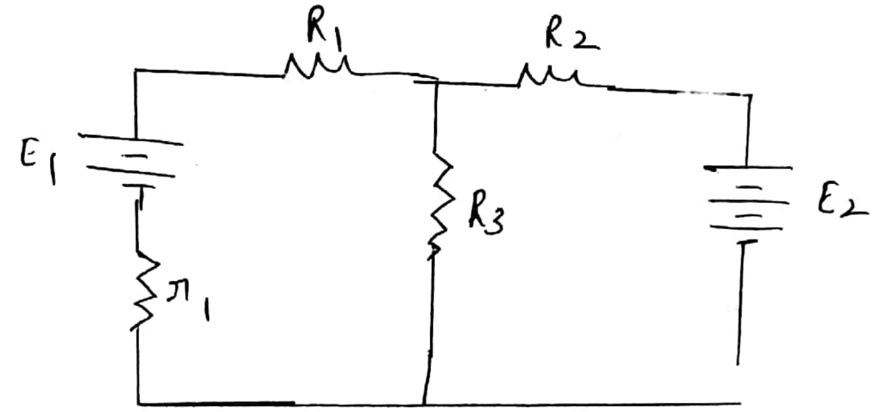
$$17\left(\frac{100}{11}\right) - 5V_2 = 100$$

$$V_2 = 10.91V$$

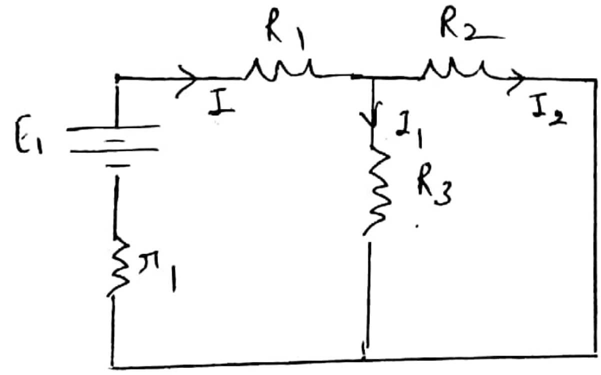
Superposition Theorem :-

This theorem is applicable to linear bilateral network having two or more than two sources.

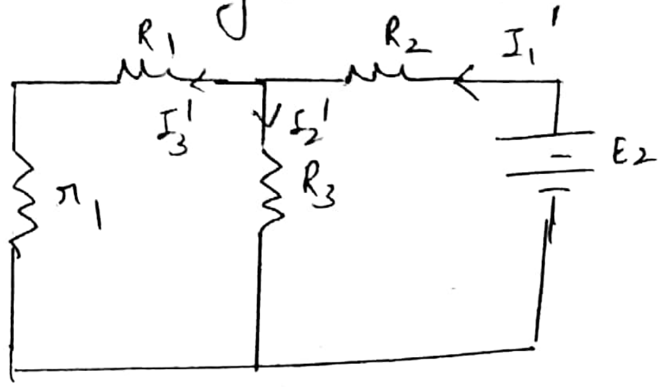
This theorem states that current flowing through any section is the algebraic sum of all currents which should flow in that section if each source of emf would be considered separately and other sources are replaced by their internal resistance.



First we activate source of emf E_1 & E_2 is disactivated replaced by short circuit



