UNIT-05

D.C. Circuits

Syllabus

- Classification of electrical networks,
- Kirchhoff's law and their applications for network solutions using loop analysis,
- Simplifications of networks using series and parallel combinations and star-delta conversions.
- Energy sources-ideal and practical voltage and current sources.
- Superposition theorem
- Thevenin's theorem

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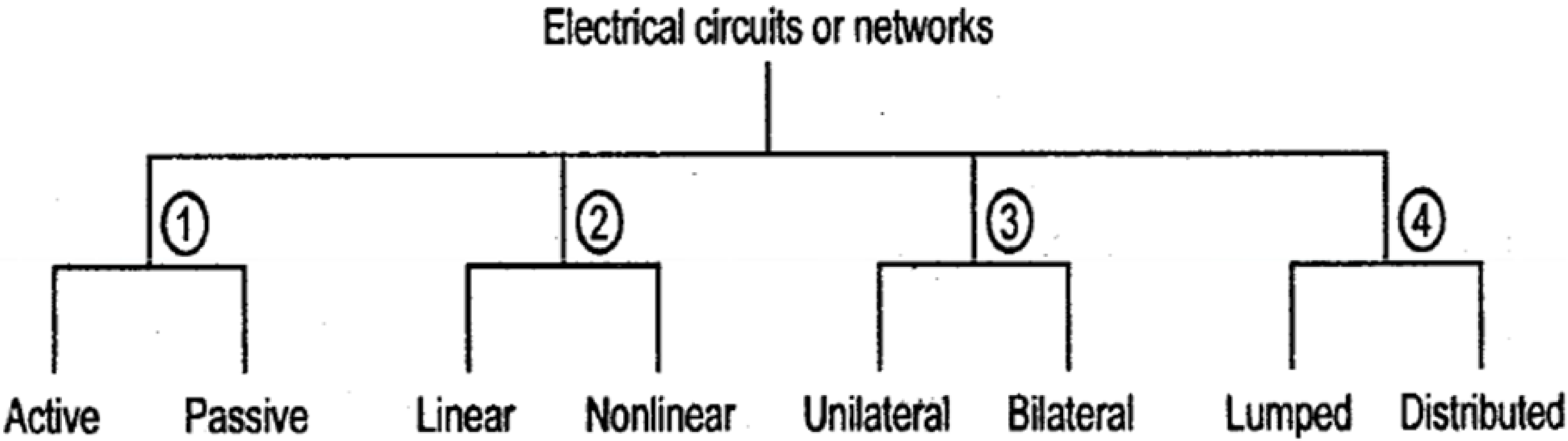
Network Terminology

1. Network:-Any arrangement of the various electrical energy sources along with the different circuit elements is called an electrical network.
2. Network Element:-Any individual circuit element with two terminals which can be connected to other circuit element, is called a network element.
3 Branch:- A Part of the network which connects the various points of the network with one another is called a branch
4. Loop: A loop is a closed path in a circuit.
5. Mesh: A mesh is also a closed path, however, it does not have another closed path within it. Hence, a loop may have one or more meshes within it but a mesh does not have a loop within it.

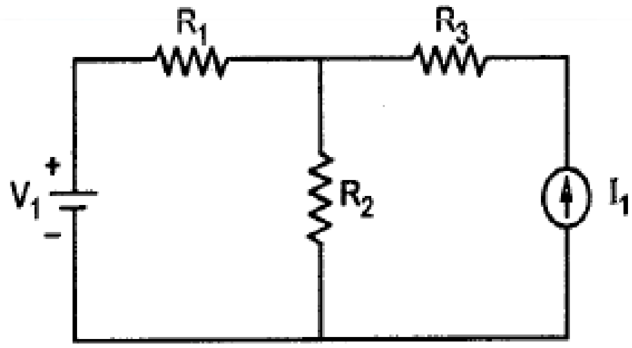
Classification of Electrical Networks



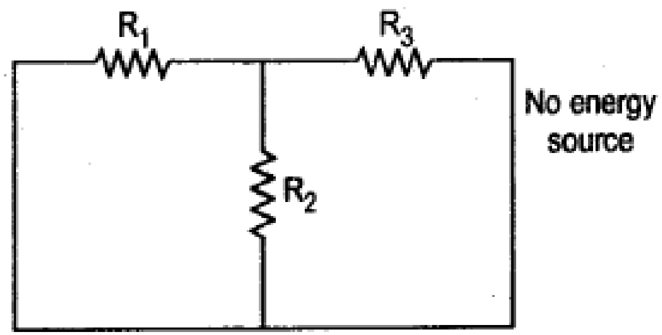
Types of Networks:

i)Active Network : A circuit which contains at least one source of energy is called active. An energy source may be a voltage or current source.

ii) Passive Network : A circuit which contains no energy source is called passive circuit.



(a) Active network



(b) Passive network

iii) A linear circuit: In a linear circuit, the values of elements are always constant i.e., they do not depend on the value of voltage across them or value of current through them.

e.g. circuits containing normal resistors, inductors etc. are liner circuits

iv) A non-linear circuit: In a non-linear circuit, the values of elements may change according to the variation in voltage across them or current flowing through them.

e.g. circuits containing diodes, transistors, non-linear resistances etc. are non-liner circuits

v) Unilateral (Unidirectional) circuit: In a unilateral circuit, the behavior (i.e. the properties) of the circuit as a whole changes when its direction of operation is reversed. E.g. a diode does not conduct when reverse biased and conducts when forward biased.

vi) Bilateral (bi-directional) circuit: In a bilateral circuit, the properties of the circuit as a whole are same in either of the directions. E.g. circuits having normal resistors or inductors behave in same way in either direction.

vii) Lumped Network: A network in which all the network elements are physically separable is known as lumped network

viii) Distributed Network : A network in which the circuit elements like resistance, inductance etc. cannot be physically separable for analysis Purposes, is called Distributed Network.

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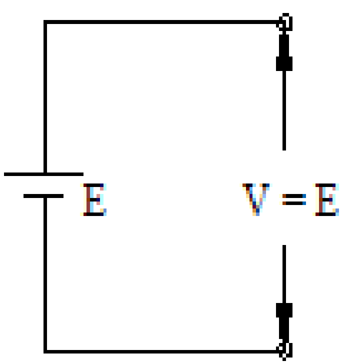
Energy sources (Power sources)

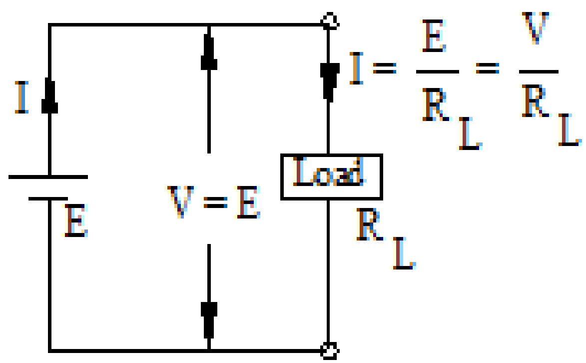
- Independent source: A source, for which the value of the source (either its voltage or current) does not depend on the parameters of the load connected to it, is called as an independent source
- Dependent Source: a source for which the source value depends on the parameters of the load is called as a dependent source.

An ideal voltage source:

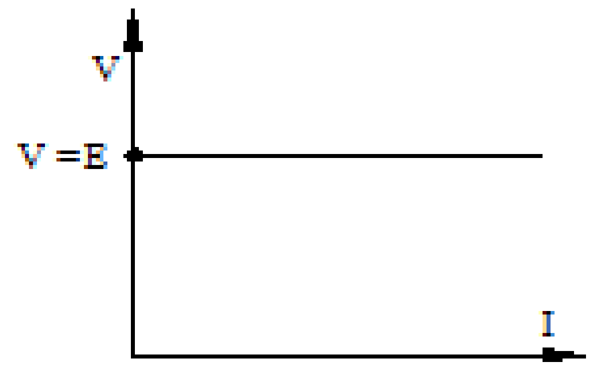
- A source which always maintains a constant voltage (equal to its e.m.f.) across the load terminals, irrespective of current delivered by it, is called as an ideal voltage source.



(Open circuit)

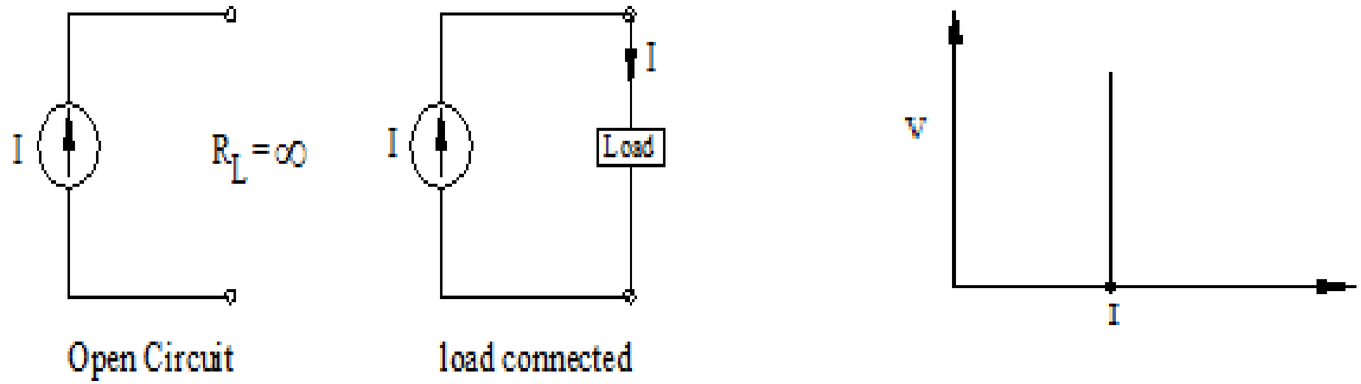


(Load connected)



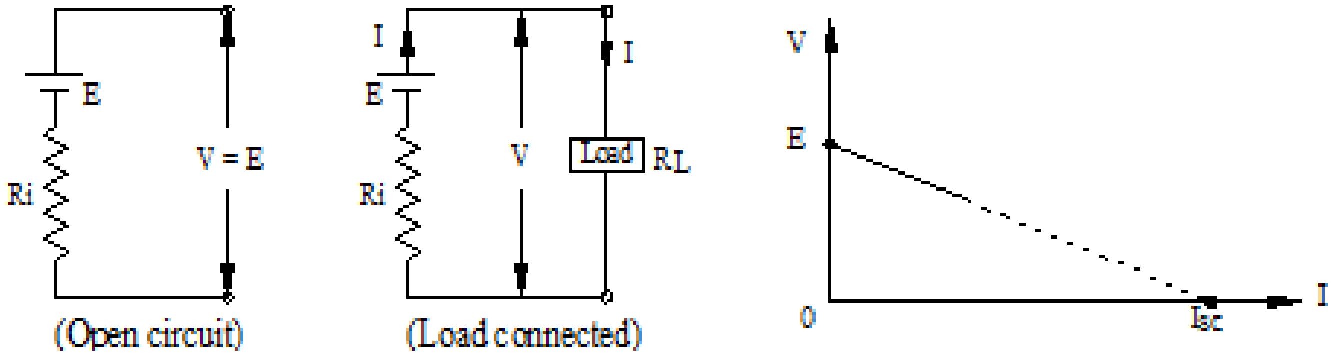
An ideal current source:

- A source which always delivers a constant current (equal to its value) to the load, irrespective of the voltage across its terminals is called as an ideal current source.



A practical voltage source:

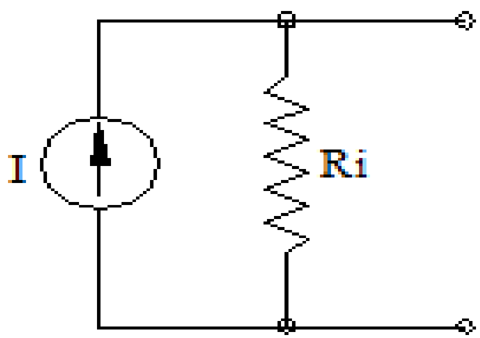
- A practical voltage source is ‘an ideal voltage source in series with its internal resistance (Ri)

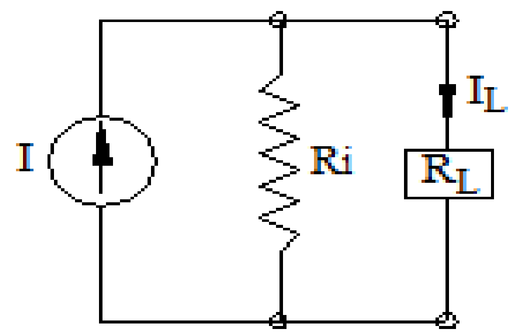


- $I = \dfrac{E}{(R_i + R_L)}$ and, $V = I \times R_L$
- i.e. $E = I\,Ri + I\,R_L = I\,Ri + V$
- i.e. $V = E – I\,Ri$

A practical current source:

- A practical current source is ‘an ideal current source in parallel with its internal resistance (Ri)’.

