BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

(Computer *Science Engineering*)

Presented by

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UNIT-1
DC CIRCUITS

PARALLEL CIRCUITS

- An electrical circuit is a combination of two or more electrical components that are interconnected by conducting paths
- The electrical components may be active components or inactive components or combination of both
- The components of the electrical DC circuit are mainly Resistive, where as components of the AC circuits may be reactive as well as resistive

What is Parallel Circuits:

- A circuit is said to be parallel when the electric current has multiple paths to flow through the circuit
- The components that are a part of the parallel circuits will have a constant voltage across all ends

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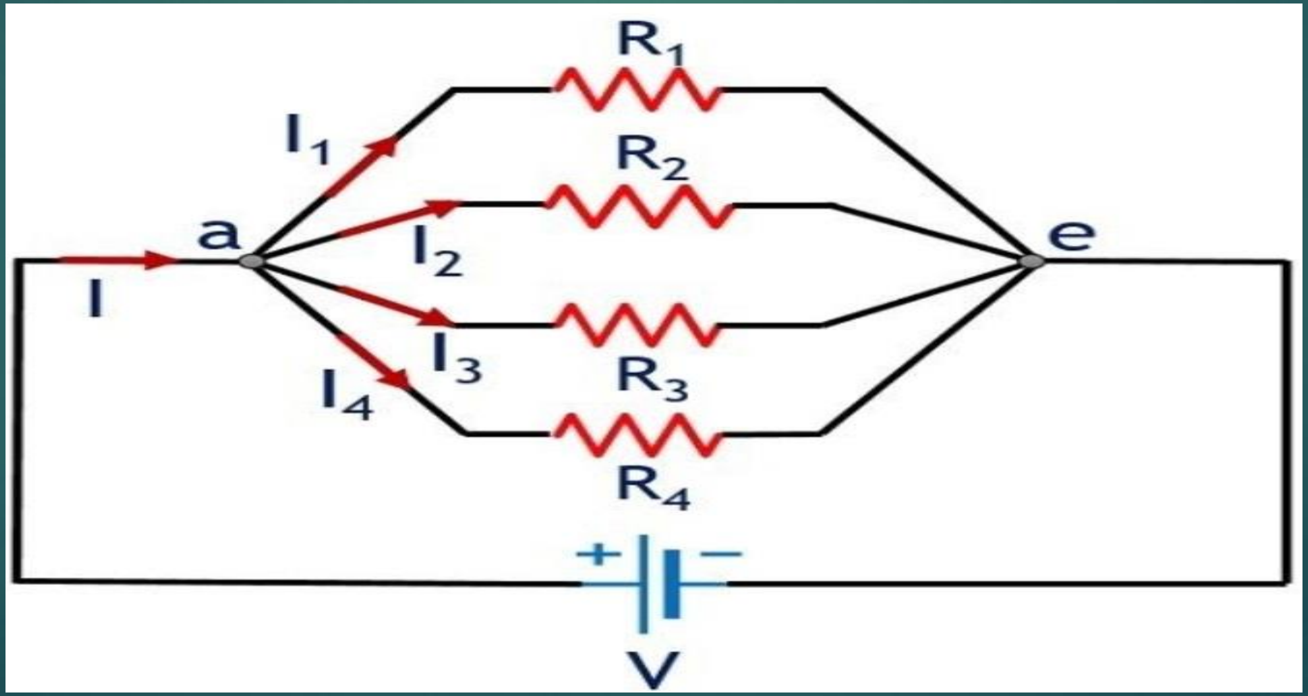
- In a parallel circuit the components are arranged in a way that the heads of the each components are connected together with a common point
- While the tails are connected together with another common point
- Thereby forming multiple parallel branches in the circuit



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- If two or more components are connected in parallel ,they have same difference potential or voltage across their ends
- The same voltage applied is applied all circuit components connected in parallel

Voltage:

- Voltage is equal across all components in a parallel circuit

$V= V_1=V_2=V_3=\ldots\ldots.=V_n$

Current:

- Total circuit current is equal to the sum of the individual branch currents

$I= I_1+I_2+I_3+\ldots\ldots.+I_n$

Resistance: Individual resistances diminish(decreases) to equal a smaller total resistance rather than add to make the total

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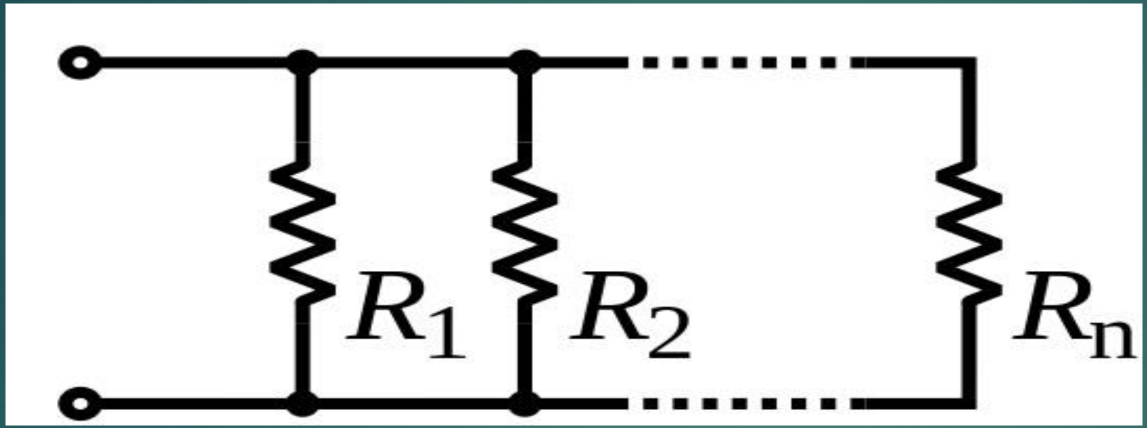
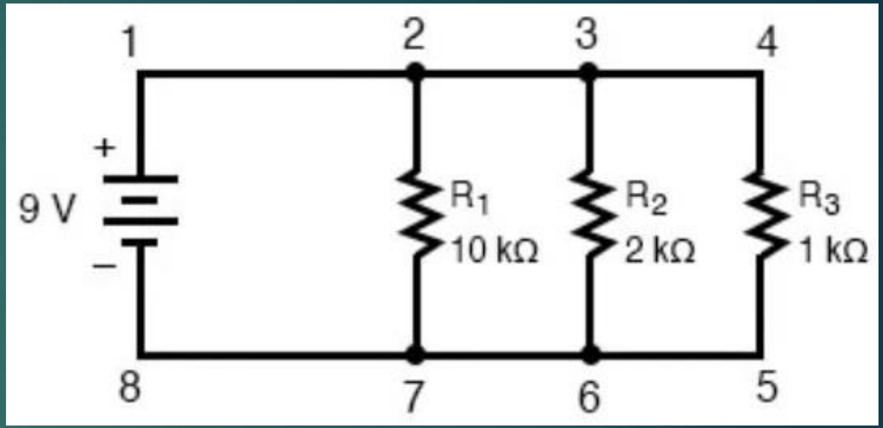
- If “N” no of resistors are connected in parallel





- $1/R_{total} = 1/R_1 + 1/R_2 + \ldots\ldots + 1/Rn$
- If two resistors are in parallel Total resistance= $R_1 \times R_2/R_1+R_2$
- Inductors are also same as Resistors parallel connection

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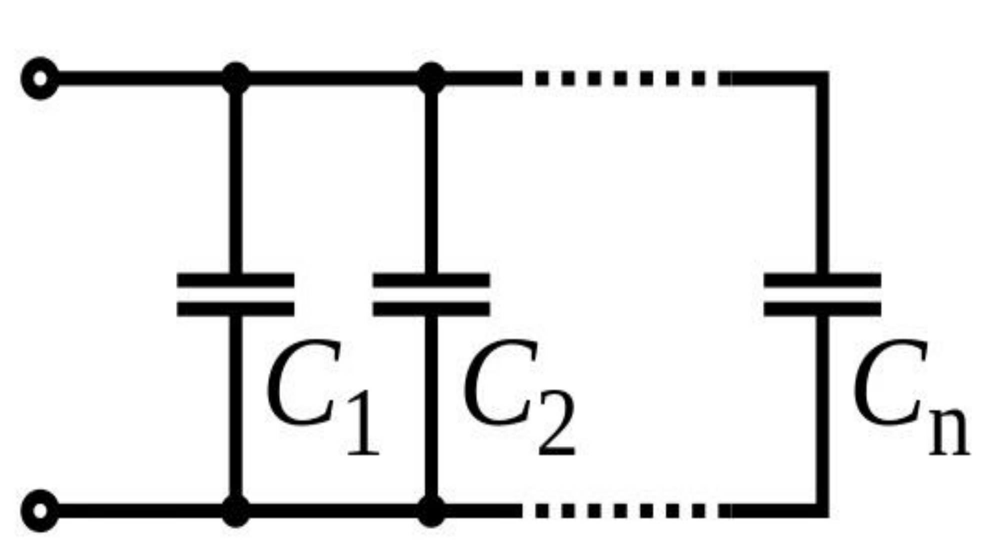
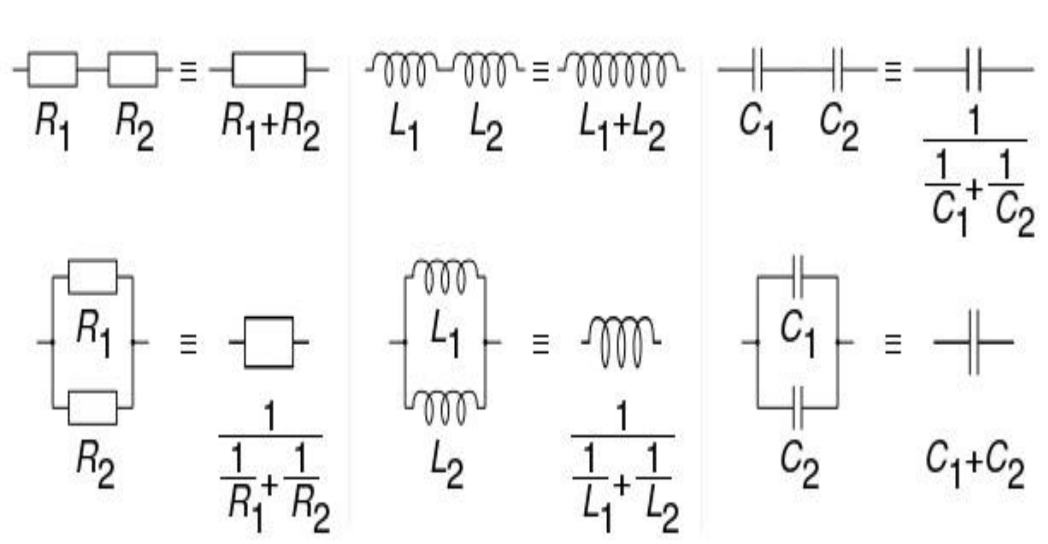
Capacitors are in parallel:

- The total capacitance of a capacitors in parallel circuits equals to the sum of the their individual capacitances





C_{total}: $C_1+C_2+C_3+\ldots. +Cn$

- Parallel circuits can be solved by using KCL

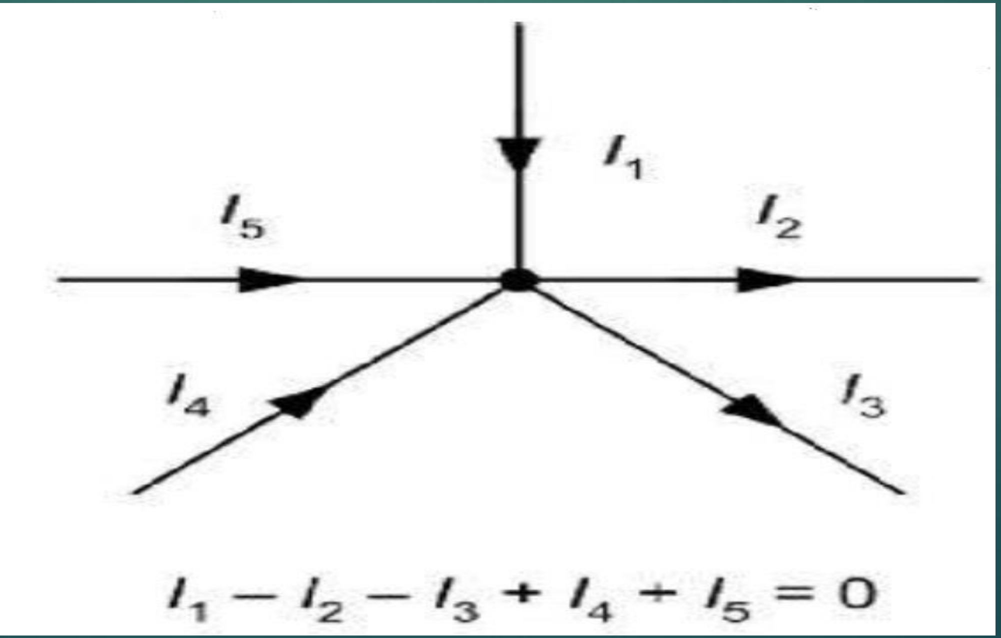
Kirchoff's Current Law(KCL)

- Statement: The algebraic sum of all currents entering and leaving (exiting) a node must be equal zero

or

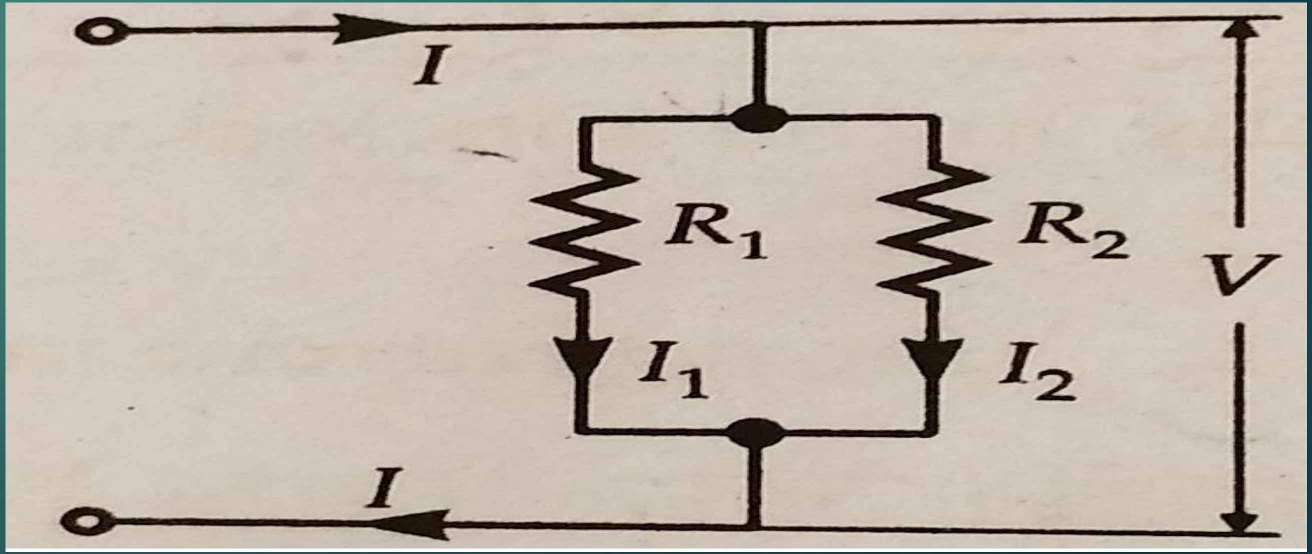
The algebraic sum of entering currents = leaving currents at a node

$$I_{entering} + (-I_{exiting\ or\ leaving}) = 0$$



Current Division Rule

- A parallel circuit acts as a current divider as the current divides in all branches in a parallel circuit
- The current ‘I’ has been divided into I1 and I2 in two parallel branches with resistances R1 and R2
- While ‘V’ represents the drop across R1 or R2
- Obviously $I_1 = V/R_1$ & $I_2 = V/R_2$



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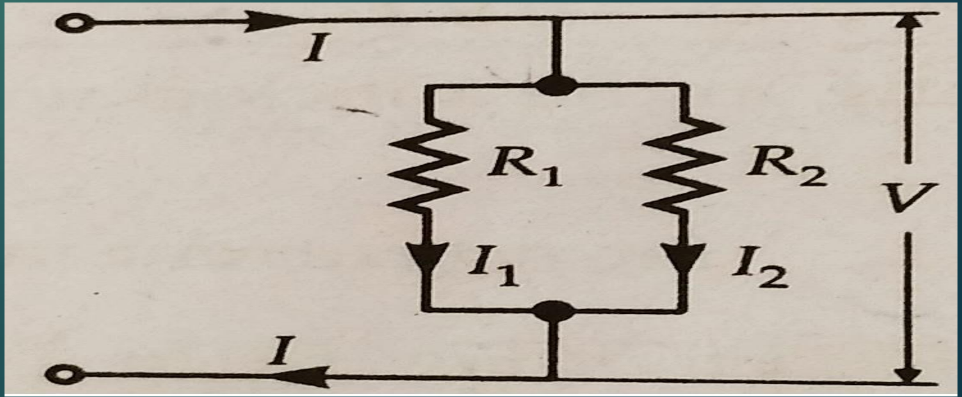
- Statement: It states that total current available in the network is multiplied by opposite resistance and divided by sum of the resistances
- From the above circuit current across R_1 is I_1 given by

  According to Current Division Rule : $I_1 = I \times R_2/R_1+R_2$
- From the above circuit current across R_2 is I_2 given by

  According to Current Division Rule : $I_2 = I \times R_1/R_1+R_2$
- From the figure $I=6$ A, $R_1=1K\Omega$, $R_2= 2\ K\Omega$ Find I_1&I_2

