Unit 4 Network Reduction Method for DC Circuits

• Basic Definitions :

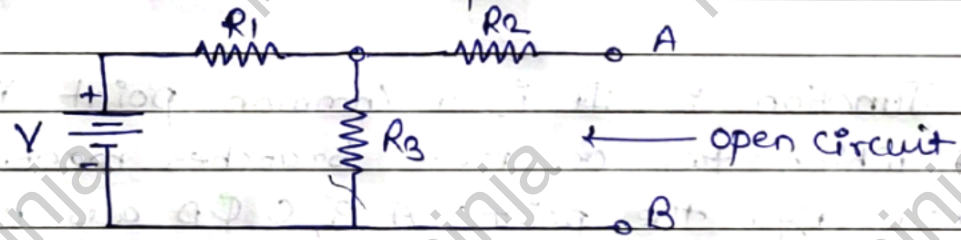
* Network or Circuit : A network or circuit is an electrical configuration which electrically connects various components such as resistor, capacitor & inductor, etc and voltage source or current source to each other.

Network or Circuit
- DC Circuits
- AC Circuits
  - Single Phase AC Circuit
  - Three Phase AC Circuits

fig. classification of networks

• Concept of open & Short Circuit :

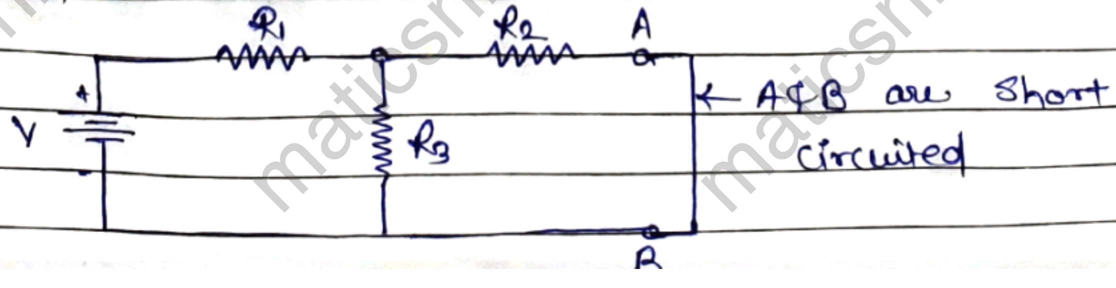
* Open Circuit : If there is no circuit elements or direct connection between them two points then that circuit is called as open circuit.



- The resistance betn the open circuited points is infinite.

$$\therefore R_{AB} = \infty$$

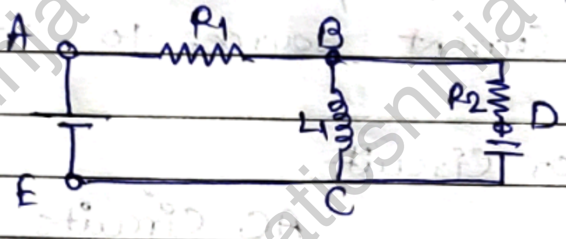
* Short Circuit : When the circuit elements are connected to each other by a good conducting wire then that circuit is called as short circuit.



- The resistance betⁿ the short circuited points is zero

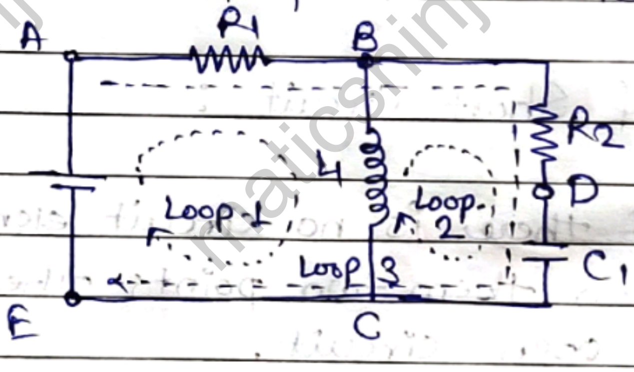
$\therefore R_{AB} = 0\,\Omega$

• **Branch :** A branch of a network is defined as the group of elements connected in series or parallel & which has two terminals from connection.



- Branches of the above circuit are AB, BC, BDC & AE

• **Mesh or loop :** A mesh or loop is a set of branch forming a closed path in a network.



Loop I = A-B-C-E-A

Loop II = B-D-C-B

Loop III = A-B-D-C-E-A

• **Node or Junction :** It is a common point in a network at which two or more branches meet.

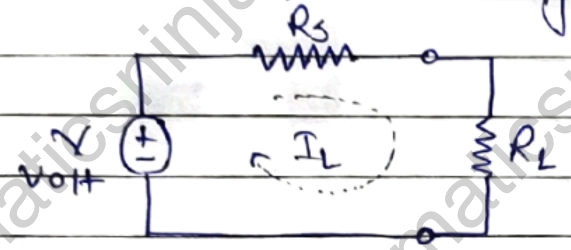
- In above fig. the points A, B, C & D are nodes.

• Source Transformation :

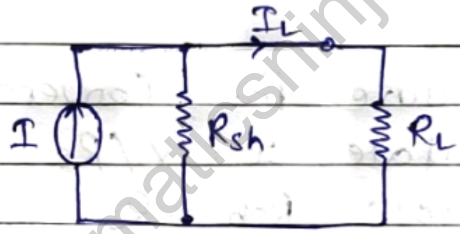
*** Need of Source Transformation :**

- For the simplification of complex networks the transformation of voltage source to an equivalent current source is necessary.

• Conversion of Voltage Source to Current Source :



a) Given voltage source



b) Equivalent Current Source

Step 1 : Calculate the load current I_L for the voltage source :

$$I_L = \frac{V}{R_T} = \frac{V}{(R_{sh}+R_L)} \quad \text{—— ①}$$

Step 2 : Write the expression for I_L of current source :

$$I_L = \frac{R_{sh}}{(R_{sh}+R_L)} \times I \quad \text{—— ②}$$

Step 3 : Equate the load currents :

$$\therefore \frac{V}{(R_{sh}+R_L)} = \frac{R_{sh}}{(R_{sh}+R_L)} \times I$$

$\therefore V = R_{sh} . I$ & $R_s + R_L = R_{sh} + R_L$

$\therefore V = I . R_{sh}$ & $R_s = R_{sh}$

$\therefore I = \frac{V}{R_{sh}}$ & $R_{sh} = R_s$

- Thus the magnitude of the current of equivalent current source should be V/R_s & the shunt internal resistance is $R_{sh} = R_s$.

- The equivalent Current Source is shown in below fig.