Now E_2 is activated & E_1 is replaced by short circuit

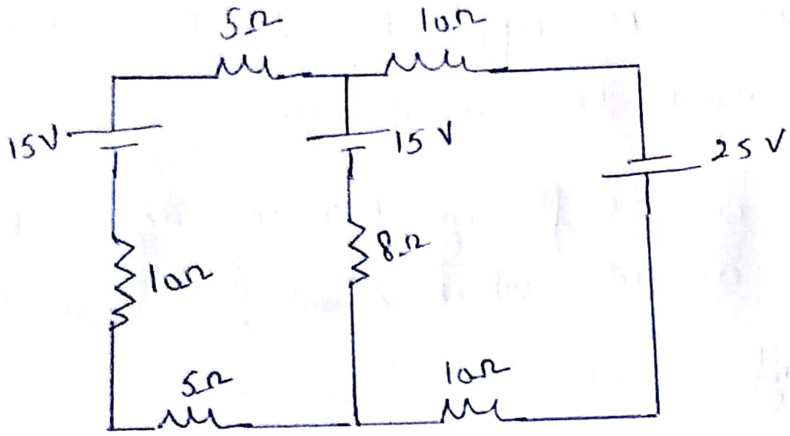


Determine the current in each section $(I, I_1 + I_2)$

Then current in each branch is $I_1 = I - I_3'$ & $I_3 = I_1 + I_2'$

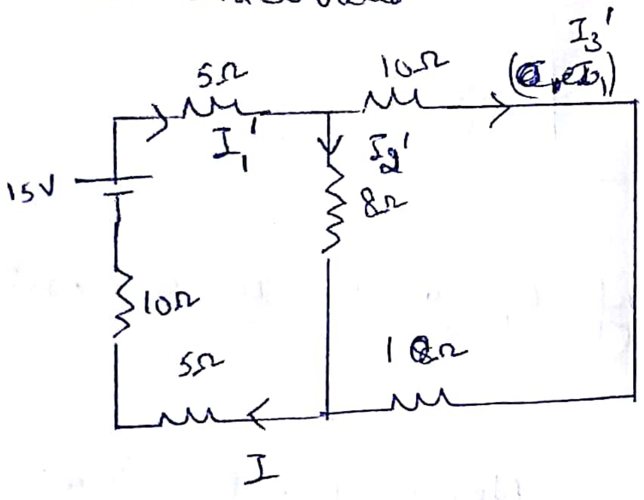
$I_2 = I_2 - I_1'$

Ques:-1 Find the current in different branches of the Network

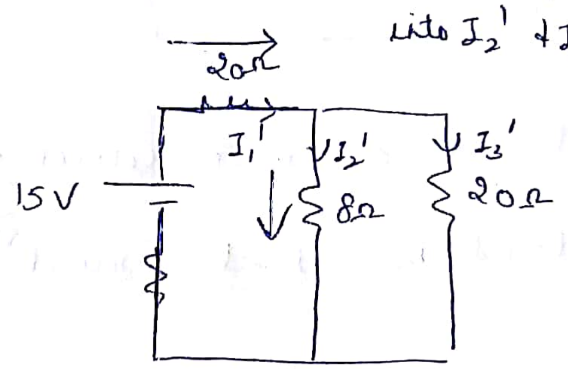


Solution:-

First we activate 15 V (battery) & all the voltage sources are deactivated



Total Current I_1' is splitted into I_2' & I_3'



Total resistance is $= (20 \| 8) + 20$

$= \frac{8 \times 20}{28} + 20$

$= 5.714 + 20$

$= 25.714\ \Omega$

Total Current =

$I_1' = \frac{15}{25.714} = 0.583A$

$I_2' = \frac{20}{28} \times 0.5833$

$= 0.4166A$

$I_3' = \frac{8}{28} \times 0.583$

$= 0.168\ A$

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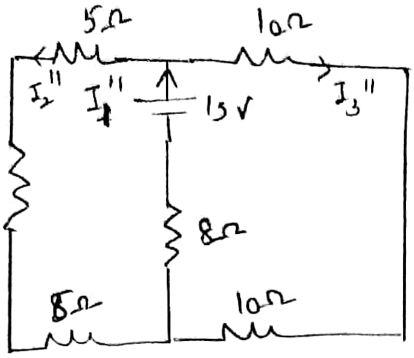
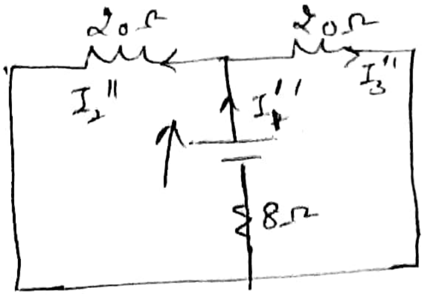
(26)

Now activate the source of emf 15V in branch '2' & all voltage are deactivated





Total resistance $= (20 \| 20) + 8$

$$= \frac{20 \times 20}{40} + 8 = 10 + 8$$

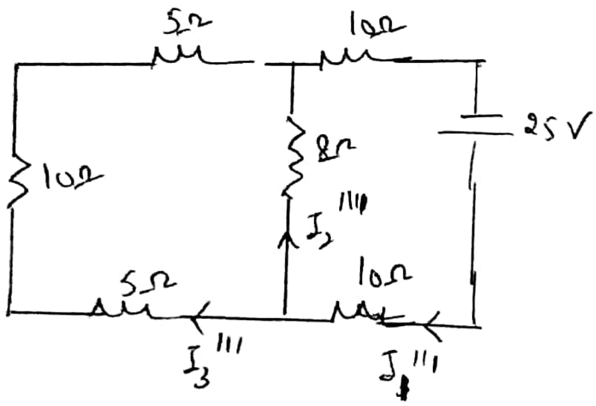
$= 18\ \Omega$

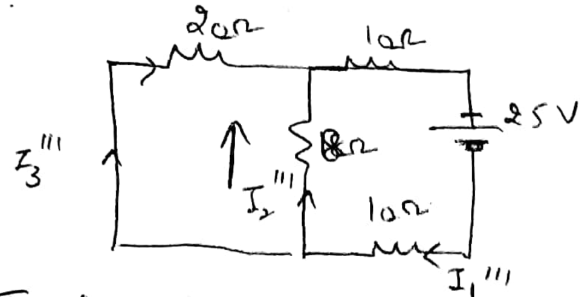
Current supply $I_1'' = \frac{15}{18} = 0.833A$