  Solution: $I_1=6 \times 2\ K\ \Omega/(2+1)\ K\Omega =12/3= 4$ A

  $I_2=6 \times 1\ K\ \Omega/(2+1)\ K\Omega =6/3= 2$ A



Nodal Analysis

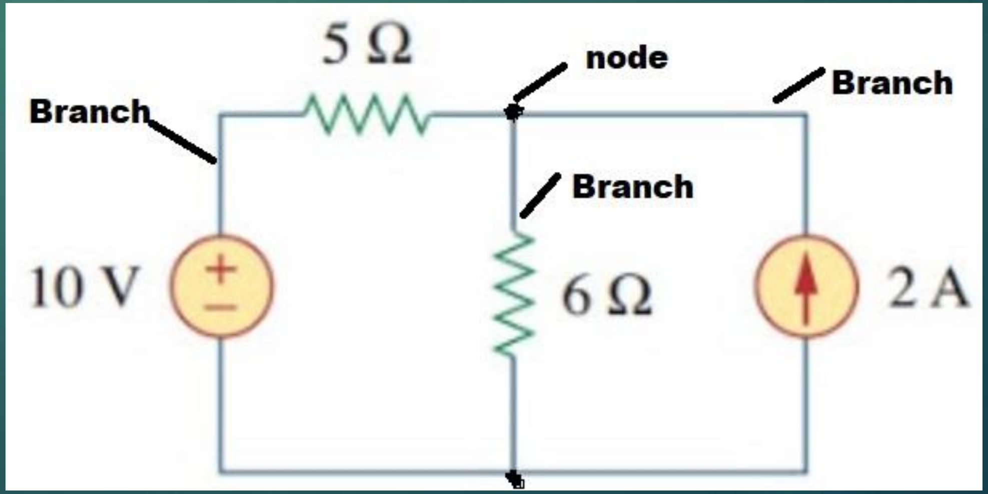
- Node: It is a circuit point at which two or more elements meet at a single point (or) a node is the point of connection between two or more branches
- Branch: It is a path between two adjacent nodes (or) a branch represents a single element such as a voltage source or resistor
- Path: Transversal path through elements from node 1 to node 2
- Mesh: It is also loop but it doesnot contain any other loop with in it
- Loop: A loop is any closed path in a circuit
- From the circuit

  No.of Nodes :2

  No.of branches:3

  No.of loops:2

  No.of equations:2



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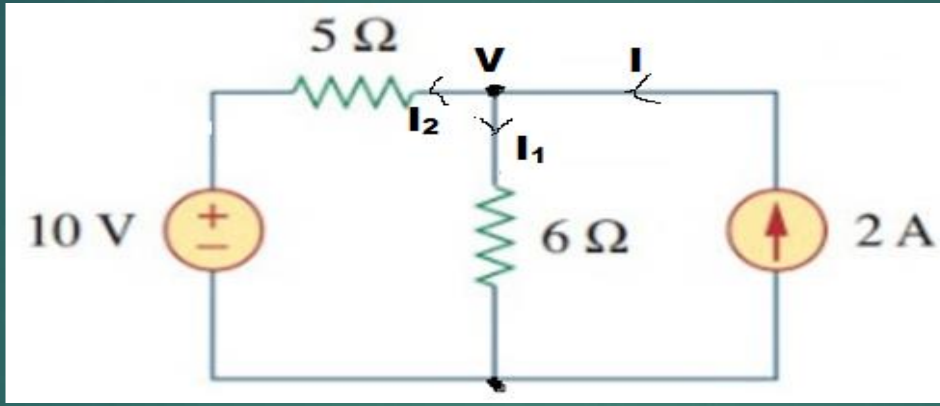
- Analysis using KCL to solve for voltages at each common node of the network and hence determine the currents through and voltages across each element of the network
- Nodal Analysis Procedure:
- Identify the no.of common nodes and reference nodes
- Assign the current direction of each distinct branch of the nodes in a network
- Apply KCL at each of the common nodes in the network
- Solve the resulting simultaneous linear equation for the node voltages
- Determine the current through and voltages across each element in the network

Nodal Analysis Problem

- Problem: Find the Voltage and Current across each element using nodal analysis



Solution: No.of nodes present in given network :2

No.of nodal equations possible for given network

$e = N-1=2-1=1$

From the circuit $I = I_1 + I_2$

Continued………..

- Apply KCL at node ‘V’

$$V-10/5 + V/6 = 2$$

$$V/5-10/5+V/6 = 2$$

$$V/5 + V/6 = 4$$

$$6\ V + 5\ V = 4x6x5$$

$$11\ V = 120$$

$$V = 120/11 = 10.90\ V$$

From the circuit $I_1 = V/6 = 10.90/6 = 1.81$ A

$$I_2 = V-10/5 = 10.90-10/5 = 0.18\ A$$

Voltage across 6 ohm resistor : 6 x 0.18 = 1.08 V

Voltage across 5 ohm resitor : 5 x 1.81 = 9.09 V

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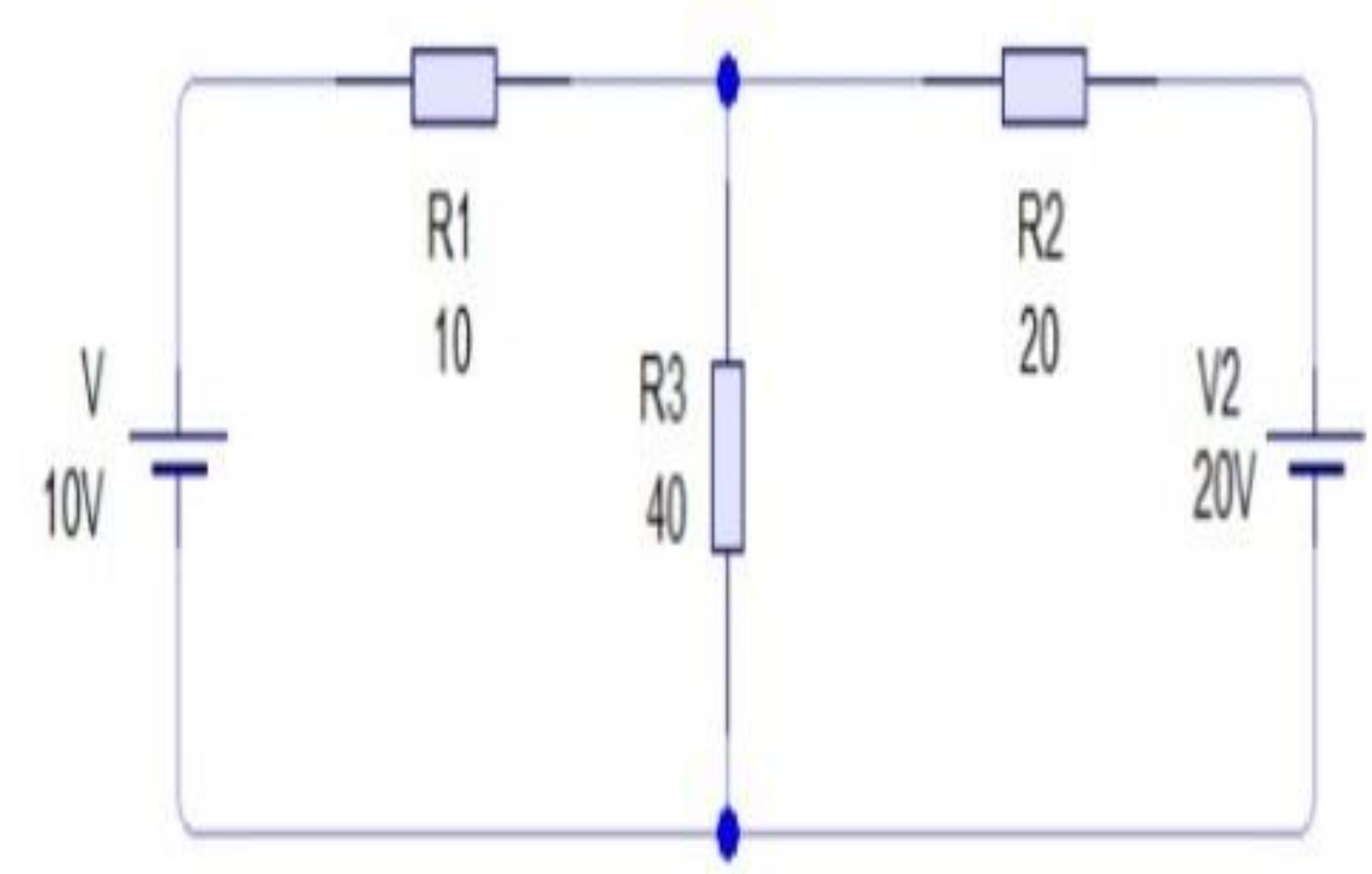
- Problem: Find the current flowing through the each resistor using nodal analysis



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- Apply KCL at node “V”

$$(V-10)/10 + V/40 + (V-20)/20 = 0$$

$$V/10 + V/40 + V/20 = 2$$

$$4\,V + V + 2\,V = 80$$

$$7\,V = 80$$

$$V = 80/7 = 11.42\ V$$

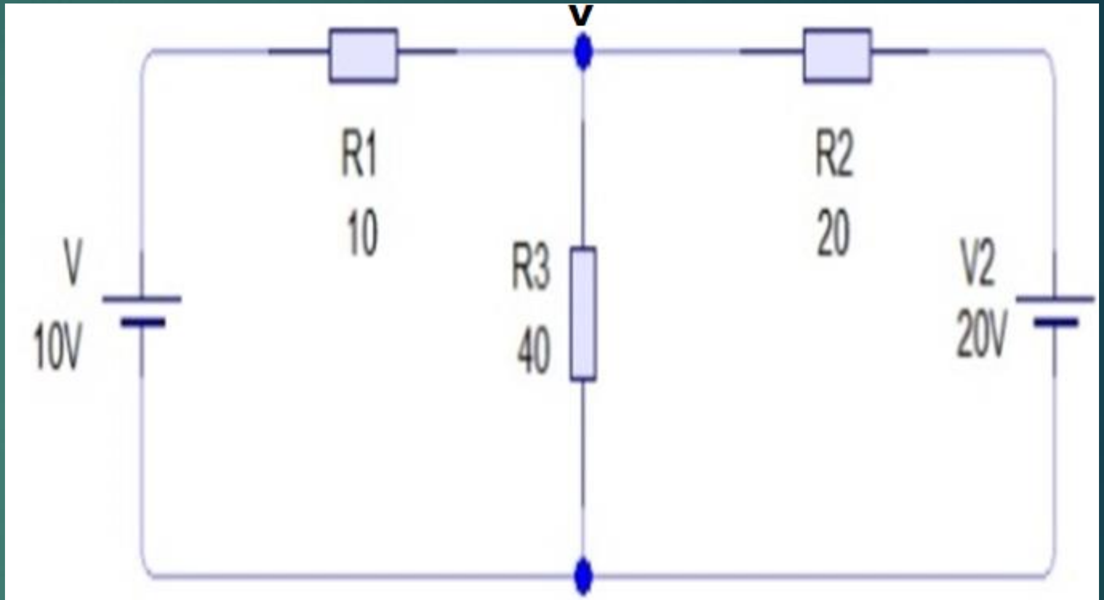
Current across 40 Ohm resistor

$$I_3 = V/40 = 11.42/40 = 0.2855\ A$$

Current across 10 Ohm resistor

$$I_2 = V-10/10 = 11.42-10/10 = 0.142\ A$$

$$I_1 = V-20/20 = 11.42-20/20 = -0.429\ A$$



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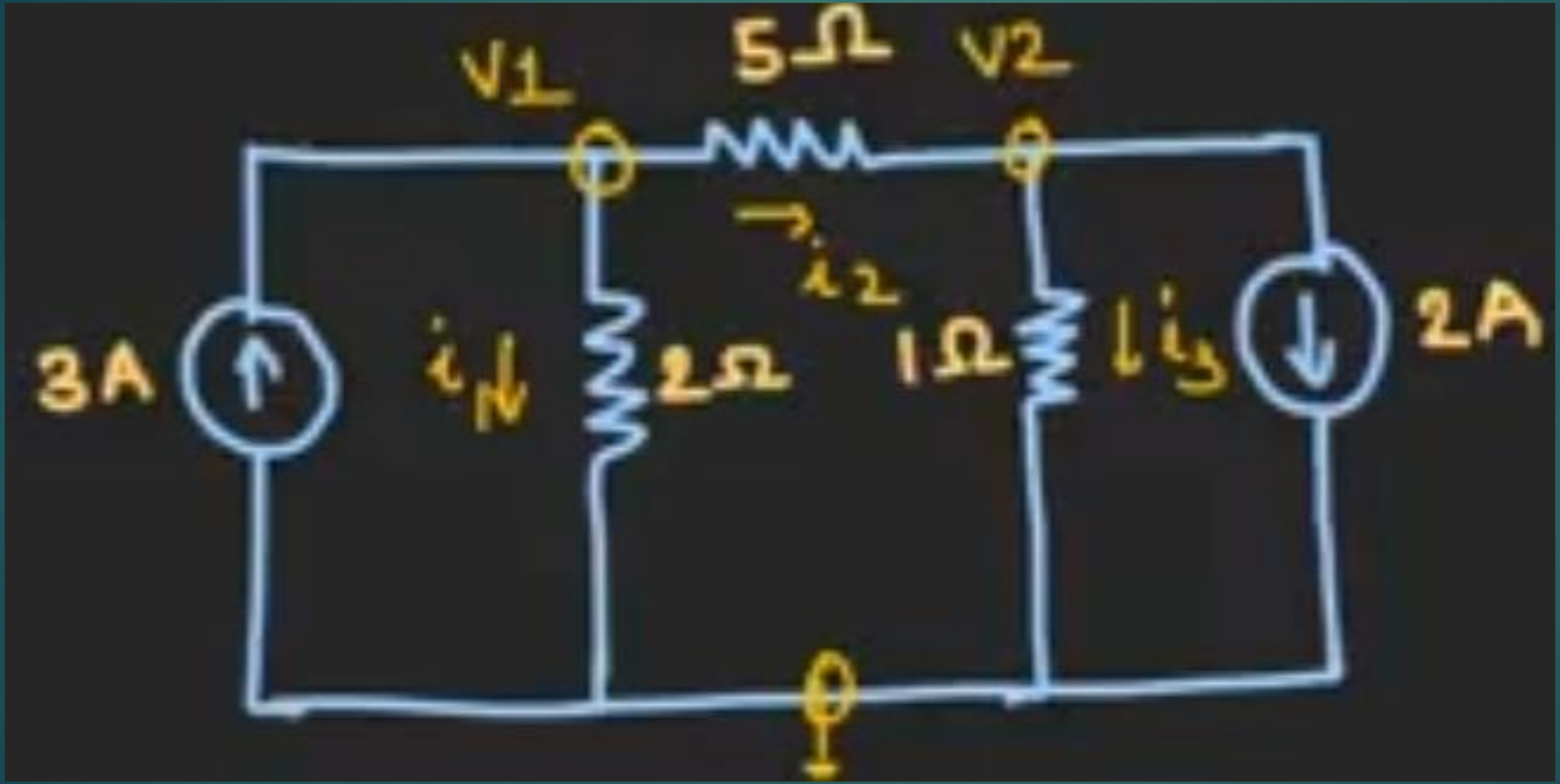
- Problem: Find the current flowing through the each resistor using nodal analysis



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- Solution: Apply KCL at V1 node

  From circuit : $I_1 + I_2 = 3$

  $V1/2 + (V1-V2)/5 = 3$

  $7\,V1-2V2= 30$ ------------(1)

  Apply KCL at V2 node

  From Circuit: $I_3 + 2 = I_2$

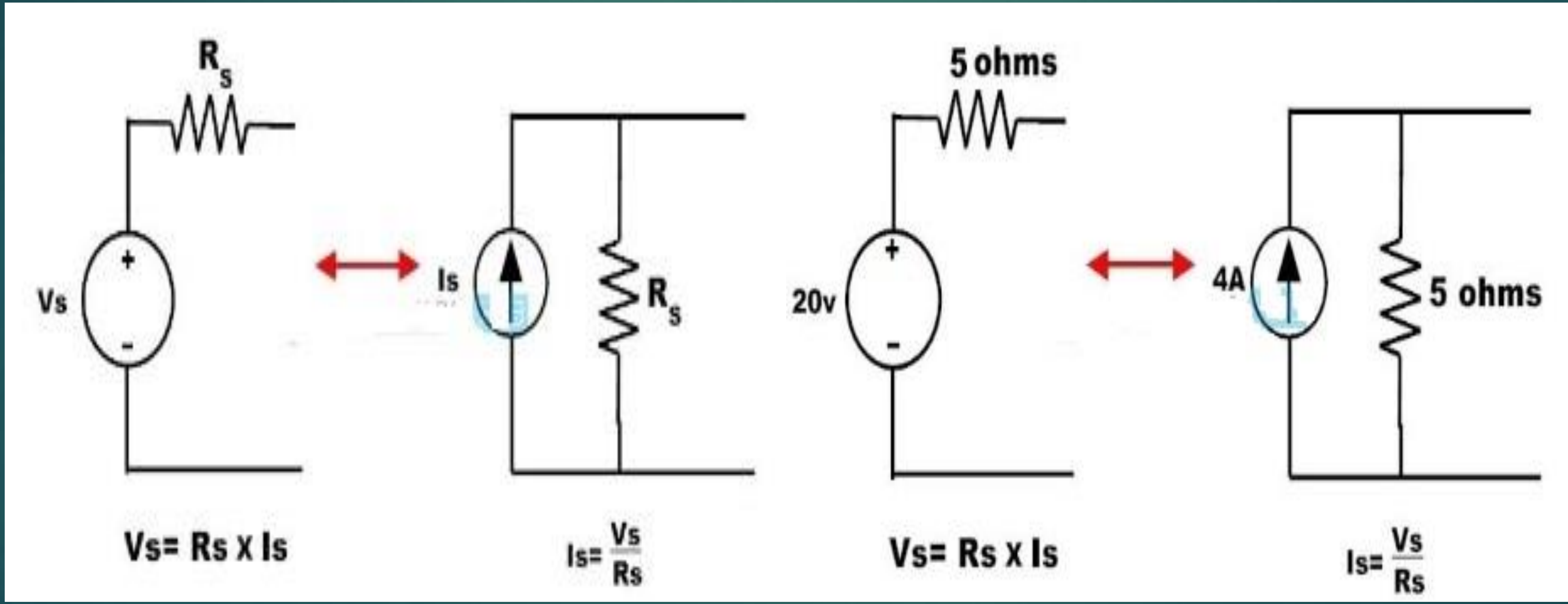
  $V2/1 + 2 = (V1-V2)/5$

  $V1 – 6\,V2 = 10$ ----------(2)