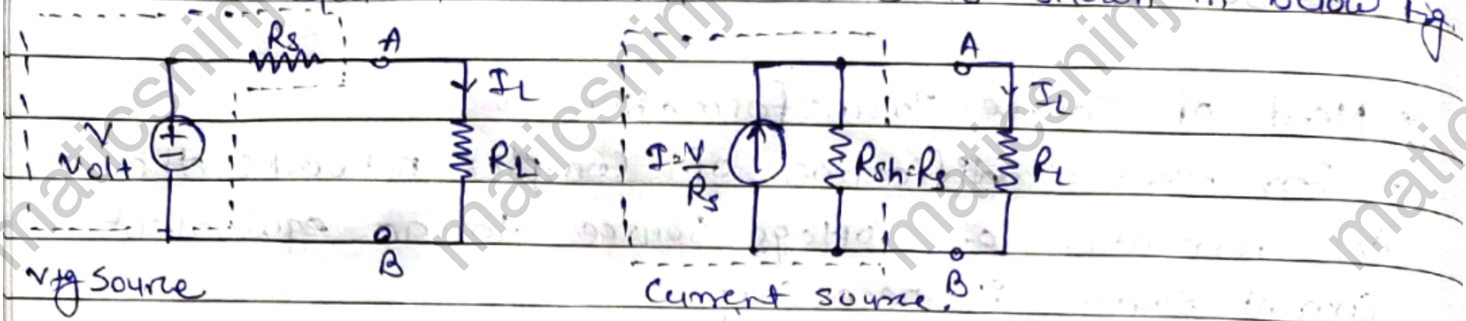


fig. Vtg Source transformed into Current Source

- **Procedure for Conversion :**

① Calculate $I = V/R_s$

② Calculate $R_{sh} = R_s$

③ Draw the equivalent Current Source

- **Numerical :**

① Transform voltage Source into an equivalent Current Source

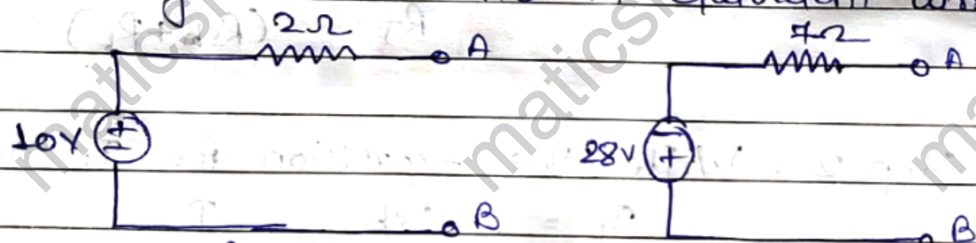
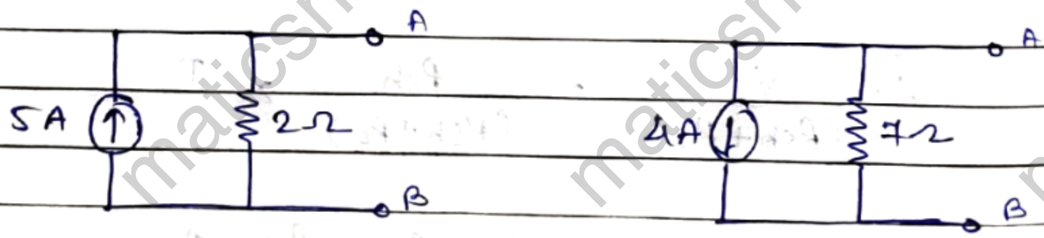


fig. (a) fig (b)

Solⁿ :

$I = \frac{V}{R} = \frac{10}{2} = 5A.$ $I = \frac{V}{R} = \frac{28}{7} = 4A.$



② Transform vtg Source into an equivalent Current Source

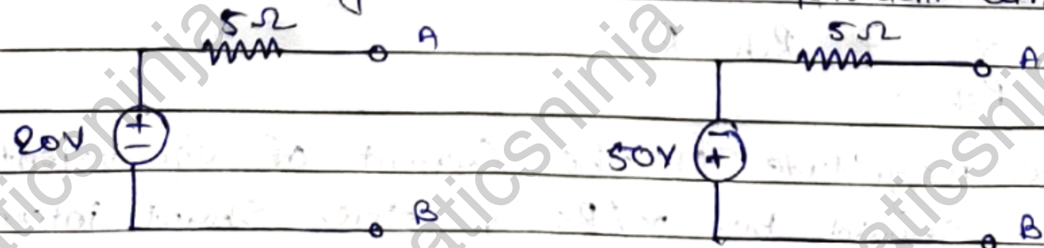
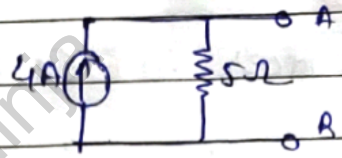


fig. (a) fig. (b)

For fig-(a)

$I = \frac{V}{R} = \frac{20}{5} = 4\,A.$



For fig. (b)

$I = \frac{V}{R} = \frac{50}{5} = 10A.$

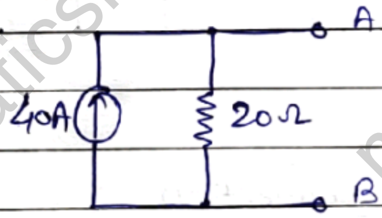
- **Conversion of Current Source to Voltage Source :**

* **Procedure for Conversion :**

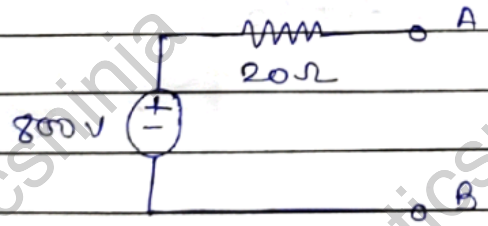
1. Calculate $V = I \times R_{sh}$
2. Calculate $R_s = R_{sh}$
3. Draw the Voltage Source;

- **Numerical :**

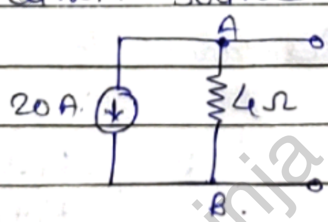
1. Convert the Current Source into an equivalent Voltage Source.



Solⁿ : $V = I \times R_{sh} = 40 \times 20 = 800V.$

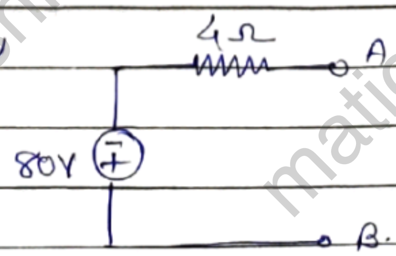


2. Convert the Current Source to its equivalent Voltage Source.



Solⁿ :

$V = I \times R_{sh} = 20 \times 4 = 80V$



* Voltage Sources in Series :

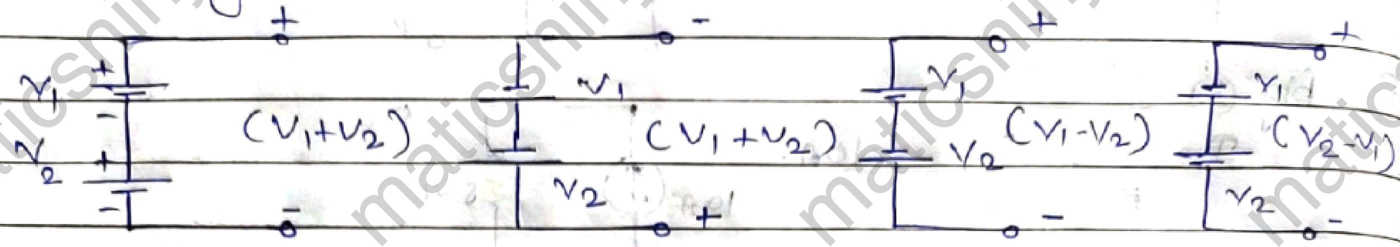


fig. (a) fig (b) fig. (c) fig (d)