$$I_2'' = \frac{20}{40} \times 0.833 = 0.4167\ A$$

$$I_3'' = \frac{20}{40} \times 0.833 = 0.4167\ A$$

Now activate 25V voltage source





Total resistance $= \frac{20 \times 8}{28} + 20$

$= 5.714 + 20$

$= 25.714$

$$I_1''' = \frac{25}{25.714} = 0.9722\,A$$

$$I_2''' = \frac{20}{28} \times 0.9722$$

$$= 0.6944\,A$$

$$I_3''' = \frac{8}{28} \times 0.9722$$

$$= 0.277\,A$$

Now current in each branch is

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

$$= 0.444\,A$$

$$I_2 = \cancel{I_2' \ldots I_3'''}$$

$$= -I_2' + I_1'' + I_2'''$$

$$= 1.111\,A$$

$$I_3 = I_3' + I_3'' + I_3'''$$

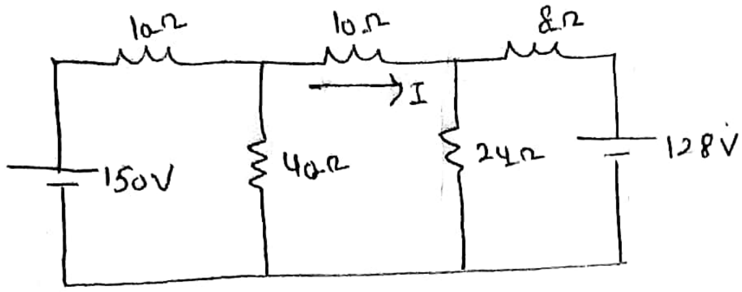
$$= 1.555\,A$$

So

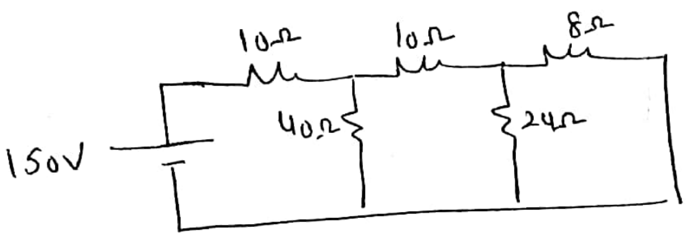
10
-2
7

(27)

Ques. 2 Find I using superposition theorem

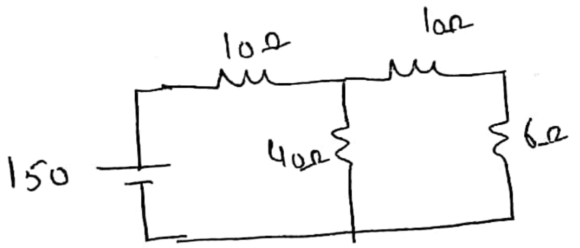


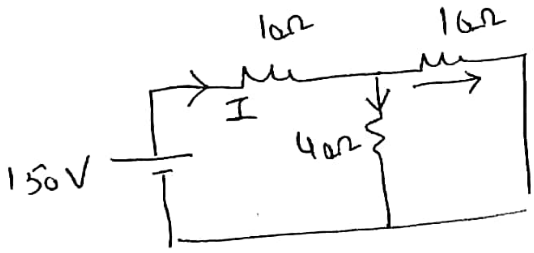
Solution First we activate 150 V battery source & deactivate 128V