  By solving those two equations we get V1 & V2 values

Source Transformation

- The voltage source transformed into current source by interchanging series resistance in parallel with current source



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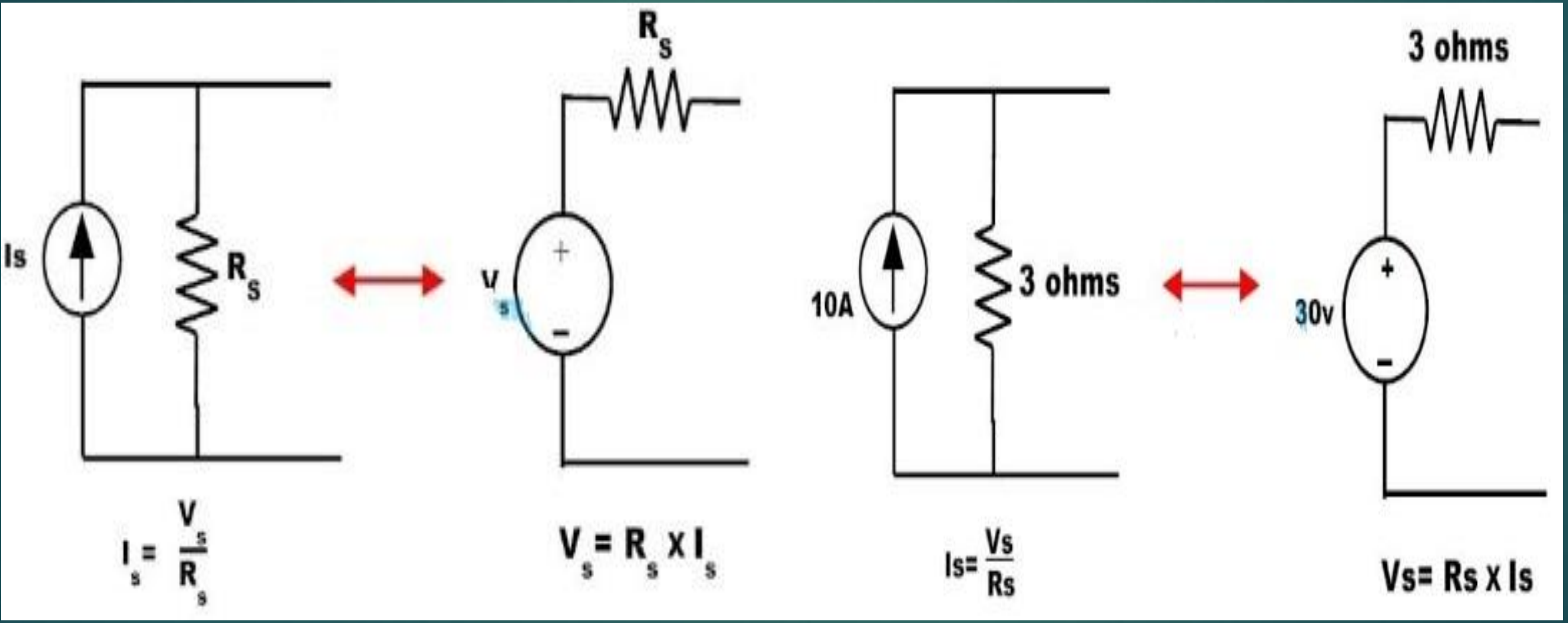
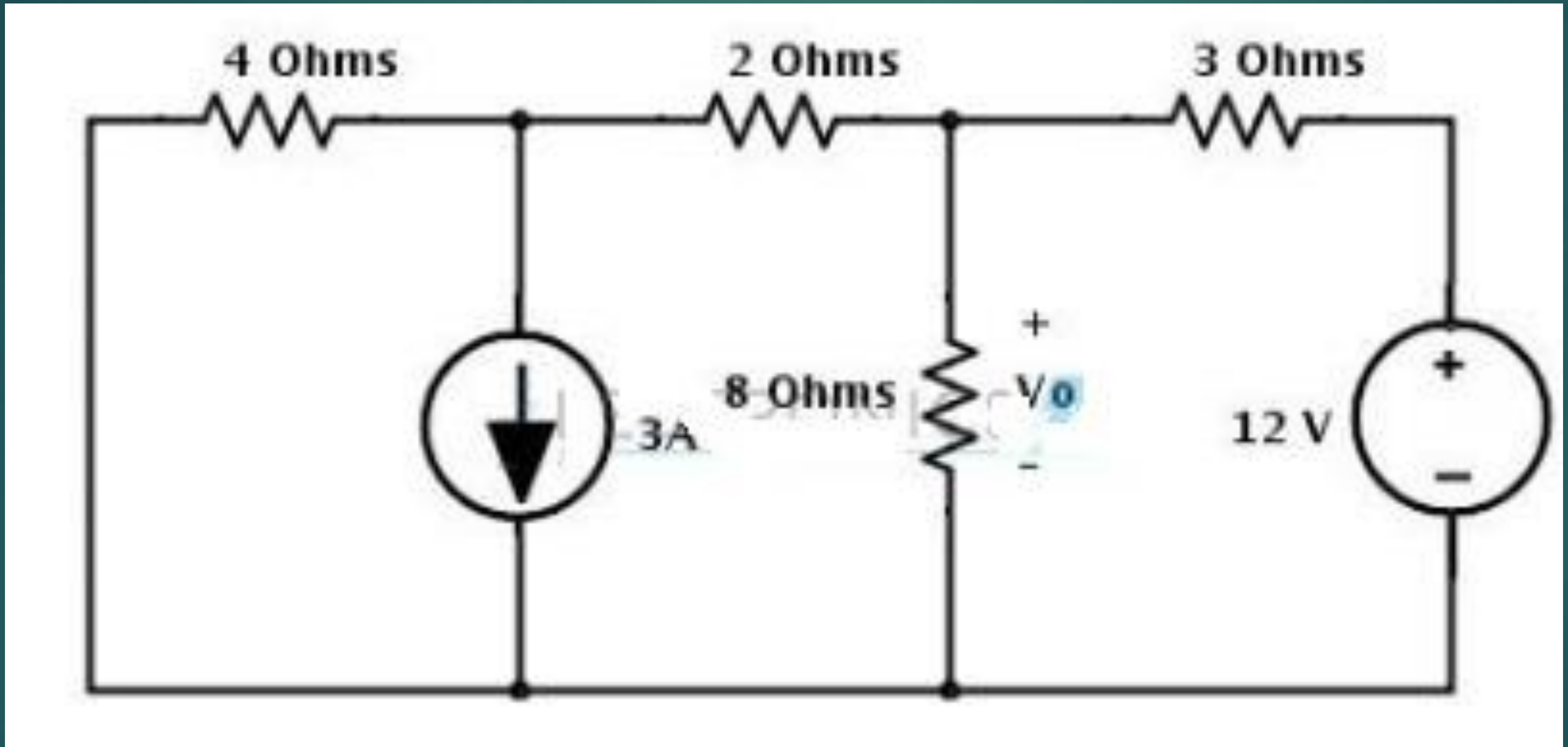
- The Current source transformed into voltage source by interchanging parallel resistance in series with voltage source



Source Transformation Problem

- Problem: Apply source transformation and solve the problem using nodal analysis



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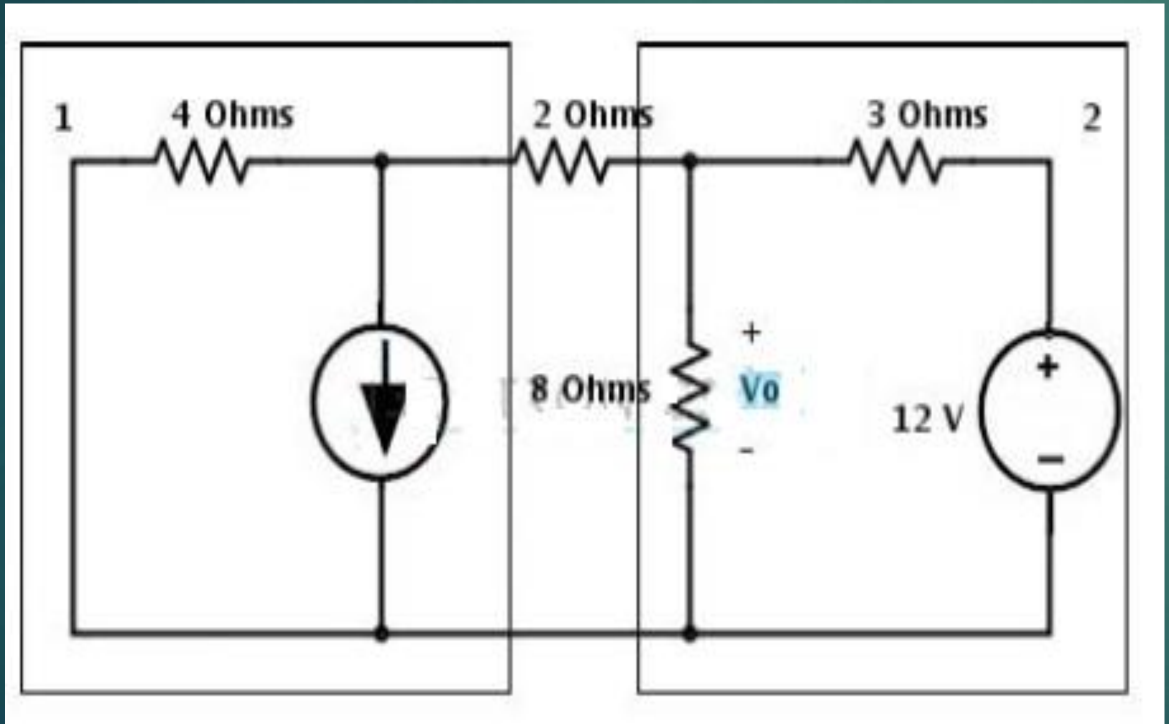
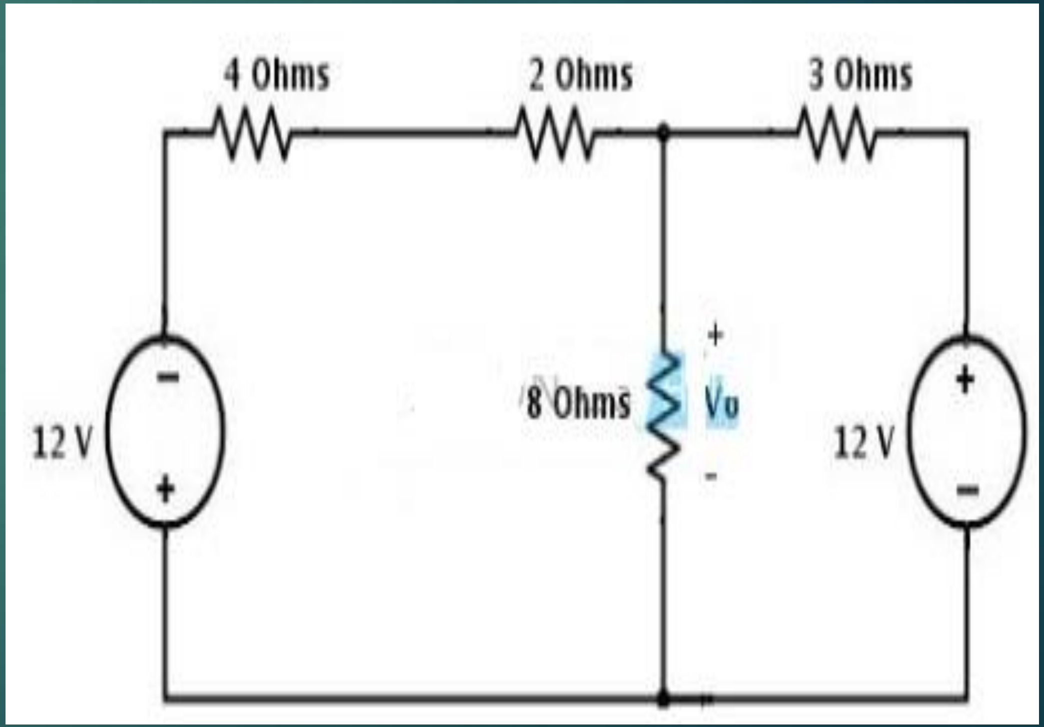
- Solution: Apply the source transformation technique and convert current source in parallel with resistance into voltage source in series with resistance
- Apply the nodal analysis and solve the problem





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- Apply KCL at node "V"

$$(V+12)/6 + V/8 + (V-12)/3 = 0$$

$$V/6 + V/8 + V/3 = 6$$

$$4\,V + 3\,V + 8\,V = 6x24$$

$$15\,V = 144$$

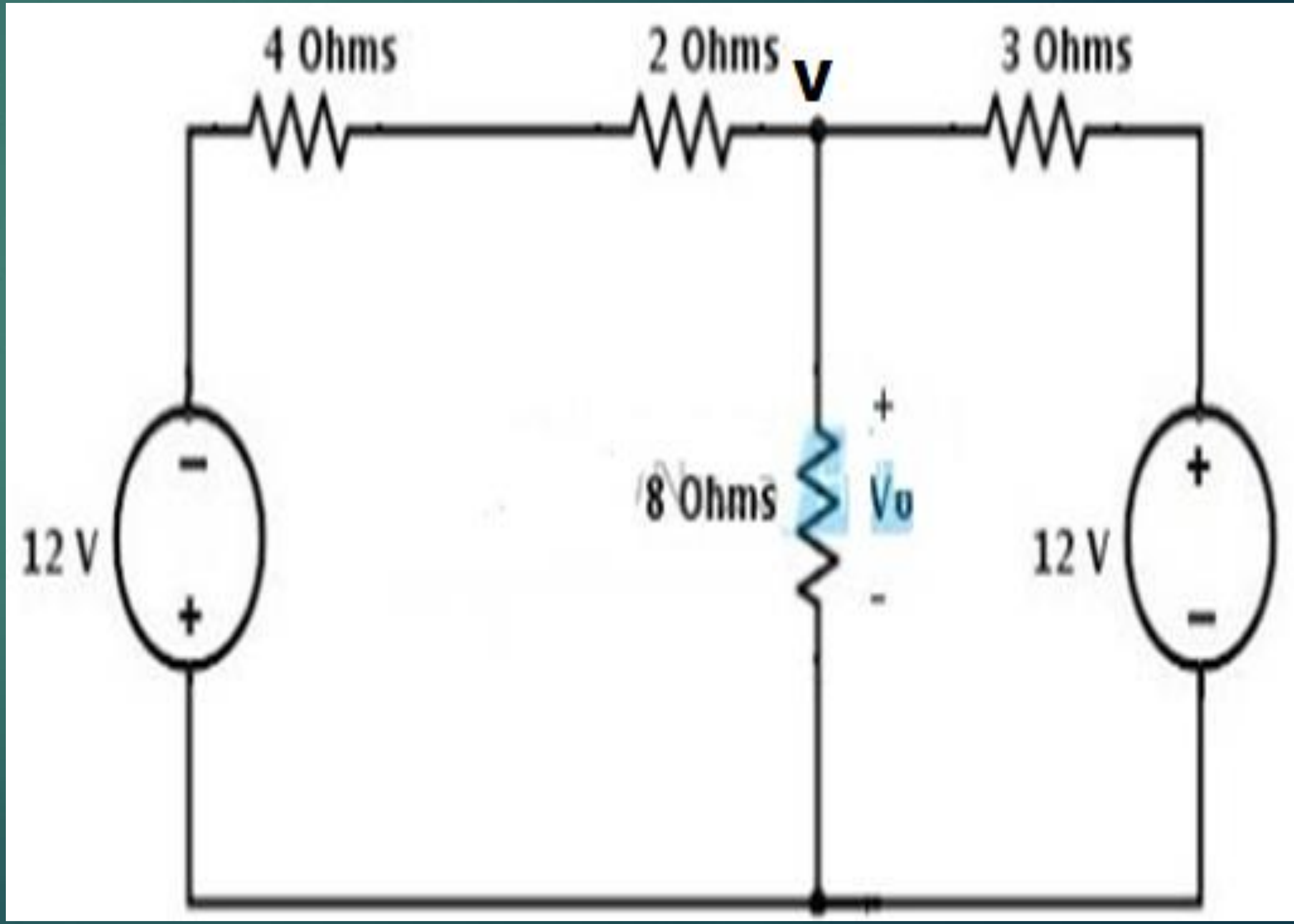
$$V = 144/15 = 3.06\,V$$

Current across 8 ohms resistor

$$I_{8\ ohm} = 3.06/8 = 0.38\ A$$

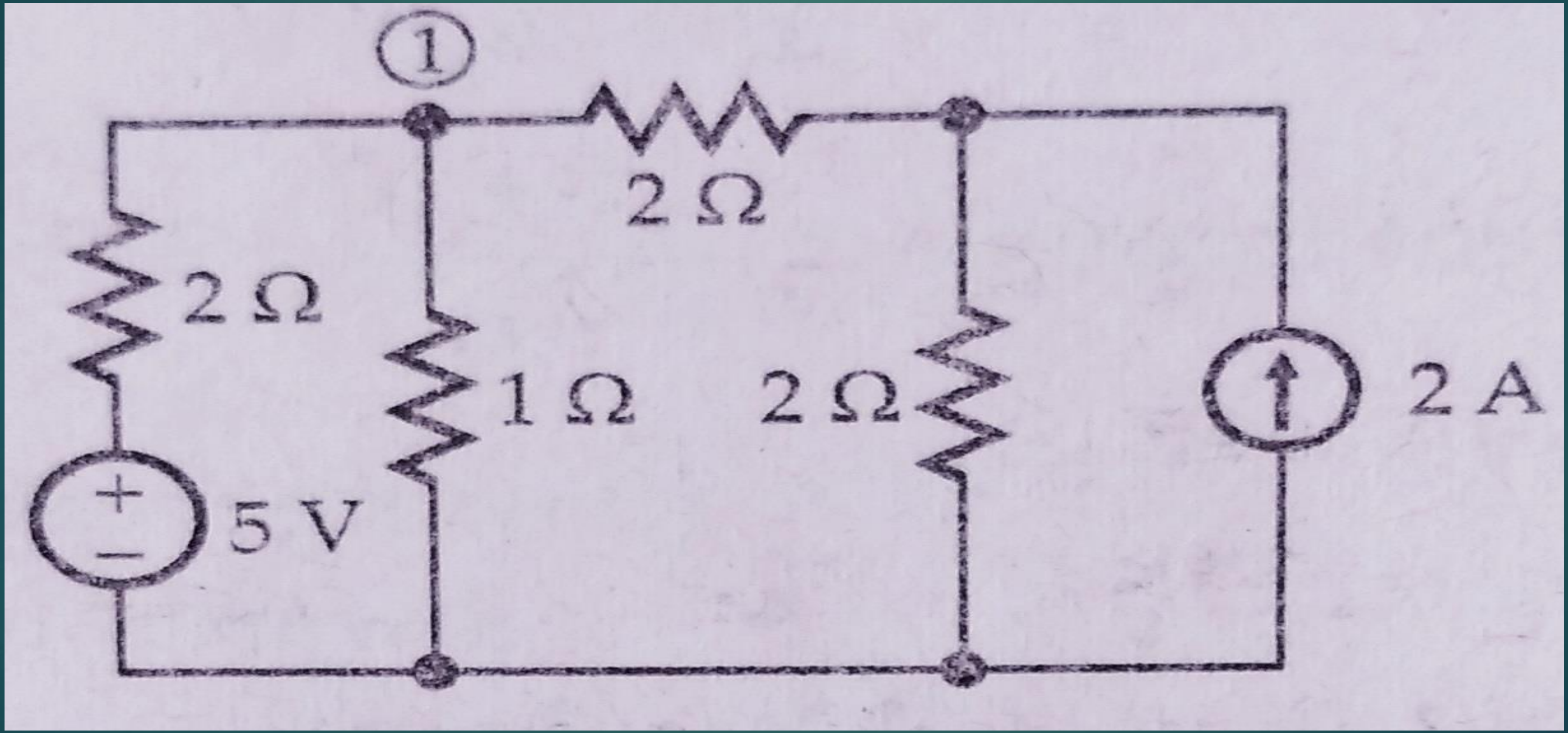
Voltage across 8 ohms resistor

$$V_0 = I_{8\ ohm}\ x\ 8 = 3.06\ V$$



Source Transformation Problem

- Problem: Apply source transformation and find current across 1 ohm resistor using nodal analysis



Super Node Analysis

- Super node is a large node ,that is connected in between the two non reference nodes with known voltage source
- Procedure to Analyse the super node analysis:
- Identify the total no.of nodes present in the given circuit
- Assign the node voltages
- Identify the super node and find the voltage difference between the nodes of the independent voltage sources
- Replace the independent voltage source with short circuit and redraw the circuit diagram
- Apply KCL for super node ,by solving KCL equations we find nodal voltages

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Problem:

Problem : Use the supernode concept to find the current I_x in the circuit of Fig.