* Current Source in Parallel :

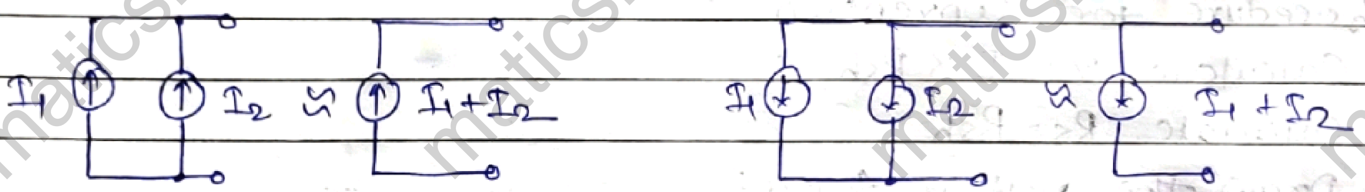


fig. (a) fig. (b)

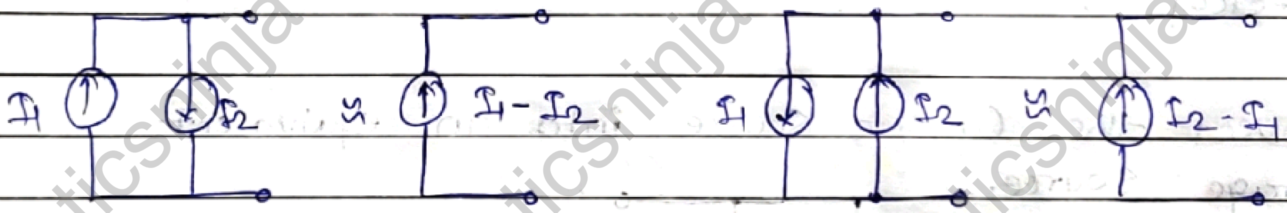
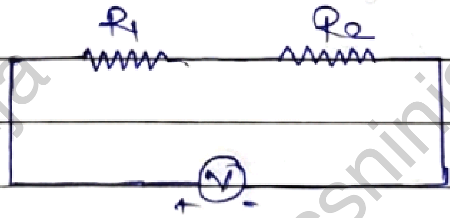


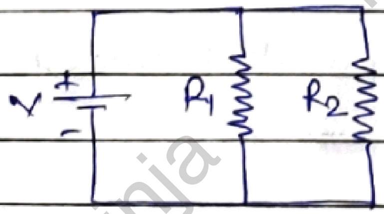
fig. (c) fig. (d)

* Resistor in Series Connection :



$$\boxed{R_T = R_1 + R_2}$$

* Resistor in Parallel Connection :

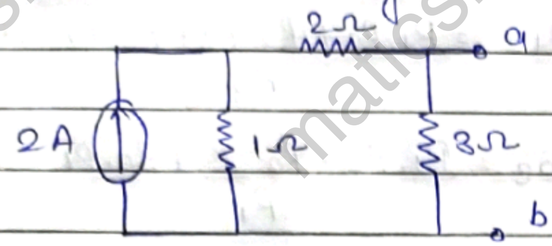


Total Resistance $(R_T) = \frac{1}{R_1} + \frac{1}{R_2}$

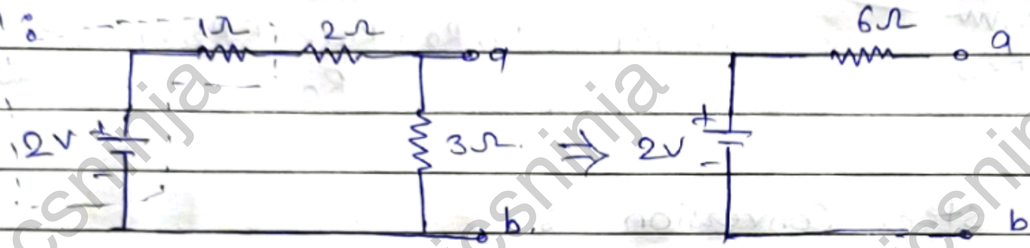
$$\boxed{R_T = \frac{R_1 \cdot R_2}{R_1 + R_2}}$$

Numerical :

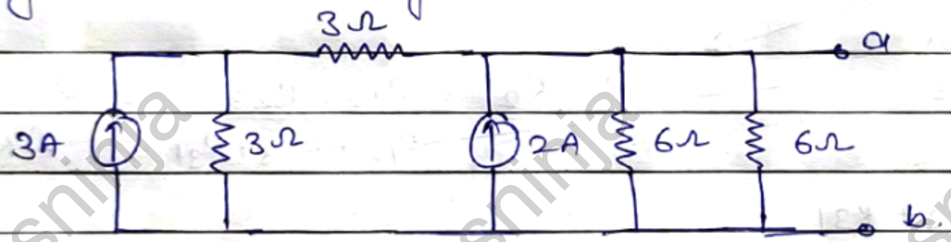
① Using Source Conversion reduce the circuit shown in fig. into a voltage source, in series with single resistance



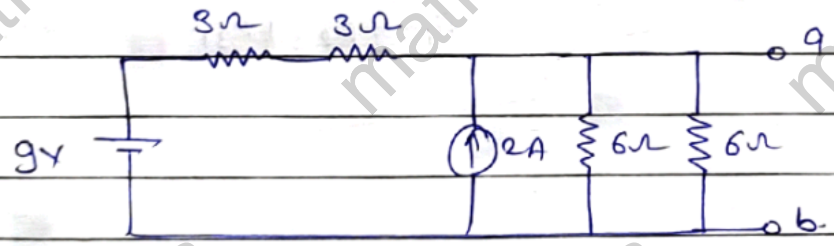
Soln :

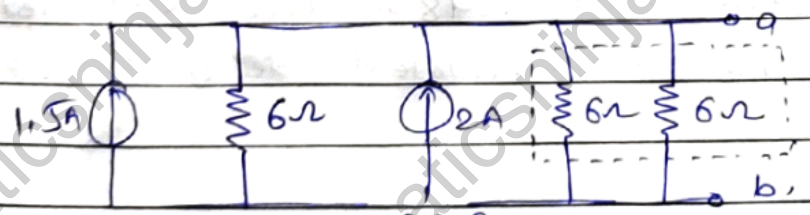


② Using Source Conversion reduce the circuit shown in fig. into a voltage source in series with single resistance

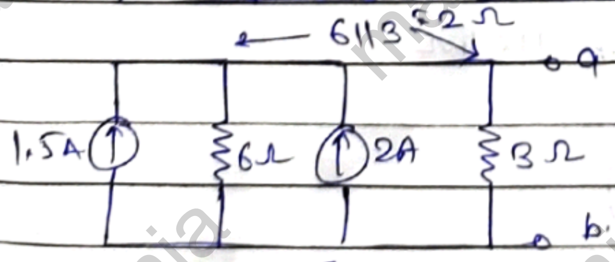


Soln :