24 & 8 are in ||el

$\frac{24 \times 8}{32} = 6\Omega$





Total equivalent resistance $= \frac{40 \times 16}{56} + 10$

$= 21.49\Omega$

Total current supplied $(I) = \frac{150}{21.49}$

$= 6.97$

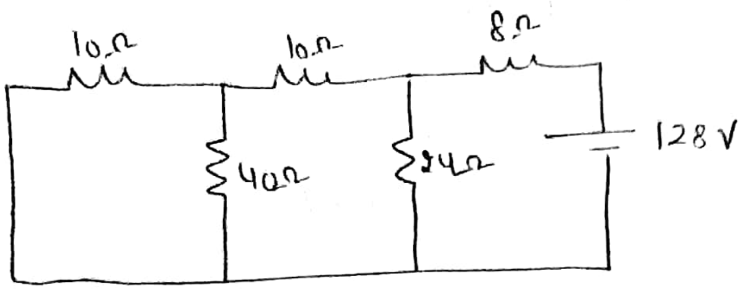
Current in 10Ω resistor =

$= 6.97 \times \frac{40}{56}$

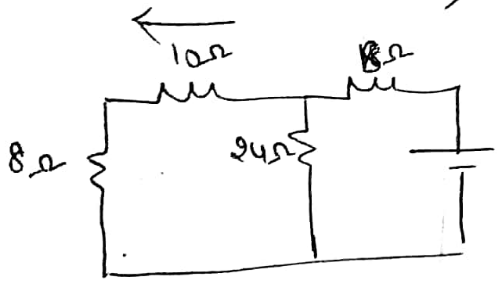
$= 4.98A$

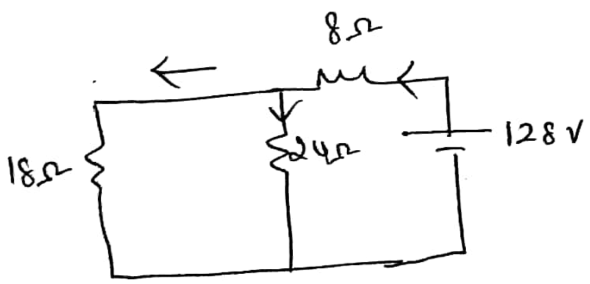
$= 5A$

Now activated 128 V, & deactivated the 150V battery source



40 & 10 are in ||el i.e. $\frac{40 \times 10}{50} = 8\Omega$





Total resistance $= \frac{18 \times 24}{42} + 8$

$= \frac{72}{7} + 8$

$= 18.286\,\Omega$

Total current supplied $= \frac{128}{18.286} = 6.99\text{ A}$

Current in 10Ω resistor $= \frac{24}{42} \times 6.99 = 3.99\text{ A}$

$= 4\text{A}$

Total current in 10Ω $= 5 - 4 = 1\text{ A}$

[De]lta - Star and Star - Delta Transformation :-

[Th]ree resistances connected nose - to - tail as shown in fig are said to be delta or mesh connected (or Δ)

· Three resistances connected together at a common point O are said to be star - (or Y) connected.

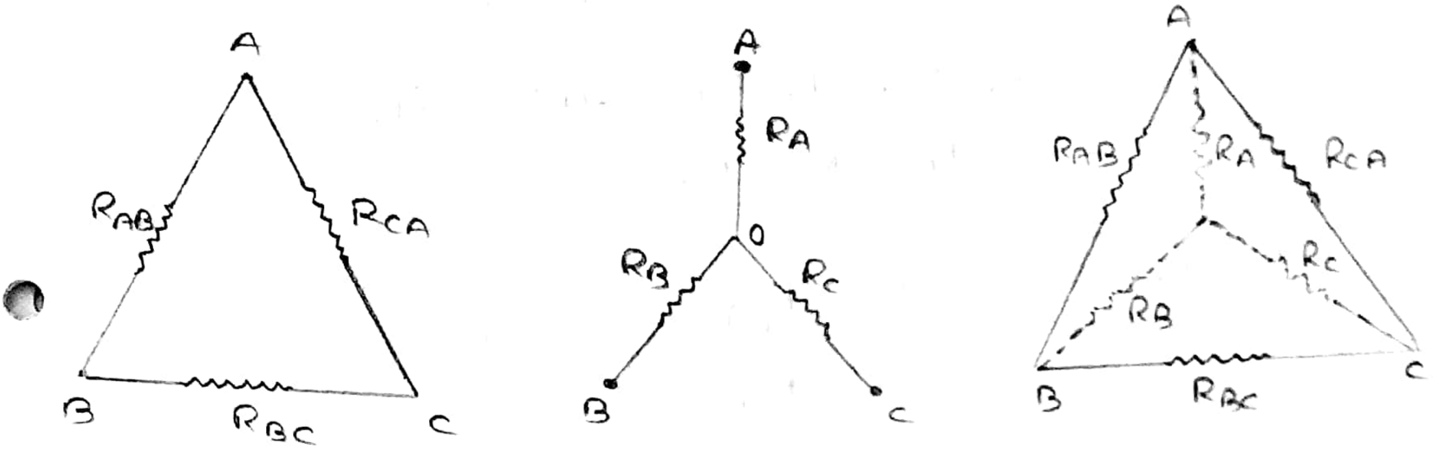


fig (a) fig (b) fig (c)

Delta - Star transformation :-

Consider a circuit as shown in fig where three resistances R_{AB}, R_{BC} and R_{CA} are connected in Delta. If this circuit is converted to star connections. Let the resistance be R_A, R_B and R_C.