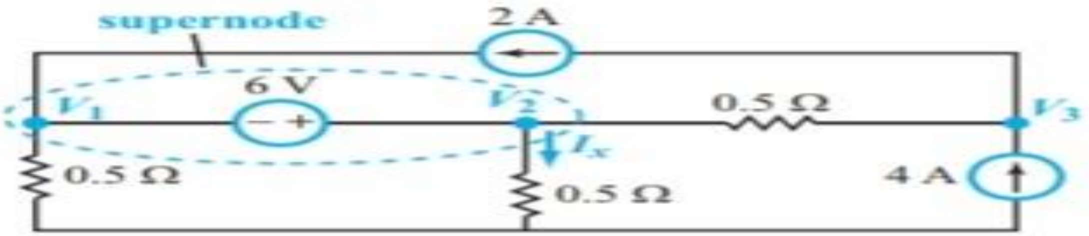

Figure : Circuit for Problem

Solution: The presence of a voltage source between designated nodes 1 and 2 makes the combination of nodes 1 and 2 a supernode. Hence,

$$\frac{V_1}{0.5} - 2 + \frac{V_2}{0.5} + \frac{V_2 - V_3}{0.5} = 0. \qquad (1)$$

For node 3,

$$\frac{V_3 - V_2}{0.5} - 4 + 2 = 0, \qquad (2)$$

and the auxiliary equation is

$$V_2 - V_1 = 6. \qquad (3)$$

Combining the three equations leads to:

$$V_1 = -2 \text{ V}, \qquad V_2 = 4 \text{ V}, \qquad V_3 = 5 \text{ V}.$$

Hence,

$$I_x = \frac{V_2}{0.5} = \frac{4}{0.5} = 8 \text{ A}.$$

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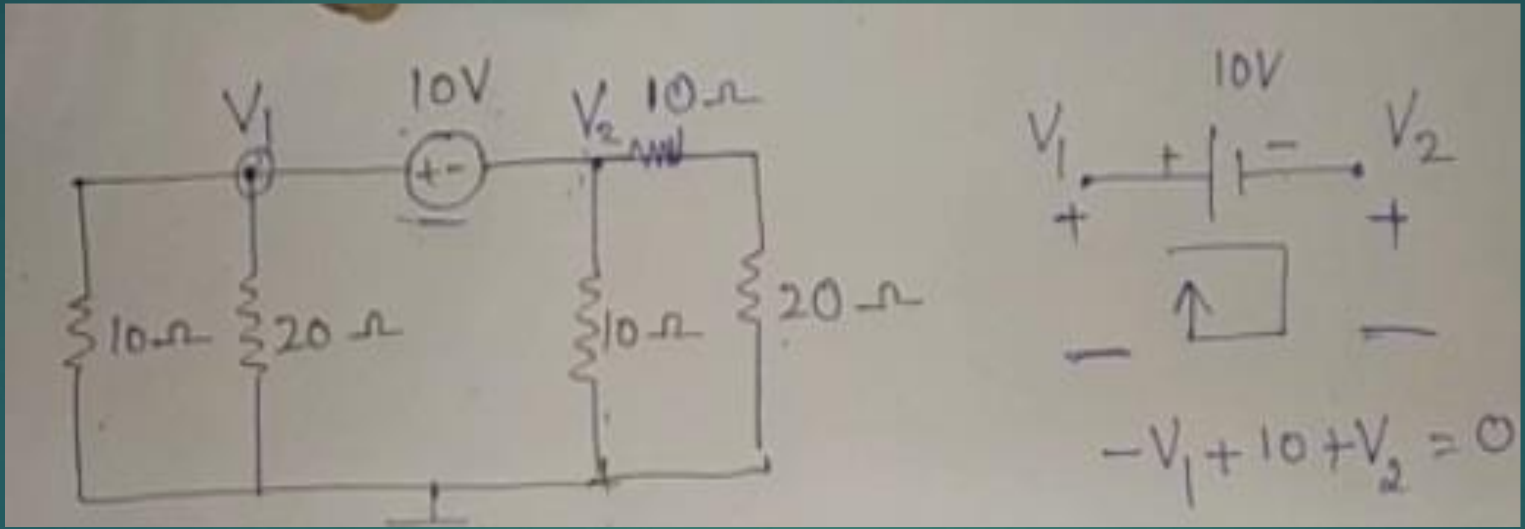
- Problem: Apply Super node analysis solve the given problem



Solution: Apply Super node analysis for the given circuit

V1/10 + V1/20 + V2/10 + V2/30 =0 --------------(1)

Apply super node concept between two nodes V1 & V2

V1-V2 = 10 --------(2)

By solving above two equations we get V1= 4.7 V & V2 = -5.3 V

Star-Delta Connection

- Star/Delta connection is an arrangement of passive elements R, L ,C such that the formed shape resembles a star or a delta symbol
- These connections are neither series and nor parallel
- Such connections are simplified using star to delta or delta to star conversion
- Such connections are found in complex DC circuits

Star Connection:

- A star network is rearranged in the form Tee network(T)
- Three ends of resistors are connected in Wye(Y) or star fashion
- A common node point of star connection is known as Neutral

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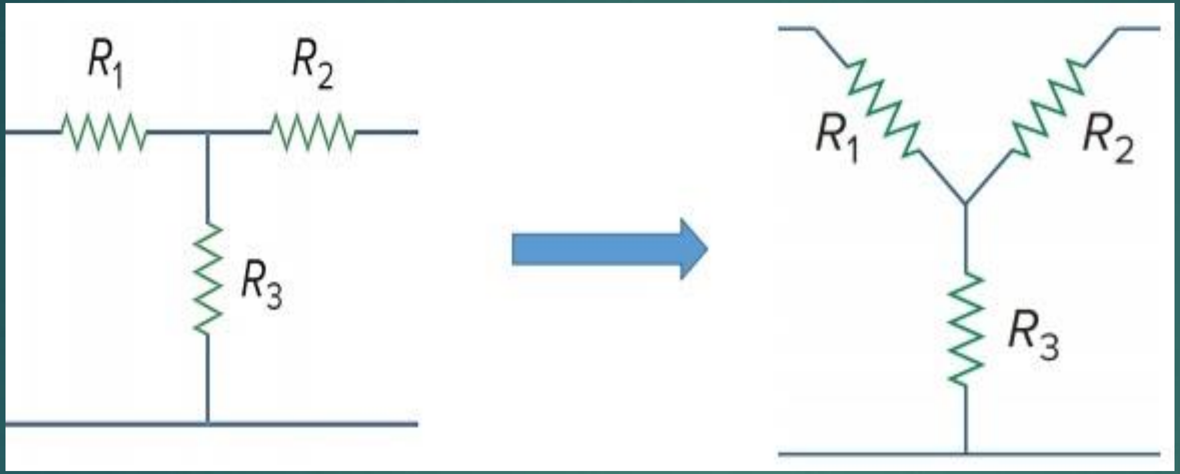
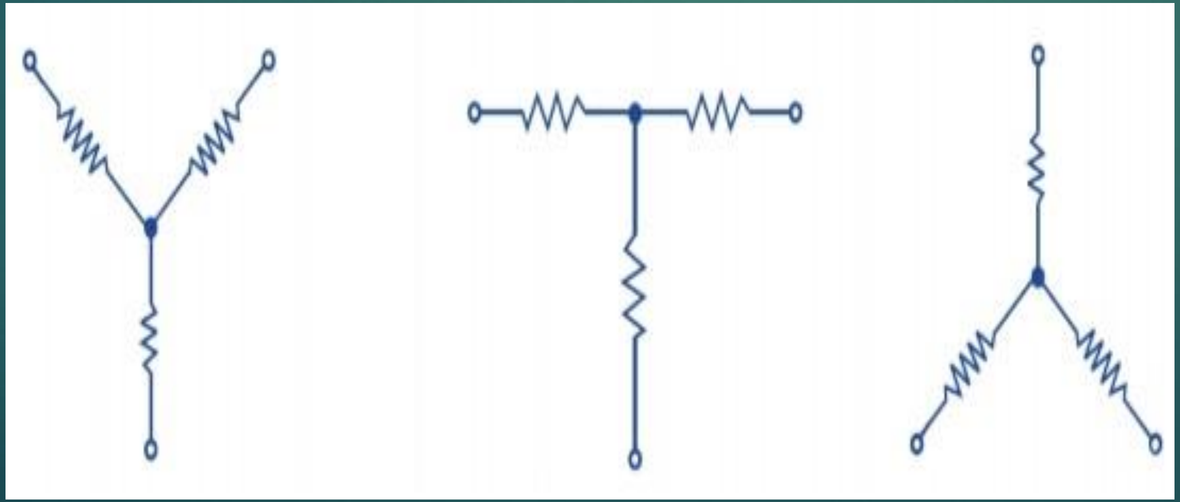
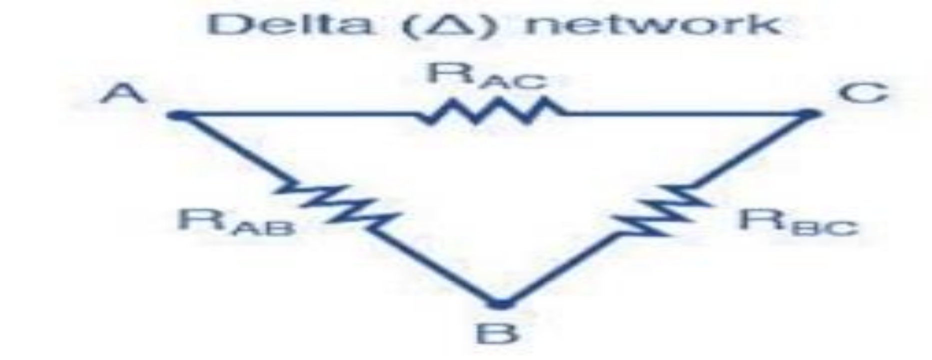


Three ways in which star connection may appear in a circuit

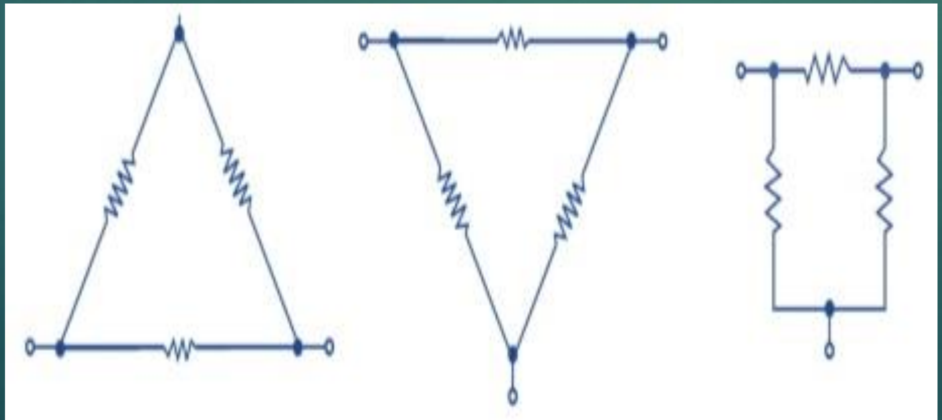


Delta Connection

- Delta: when three resistors are connected in a fashion to form a closed mesh delta connection is formed
- A delta network is rearranged in the form pi - network(Pi)

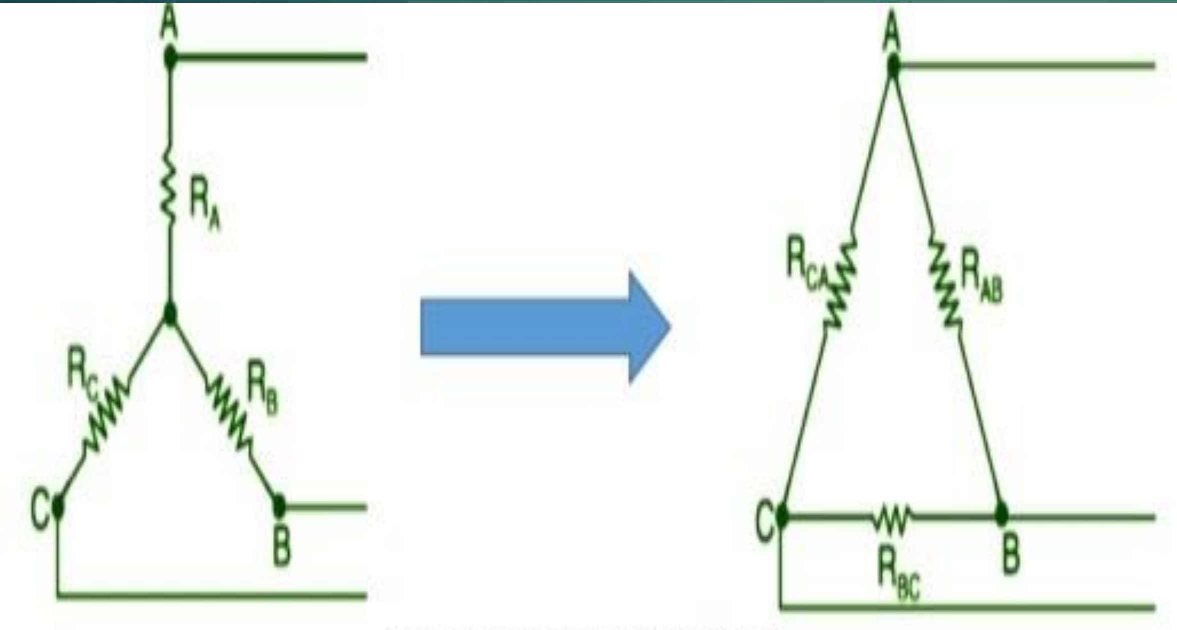


Three ways in which delta connection may appear in a circuit

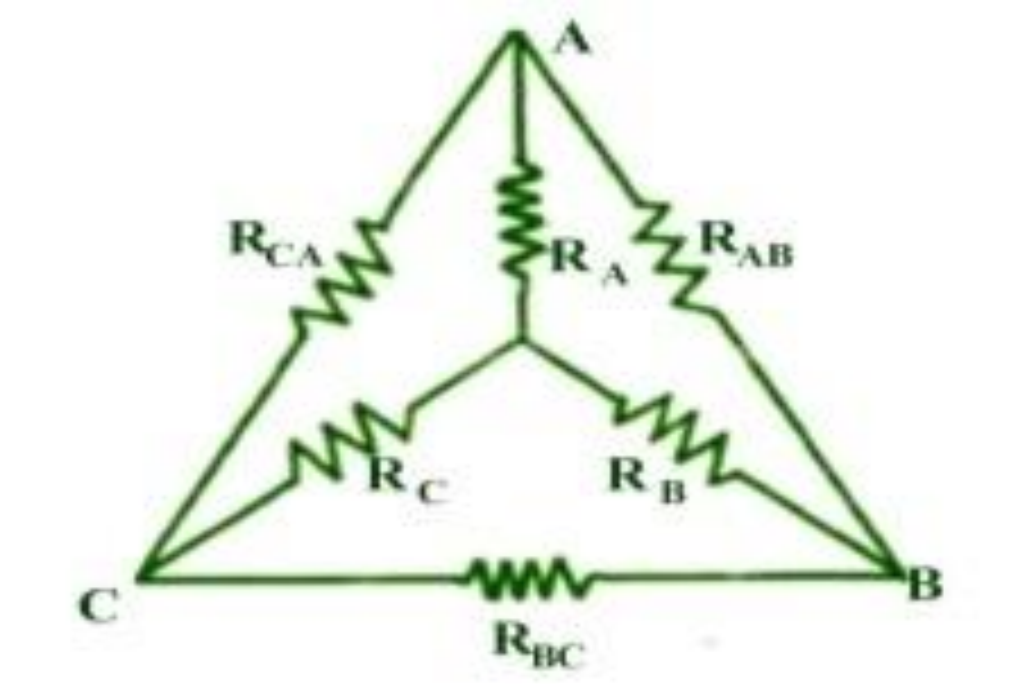


Star-Delta Conversion

- Resistance between two terminals of Delta = sum of star resistances connected to those terminals + product of same two resistances divided by third
- Three resistors are R_A,R_B and R_C connected in star fashion and its equivalent delta connection as shown in figure