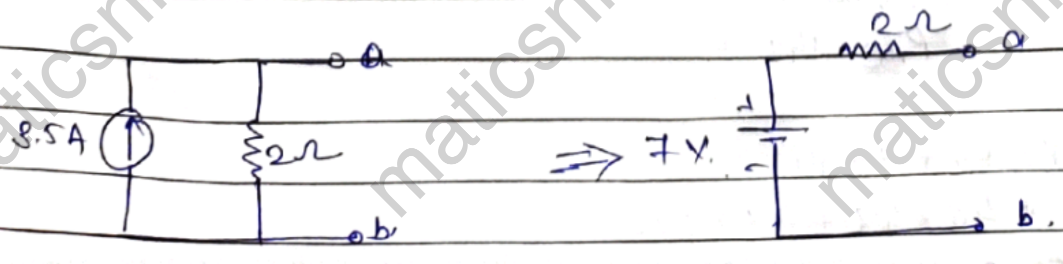




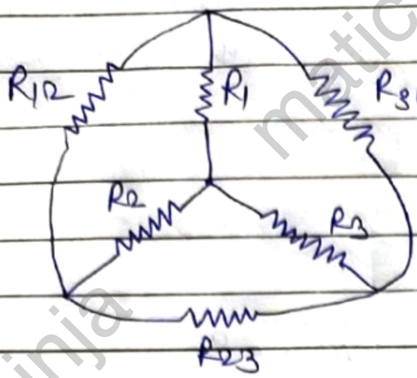
$R_{eq} = \frac{6 \times 6}{6+6} = \frac{36}{12} = 3\Omega$



$1.5 + 2 = 3.5\ A.$



* Star to Delta Conversion :

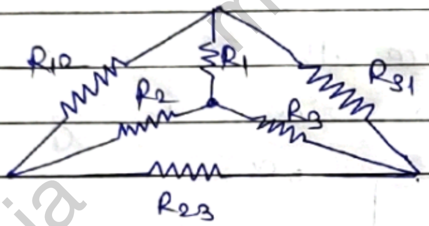


$\therefore R_{12} = \dfrac{R_1.R_2 + R_2.R_3 + R_3.R_1}{R_3} = \dfrac{*R}{R_3}$

$\therefore R_{23} = \dfrac{R_1.R_2 + R_2.R_3 + R_3.R_1}{R_1} = \dfrac{*R}{R_1}$

$\therefore R_{31} = \dfrac{R_1.R_2 + R_2.R_3 + R_3.R_1}{R_2} = \dfrac{*R}{R_2}$

* Delta to star Conversion :



$\therefore R_1 = \dfrac{R_{12}.R_{31}}{R_{12}+R_{23}+R_{31}} = \dfrac{R_{12}.R_{31}}{\Delta R}$

$\therefore R_2 = \dfrac{R_{12}.R_{23}}{R_{12}+R_{23}+R_{31}} = \dfrac{R_{12}.R_{23}}{\Delta R}$

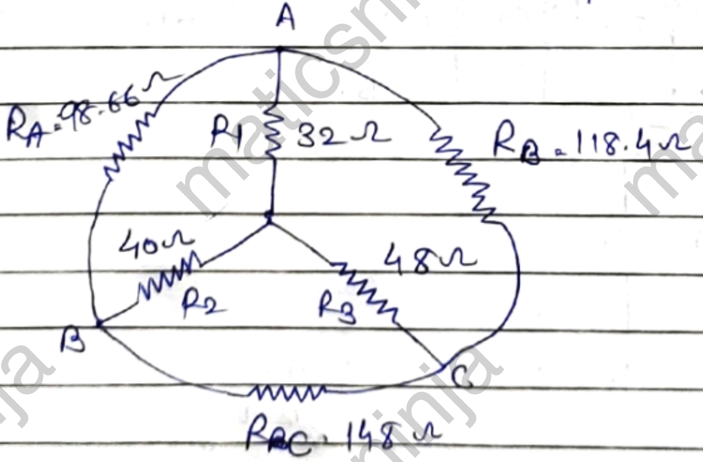
$\because \Delta R = R_{12}+R_{23}+R_{31}$
(Total Resistance in Δ)

$\therefore R_3 = \dfrac{R_{23}.R_{31}}{R_{12}+R_{23}+R_{31}} = \dfrac{R_{23}.R_{31}}{\Delta R}$

- Numerical :

① Three resistance $32\,\Omega$, $40\,\Omega$ & $48\,\Omega$ are connected in star circuit. Determine its equivalent delta-circuit.

Sol^n:



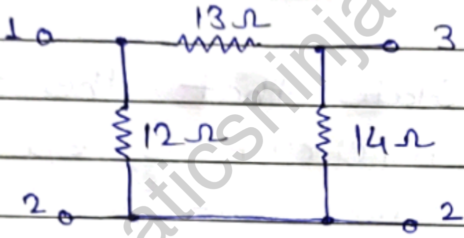
$R = R_1.R_2 + R_2.R_3 + R_3.R_1 =$
$= 32 \times 40 + 40 \times 48 + 48 \times 32$
$\therefore R = 4736\ \Omega$

$R_A = \frac{R}{R_3} = \frac{4736}{48} = 98.66\,\Omega$

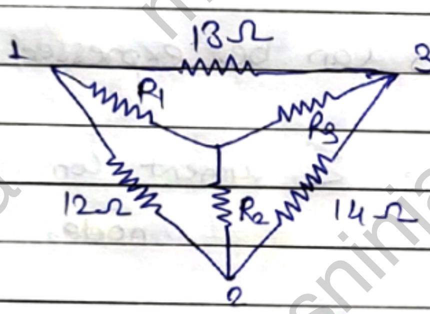
$R_B = \frac{R}{R_2} = \frac{4736}{40} = 118.4\,\Omega$

$R_C = \frac{R}{R_1} = \frac{4736}{32} = 148\,\Omega$

② Obtain the star network from the delta network shown in fig.



Soln :

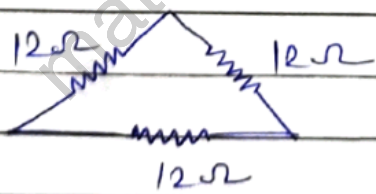


$R_1 = \frac{13 \times 12}{13+12+14} = 4\,\Omega$

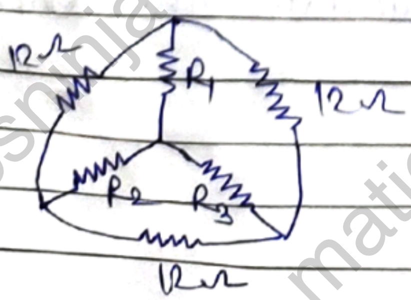
$R_2 = \frac{12 \times 14}{13+12+14} = 4.3\,\Omega$

$R_3 = \frac{13 \times 14}{13+12+14} = 4.66\,\Omega$

③ Obtain the star network from the delta network



Soln :

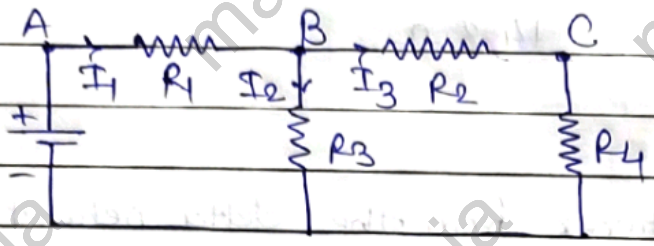


$R_1 = R_2 = R_3 = \frac{12 \times 12}{12+12+12} = 4\,\Omega$

* Kirchhoff's Laws :

1) Kirchhoff's Voltage Law (KVL)
2) Kirchhoff's Current Law (KCL)

1. Kirchhoff's Current Law (KCL) :



Statement : It state that the sum of currents directed into any node in a circuit is equal to the sum of the currents coming out of the same node.