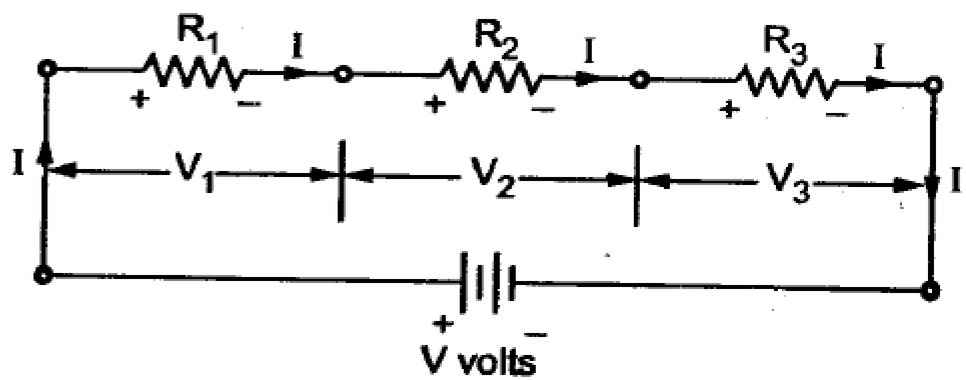




$$I_L = I\left(\frac{R_i}{R_i + R_L}\right)$$

Series circuit

- A series circuit is one in which several resistances are connected one after the other. such connection is also called end to end connection or cascade connection. There is only one path for the flow of current.
- $R_{eq}=R_1+R_2+R_3$



Characteristics of Series Circuits

1) The same current flows through each resistance.
2) The supply voltage V is the sum of the individual voltage drops across the resistances.

   $V = V1 + V2 + \ldots\ldots + Vn$

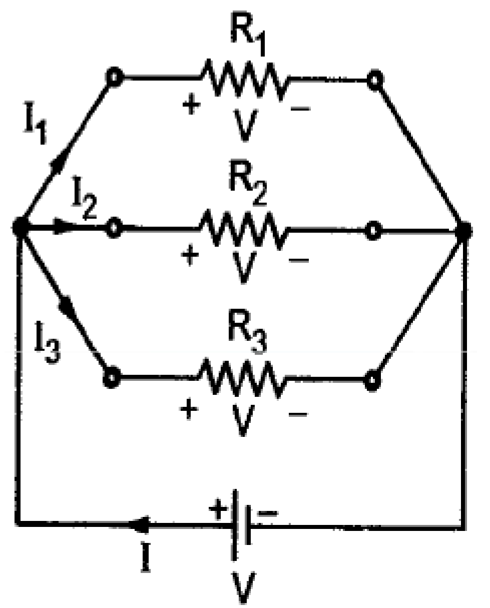
3) The equivalent resistance is equal to the sum of the individual resistances.
4) The equivalent resistance is the largest of all the individual resistances.

   $R > Rr, R > R2, \ldots\ldots R > R1$

Parallel Circuit

- The parallel circuit is one in which several resistances are connected across one another in such a way that one terminal of each is connected to form a junction point while the remaining ends are also joined to form another junction point.

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



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Characteristics of Parallel Circuits

l) The same potential difference gets across all the resistances in parallel

2) The total current gets divided into the number of paths equal to the number of resistances in parallel . The total current is always sum of all the individual currents.

$$I = I1 + I2 + I3 + ... + In$$

3) The reciprocal of the equivalent resistance of a parallel circuit is equal to the sum of the reciprocal of the individual resistances.

4) The equivalent resistance is the smallest of all the resistances.

$$R < R1, R < R2, ..., R < Rn$$

5) The equivalent conductance is the arithmetic addition of the individual conductance.

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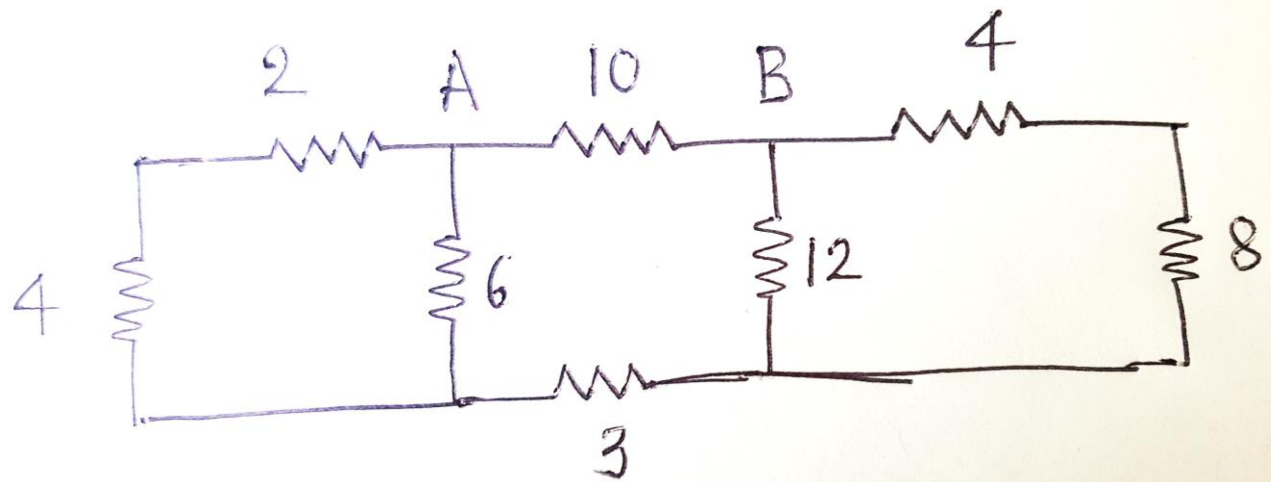
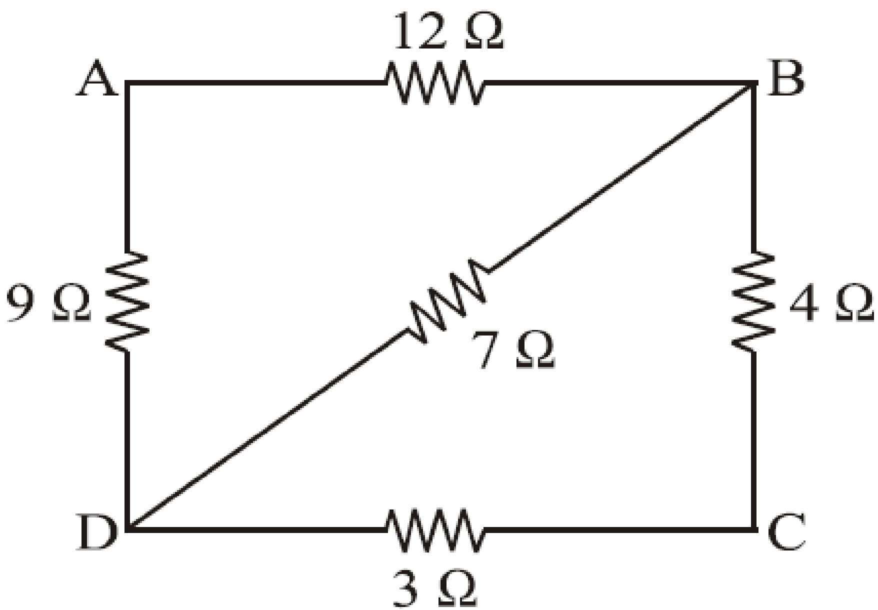
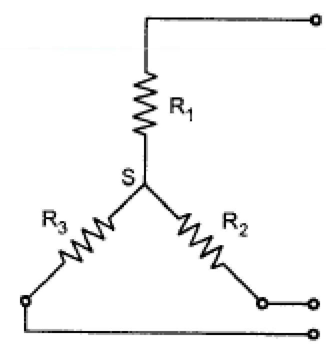


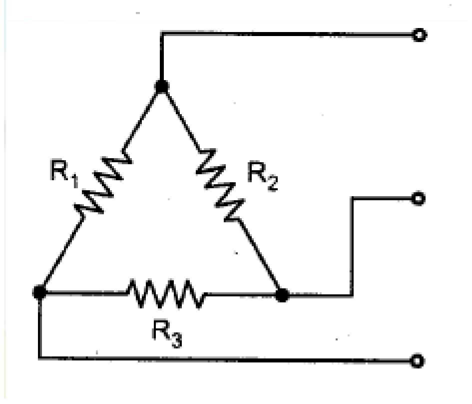


Star and Delta Connection of Resistances

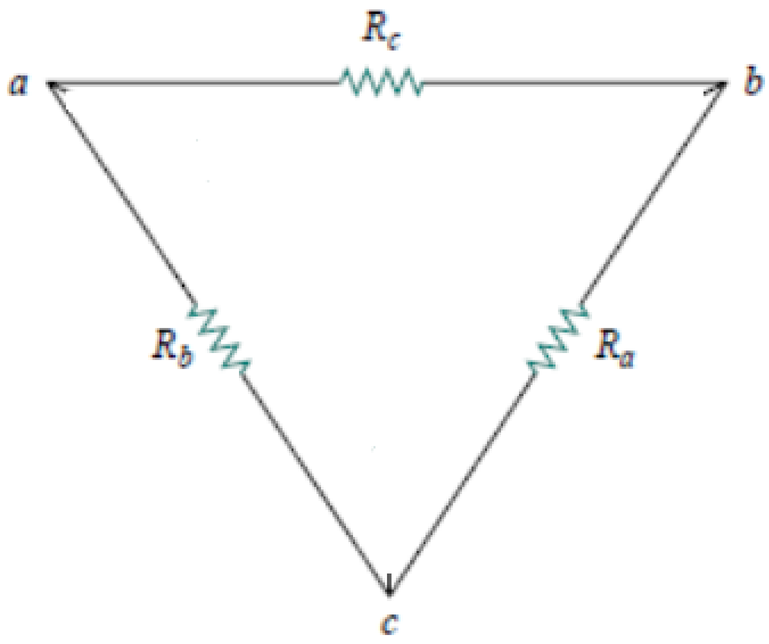
- **Star Connection:-**If the three resistances are connected in such a manner that one end of each is connected together to form a junction point called Star point, the resistances are said to be connected in Star.

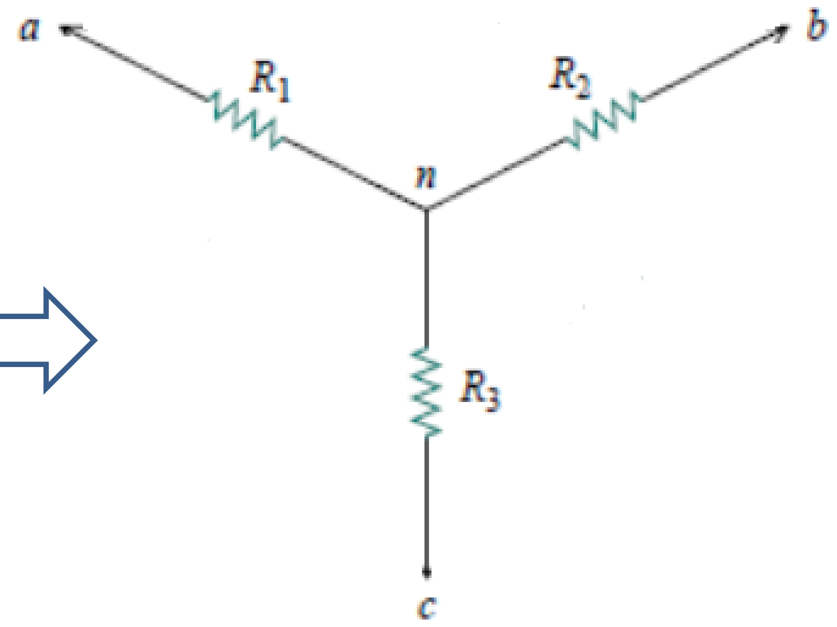


- **Delta Connection:-** If the three resistances are connected in such a manner that the starting terminal of one is connected to finishing terminal of the other. If it complete a loop then the resistances are said to be connected in Delta.