For two circuits to be equivalent, the resistance measured between any two of the terminals A, B and C must be same in the two cases

R_{AB} for star connection = R_{AB} for delta connection

$$R_A + R_B = R_{AB} \parallel (R_{BC} + R_{CA})$$

$$R_A + R_B = \frac{R_{AB} \cdot (R_{BC} + R_{CA})}{R_{AB} + R_{BC} + R_{CA}} \quad \text{—— (i)}$$

Similarly

$$R_B + R_C = \frac{R_{BC}(R_{AB} + R_{CA})}{R_{AB} + R_{BC} + R_{CA}} \quad \text{—— (ii)}$$

$$R_C + R_A = \frac{R_{CA}(R_{AB}+R_{BC})}{R_{AB}+R_{BC}+R_{CA}} \quad \text{——— (iii)}$$

Subtract (ii) - (i)

$$R_C - R_A = \frac{R_{BC}(R_{AB}+R_{CA})}{R_{AB}+R_{BC}+R_{CA}} - \frac{R_{AB}(R_{BC}+R_{CA})}{R_{AB}+R_{BC}+R_{CA}}$$

$$R_C - R_A = \frac{\cancel{R_{BC}R_{AB}} + R_{BC}R_{CA} - \cancel{R_{AB}R_{BC}} - R_{AB}R_{CA}}{R_{AB}+R_{BC}+R_{CA}}$$

$$R_C - R_A = \frac{R_{CA}(R_{BC}-R_{AB})}{R_{AB}+R_{BC}+R_{CA}} \quad \text{——— (iv)}$$

Add (iii) & (iv)

$$2R_C = \frac{R_{CA}(R_{AB}+R_{BC})}{R_{AB}+R_{BC}+R_{CA}} + \frac{R_{CA}(R_{BC}-R_{AB})}{R_{AB}+R_{BC}+R_{CA}}$$

$$2R_C = \frac{\cancel{R_{CA}R_{AB}} + R_{CA}R_{BC} + R_{CA}R_{BC} - \cancel{R_{CA}R_{AB}}}{R_{AB}+R_{BC}+R_{CA}}$$

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

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

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

...r - Delta Transformation

We know that

$$R_A = \frac{R_{AB} R_{CA}}{R_{AB} + R_{BC} + R_{CA}} \quad \text{--- (i)}$$

$$R_B = \frac{R_{AB} R_{BC}}{R_{AB} + R_{BC} + R_{CA}} \quad \text{--- (ii)}$$

$$R_C = \frac{R_{BC} . R_{CA}}{R_{AB} + R_{BC} + R_{CA}} \quad \text{--- (iii)}$$

Divide (i) by (ii)

$$\frac{R_A}{R_B} = \frac{R_{CA}}{R_{BC}}$$

$$\boxed{R_{CA} = \frac{R_A}{R_B} \times R_{BC}} \quad \text{--- (iv)} \qquad R_{BC} = \frac{R_B}{R_A} \times R_{CA}$$

Divide (i) by (iii)

$$\frac{R_A}{R_C} = \frac{R_{AB}}{R_{BC}}$$

$$\boxed{R_{AB} = \frac{R_A}{R_C} \times R_{BC}} \quad \text{--- (v)}$$

put these values in (i)

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

$$\cancel{R_A} = \frac{\frac{R_{BC} \ R_A^2}{R_B \ R_C}}{\frac{R_A}{R_C} + 1 + \frac{R_A}{R_B}}$$

$$1 = \frac{\dfrac{R_{BC} R_A}{\cancel{R_B R_C}}}{\dfrac{R_A R_B + R_B R_C + R_A R_C}{\cancel{R_B R_C}}}$$