Mathematically this can be expressed as

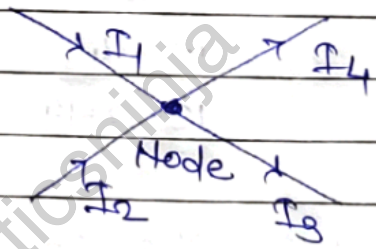
Σ Current entering node n = Σ current coming out of node n.

OR =

- The algebraic sum of all currents entering or leaving a node must be equal to zero.

$\therefore \Sigma I = 0$

- I_1 & I_2 is incoming current & I_3 & I_4 is outgoing current



According to KCL

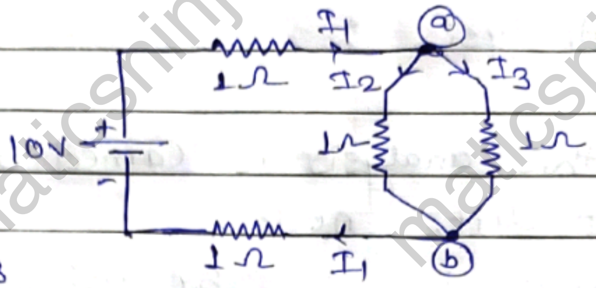
$I_1 + I_2 = I_3 + I_4$

$I_1 + I_2 - I_3 - I_4 = 0$

$\therefore \Sigma I = 0$

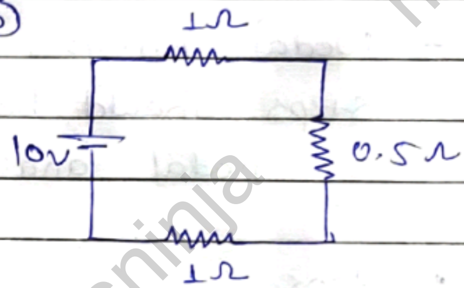
- KCL is generally used to calculate the unknown voltage in the given circuit.

① Verify Krichhoff's Current Law (KCL) for the node points ⓐ & ⓑ



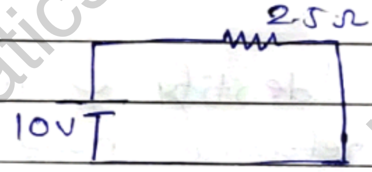
Sol^n: $I_1 = I_2 + I_3$

$$R = \frac{1 \times 1}{1+1} = \frac{1}{2} = 0.5\,\Omega$$



$$R_T = 1 + 0.5 + 1 = 2.5\,\Omega$$

$$I_1 = \frac{V}{R_T} = \frac{10}{2.5} = 4\,A$$



$$I_2 = \frac{R_{sh}}{R_{sh}+R_1} \times I_1 = \frac{1}{1+1} \times 4 = \frac{1}{2} \times 4 = 2\,A.$$

$$I_3 = \frac{R_{sh}}{R_{sh}+R_1} \times I_1 = \frac{1}{1+1} \times 4 = \frac{1}{2} \times 4 = 2\,A.$$

$I_1 = I_2 + I_3$

$4 = 2 + 2$

$4 = 4$

∴ Hence Proved

Nodal Analysis :

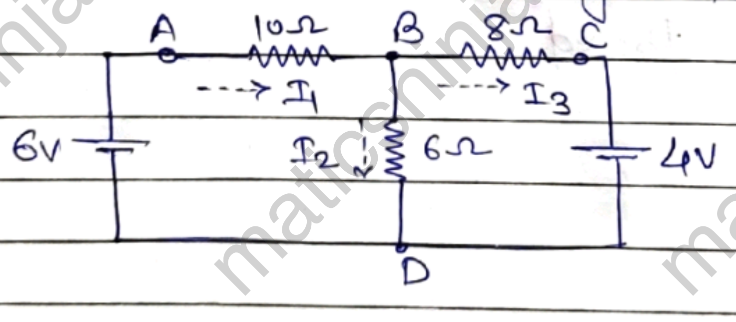
- Normally this analysis is carried out to determine voltages at diff. nodes.
- Nodal Analysis is done by using KCL, following steps should be taken while solving problems by nodal analysis.

• Steps :

1) Identify & mark all the nodes (including the reference node) & the corresponding node voltages.
2) Mark all the branch currents.
3) Write the KCL equation at every node in terms of conductance (G), node voltage & currents.
4) Transform the KCL eqn into the matrix form & solve them using the cramer's rule to obtain various node voltages.

* Numericals on Nodal Analysis :

(1) Calculate the node voltage V_B using nodal analysis.



Soln :

Apply KCL at node B

$$I_1 = I_2 + I_3$$

$$I_1 = \frac{V_A - V_B}{10}, \quad I_2 = \frac{V_B}{6} \quad \& \quad I_3 = \frac{V_B - V_C}{8}$$

Substitute the value of I_1, I_2 & I_3 we get

$$\frac{V_A - V_B}{10} = \frac{V_B}{6} + \frac{V_B - V_C}{8}$$

But $V_A = 6V$ & $V_C = 4V$

$$\therefore \frac{6-V_B}{10} = \frac{V_B}{6} + \frac{V_B-4}{8}$$

$$\frac{6-V_B}{10} = \frac{8V_B + 6V_B - 24}{48}$$

$$48(6-V_B) = 10(8V_B + 6V_B - 24)$$

$$288 - 48V_B = 80V_B + 60V_B - 240$$

$$-48V_B - 60V_B - 80V_B = -288 - 240$$

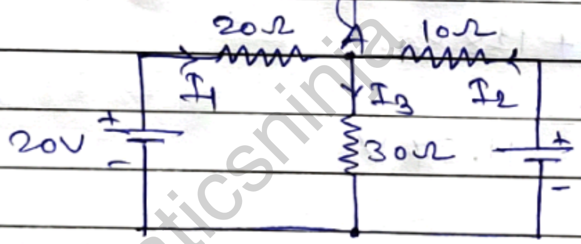
$$-188V_B = -528$$

$$V_B = \frac{-528}{-188}$$

$$\boxed{V_B = 2.80V}$$ ... Ans

② Calculate current through 30Ω resistance using nodal analysis.

soln :



Apply KCL at node A.

$$I_1 + I_2 = I_3$$

$$\frac{20-V_A}{20} + \frac{10-V_A}{10} = \frac{V_A}{30}$$

$$\frac{200 - 10V_A + 200 - 20V_A}{200} = \frac{V_A}{30}$$

$$30(200 - 10V_A + 200 - 20V_A) = 200V_A$$

$$6000 - 300V_A + 6000 - 600V_A = 200V_A$$

$$12000 - 900V_A = 200V_A$$

$$12000 = 200V_A + 900V_A$$

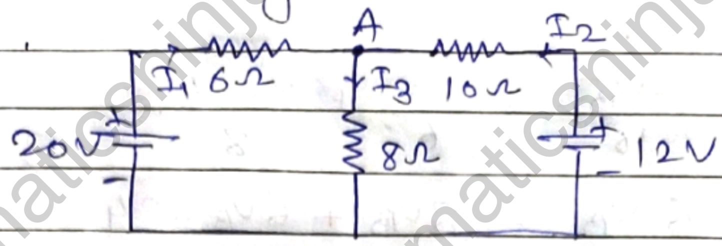
$$12000 = 1100V_A$$

$$\therefore V_A = \frac{12000}{1100} = 10.90V$$ ... Ans

$$I_3 = \frac{V_A}{30} = \frac{10.90}{30} = 0.363A$$ ... Ans

③ Find the current through 8Ω resistance using nodal analysis.