Delta Star Transformation





Resistance between two any two terminals in star is equal to resistance between same two terminals in delta

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$$R_1 + R_2 = \frac{R_c(R_a + R_b)}{R_a + R_b + R_c} -----(1)$$

$$R_2 + R_3 = \frac{R_a(R_b + R_c)}{R_a + R_b + R_c} -----(2)$$

$$R_3 + R_1 = \frac{R_b(R_c + R_a)}{R_a + R_b + R_c} -----(3)$$

$(1) + (3) - (2)$: $$2R_1 = \frac{\cancel{R_a R_c} + R_b R_c + R_b R_c + \cancel{R_a R_b} - \cancel{R_a R_b} - \cancel{R_a R_c}}{R_a + R_b + R_c}$$

$$2R_1 = \frac{2.\,R_b R_c}{R_a + R_b + R_c} \qquad R_1 = \frac{R_b R_c}{R_a + R_b + R_c} -----(4)$$

$(1) - (3) + (2)$ $$R_2 = \frac{R_a R_c}{R_a + R_b + R_c} -----(5)$$

$(2) + (3) - (1)$ $$R_3 = \frac{R_a R_b}{R_a + R_b + R_c} -----(6)$$

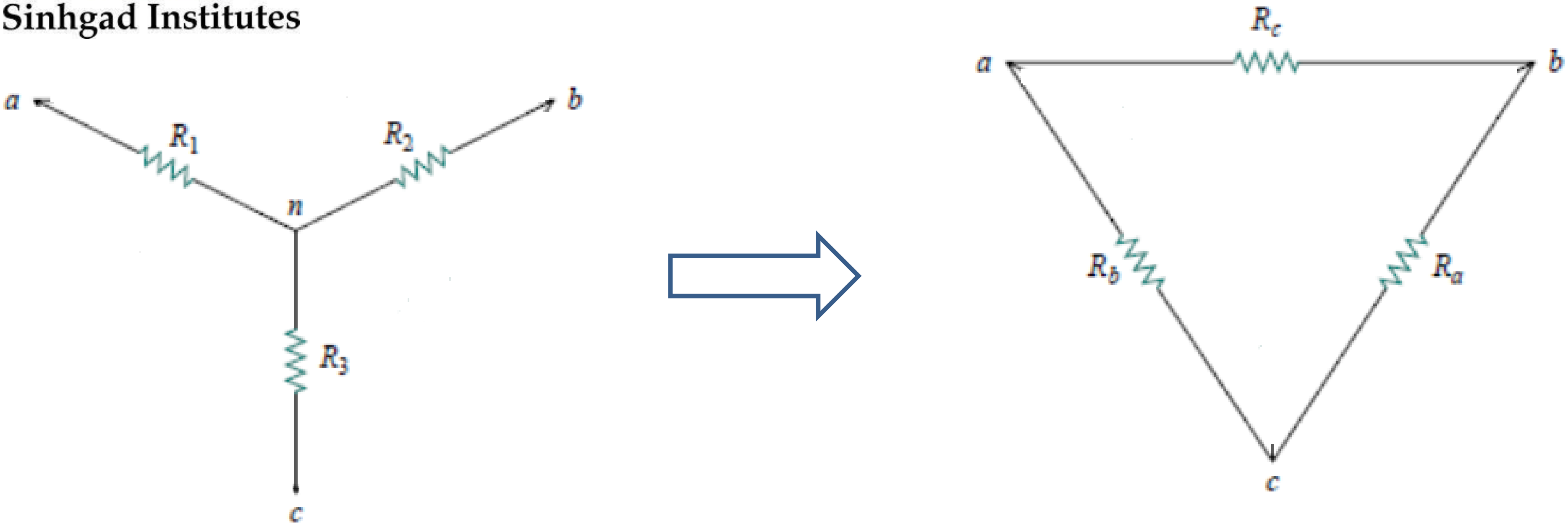
$$R_1 = \frac{R_c R_b}{R_a + R_b + R_c} ----- -(4)$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c} ----- -(5)$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c} ----- -(6)$$

the equivalent star resistance connected to a given terminal is equal to the product of the two delta resistances connected to the same terminal divided by the sum of the delta resistances.

Star-Delta Transformation



$$\frac{(4)}{(5)} \qquad \frac{R_1}{R_2} = \frac{R_b}{R_c} \text{ ------ } (7) \qquad R_b = R_c\,\frac{R_1}{R_2}$$

$$\frac{(4)}{(6)} \qquad \frac{R_1}{R_3} = \frac{R_c}{R_a} \text{ ------ } (8) \qquad R_a = R_c\,\frac{R_3}{R_1}$$

substituting the R_b and R_a *from above in equation* (4)

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$$R_1 = \frac{R_c R_b}{R_a + R_b + R_c}$$

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

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

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

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

the equivalent delta resistance between two terminals is the sum of the two star resistances connected to those terminals plus the product of the same two star resistances divided by the third star resistance.

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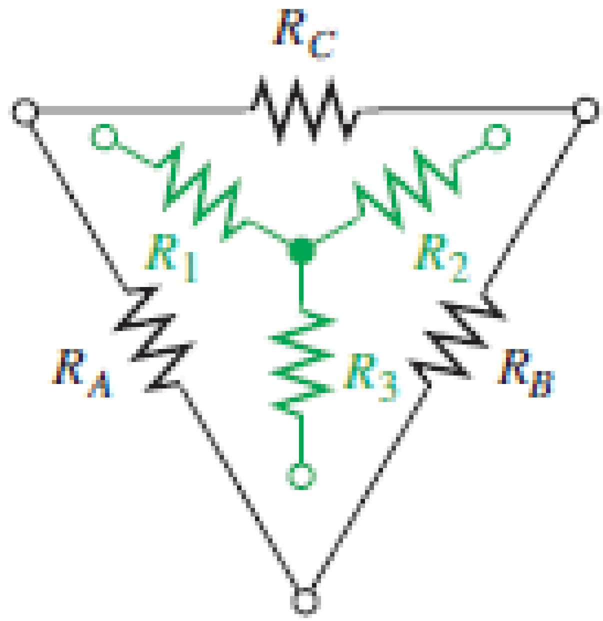

Star to Delta

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

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

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

Delta to Star

$$R_1 = \frac{R_C R_A}{R_A + R_B + R_C}$$

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

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

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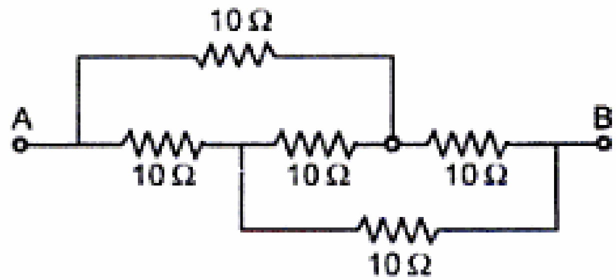
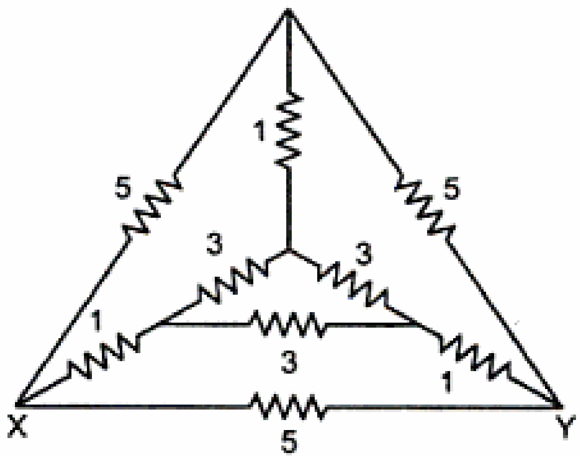
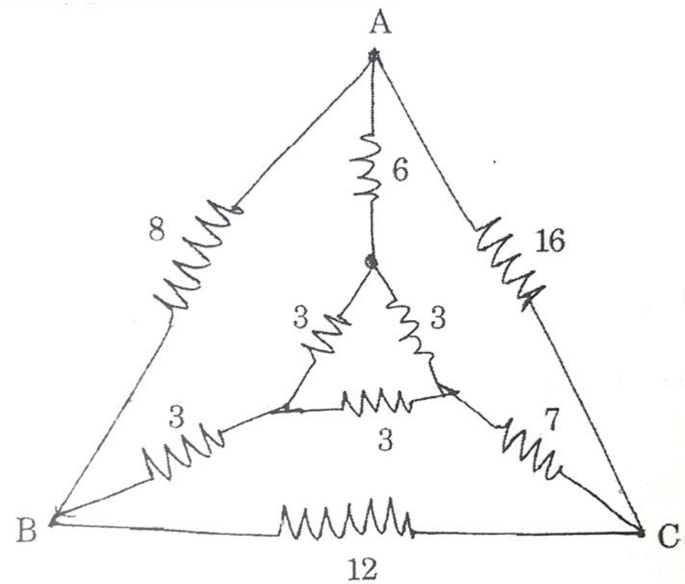
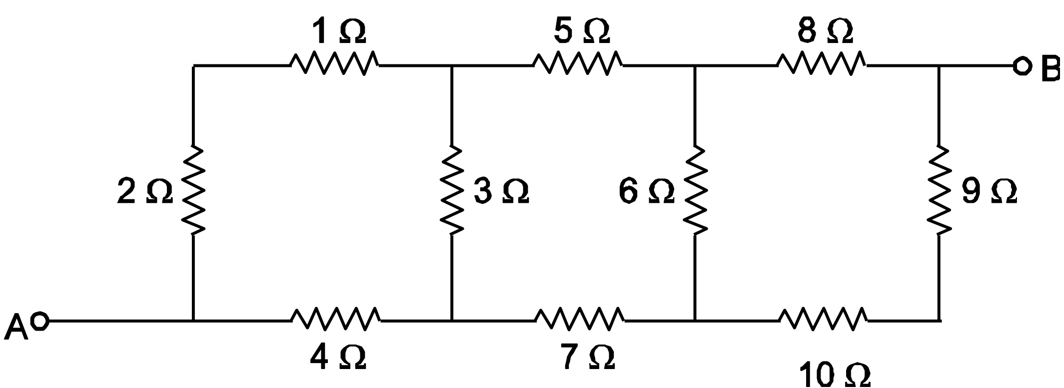




(All resistances in ohm)





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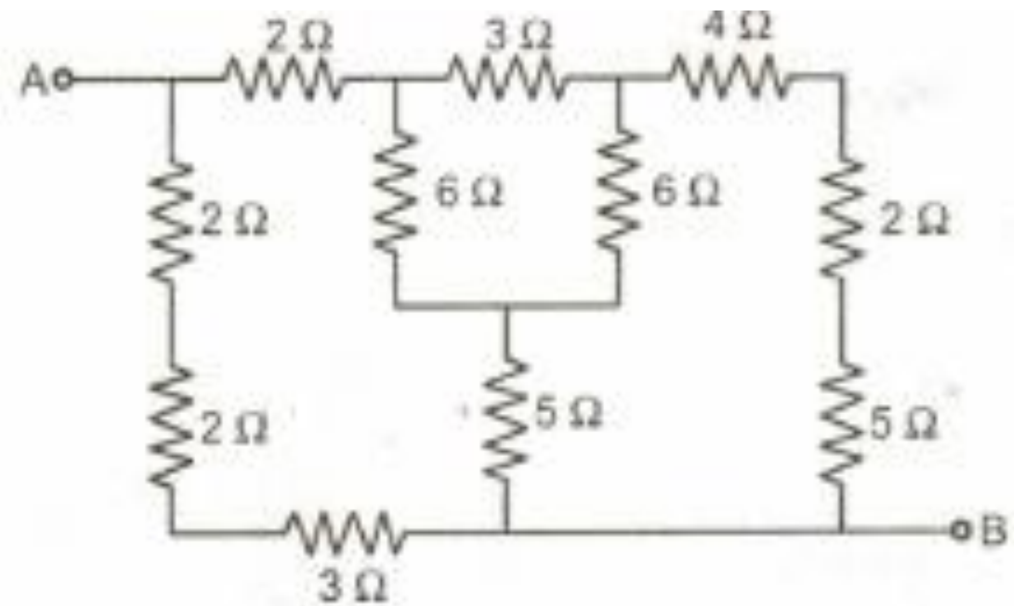
Q: Calculate the effective resistance between points A and B in the given fig.



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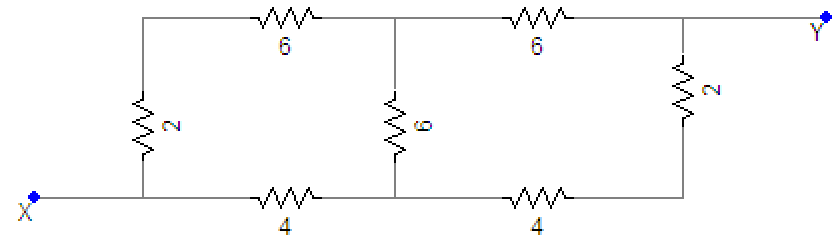
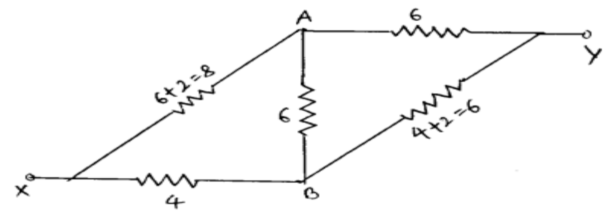
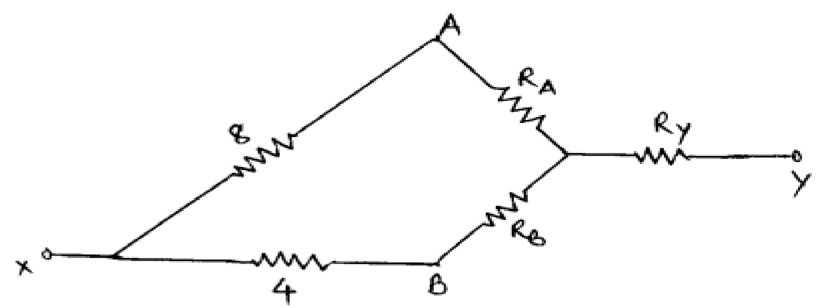
Q. Calculate the resistance between terminals X and Y