$$1 = \frac{R_{BC} \; R_A}{R_A R_B + R_B R_C + R_A R_C}$$

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

$$R_{BC} = R_B + R_C + \frac{R_B R_C}{R_A} \quad \text{———} \quad (vi)$$

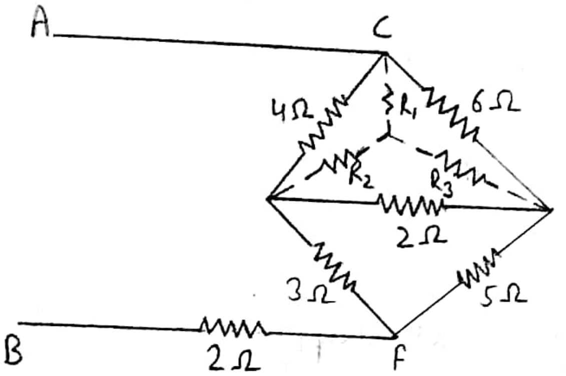
Similarly

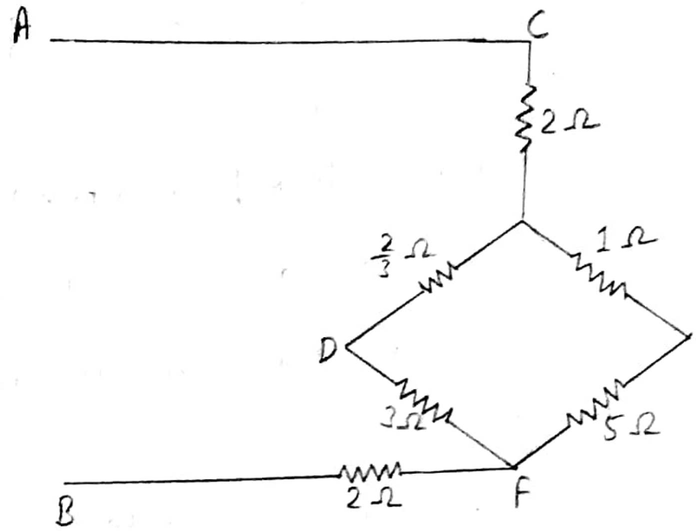
$$R_{AB} = R_A + R_B + \frac{R_A R_B}{R_C}$$

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

Numericals on Star-Delta

1- Find the resistance between AB of the circuit shown in the figure using Star-Delta Transformation





Solution:-

$$R_1 = \frac{4\times 6}{4+6+2} = \frac{24}{12} = 2\Omega$$

$$R_2 = \frac{4\times 2}{4+6+2} = \frac{8}{12} = \frac{4}{6} = \frac{2}{3}\Omega$$

$$R_3 = \frac{2\times 6}{4+6+2} = \frac{12}{12} = 1\Omega$$

Resistance across CF or AB

$$R_{AB} = 2 + \left[\left(\frac{2}{3}+3\right) \parallel (5+1)\right] + 2$$

$$= 2 + \left[\frac{11}{3} \parallel 6\right] + 2$$

$$= 2 + \frac{\frac{11}{3}\times 6}{\frac{11}{3}+6} + 2$$

$$= 2 + \frac{22\times 3}{29} + 2$$

$$= 4 + \frac{66}{29} = \frac{116+66}{29} = \frac{182}{29} = 6.276\Omega$$

Transient Response:-

The short-timed electrical phenomenon that occurs in a system due to sudden change in voltage, current or load is called transient response.

In general, transient took place whenever:

1) load is connected or disconnected to/from the supply.

2) There is a sudden change in the applied voltage from one finite value to the other.

3) The circuits get short-circuited

Infact, transients are not caused due to any part of the applied voltage rather these are associated with the changes that occur in the stored energy in inductors & capacitors.

Since, no energy is stored in the resistors, no transient occur in pure resistive circuit.

In inductive circuit, energy is stored in the form of electromagnetic field.

In capacitive circuit, energy is stored in the form of electrostatic field.

When the circuit is associated with single energy storing element i.e. R-L or R-C circuit, the transient which occurs are called single energy transients.

When the circuit is associated with both energy storing elements i.e. R-L-C circuits, the transient which occurs are called double energy transients

...sient Response of R-L series circuit:-

Consider a circuit containing resistance R (ohms) & inductance L (henry) with a switch as shown in the fig. The switch has been kept open for a long time, & is closed at $t=0$

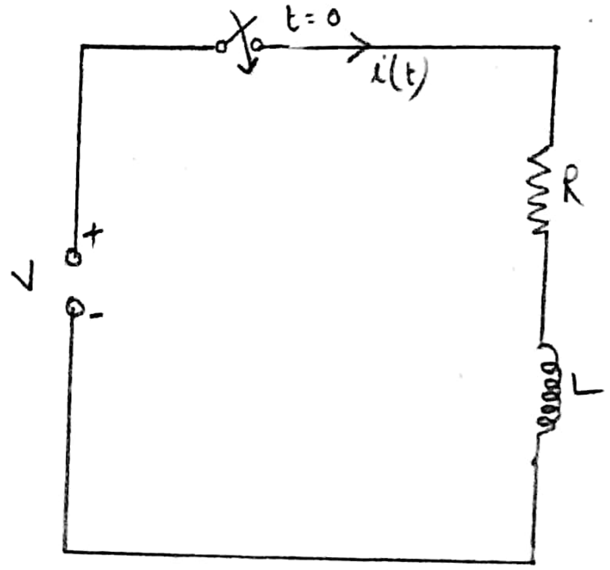
Applying kirchoff's voltage law to the circuit after switching

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

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

$$\frac{di}{dt} = \frac{V}{L} - \frac{R}{L}i$$

$$\frac{di}{dt} + \frac{R}{L}i = \frac{V}{L} \quad \text{——— (i)}$$



R-L series circuit

We know that

$$\frac{dy}{dx} + Py = Q$$ (is a linear differential equation) — (1)