Soln:



Apply KCL at node A

$$I_1 + I_2 = I_3$$

$$\frac{20 - V_A}{6} + \frac{12 - V_A}{10} = \frac{V_A}{8}$$

$$\frac{200 - 10V_A + 72 - 6V_A}{60} = \frac{V_A}{8}$$

$$8(200 - 10V_A + 72 - 6V_A) = 60V_A$$

$$1600 - 80V_A + 576 - 48V_A = 60V_A.$$

$$2176 - 128V_A = 60V_A$$

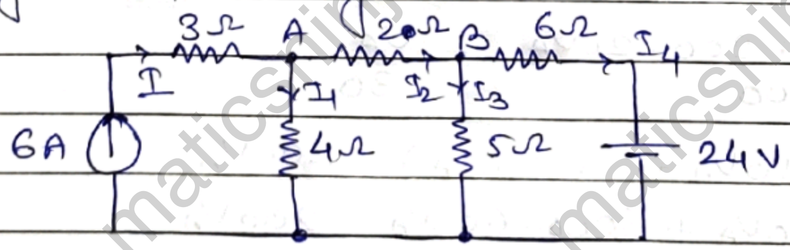
$$2176 = 60V_A + 128V_A.$$

$$2176 = 188V_A$$

$$V_A = \frac{2176}{188} = 11.57V$$

$$I_3 = \frac{V_A}{8} = \frac{11.57}{8} = 1.44A.$$

④ Find the voltages at node A & B in the network by using nodal analysis.



Soln: Apply KCL at node A

$$I = I_1 + I_2$$

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

$$6 = \frac{2V_A + 4V_A - 4V_B}{8}$$

$$48 = 2V_A + 4V_A - 4V_B$$

$$48 = 6V_A - 4V_B \quad \text{--- (1)}$$

Apply KCL at node B

$$I_2 = I_3 + I_4$$

$$\frac{V_A - V_B}{2} = \frac{V_B}{5} + \frac{V_B - 24}{6}$$

$$\frac{V_A - V_B}{2} = \frac{6V_B + 5V_B - 120}{30}$$

$$30(V_A - V_B) = 2(6V_B + 5V_B - 120)$$

$$30V_A - 30V_B = 12V_B + 10V_B - 240$$

$$30V_A - 30V_B - 12V_B - 10V_B = -240$$

$$30V_A - 52V_B = -240 \quad \text{--- (2)}$$

Multiply eqn (1) by 30 & eqn (2) by 6 we get,

$$30(48 = 6V_A - 4V_B)$$

$$1440 = 180V_A - 120V_B \quad \text{--- (3)}$$

$$6(30V_A - 52V_B = -240)$$

$$180V_A - 312V_B = -1440 \quad \text{--- (4)}$$

Add eqn (3) & (4)

$$\cancel{180V_A} - 120V_B = 1440$$

$$\underset{(-)}{\cancel{180V_A}} \underset{(+)}{-} 312V_B = \underset{(+)}{-}1440$$

$$192V_B = 2880$$

$$V_B = \frac{2880}{192}$$

$$\boxed{\therefore V_B = 15V}$$

Put $V_B = 15$ in eqn (1)

$$48 = 6V_A - 4(15)$$

$$48 = 6V_A - 60$$

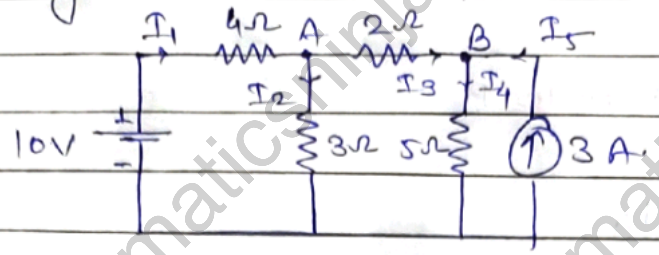
$$48 + 60 = 6V_A$$

$$108 = 6V_A$$

$$V_A = \frac{108}{6}$$

$$\boxed{\therefore V_A = 18V}$$

⑤ Find voltage across 3 Ω Resistor, using nodal analysis.



Sol^n :

Apply KCL at node A.

$$I_1 = I_2 + I_3$$

$$\frac{10 - V_A}{4} = \frac{V_A}{3} + \frac{V_A - V_B}{2}$$

$$\frac{10 - V_A}{4} = \frac{2V_A + 3V_A - 3V_B}{6}$$

$$6(10 - V_A) = 4(2V_A + 3V_A - 3V_B)$$

$$60 - 6V_A = 8V_A + 12V_A - 12V_B$$

$$60 = 8V_A + 12V_A + 6V_A - 12V_B$$

$$60 = 26V_A - 12V_B \quad \text{——} \quad (1)$$

Apply KCL at node B.

$$I_3 + I_5 = I_4$$

$$\frac{V_A - V_B}{2} + 3 = \frac{V_B}{5}$$

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

$$5V_A - 5V_B + 30 = 2V_B$$

$$5V_A - 5V_B - 2V_B = -30$$

$$5V_A - 7V_B = -30 \quad \text{——} \quad (2)$$

Multiply 7 with eq^n (1) & 12 with eq^n (2)

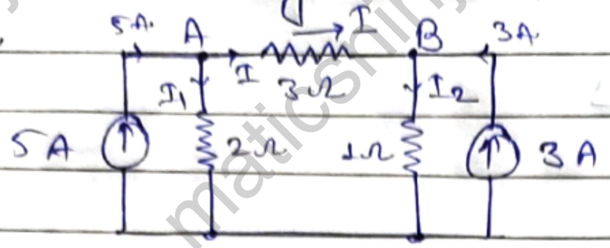
$$182V_A - \cancel{84V_B} = 420$$

$$\underset{(-)}{60V_A} - \underset{(+)}{\cancel{84V_B}} = \underset{(+)}{-360}$$

$$122V_A = 780$$

$$V_A = \frac{780}{122} \qquad \boxed{\therefore V_A = 6.39\,V}$$

(6) Using nodal Analysis, find current I in the given circuit.