6Ω and 2Ω resistances are in series as well as 4Ω and 2Ω resistances are in series The network will be

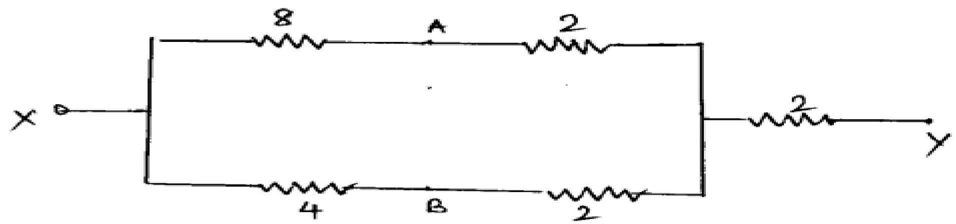


Convert delta connected network ABY into star connected network. The network will be



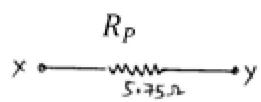
- RA=6X6/(6+6+6)=2Ω=Ry=RB

Resistances RA =2Ωand 8 Ω are in series as well as Resistances RB=2Ω and 4 Ω are in series



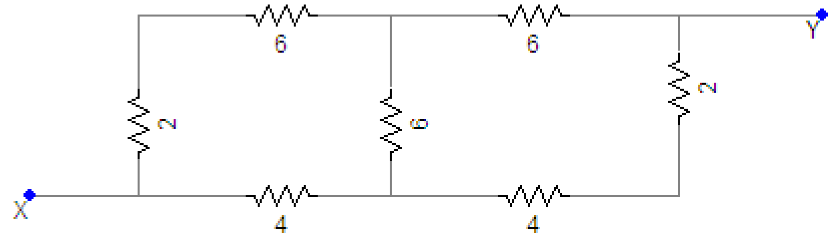
Rp=10X6/(10+6)=3.75 Ω

Resistance   Rp=3.75 Ω and 2 Ω are in series

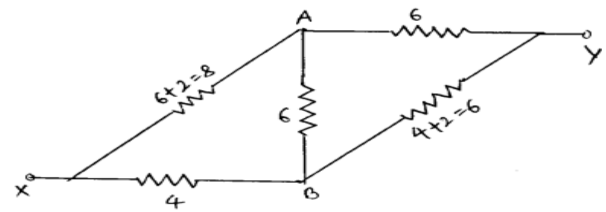


So Equivalent resistance, Req= 3.75+2=5.75 Ω

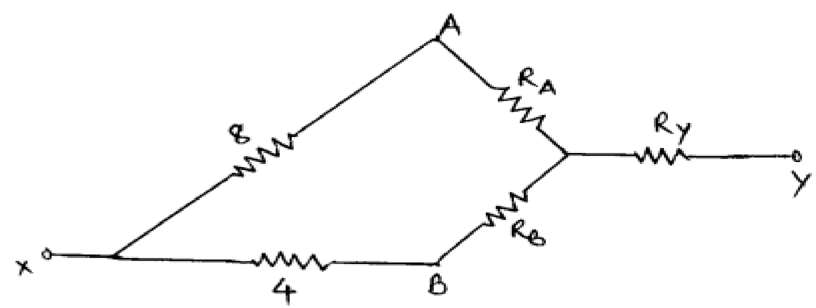
Q. Calculate the resistance between terminals X and Y



6Ω and 2Ω resistances are in series as well as 4Ω and 2Ω resistances are in series The network will be

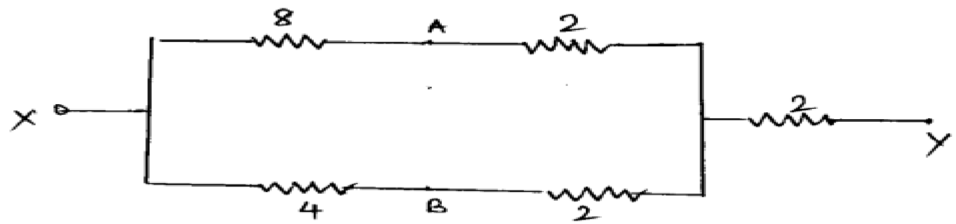


Convert delta connected network ABY into star connected network. The network will be

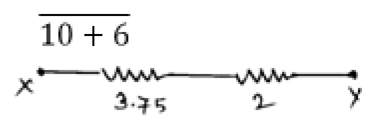


- RA=6X6/(6+6+6)=2Ω=Ry=RB

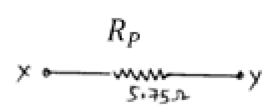
Resistances RA =2Ωand 8 Ω are in series as well as Resistances RB=2Ω and 4 Ω are in series



Rp=10X6/(10+6)=3.75 Ω



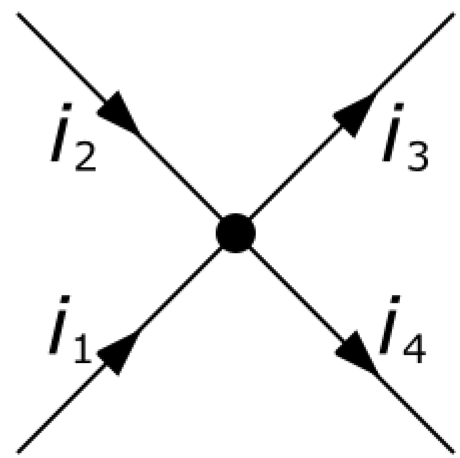
Resistance   Rp=3.75 Ω and 2 Ω are in series



So Equivalent resistance, Req= 3.75+2=5.75 Ω

Kirchhoff's Laws

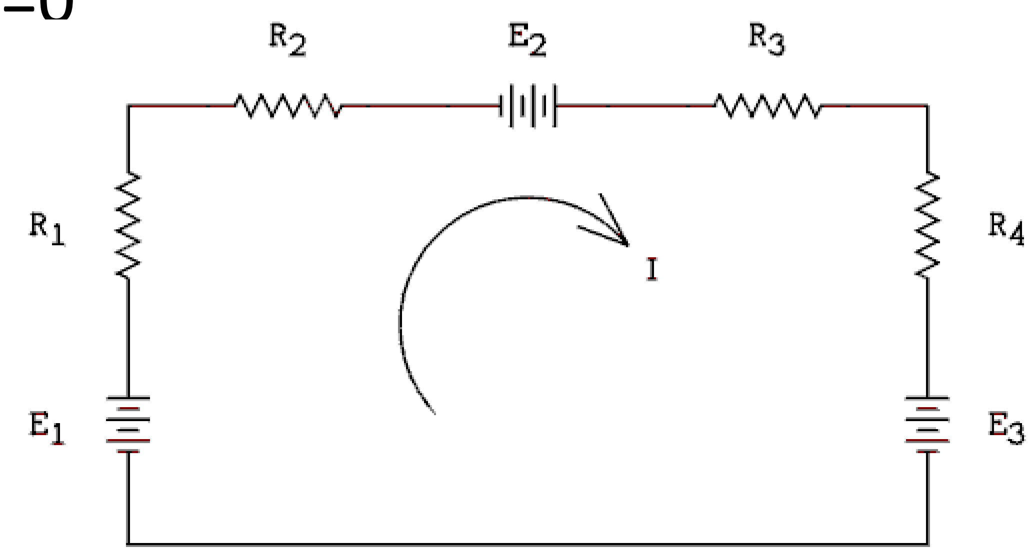
- **Kirchhoff's Current Law (KCL):-** "The total current flowing towards a junction point is equal to the total current flowing away from that junction point". Consider a junction point in a complex network as shown in the Fig.
- $\sum I$ at junction point = 0 ⇨ $I_1+I_2-I_3-I_4 = 0$
- i.e. $I_1+I_2 = I_3 + I_4$



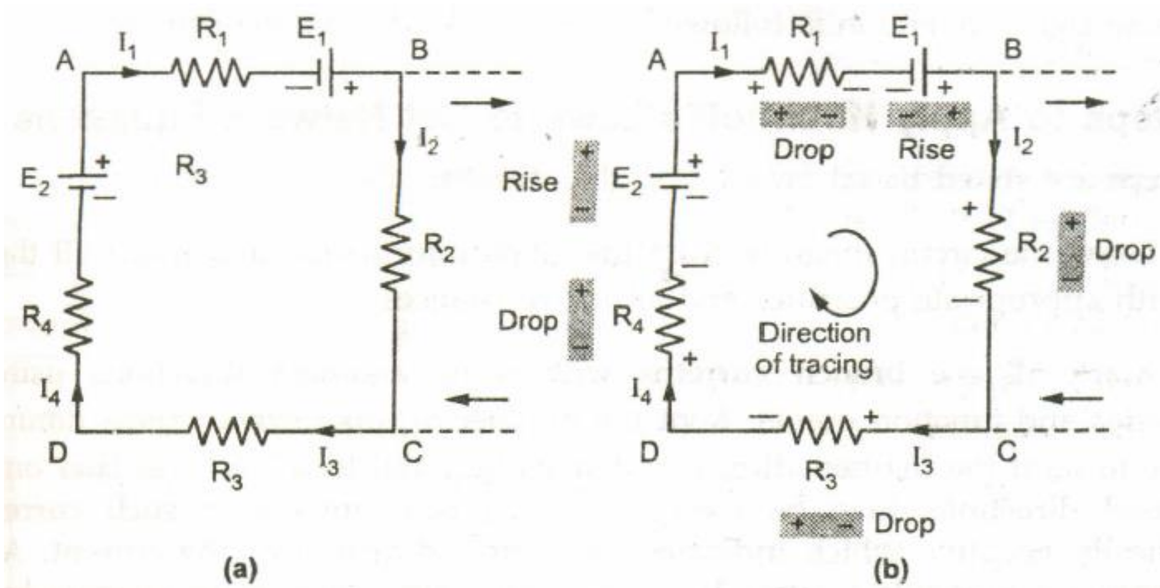
$$i_1+i_2=i_3+i_4$$

- **Kirchhoff’s Voltage Law (KVL):-** "If any network the algebraic sum of the voltage drops across the circuit elements of any closed path (or loop or mesh) is equal to the algebraic sum of the e.m.f s in the path“
- Around a closed path $\sum E = 0$
- $E_1 - IR_1 - IR_2 + E_2 - IR_3 - IR_4 - E_3 = 0$
- $IR_1 + IR_2 + IR_3 + IR_4$

  $= E_1 + E_2 - E_3$



Loop Analysis

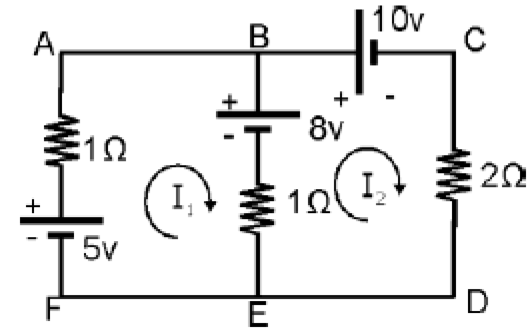


- We can write an equation by using KVL around this closed path as,

  -I1 R1+ E1- I2R2- I3R3- I4R4 +E2 = 0

  i.e. E1 +E2 = 11 R1 +I2R2 +I3R3 +I4R4

Q. Find applying Kirchhoff's Laws currents in three voltage sources in the network



Solution:

Current supplied by 5 V source is I1Amp

Current supplies by 8 V source is (I1 – I2) Amp

Current supplied by 10 V source is I2 Amp

Applying Kirchhoff's voltage law for loop ABEFA

$2\ I1 - I2 = 5 - 8,\ 2\ I1 - I2 = -3$ ...(I)

for loop BCDEB

$-\ I1 + 3I2 = 8 - 10,\ I1 - 3I2 = -\ 2$ ...(II)

multiplying equation (II) by (– 2)

$2I1 - I2 = -\ 3 - 2I1 + 6I2 = -\ 4$

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$5I2 = -7$

$I2 = -75 = -1.4$ Amp Putting $I2 = -1.4$ Amp in equation (I)