P, Q are the functions of x only

$$I.F = e^{\int P dx}$$

Soln of this equation is

$$\boxed{y \times I.F = \int Q \times IF\, dx + C}$$

$$\frac{di}{dt} + \frac{R}{L}i = \frac{V}{L}$$ (compare it with 1)

$$P = \frac{R}{L}, \quad Q = \frac{V}{L} \qquad I.F = e^{\int P dt} = e^{\int \frac{R}{L} dt} = e^{\frac{R}{L}t}$$

Solution is

$$i \times e^{\frac{R}{L}t} = \int \frac{V}{L} e^{\frac{R}{L}t} dt + c$$

$$i e^{\frac{R}{L}t} = \frac{V}{\cancel{L}} \frac{e^{\frac{R}{L}t}}{\frac{R}{\cancel{L}}} + c$$

$$i e^{\frac{R}{L}t} = \frac{V}{R} e^{\frac{R}{L}t} + c$$

$$i = \frac{V}{R} + c e^{-\frac{R}{L}t} \quad \text{——— (ii)}$$

where c is a constant & it must satisfy the initial condition on inductance current

$$i(0^+) = i(0^-) = 0$$

substituting in equation (ii)

$$0 = \frac{V}{R} + c$$

$$c = -\frac{V}{R}$$

Hence

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

$$\boxed{i = \frac{V}{R}\left(1 - e^{-R/L\, t}\right)} \quad \text{——— (iii)}$$

In above expression, the first term

$\frac{V}{R} \rightarrow$ corresponds to steady state condition force response (I_f)

$-\frac{V}{R} e^{-R/L\, t}$ corresponds to transient state (natural response)

which approaches to zero as $t \rightarrow \infty$

ratio $\frac{L}{R}$ is called time constant & denoted by τ.

- The reciprocal of the time constant (i.e. $\frac{R}{L}$) is called damping co-efficient of the circuit.

The voltage across the resistor is

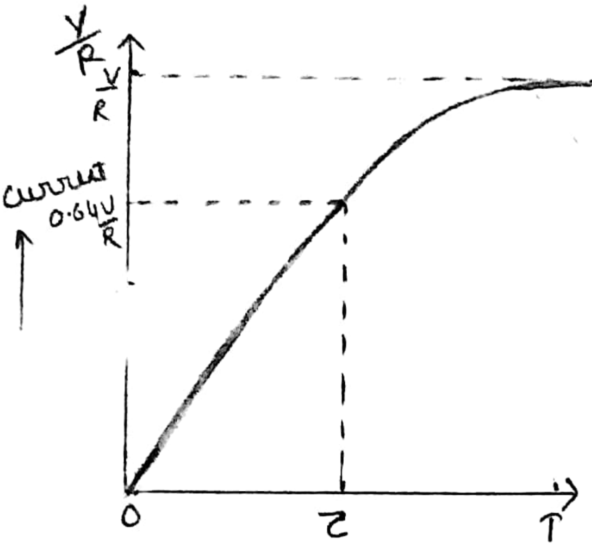
$$V_R(t) = i(t) \cdot R$$
$$= R\frac{V}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$
$$= V\left(1 - e^{-\frac{R}{L}t}\right)$$
$$= V\left(1 - e^{-\frac{t}{\tau}}\right) \quad \text{——— (iv)}$$

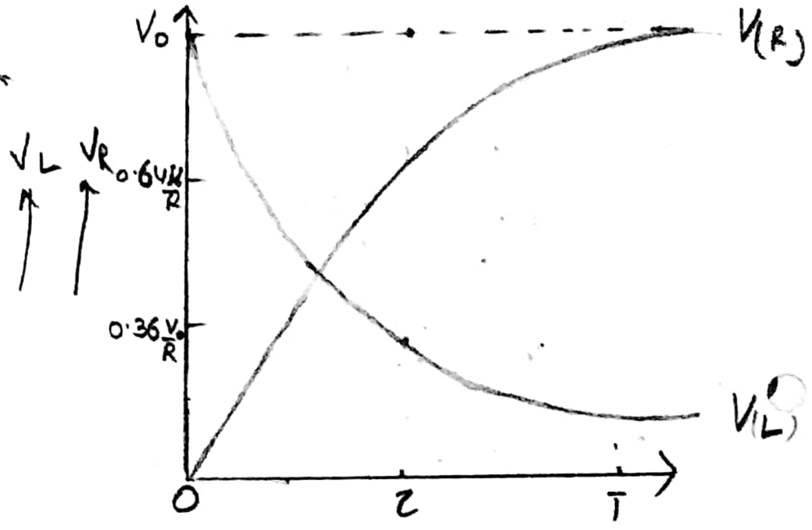
The voltage across inductance is

$$V = V_R + V_L$$
$$V_L = V - V_R$$
$$= V - V\left(1 - e^{-\frac{t}{\tau}}\right)$$
$$= Ve^{-\frac{t}{\tau}}$$