Star and its Equivalent Delta



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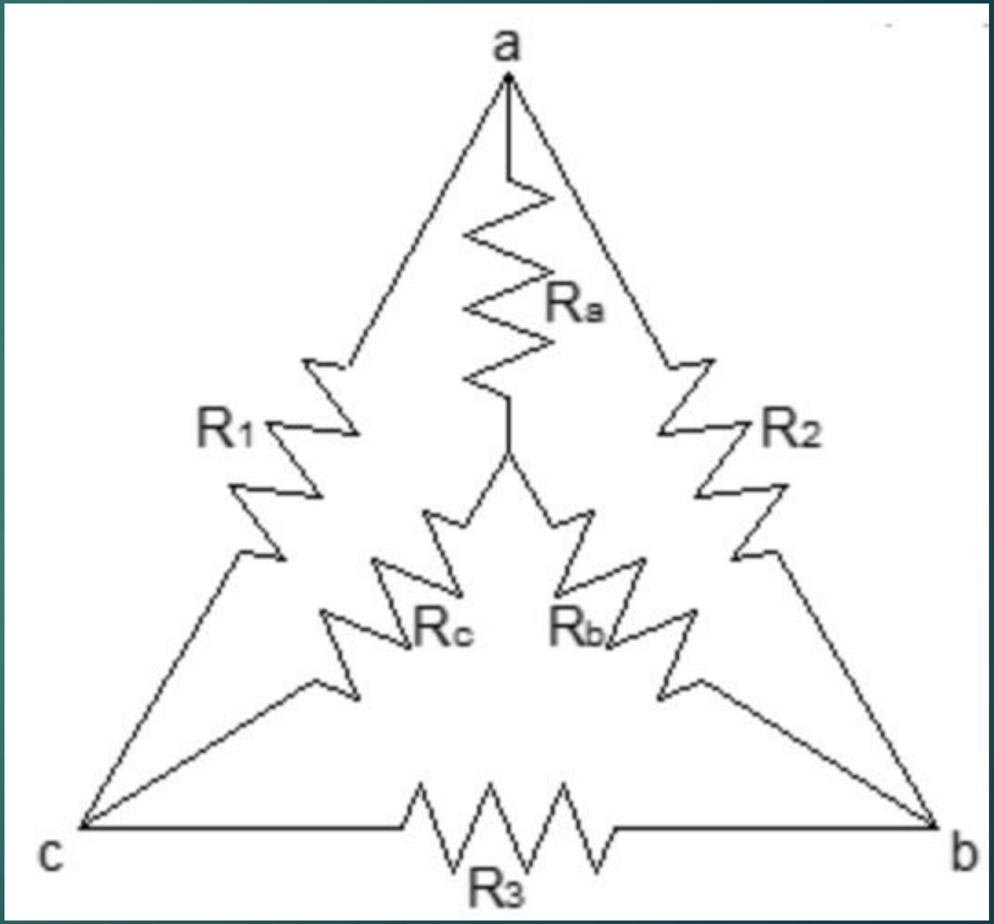
- Star to Delta transformation:

$$R_1 = \frac{R_aR_b + R_bR_c + R_cR_a}{R_b}$$

$$R_2 = \frac{R_aR_b + R_bR_c + R_cR_a}{R_c}$$

$$R_3 = \frac{R_aR_b + R_bR_c + R_cR_a}{R_a}$$



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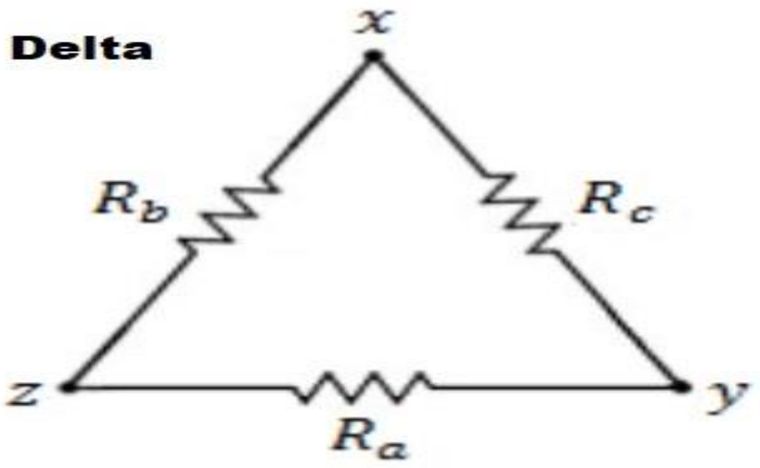
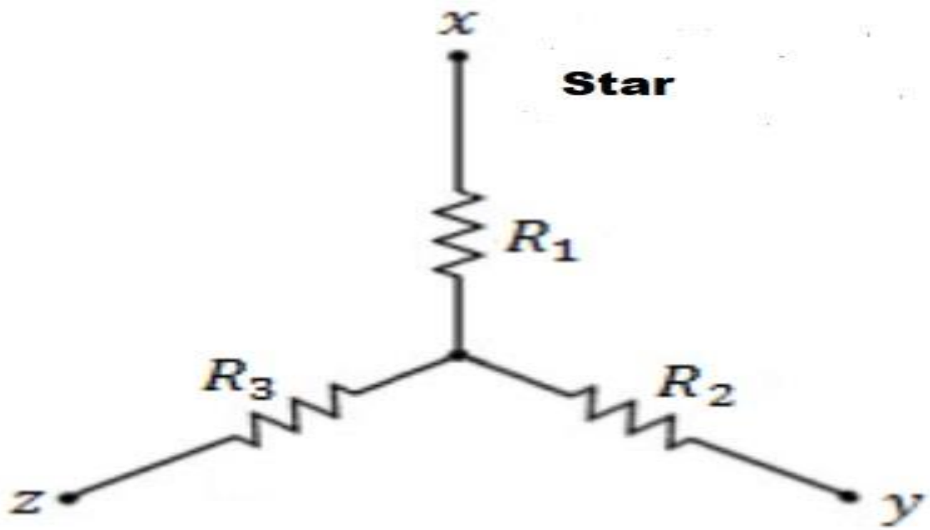




$$R_a = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1}$$

$$R_b = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2}$$

$$R_c = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$$

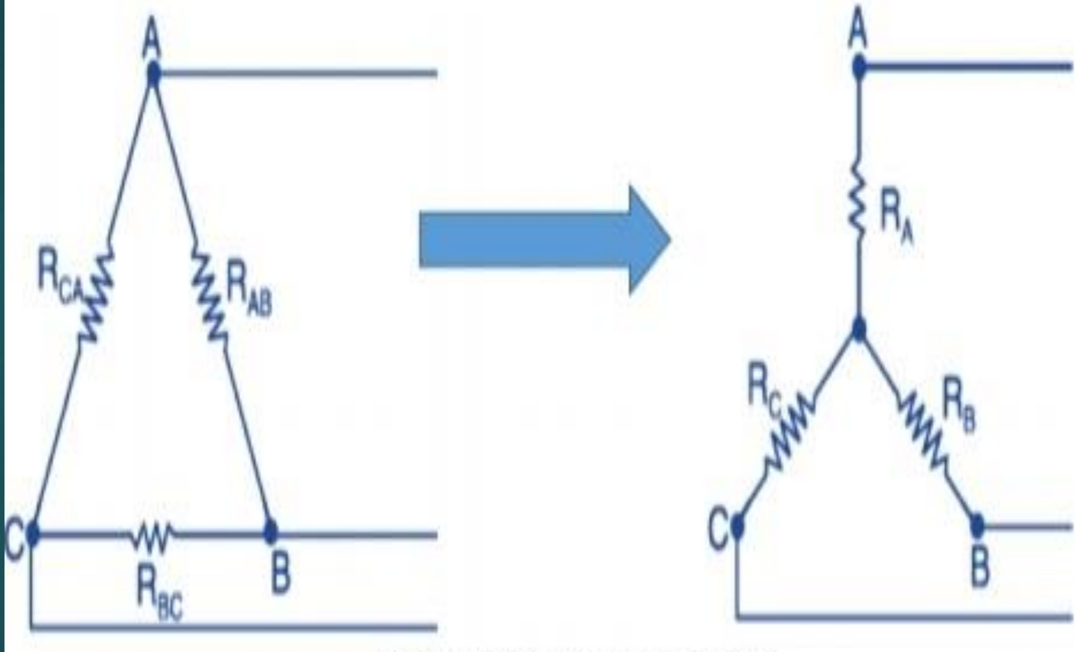
$$R_1 = \frac{R_bR_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_aR_c}{R_a + R_b + R_c}$$

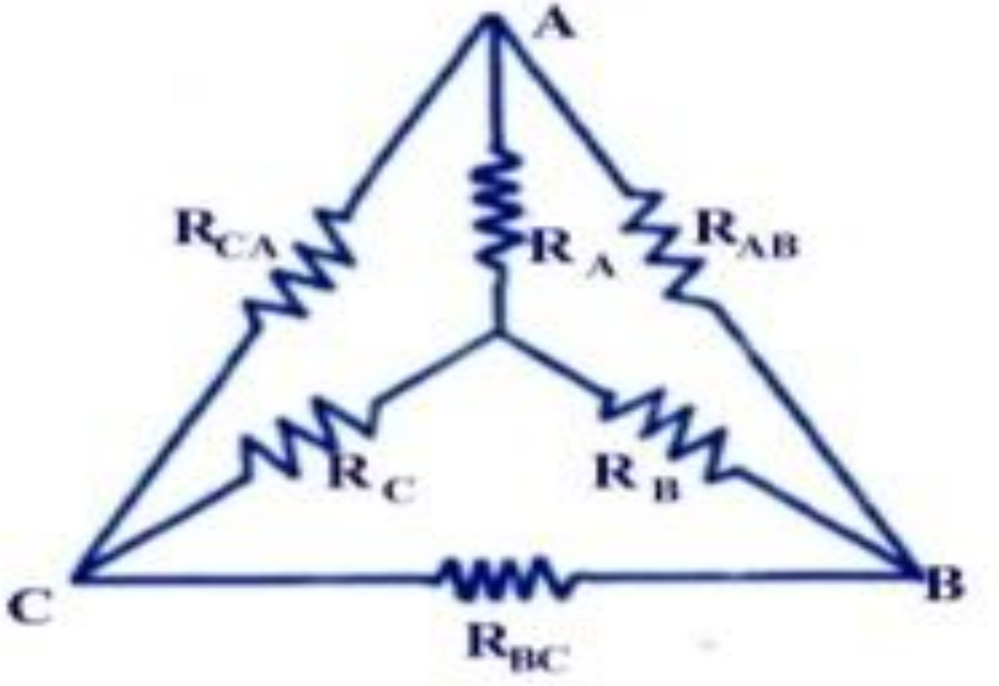
$$R_3 = \frac{R_aR_b}{R_a + R_b + R_c}$$

Delta – Star Conversion

- Any arm of Star connection = Product of two adjacent arms of Delta/Sum of arms of delta
- Three resistors are R_{AB},R_{BC} and R_{CA} connected in delta fashion and its equivalent star connection as shown in figure



Delta and its equivalent Star



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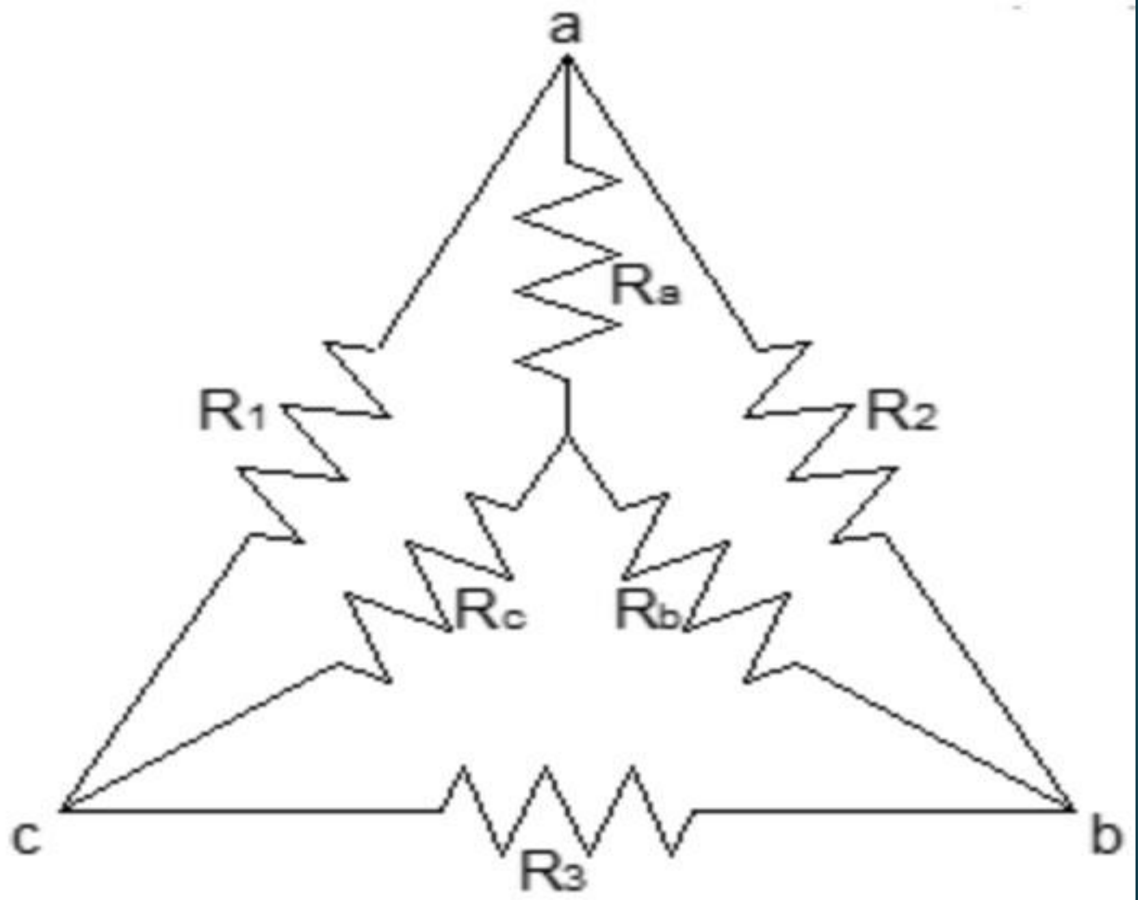
- Delta to Star transformation:

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

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

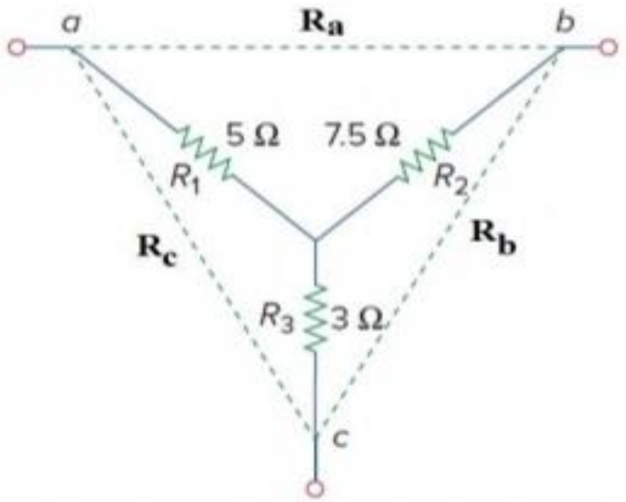
$$R_c = \frac{R_1 R_3}{R_1 + R_2 + R_3}$$

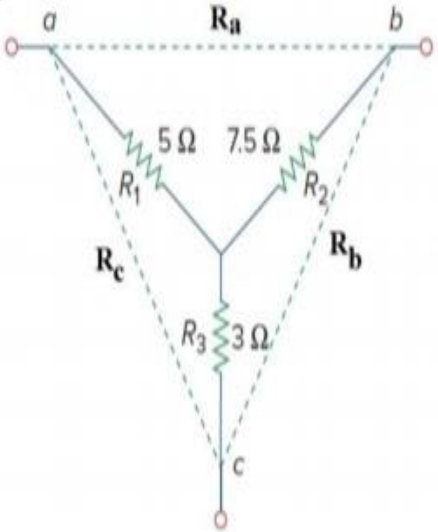


Problems on Star-Delta Transformation

- Problem:

Q. Convert the Y network to an equivalent Δ network. Soln:



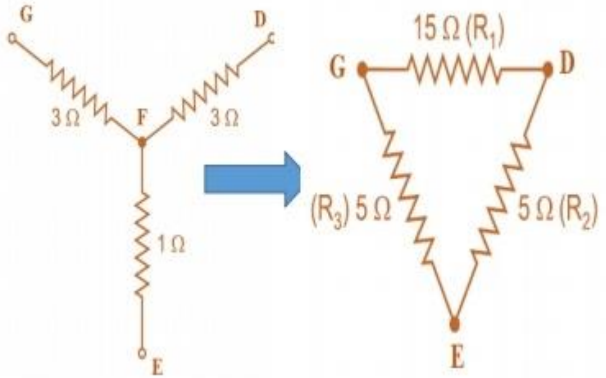


$$R_a = 7.5 + 5 + \frac{7.5 \times 5}{3} = 25\ ohms$$

$$R_b = 7.5 + 3 + \frac{7.5 \times 3}{5} = 15\ ohms$$

$$R_c = 5 + 3 + \frac{5 \times 3}{7.5} = 10\ ohms$$

Q: Converting inner STAR (3 ohms, 3 ohms and 1 ohms) into Delta.



$$R_1 = 3 + 3 + \frac{3 \times 3}{1} = 15\ ohms$$

$$R_2 = 3 + 1 + \frac{3 \times 1}{3} = 5\ ohms$$

$$R_3 = 1 + 3 + \frac{1 \times 3}{3} = 5\ ohms$$

Continued…….