$2I1 + 1.4 = -3$, $2I1 = -3 - 1.4 = -4.4$

$I1 = -4.42 = -2.2$ Amp

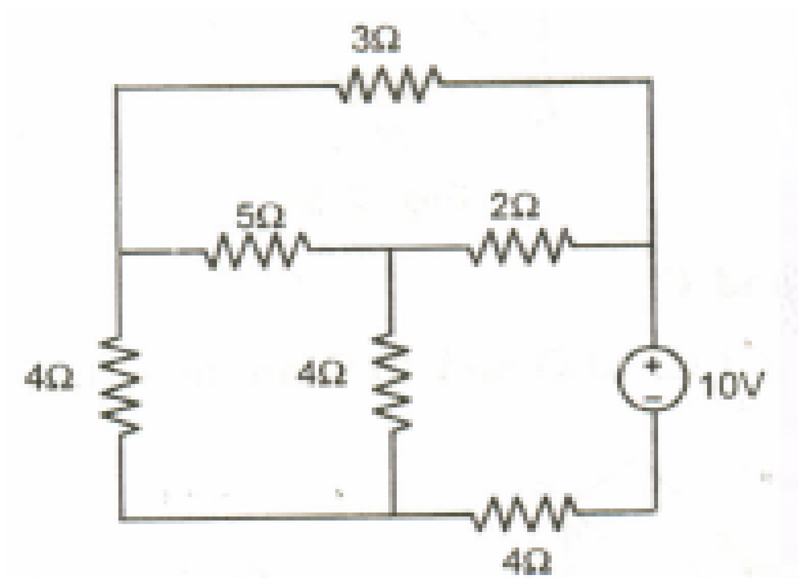
$I1 - I2 = -2.2 - (-1.4) = -0.8$ Amp

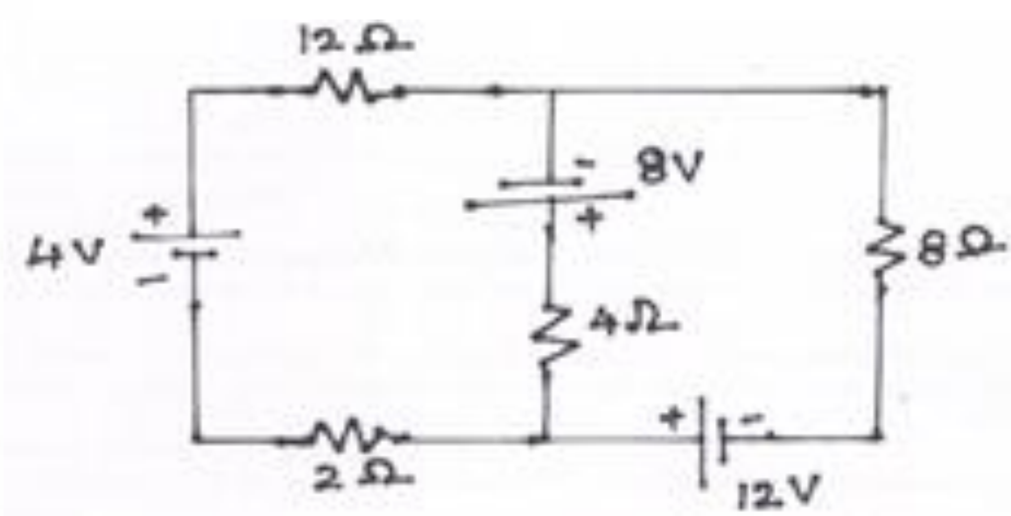
$I1 = -2.2$ Amp (Current flows in opposite direction)

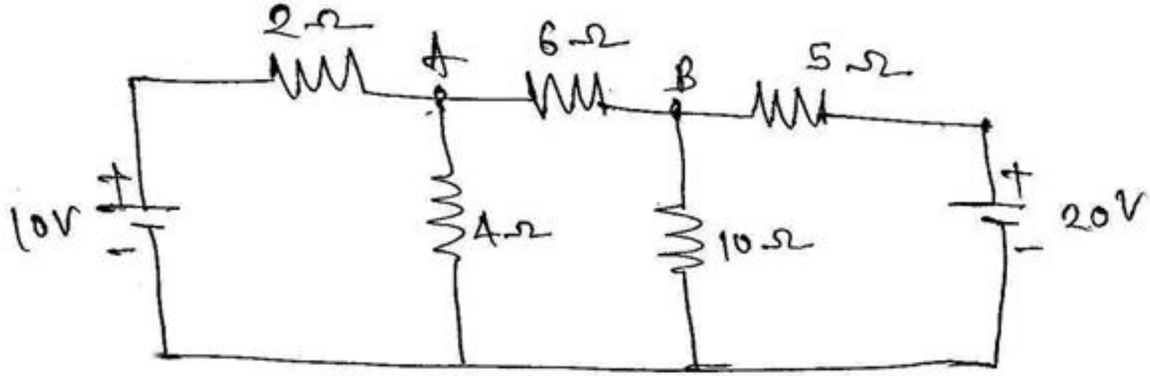
$I2 = -1.4$ Amp(Current flows in opposite direction)

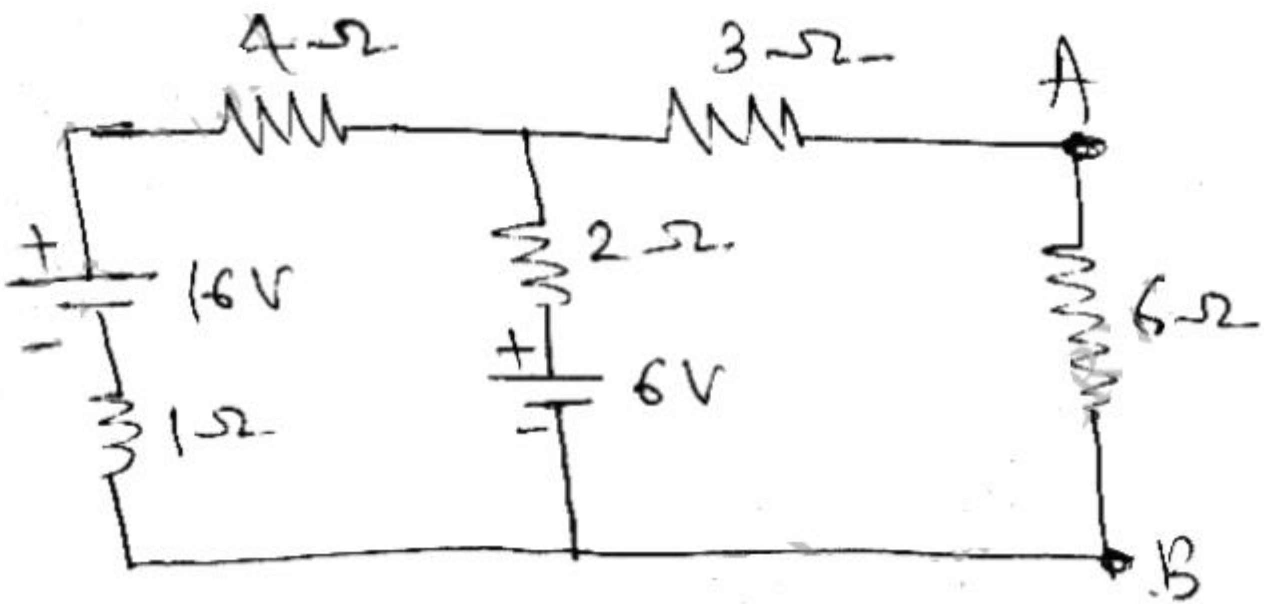
$I1 - I2 = -0.8$ Amp (Current flows in opposite direction

Q: Using Kirchhoff's voltage law, find the current delivered by the battery shown in Fig.






2Ω
A
6Ω
B
5Ω
10V
4Ω
10Ω
20V


4Ω
3Ω
A
16V
2Ω
6V
1Ω
6Ω
B

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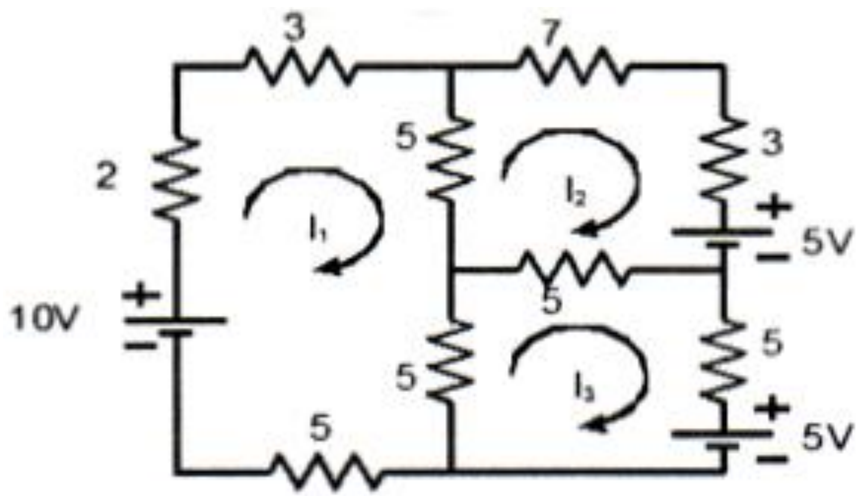
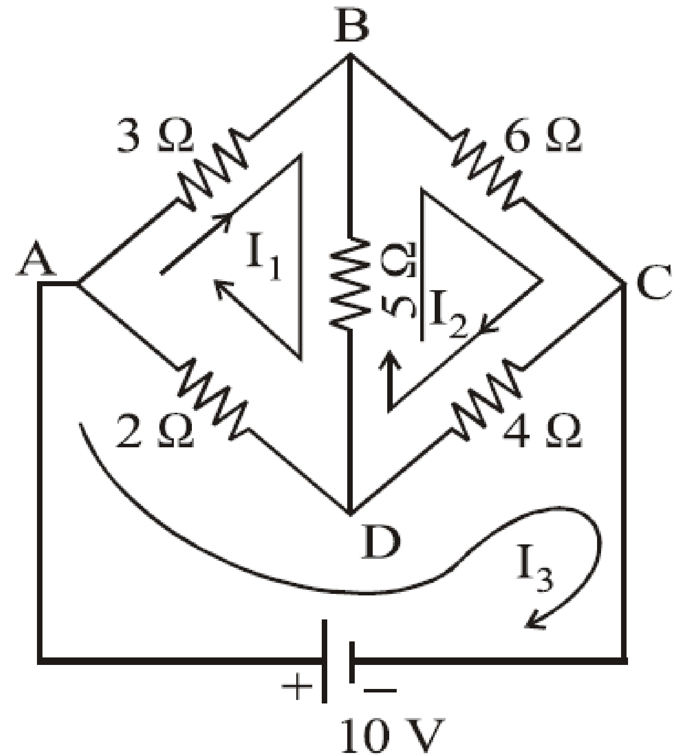
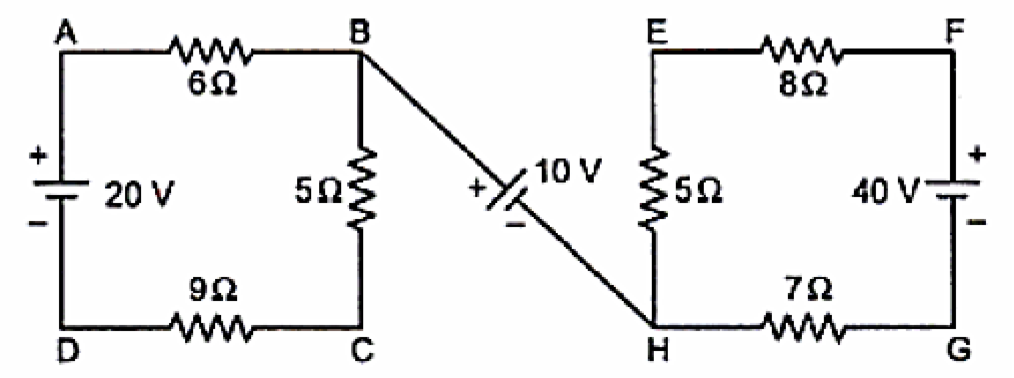
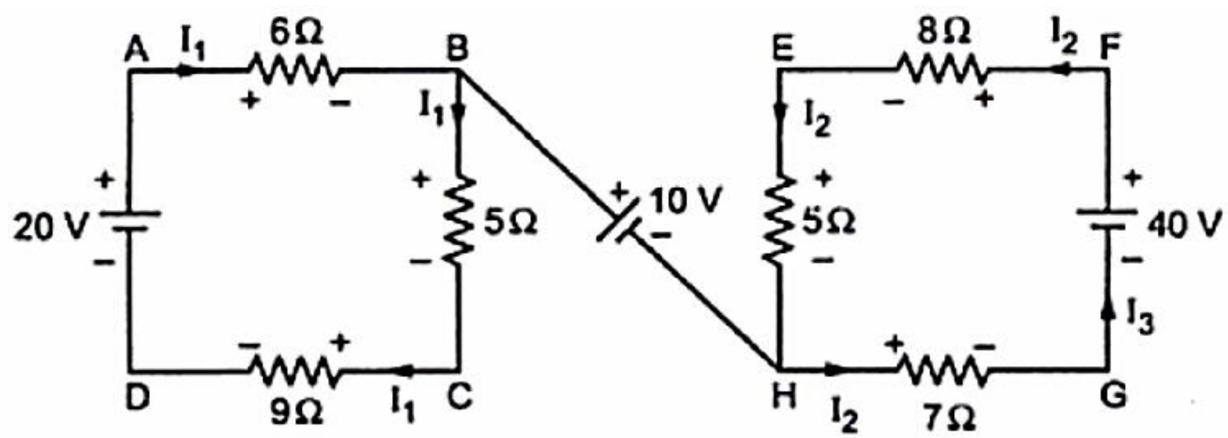




Find the voltages V_{AG} and V_{CE} for the circuit given



Solution:



$$\boldsymbol{I_1} = 1A$$

$$\boldsymbol{I_2} = 2A$$

$$\boldsymbol{V_{AG} = 30V}$$

$$\boldsymbol{V_{CE} = -5V}$$

Superposition Theorem:

- Statement:

  In a linear circuit consisting of two or more independent energy sources, the current through a particular branch or element is equal to sum of all such currents which would flow through that branch or element, when each source is assumed to act in the circuit at a time while replacing all other sources by their internal resistances, if any.