Soln: Find V_A & V_B

Apply KCL at node A.

$$I_1 + I = 5$$

$$\frac{V_A}{2} + \frac{V_A - V_B}{3} = 5$$

$$\frac{3V_A + 2V_A - 2V_B}{6} = 5$$

$$3V_A + 2V_A - 2V_B = 30$$

$$5V_A - 2V_B = 30 \quad \text{——— (1)}$$

Apply KCL at node B.

$$I + I_3 = I_2$$

$$\frac{V_A - V_B}{3} + 3 = \frac{V_B}{1}$$

$$\frac{V_A - V_B + 9}{3} = V_B$$

$$3V_B = V_A - V_B + 9$$

$$-9 = V_A - V_B - 3V_B$$

$$-9 = V_A - 4V_B \quad \text{——— (2)}$$

$$\therefore V_A = 4V_B - 9 \quad \text{——— (3)}$$

Substitute eqn (3) in eqn (1)

$$5(4V_B - 9) - 2V_B = 30$$

$$20V_B - 45 - 2V_B = 30$$

$$18V_B = 30 + 45$$

$$18V_B = 75$$

$$V_B = \frac{75}{18}$$

$$\therefore \boxed{V_B = 4.16\,V} \quad \text{——— (4)}$$

Substitute in eqⁿ (3) we get

$V_A = 4(4.16) - 9$

$V_A = 16.64 - 9$

$\therefore \boxed{V_A = 7.64\ V}$

Find: $I = \dfrac{V_A - V_B}{3} = \dfrac{7.64 - 4.16}{3} = 1.16\ A.$

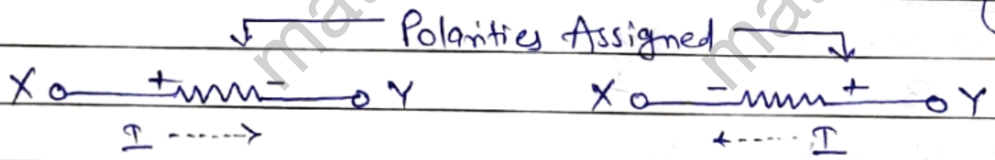
$\boxed{I = 1.16\ A}$

* Mesh or loop & sign Convention :

(1) Mesh or loop (2) Sign Convention (3) Potential rise (4) P. Drop

1) Mesh or loop : It is defined as a set of branches forming a closed path.

2) Sign Convention : The polarities across a resistor depend on the direction of current flowing through it.



- The current always flows from higher potential to lower potential. Hence when current flows from X to Y the terminal X is marked positive & Y is marked with -ve sign.
- As the current flows from Y to X, terminal Y is marked as positive & terminal X is marked as -ve.

3) Potential rise : If we trace the path along a closed loop from the negatively marked terminal to positive terminal of a resistor then the associated potential change is called as potential rise.

4) Potential drop : If we trace the path along the closed loop from the positive marked terminal to negative terminal, then the associated potential change is called as the potential drop.

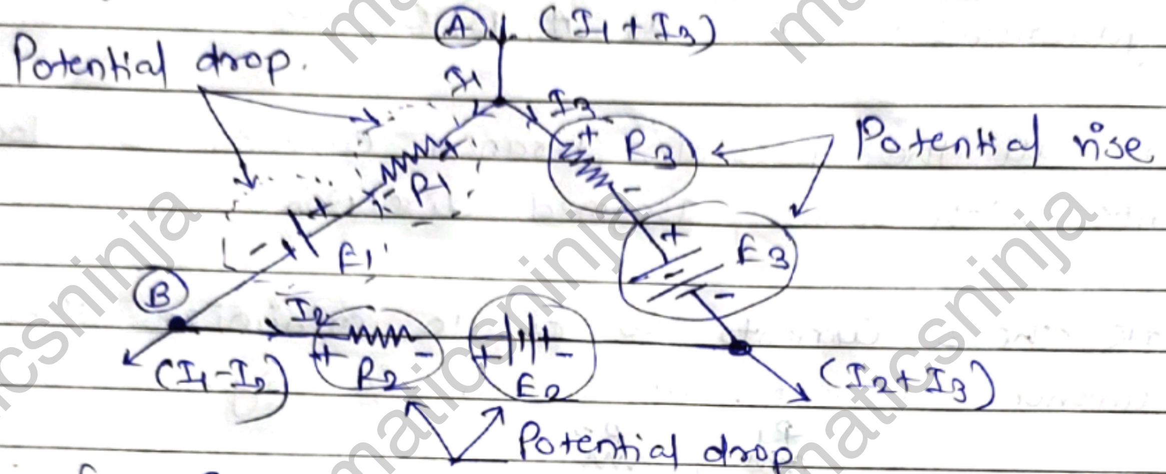


fig. Concept of potential rise & Potential drop.

* Kirchhoff's Voltage Law :
(Mesh or loop Law)

• Statement of KVL :

- The Kirchhoff's voltage Law (KVL) states that the algebric sum of the voltage around a closed loop in a circuit must be equal to zero.

This is mathematically expressed as :

$$\sum_{loop} \text{Voltage across the elements} = 0$$

OR

- The other statement of KVL is that the sum of the voltage rises is equal to the sum of the voltage drops around a closed loop in a circuit.

- KVL is generally used to calculate the unknown current in a circuit.

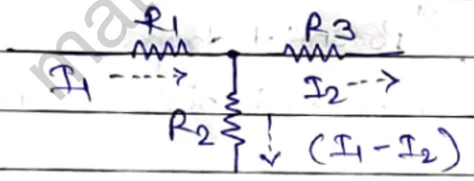
Loop Analysis :

- Steps :

1) Draw the correct circuit diagram & name all the junctions (nodes) as A, B, C, etc.

2) Mark all the possible branch currents or loop currents with some assumed directions.

3) Mark these currents so as to minimize the no. of unknown currents, as shown in fig.



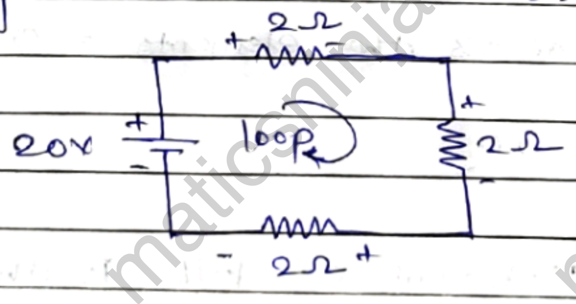
4) Then apply KVL to the various closed paths & write the corresponding simultaneous eqⁿ.

5) Solve these simultaneous eqⁿ & obtain the magnitude & direction of all the unknown currents.

* Numerical :

1) Verify KVL for circuit as shown in fig.