- Problem: Find the equivalent resistance of Star/Delta circuit

Solution: Circuit is the combination of neither series nor parallel circuit

Such circuit form star/delta. Use star/delta transformation and convert to equivalent series – parallel circuit

Changing delta formed by points A,B,C into equivalent star

R_{star} = R x R/R+R+R = R/3

the circuit is formed is now combination of series-parallel circuit

the series- parallel circuit is further simplified to series circuit

the circuit is now becomes a simple series- parallel circuit and can be solved easily

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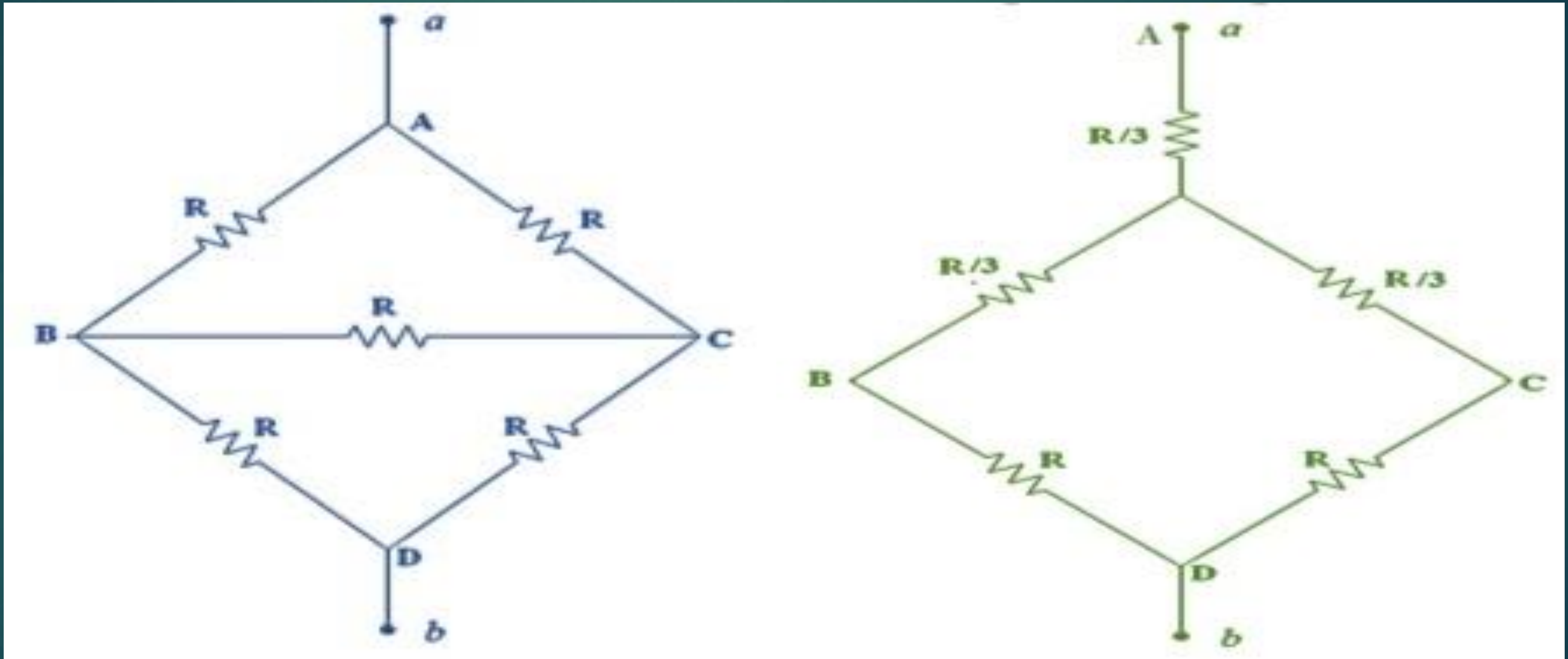

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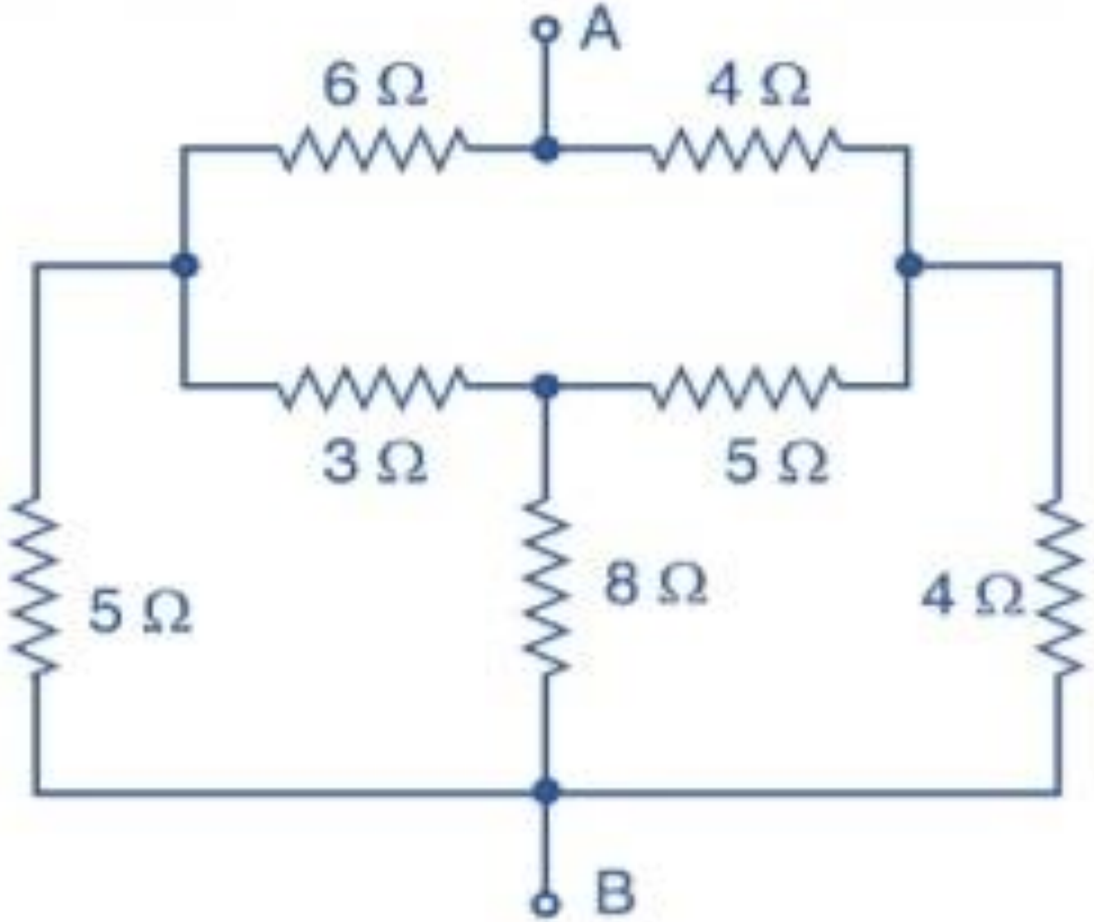
Q. Calculate equivalent resistance across terminals A and B.



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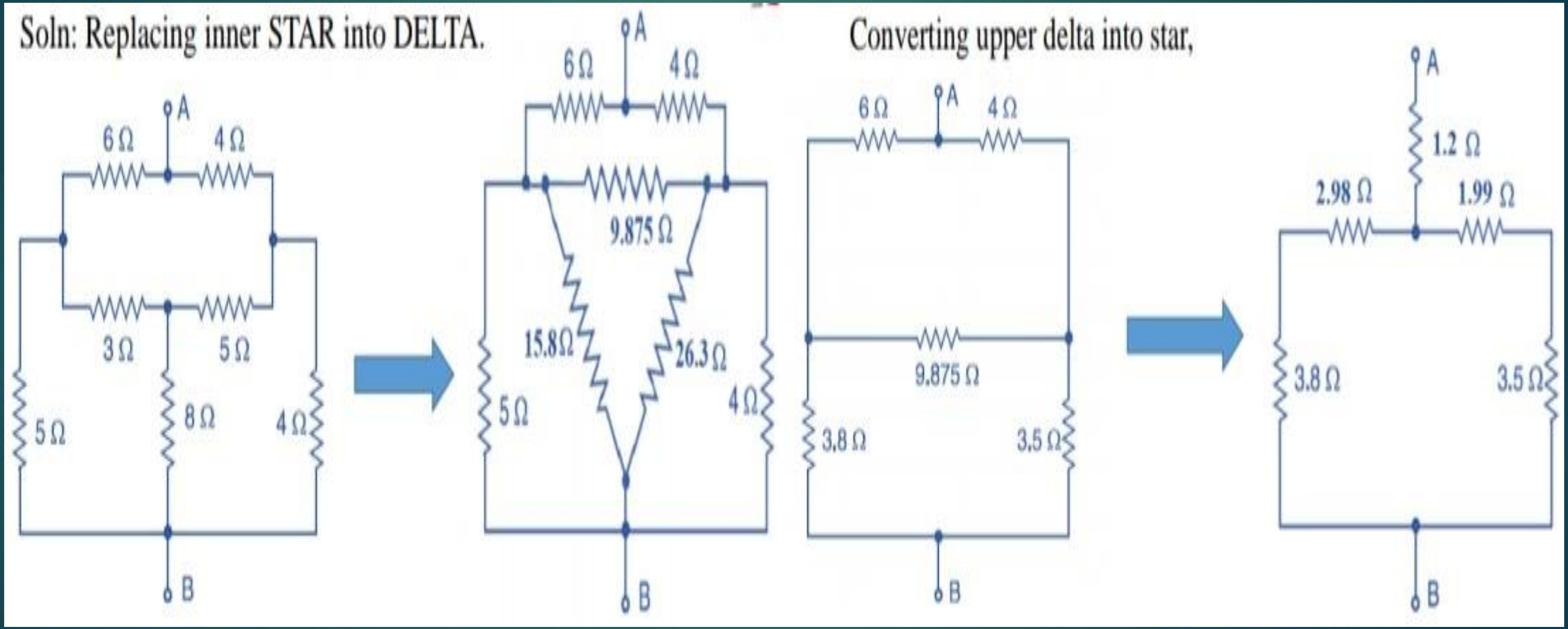
Solution:



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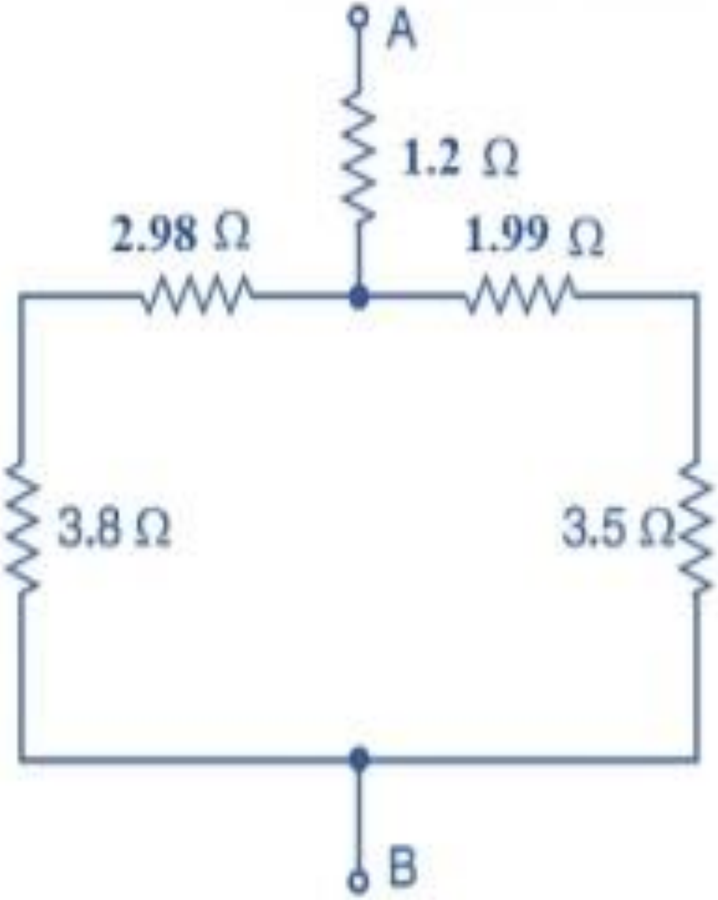
Now equivalent resistance can be calculated as,



$$R_{eq} = (3{\cdot}8 + 2{\cdot}98) \,||\, (1{\cdot}99 + 3{\cdot}5) + 1{\cdot}2$$
$$= 4.23 \text{ ohms}$$

Network Theorems

- Types of theorems:
  1.Super Position Theorem
  2.Thevinens Theorem
  3.Maximum Power Transfer Theorem
  4.Nortons Theorem
  5.Millimans Theorem
  6. Telligens Theorem

Super Position Theorem

- Statement: It states that any linear bi-lateral/bi-directional circuit/network having more than one source, the response in any one of the branches is equal to algebraic responses caused by the individual sources

or

Super position states that the voltage across (or current through) an element in a linear circuit is the algebraic sum of the voltage across (or current through) that element due to each independent source acting alone

- The principle of super position helps us to analyse linear circuit with more than one independent source by calculating the contribution of each independent source separately
- In super position theorem replace every voltage source by 0 V(or a short circuit) and every current source by 0 A(or a open circuit)

Continued……

- Steps to analyse the super position theorem:

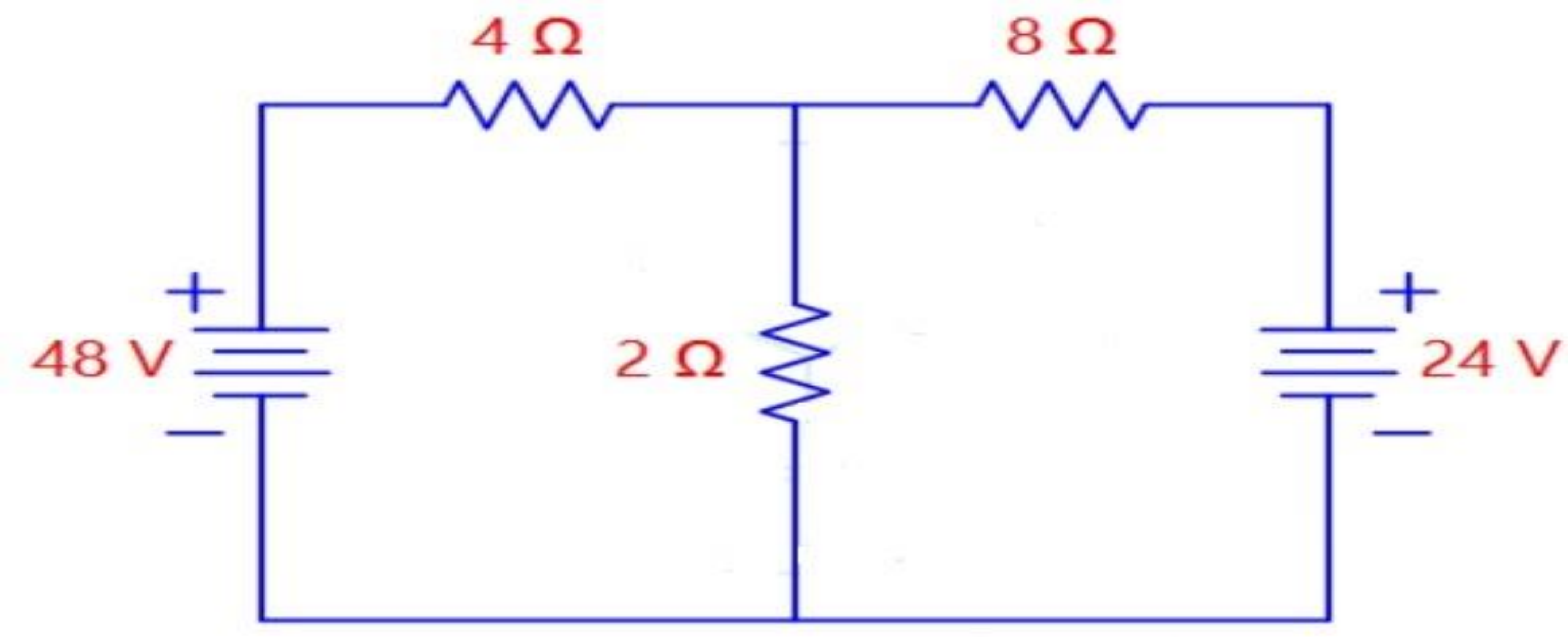
  1.Turn off all independent sources except one source .Find the output (V or I) due to that active source using mesh or nodal analysis

  2. Repeat step 1 for each of the independent sources

  3. Find total current by adding all individual currents from independent sources

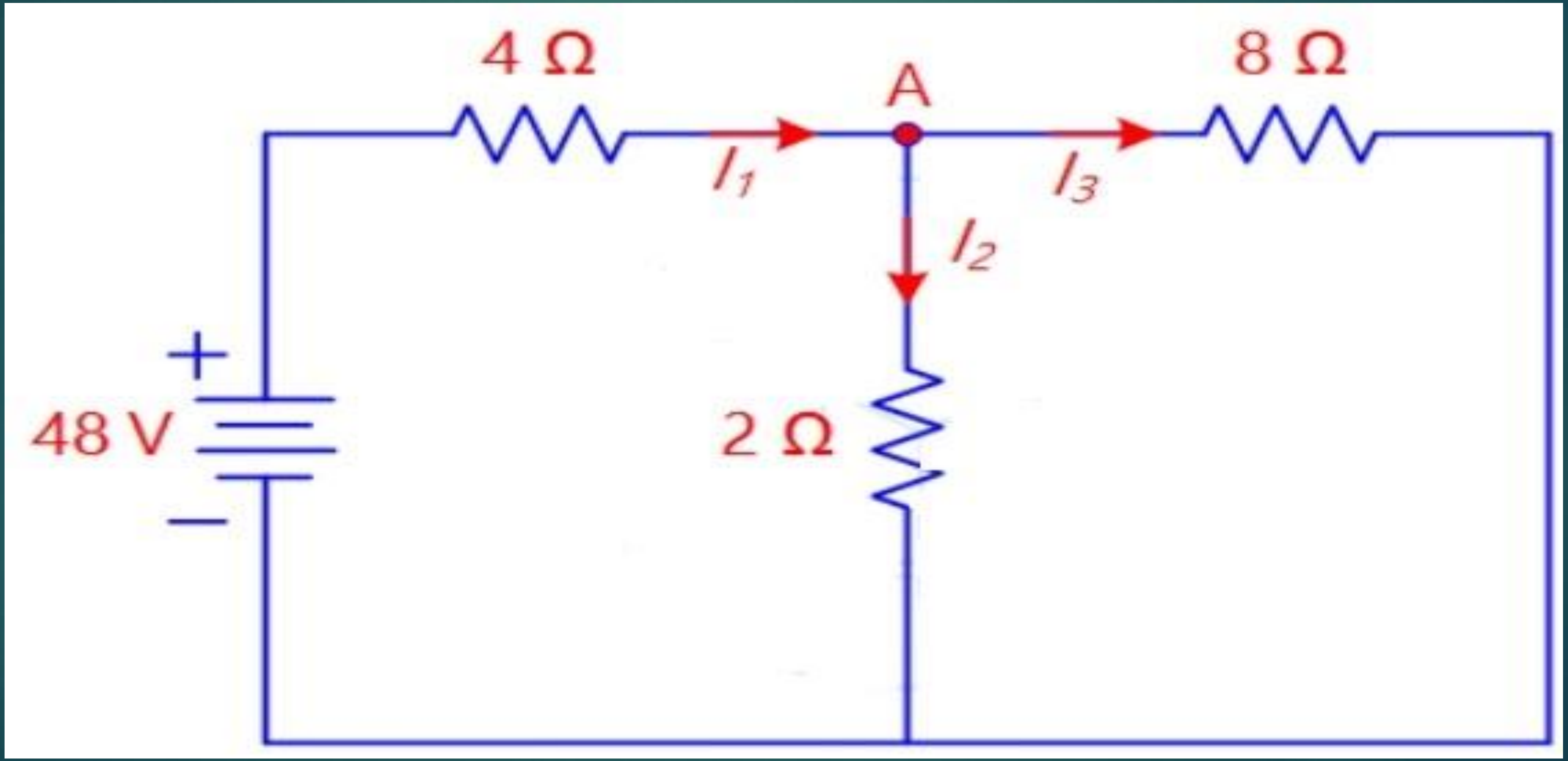
Super Position Theorem Problem

- Problem: Find the current through the 2 ohms resistor using super position theorem for the following circuit?