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Explanation

Step 1: Consider a circuit as shown.

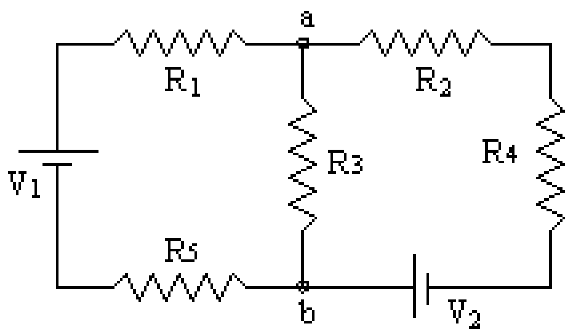

Fig.1

Let us assume that, the sources V_1 and V_2 have internal resistances of $Ri_{(1)}$ and $Ri_{(2)}$ respectively. Let us find current flowing through resistor R_3.

Step 2: Considering the source V_1 acting alone in the circuit, the other source (i.e. V_2) is replaced by its internal resistance as shown. By using Kirchhoff's laws or other methods, the current through R_3 is calculated. Let us assume that the current is (I_1) and flows from 'a' to 'b'.

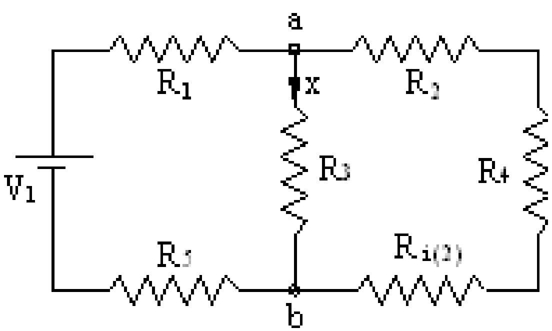

Fig. 2

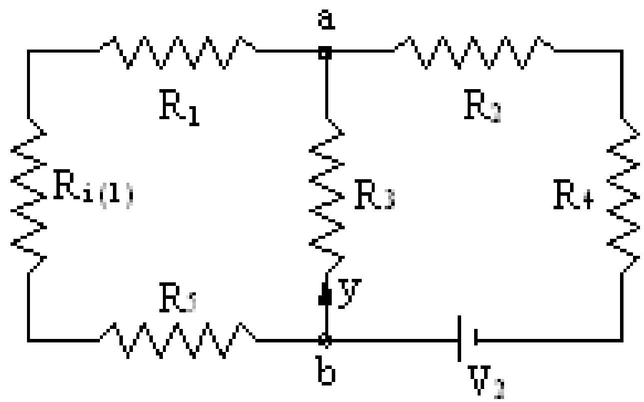

Fig. 3

Step 3: Now considering the source V_2 acting alone in the circuit, the other source, (i.e., V_1) is replaced by its internal resistance. Let us assume that, under this situation the current in R_3 is (I_2) flowing from ‘b’ to ‘a’.Hence, net current flowing through R_3 in the circuit will be ($I_1 - I_2$) flowing from ‘a’ to ‘b’ [or ($I_2 - I_1$) flowing from ‘b’ to ‘a’].

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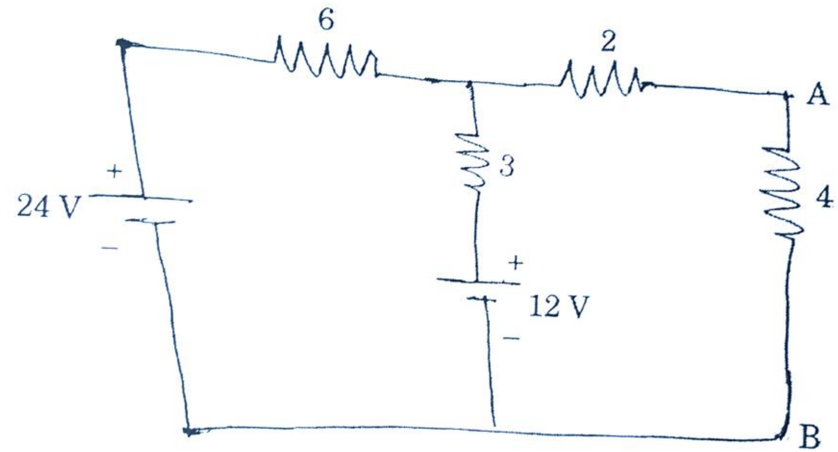

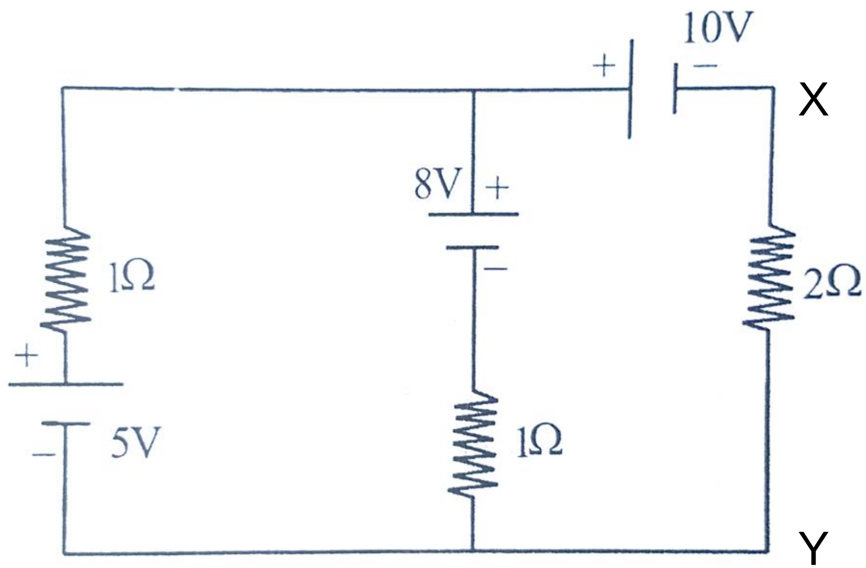

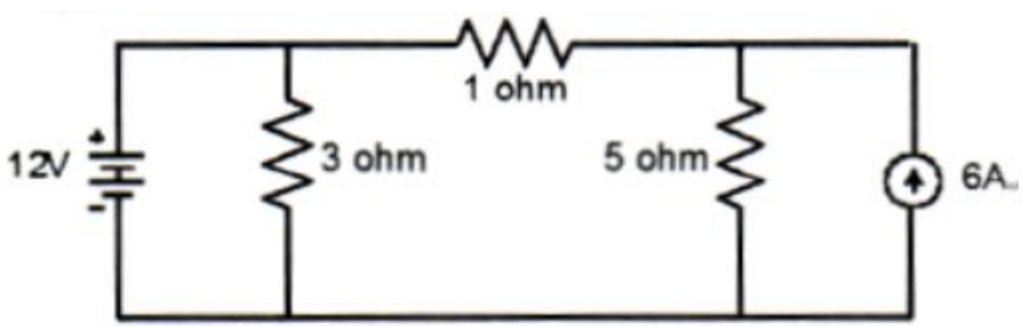

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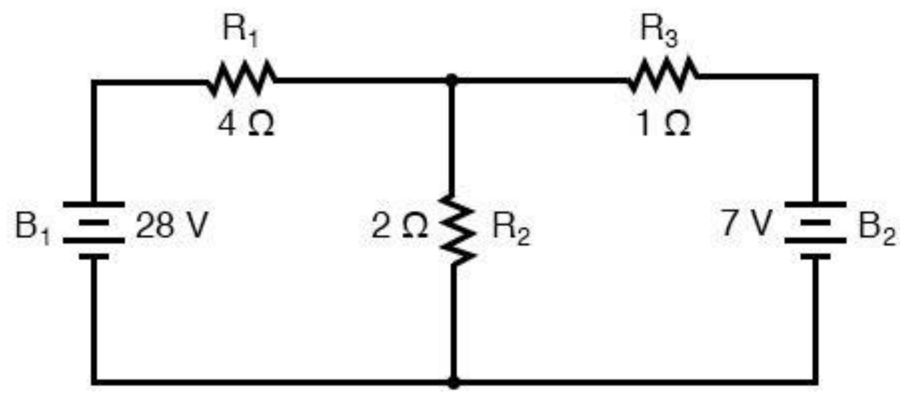
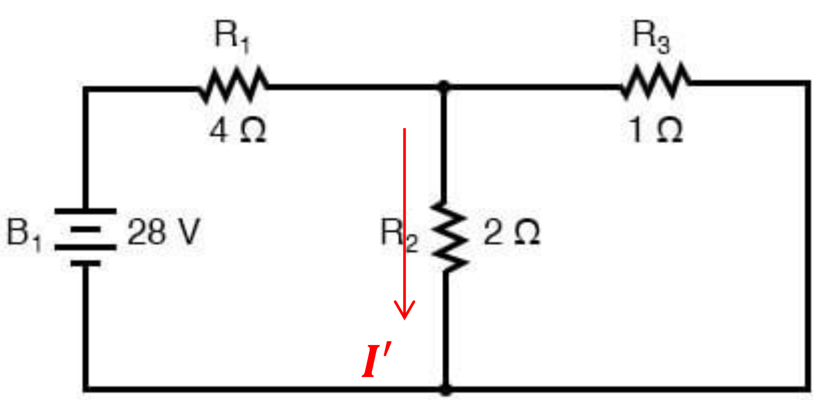
Q: Find the current through the 2 ohm resistance shown in the Figure by Using Superposition theorem.



Step 1



$$I = \frac{28}{[4 + (2||1)]} = 6A$$

$$I' = 6 \times \frac{1}{(1+2)} = 2A$$

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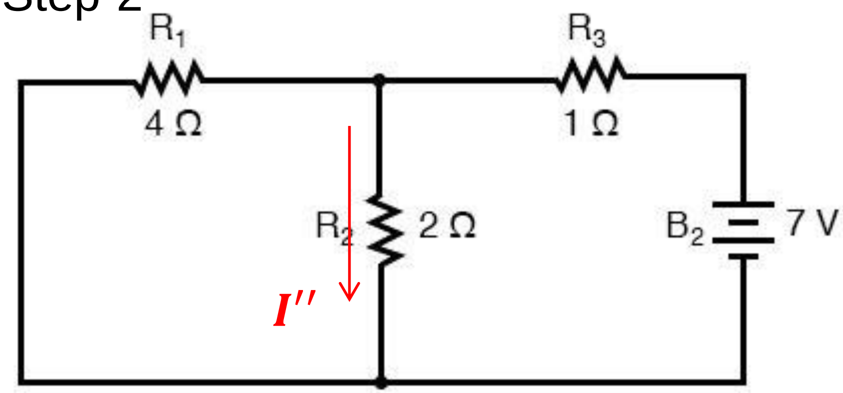
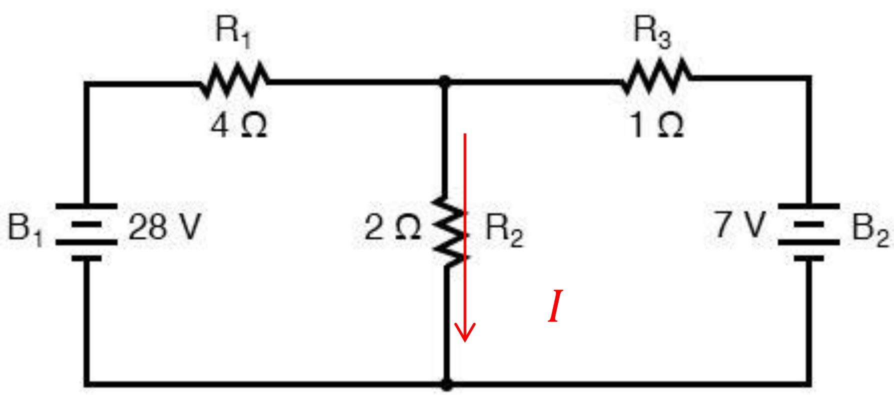
Step-2



$$I = \frac{7}{[1 + (4||2)]} = 3A$$

$$I'' = 3 \times \frac{4}{(4+2)} = 2A$$



$$\boldsymbol{I = I' + I'' = 2 + 2 = 4A}$$

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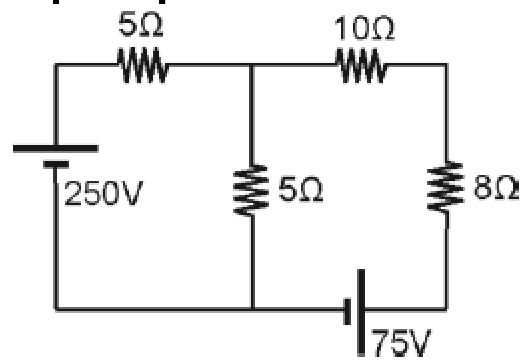
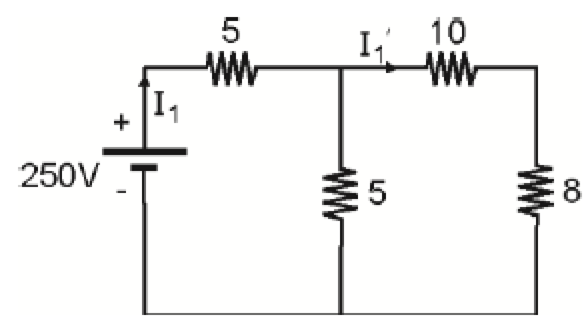
Q. Calculate current flowing in 8 Ohm resistance for the circuit shown in Fig. applying superposition theorem.