Solⁿ :



- We will prove that the sum of the voltage rises is equal to the sum of the voltage drops.

$$V = IR_1 + IR_2 + IR_3$$

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

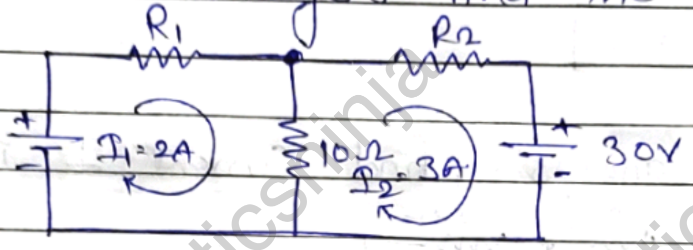
$$I = \frac{V}{R_1 + R_2 + R_3} = \frac{20}{2+2+2} = \frac{20}{6} = 3.33\text{ A}$$

$$V = I \cdot R_T$$
$$20 = 3.33 \times 6$$
$$20 = 20$$

$\therefore$ Potential rise = Potential Drop

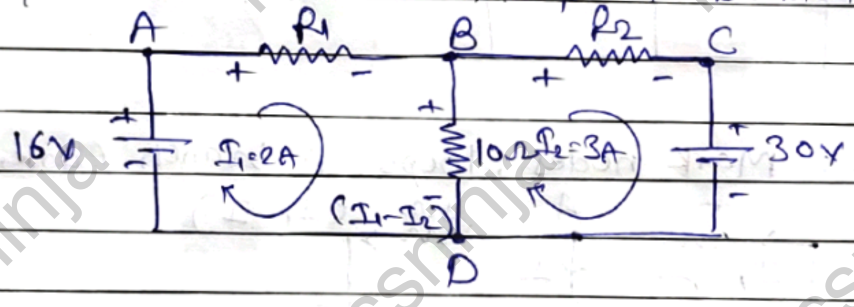
Hence KVL is verified.

2) Using mesh analysis find the values of R_1 & R_2



Soln:

Step 1 : Mark nodes, loops & branch Currents :



Step 2 : Write loop eqn

Loop 1 : ABDA

Applying KVL we get,

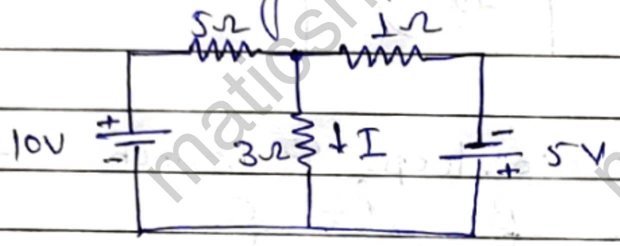
$$-2R_1 - 10(I_1 - I_2) + 16 = 0$$
$$-2R_1 - 10(2-3) + 16 = 0$$
$$-2R_1 - 10(-1) + 16 = 0$$
$$-2R_1 + 10 + 16 = 0$$
$$26 = 2R_1$$
$$R_1 = \frac{26}{2}$$
$$\boxed{R_1 = 13\,\Omega}$$

Loop 2 , BCDB

Applying KVL we get,

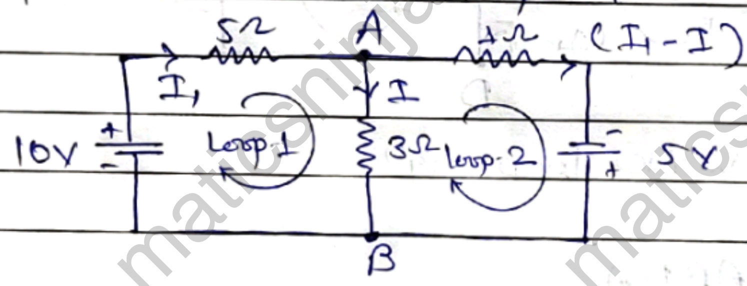
$$-3R_2 - 30 + 10(I_1 - I_2) = 0$$
$$-3R_2 - 30 + 10(2 - 3) = 0$$
$$-3R_2 - 30 + 10(-1) = 0$$
$$-3R_2 - 30 - 10 = 0$$
$$-40 = 3R_2$$
$$R_2 = -\frac{40}{3}$$
$$\boxed{R_2 = -13.33\ \Omega}$$

3) Using Mesh analysis, find Current I in the given Ckt.



Soln :

Step 1 : Mark nodes, loops & branch Current .



Loop - 1 : $5I_1 + 3I = 10$ —— (1)

Loop - 2 : $I_1 - I = 5 + 3I$

$\therefore$ $I_1 - I - 3I = 5$

$I_1 - 4I = 5$ —— (2)

$I_1 = 5 + 4I$ —— (3)

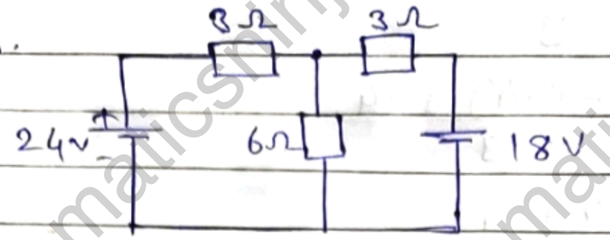
put eqn (3) in eqn (1) we get,

$$5(5 + 4I) + 3I = 10$$
$$25 + 20I + 3I = 10$$
$$23I = 10 - 25$$
$$23I = -15$$
$$I = \frac{-15}{23}$$

$\boxed{I = -0.652\ A}$ (From A to B)

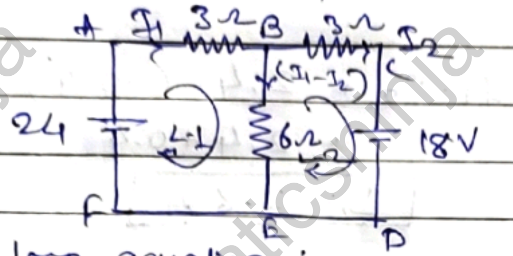
$\boxed{I = 0.652\ A}$ (from B to A)

4) Find the current in 6Ω resistor in the circuit using mesh analysis.



Sol^n :

Step 1 : Mark loops & branch currents :



Step 2 : loop equation :

Loop 1 : ABEFA.

$$3I_1 + 6(I_1 - I_2) = 24$$

$$3I_1 + 6I_1 - 6I_2 = 24$$

$$\therefore\ 9I_1 - 6I_2 = 24 \quad \text{——— ①}$$

$$I_1 = \frac{6I_2 + 24}{9} \quad \text{——— ②}$$

Loop 2 : BCDEB

$$3I_2 + 18 - 6(I_1 - I_2) = 0$$

$$3I_2 + 18 - 6I_1 + 6I_2 = 0$$

$$9I_2 - 6I_1 = -18$$

Multiply by -ve on both side

$$\therefore\ 6I_1 - 9I_2 = 18 \quad \text{—— ③}$$

Put $I_1 = \frac{6I_2 + 24}{9}$ in eq^n ③ we get

$$6\left(\frac{6I_2 + 24}{9}\right) - 9I_2 = 18$$

$$\frac{36I_2 + 144}{9} - 9I_2 = 18$$

$$\frac{36I_2 + 144 - 81I_2}{9} = 18$$

$$36I_2 + 144 - 81I_2 = 162$$

$$-4I_2 = 162 - 144$$

$$I_2 = \frac{18}{-4} \qquad \therefore\ \boxed{I_2 = -0.4\ A}$$

$$I_1 = \frac{6I_2 + 24}{9} \quad , \quad 6$$

$$= \frac{6(-0.4) + 24}{9}$$

$$= \frac{-2.4 + 24}{9}$$

$$\boxed{I_1 = 2.4\ A}$$

$\therefore$ Current through 6Ω is $I_1 - I_2 = 2.4 - (-0.4)$

$$= 2.4 + 0.4$$

$$\boxed{I_2 = 2.8\ A}$$