Now $i = \frac{V}{R}\left(1 - e^{-R/L\, t}\right)$	$V_R = V\left(1 - e^{-\frac{t}{\tau}}\right)$	$V_L = Ve^{-\frac{t}{\tau}}$
At $t = 0$ $\rightarrow i = 0$	$V_R = 0$	$V_L = V$
At $t = \frac{L}{R} = \tau$ $i = \frac{V}{R}(1 - e^{-1})$ $= \frac{V}{R}(1 - 0.37)$ $\rightarrow i = 0.63\frac{V}{R}$	$V_R = V(1 - e^{-1})$ $V_R = V(1 - 0.37)$ $V_R = 0.63V$	$V_L = Ve^{-1}$ $V_L = V(0.37)$
At $t = \infty$ $\rightarrow i = V/R$	$V_R = V$	$V_L = 0$

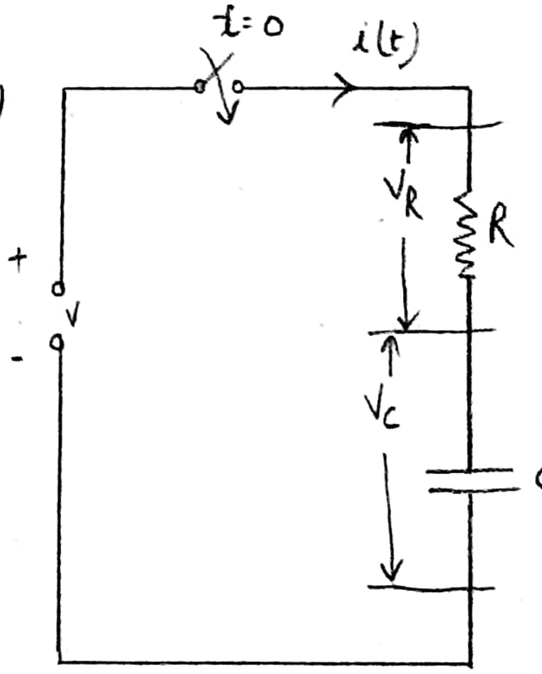
Now according to these values, the graph b/w current and time is shown in fig.





Transient Response of R-C series circuit:-

Consider a circuit containing resistance (R ohm) & capacitance C farad with a switch as shown in fig. The switch is closed at time $t=0$



R-C series circuit.

Applying kirchoff's voltage law to the circuit after switching

$$V = V_R + V_C$$

$$V = iR + \frac{1}{C}\int_{-\infty}^{t} i(t)\,dt$$

$$V = Ri + \frac{1}{C}\int_{0}^{t} i(t)\,dt + V_C(0^+)$$

Assuming capacitor initially uncharged

$$V = R\,i(t) + \frac{1}{C}\int_0^t i(t)\,dt$$

Differentiating

$$R\frac{di}{dt} + \frac{1}{C}i = 0 \qquad \text{—— (i)}$$

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

$P = \frac{1}{RC}$, $\qquad Q = 0$

- $I.F = e^{\int P\,dt} = e^{\int \frac{1}{RC}dt} = e^{\frac{t}{RC}}$

Solution

$$i \times I.F = \int Q \times I.F\,dt + C$$

$$i\,e^{\frac{t}{RC}} = \int 0 \times e^{\frac{t}{RC}}\,dt + C$$

$$i\,e^{\frac{t}{RC}} = C$$

$$i(t) = C\,e^{-\frac{t}{RC}} \qquad (C \text{ is constant})$$

- As at $t = 0^+$ = $i(0^+) = \frac{V}{R}$ since capacitor behaves as a short circuited at $t = 0^+$

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

$$\boxed{i(t) = \frac{V}{R}e^{-\frac{t}{RC}}} \qquad \text{—— (ii)}$$

$\tau = RC$ is time constant

Voltage across the resistor

$$V_R(t) = Ri(t) = Ve^{-\frac{t}{\tau}}$$

Voltage across the capacitor

$$V = V_R + V_c$$

$$V_c = V - V_R = V - Ve^{-\frac{t}{\tau}}$$

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

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

↓ At $t = 0$

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

↓ At $t = \tau = RC$

$i = \frac{V}{R} e^{-1}$

$i = 0.37 \frac{V}{R}$

↓ At $t = \infty$

$i = 0$

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

$V_R = V$

$V_R = Ve^{-1}$

$V_R = 0.37 \frac{V}{R}$

$V_R = 0$

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

$V_c = 0$

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

$V_c = V(1 - 0.37)$
$= 0.63\,V$

$V_c = V$

Using these values, Now graph between current + time.