Step I : only 250 V source acting alone

- 10 + 8 =18 and 18||5=18X5/(18+5) = 3.91Ω
- R total = 5 + 3.91 = 8.91Ω
- I1= 250/8.91 = 28.06A
- I2’=28.06X5/(18 + 5) = 6.10 A ↓



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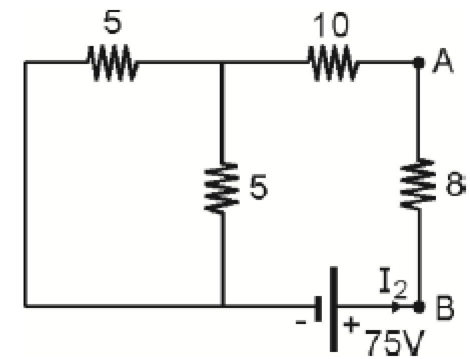
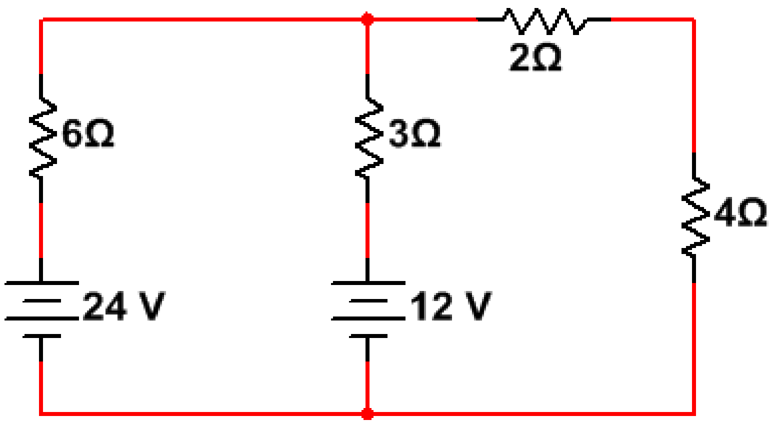
- **Step II : only 75 V source acting alone**
- 5||5 = 5X5/(5+5) = 2.5Ω
- Total Resistance = 10 + 8 + 2.5= 20.5Ω
- I2 = 75/20.5 = 3.66 A ↑ (Form B to A)

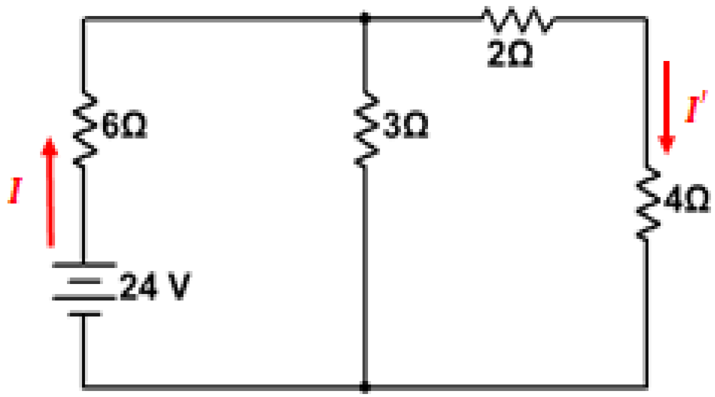


- **Step III : The resultant current flowing 8 resistance**
- I =I’1 ↓ – I2 ↑ = 6.10 – 3.66 =2.44 ↓ (from A to B)

Find the Current flowing in 4 ohm resistance by superposition Theorem.



Solution : **STEP -1** Consider 24V source alone by removing 12V source



To find the current in $4\ \Omega$ resistance we have to find the current driven by the source.

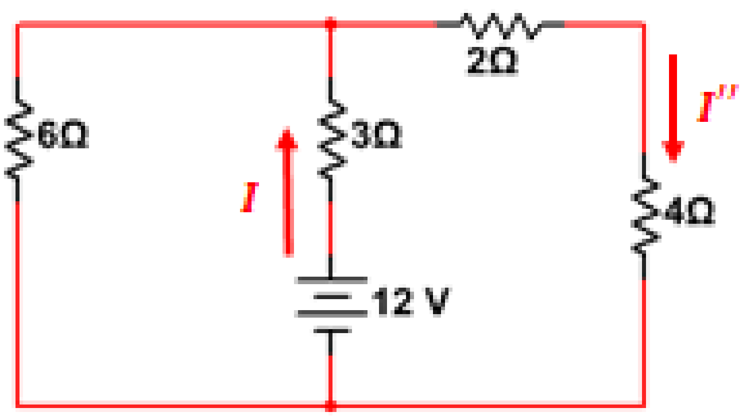
$$R_T = 6 + (\,3 \| (2+4))$$

$$R_T = 6 + \frac{3 \times 6}{(3+6)} = 8$$

$$I = \frac{24}{8} = 3\ A$$

$$I' = 3\ \times \frac{3}{3+6} = 1.0\ A\ \downarrow$$

STEP -2 Consider 12 V source alone by removing 24V source



To find the current I'' in 4 Ω resistance we have to find the current driven by the source.

Total resistance across battery terminals

$$R_T = 3 + (\ 6 \| (2+4)) = 6\ \Omega$$

$$I = \frac{12}{6} = 2\ A$$

$$I'' = 2\ \times \frac{6}{6+6} = 1.0A\ \downarrow$$

STEP -3 If both the sources present simultaneously in the network then

current flowing in the $4\ \Omega$ by superposition theorem is

$$I = I' + I'' = 1.0 + 1.0 = \mathbf{2.0}\ \ A\ \downarrow$$

THEVENIN'S THEOREM

Statement:

Any linear, two port circuit consisting of (Active sources) voltage sources and resistances can be replaced by a simple two terminal network -

1. Consisting of a single voltage source of V_{TH} volts and a single resistance Req in series with the voltage source across the two terminals of the load R_L.

2. The voltage V_{TH} is the open circuit voltage, with load resistance R_L removed. This voltage is also called Thevenin's equivalent voltage. The Req is the equivalent resistance of the given network as viewed through the terminals where R_L is connected, but with R_L removed and all the active sources are replaced by their internal resistances.

EXPLANATION OF THEVENIN'S THEOREM

The concept of Thevenin's equivalent across the terminals of interest can be explained by considering the circuit shown in the Fig. (a).The terminals A-B are the terminals of interest across which RL is connected. Then Thevenin's equivalent across the load terminals A-B can be obtained as shown in the Fig.(b).

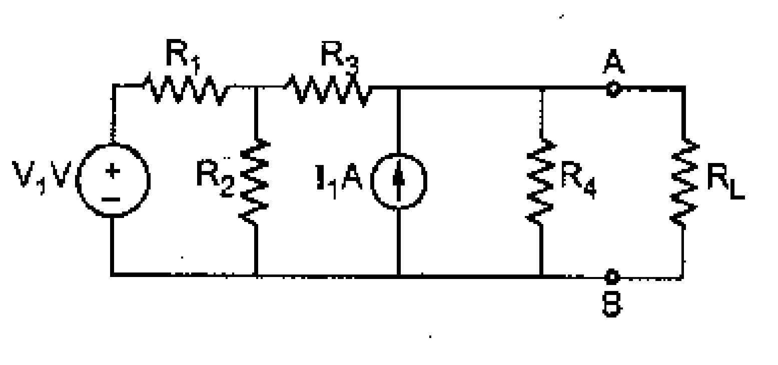


Fig a

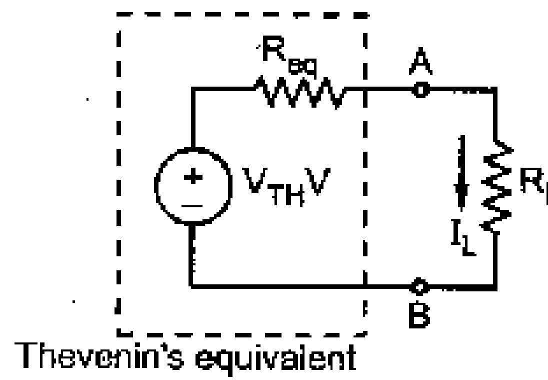
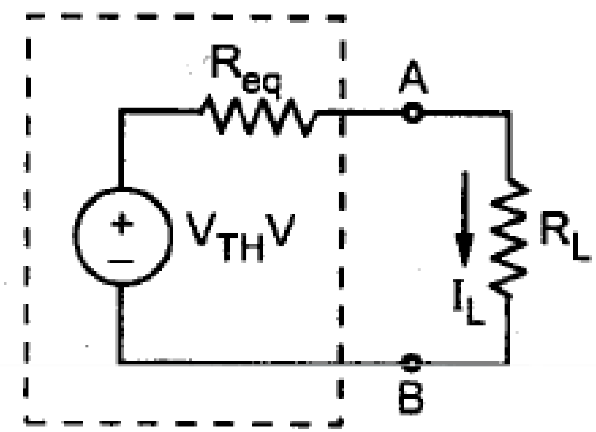


Fig b

When the circuit is replaced by Thevenin's equivalent across the load resistance, then the load current can be obtained as,

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



Thevenin's equivalent

STEPS TO APPLY THEVENIN'S THEOREM

Step 1 : Remove the branch resistance through which current is to be calculated.

Step 2 : Calculate the voltage across these open circuited terminals, By using any of the network simplification techniques. This is V_{TH}.

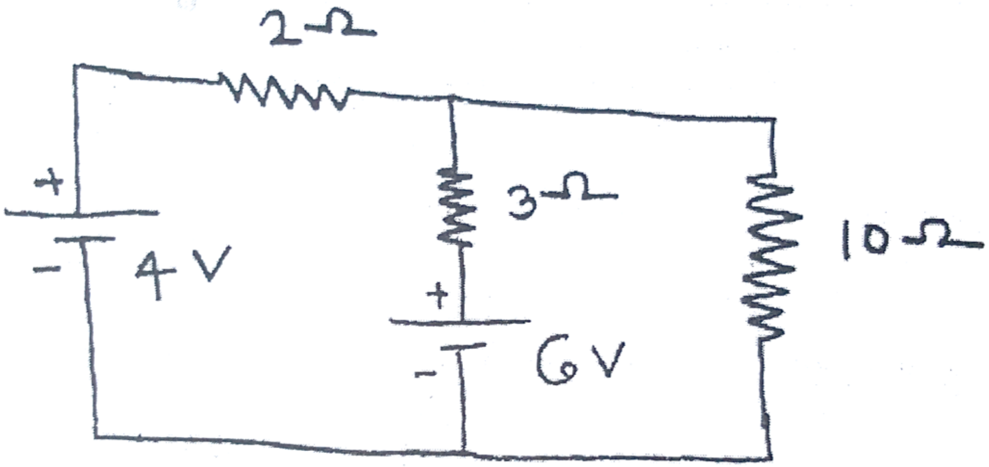
Step 3 : Calculate Req as viewed through the two terminals of the branch voltage sources by short circuits and current sources by open circuits.

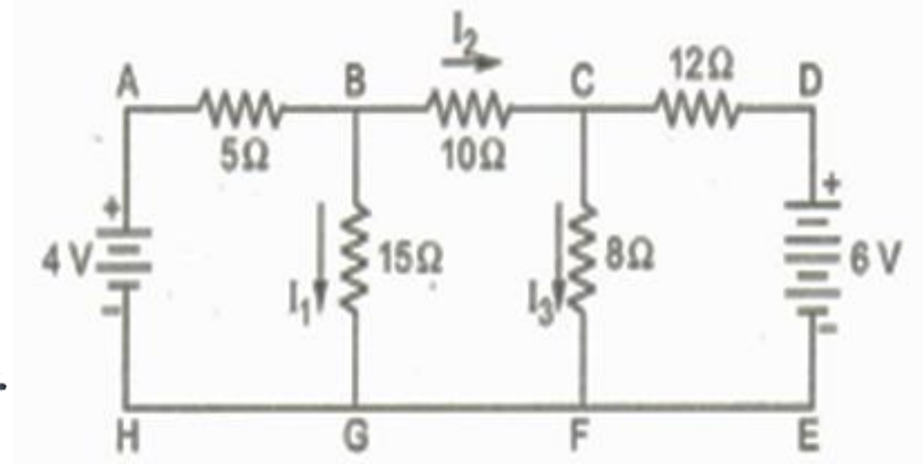
Step 4 : Draw the Thevenin's equivalent showing source V_{TH}, with the resistance Req in series with it, across the terminals of branch of interest.

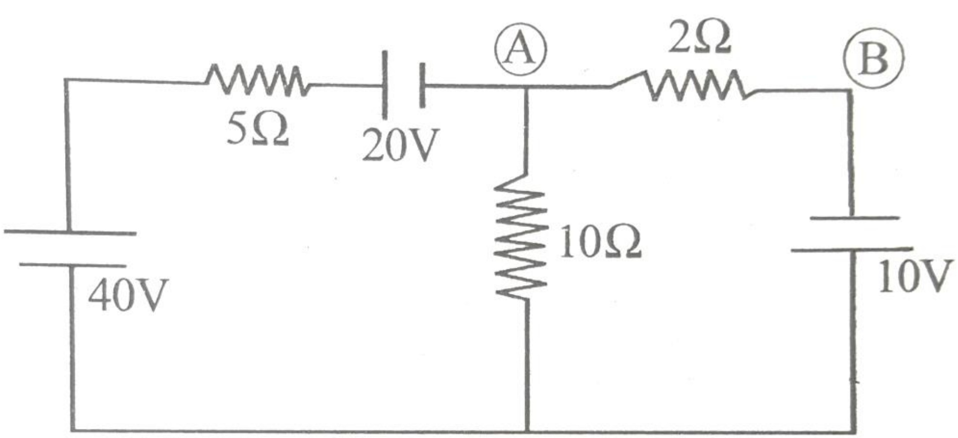
Step 5 : Reconnect the branch resistance. Let it be RL. The required current through the branch is given by,

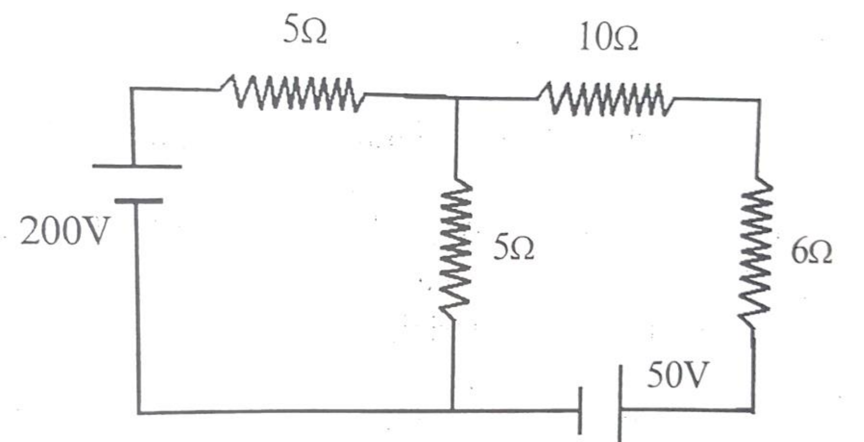
$$I = \frac{V_{TH}}{R_{TH} + R_L}$$

Q: By Thevenin's theorem find the current I_2.









Q. Apply Thevenin's theorem to calculate current flowing through branch AB

(i) To find VTH

Remove the resistance of 60Ω and find the voltage between terminals A and B.

The loop equation for loop ABDCA is

$-VTH-(120X\ I1) + 24=0$

$VTH=24- (120X\ I1)$ ----(1)

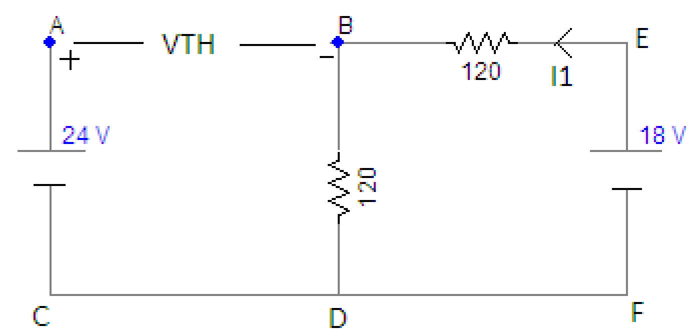
To find the value of VTH, calculate I1 by writing loop equation for loop EBDFE

$-120I1-120I1+18=0$----(2)

$I1=18/(120+120)=0.075$ A

By putting value of I1 in equation (1)

$VTH=24- (120X\ 0.075)=15$ V



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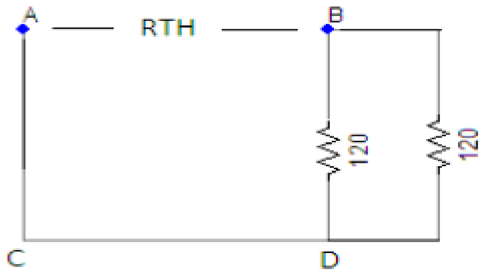
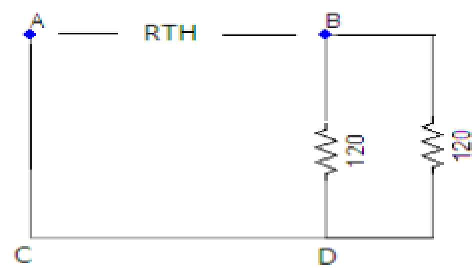
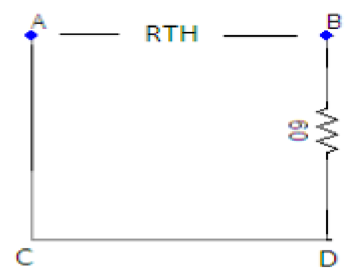
(ii) To find RTH

Remove the resistance of 60Ω and get the equivalent resistance between terminals A and B

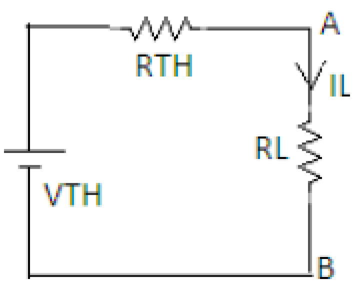
To get the equivalent resistance, replace the sources by their internal resistances





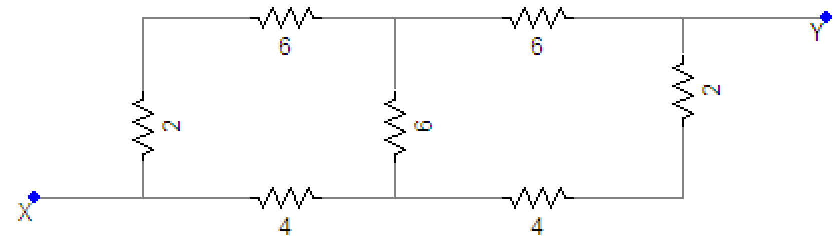


(iii)To find IL (current through branch AB) by using Thevenins equivalent circuit

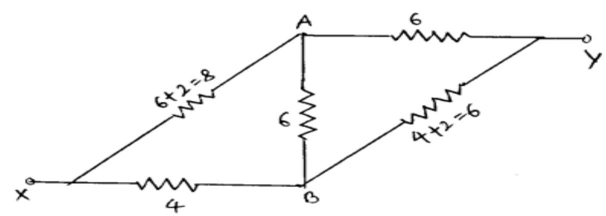


IL=VTH/(RTH+RL)=15/(60+60)= 0.125 A

Q. Calculate the resistance between terminals X and Y

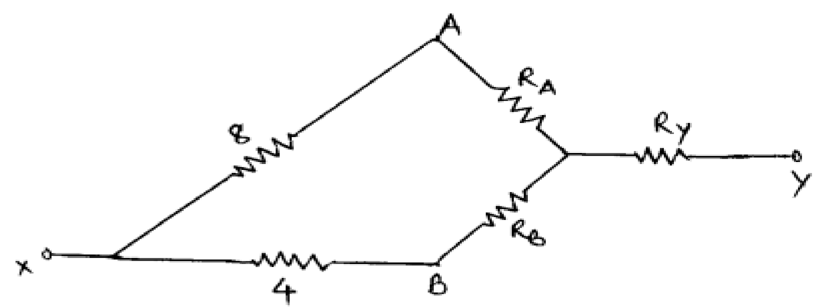


6Ω and 2Ω resistances are in series as well as 4Ω and 2Ω resistances are in series The network will be

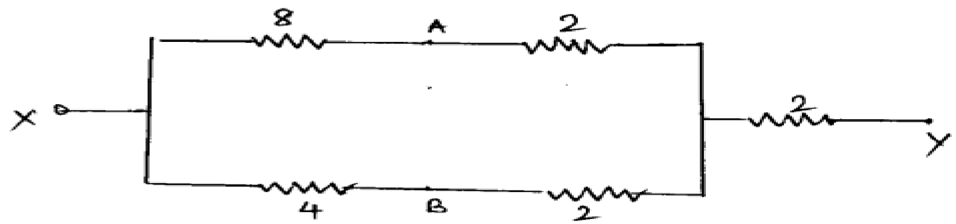


Convert delta connected network ABY into star connected network. The network will be

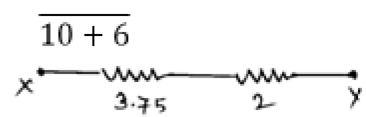
- RA=6X6/(6+6+6)=2Ω=Ry=RB



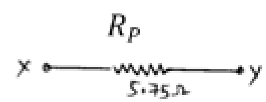
Resistances RA =2Ωand 8 Ω are in series as well as Resistances RB=2Ω and 4 Ω are in series



Rp=10X6/(10+6)=3.75 Ω

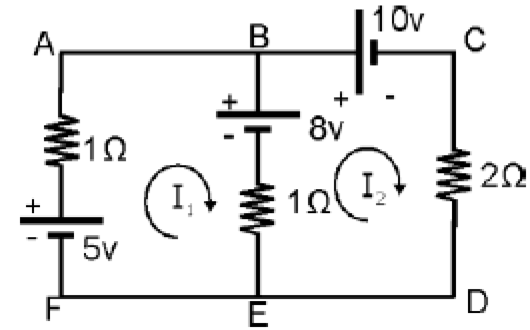


Resistance   Rp=3.75 Ω and 2 Ω are in series



So Equivalent resistance, Req= 3.75+2=5.75 Ω

Q. Find applying Kirchhoff's Laws currents in three voltage sources in the network



Solution:

Current supplied by 5 V source is I1Amp

Current supplies by 8 V source is (I1 – I2) Amp

Current supplied by 10 V source is I2 Amp

Applying Kirchhoff's voltage law for loop ABEFA

2 I1 – I2=5 – 8, 2 I1 – I2 = –3 ...(I)

for loop BCDEB

– I1 + 3I2 =8 – 10, I1 – 3I2 = – 2 ...(II)

multiplying equation (II) by (– 2)

2I1 – I2= – 3 – 2I1 + 6I2 = – 4

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5I2= – 7

I2= –75 = – 1.4 Amp Putting I2= –1.4 Amp in equation (I)

2I1 + 1.4= – 3 , 2I1= – 3 – 1.4 = – 4.4

I1 = –4.42 = – 2.2 Amp

I1 – I2= – 2.2 – (– 1.4) = – 0.8 Amp

I1 = – 2.2 Amp (Current flows in opposite direction)

I2 = – 1.4 Amp(Current flows in opposite direction)

I1 – I2= – 0.8 Amp (Current flows in opposite direction

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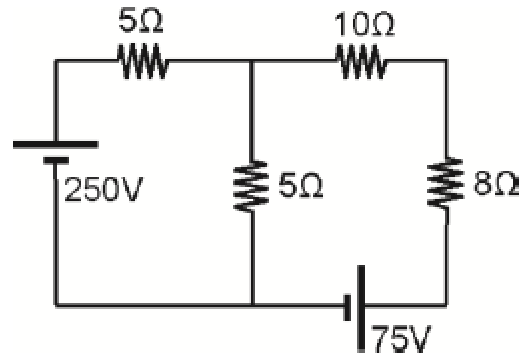
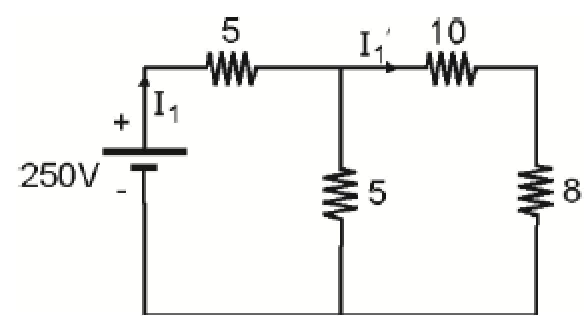
Q. Calculate current flowing in 8 Ohm resistance for the circuit shown in Fig. applying superposition theorem.



Step I : only 250 V source acting alone

- 10 + 8 =18 and 18||5=18X5/(18+5) = 3.91Ω
- R total = 5 + 3.91 = 8.91Ω
- I1= 250/8.91 = 28.06A
- I2’=28.06X5/(18 + 5) = 6.10 A ↓



- **Step II : only 75 V source acting alone**
- 5||5 = 5X5/(5+5) = 2.5Ω
- Total Resistance = 10 + 8 + 2.5= 20.5Ω
- I2 = 75/20.5 = 3.66 A ↑ (Form B to A)
- **Step III : The resultant current flowing 8 resistance**
- I =I'1 ↓ – I2 ↑ = 6.10 – 3.66 =2.44 ↓ (from A to B)