Super Position Theorem Problem

- Solution : At first find the current flowing through the 2 ohms resistor with 48 V source acting alone .Hence 24 V source replace by short circuit



Continued…………

- Hence current I_2 flows through the load resistor ,to find the load current ,first find the total current supplied by the source I_1 with its total resistance. Then apply current division rule and find the current through the 2 ohms resistor with 48 V source acting alone. calculations for this step as follows, From circuit $I_1 = I_{total}$

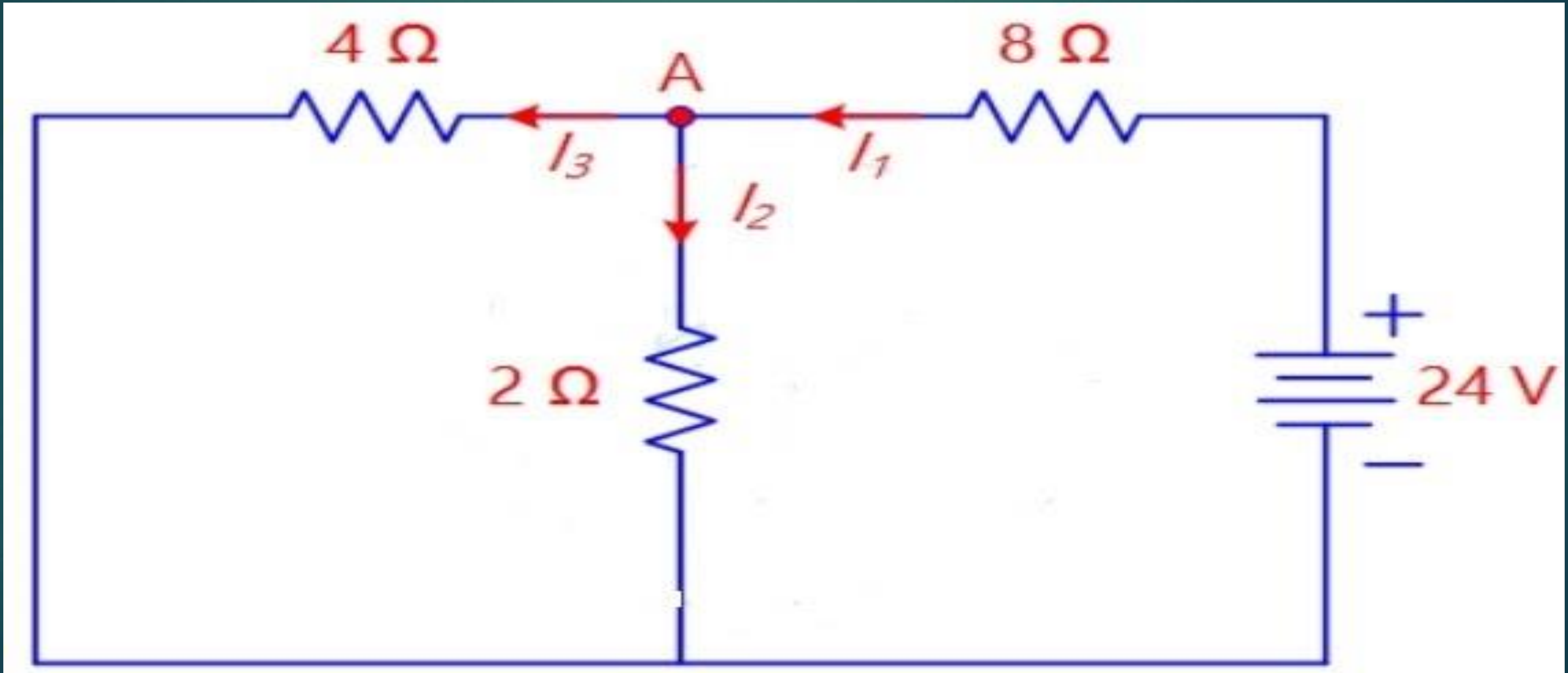
$$R_{eq} = 4 + \frac{8 \times 2}{8 + 2} = 4 + 1.6 = 5.6\ \Omega$$

$$I_{total} = \frac{48}{5.6} = 8.57\ A$$

$$I_{2\Omega(48V)} = 8.57 \times \frac{8}{8 + 2} = 6.86\ A$$

Continued…………..

- Now consider the 24 V source acting alone and replace 48 V source by short circuit ,now find total resistance of the circuit and find the total current supply by the circuit



Continued……..

- From the circuit $I_1 = I_{total}$

$$R_{eq} = 8 + \frac{4 \times 2}{4+2} = 8 + 1.33 = 9.33\ \Omega$$

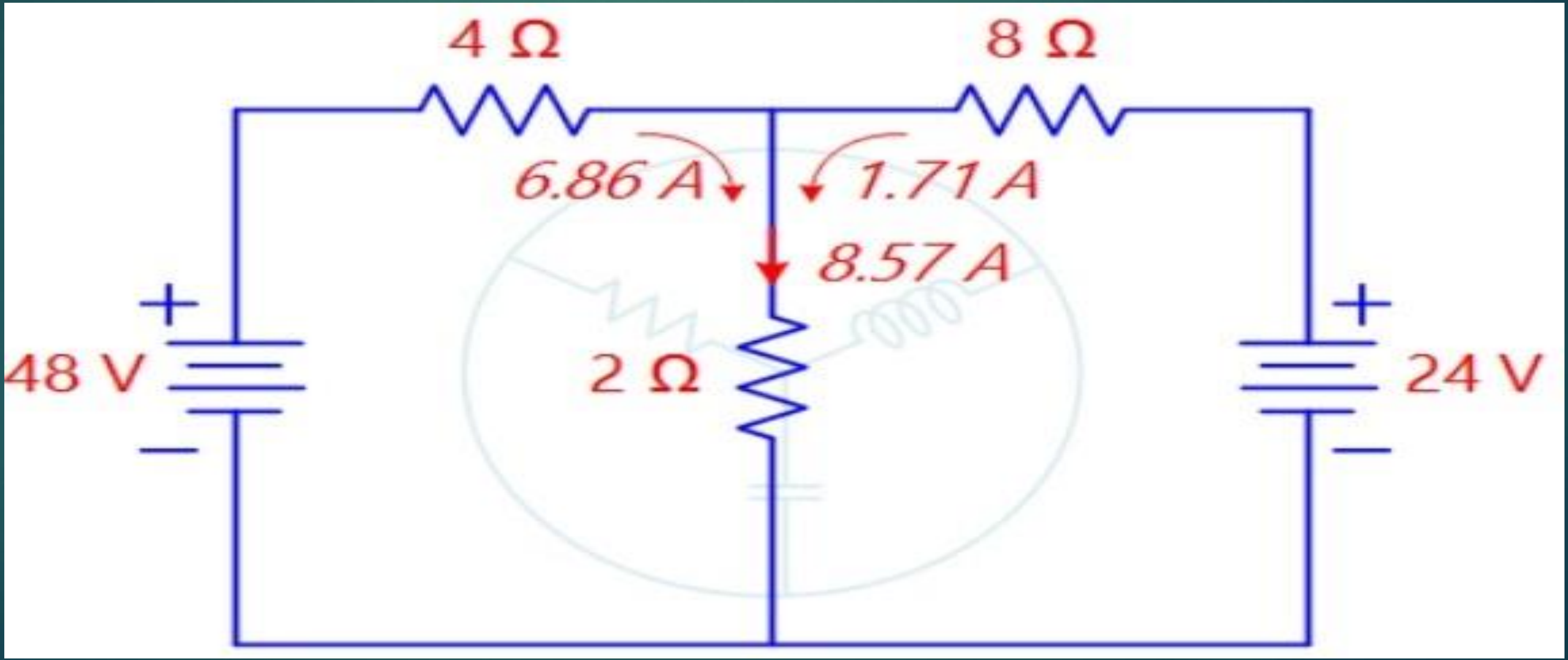
$$I_{total} = \frac{24}{9.33} = 2.57\ A$$

$$I_{2\Omega(24V)} = 2.57\frac{4}{4+2} = 1.71\ A$$

Continued……..

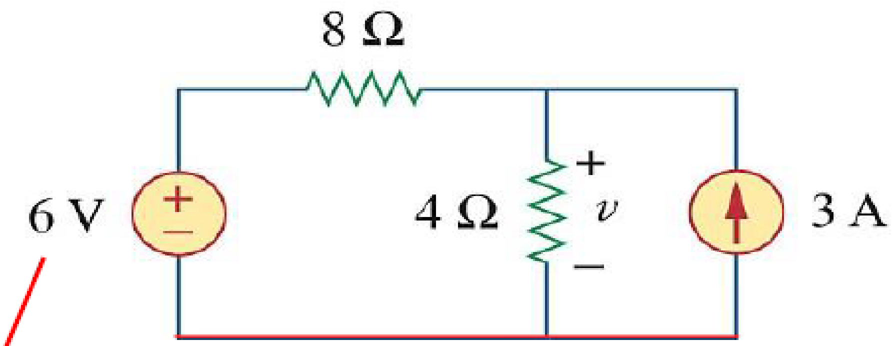
- Finally add two currents flowing through 2 ohms resistor considering their directions, hence two currents are flowing through same direction

$I_{2\ (2\ \text{ohms total})} = I_{2\ (2\text{ohms at } 48V)} + I_{2\ (2\text{ohms at } 24V)} \quad = \quad 6.86 + 1.71 = 8.57\ A$



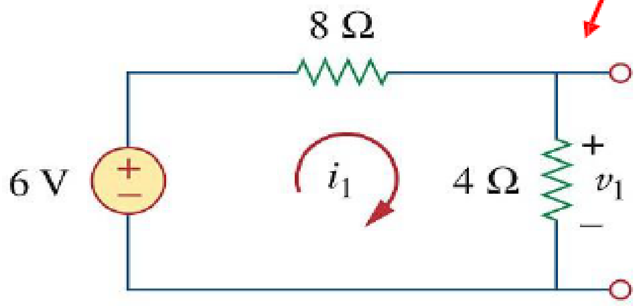
Super Position Theorem Problem

Example: Use the superposition theorem to find v in the circuit.

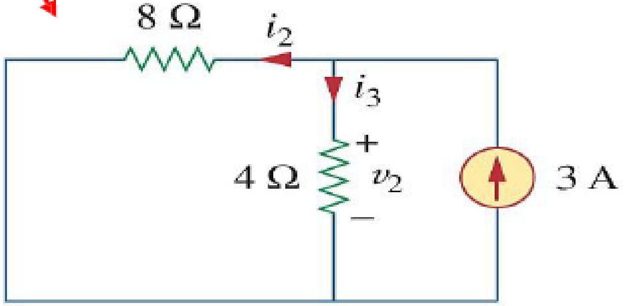


$$\boxed{v = v_1 + v_2}$$

3A is discarded by open circuit



6V is discarded by short circuit



$$v = v_1 + v_2 = 2 + 8 = 10 \text{ V}$$

$$12i_1 - 6 = 0 \quad \Rightarrow \quad i_1 = 0.5 \text{ A}$$

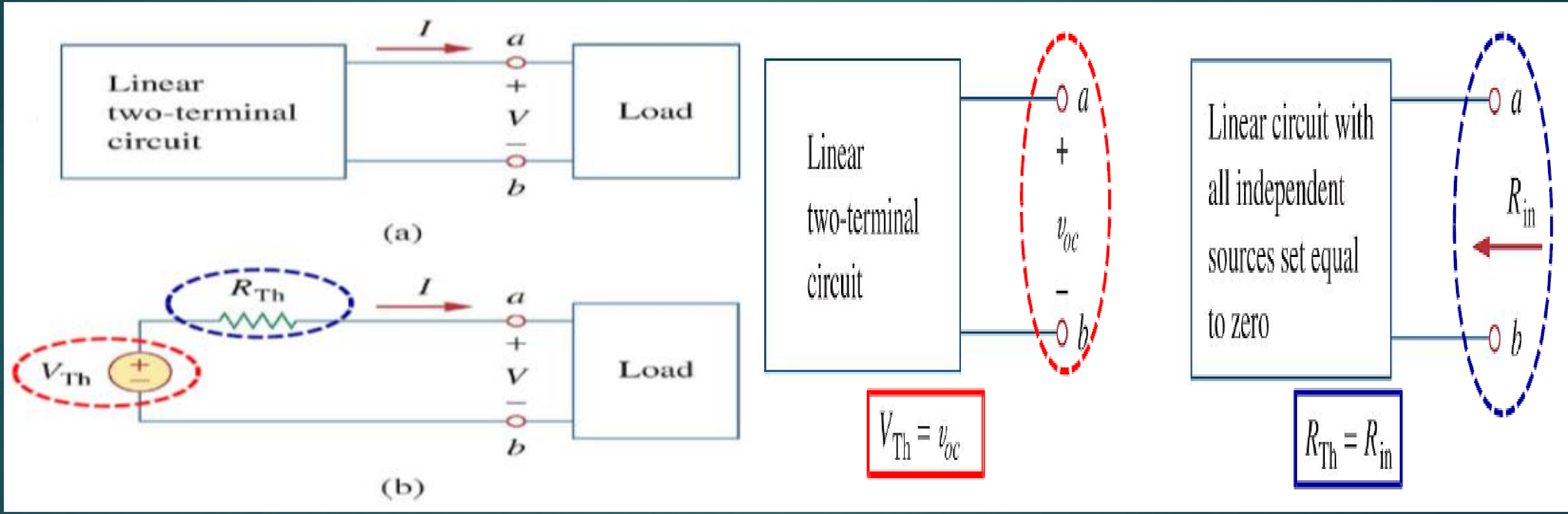
$$v_1 = 4i_1 = 2 \text{ V}$$

$$i_3 = \frac{8}{4 + 8}(3) = 2 \text{ A}$$

$$v_2 = 4i_3 = 8 \text{ V}$$

Thevenins Theorem

- Statement: It states that any linear bi-lateral/bi-directional circuit/network having more no of elements, it can be replaced by a single equivalent circuit consisting of voltage source V_{TH} in series with R_{TH}



- V_{th} is the open circuit voltage , R_{th} is the total equivalent resistance if independent sources off

Continued……

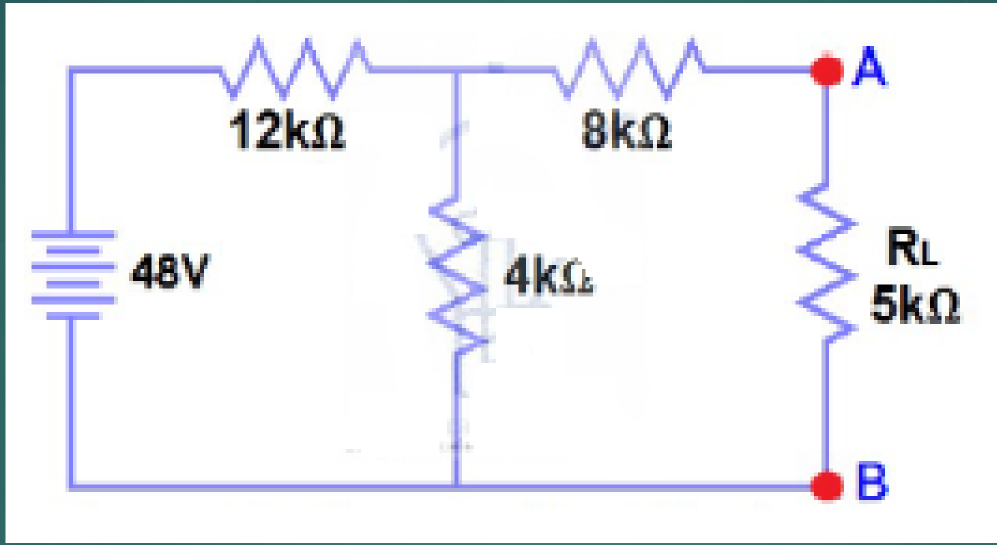
- Steps to analyse the Thevenins theorem:

1. Open the load resistor(R_L)
2. Calculate/measure the open circuit voltage .This is the Thevenins voltage V_{TH}
3. Open current sources and short circuit the voltage sources
4. Calculate / measure the open circuit resistance.This is the Thevenins Resistance R_{TH}
5. Now redraw the circuit with measured open circuit voltage V_{TH} and measured open circuit resistance R_{TH} and it is connected in series with load resistance R_L
6. Now find the total current flowing through the load resistor using ohms law

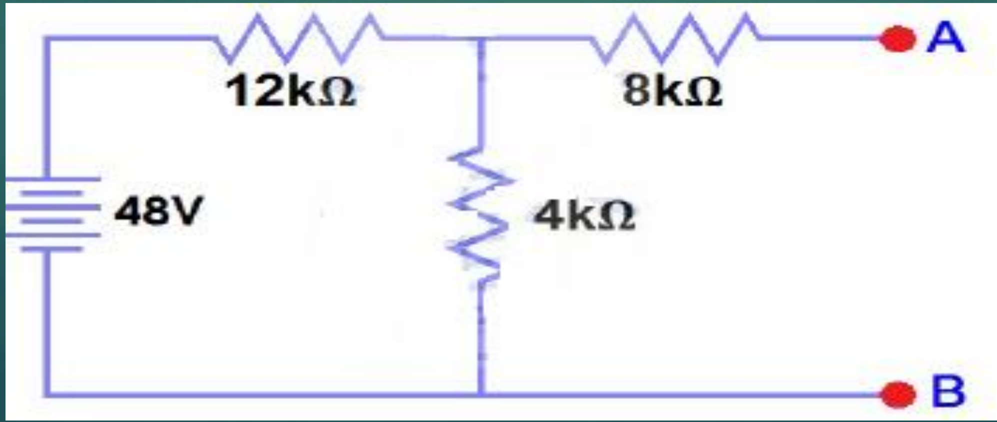
$$I_T = V_{TH} /(R_{TH}+ R_L)$$

Thevenins Theorem Problem

- Problem: Find the Thevenins equivalent circuit for the following circuit



Solution: open the load resistance (R_L)



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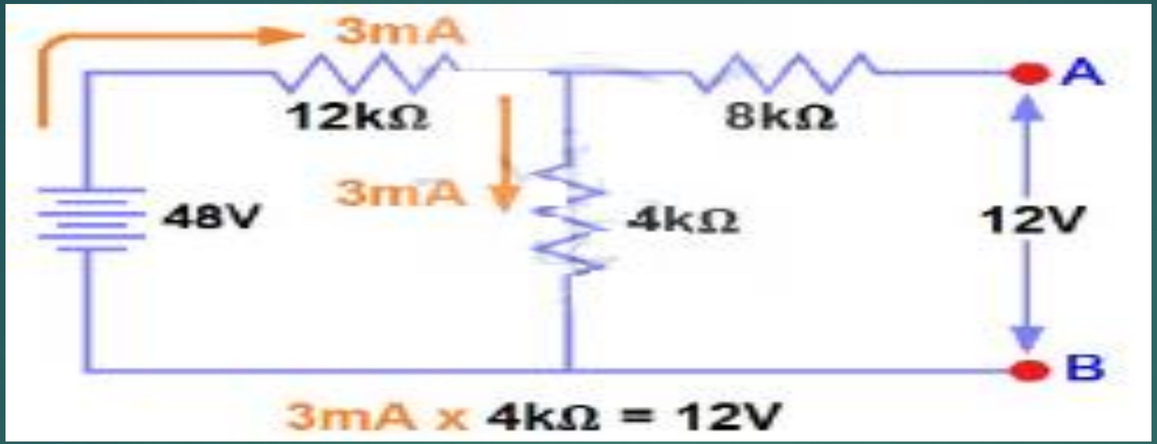


Apply KVL for the above circuit

-48 + I 12 K + I 4K =0

I 16 K = 48

I = 48/16K = 3 mA

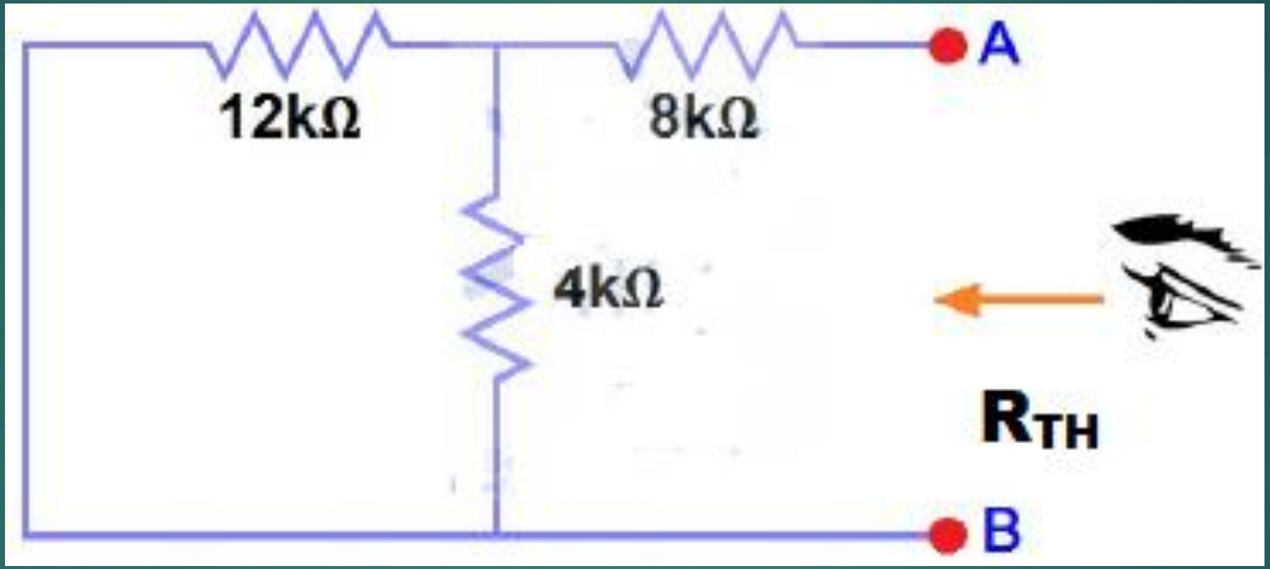
From the circuit Voltage across 4 K ohm resistor

$V_{4K} = I_{4K}$ x 4 K = 3 m x 4 K = 12 V

From the circuit $V_{4K} = V_{TH}$= 12 V

Thevenins Theorem Problem

- R_{TH} : short circuit all the independent voltage sources and open circuit the current sources



R_{TH} is the 12 K // 4 K and series combination of 8 K

so R_{TH} = (12 K x 4 K/ (12 K + 4 K)) + 8 K = 11 K ohms

Thevenins Theorem Problem

Thevenins equivalent circuit:

Apply KVL for above circuit

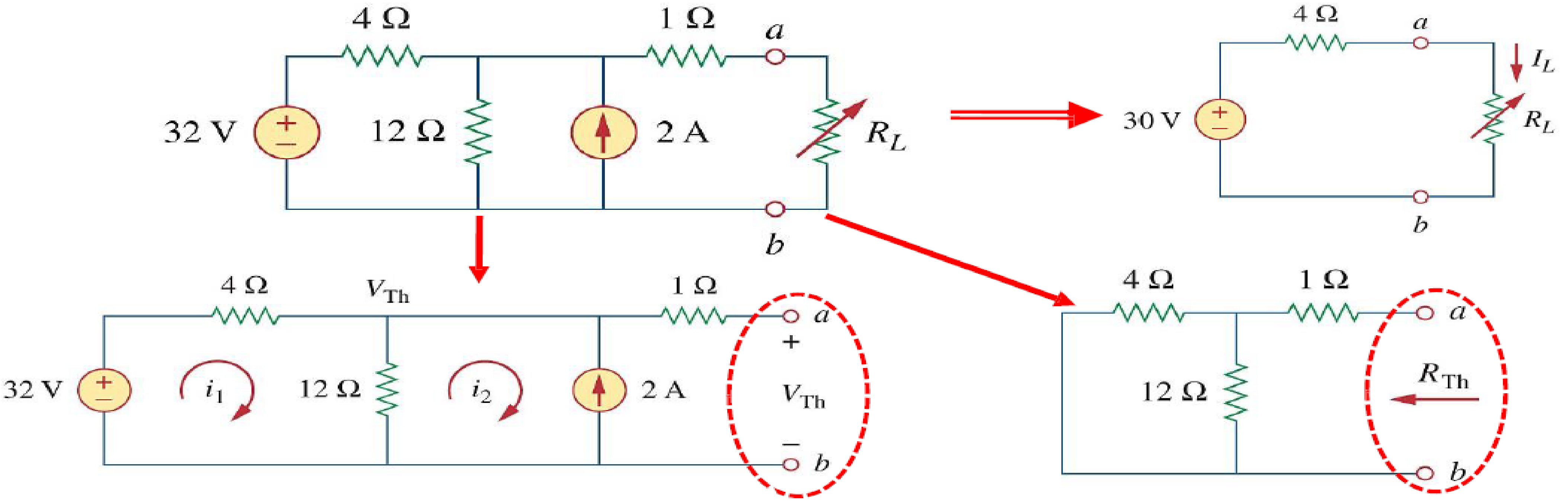
$-12 + I_L\ 11\ K + I_L\ 5\ K = 0$

$I_L = 12 / 16\ K = 0.75\ m\ A$

$V_L = I_L \times R_L = 0.75\ m\ A \times 5\ K = 3.75\ V$

Thevenins Theorem Problem

Example: Find the *Thevenin equivalent circuit* at the terminals a & b.



$$-32 + 4i_1 + 12(i_1 - i_2) = 0, \qquad i_2 = -2 \text{ A}$$

for i_1, we get $i_1 = 0.5$ A. Thus,

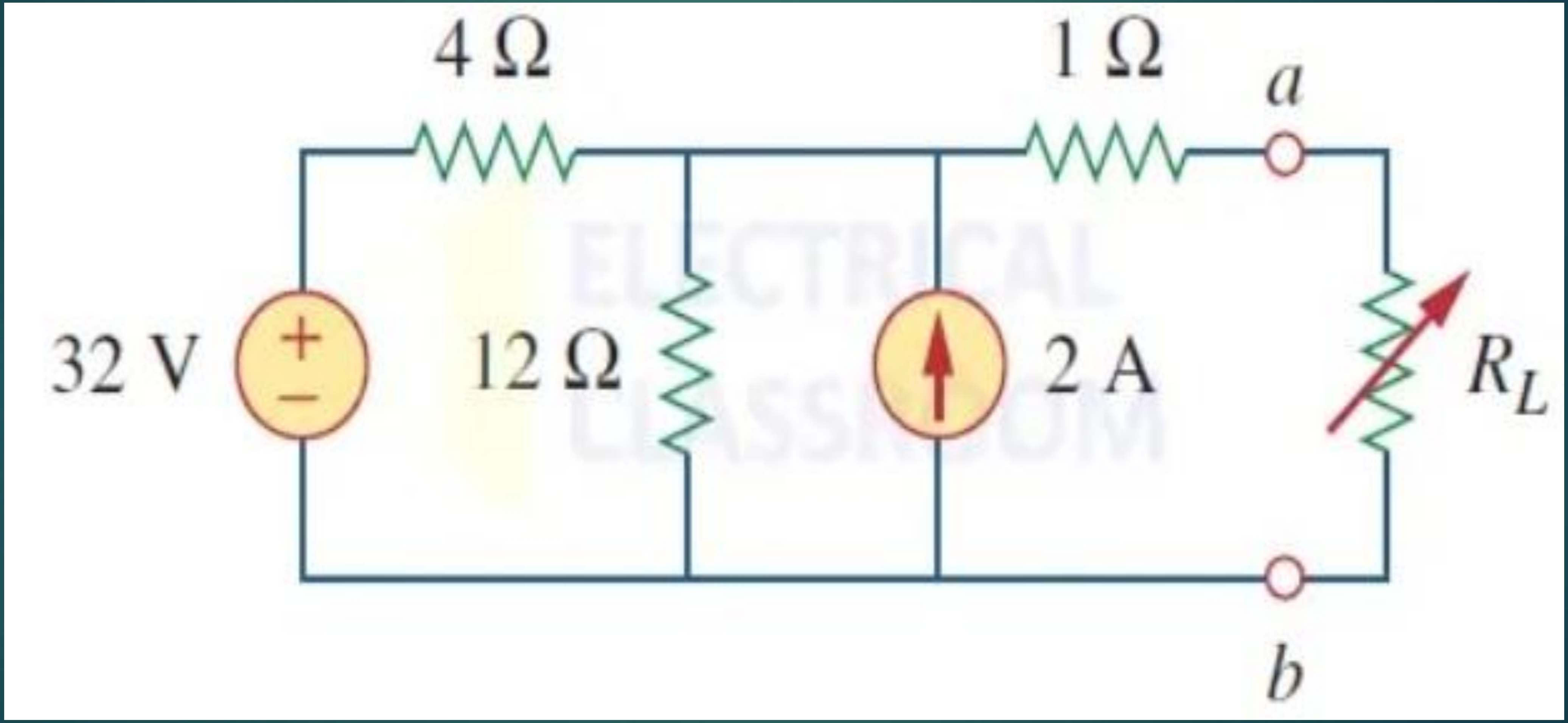
$$V_{\text{Th}} = 12(i_1 - i_2) = 12(0.5 + 2.0) = 30 \text{ V}$$

Indep. voltage source as a short circuit & the current source as an open circuit.

$$R_{\text{Th}} = 4 \parallel 12 + 1 = \frac{4 \times 12}{16} + 1 = 4\ \Omega$$

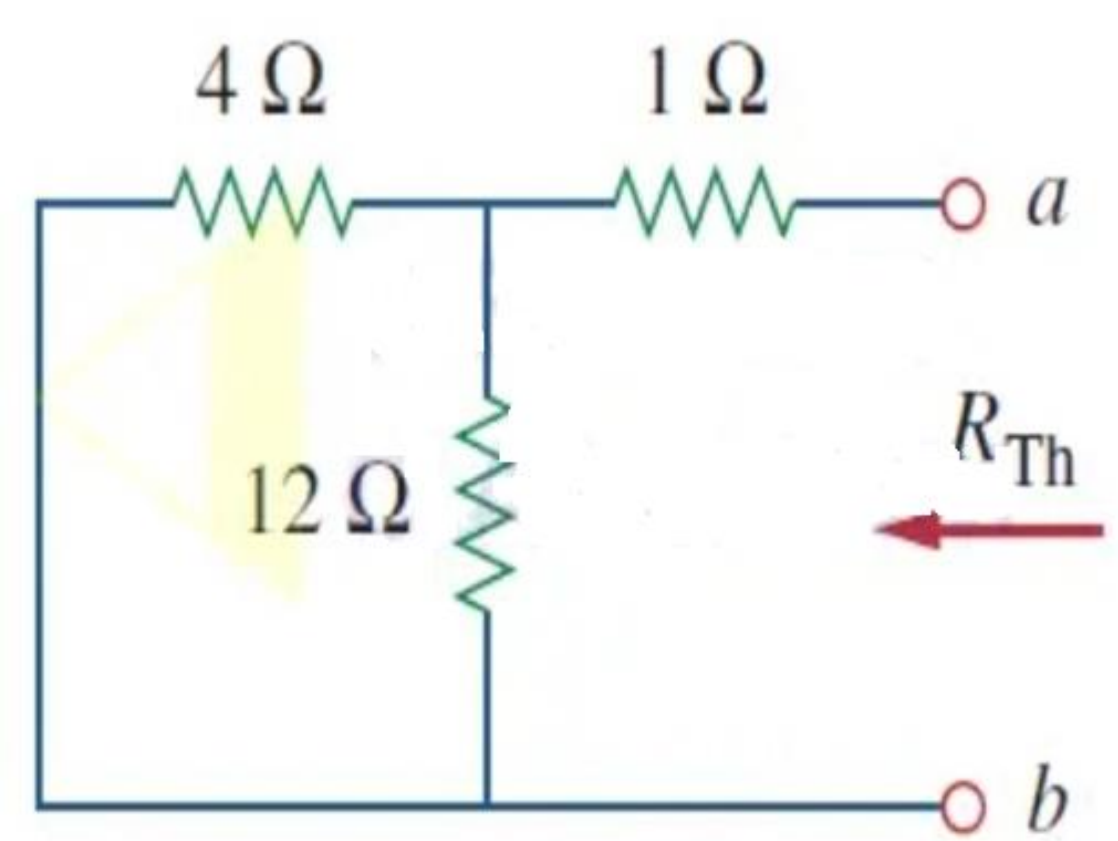
Thevenins Theorem Problem

- Problem: Find the Thevenins equivalent circuit for the following circuit

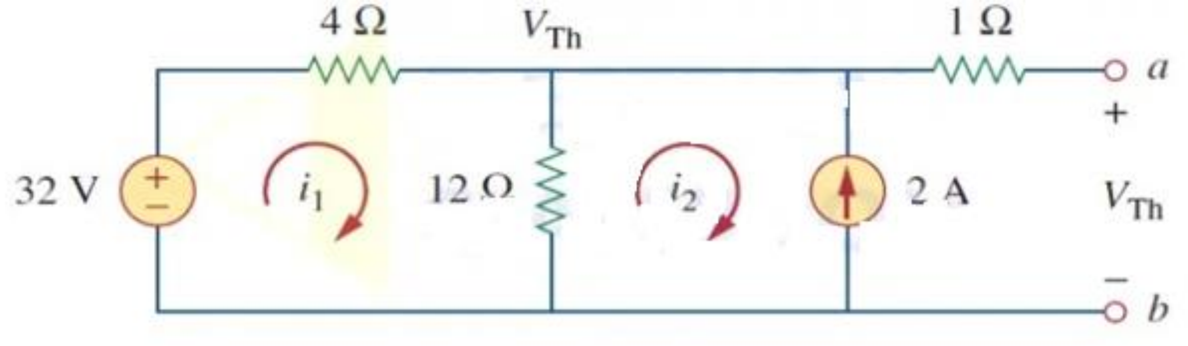


Continued……..

- Solution: Rth = 4 ohms



Thevenins voltage V_{TH} :



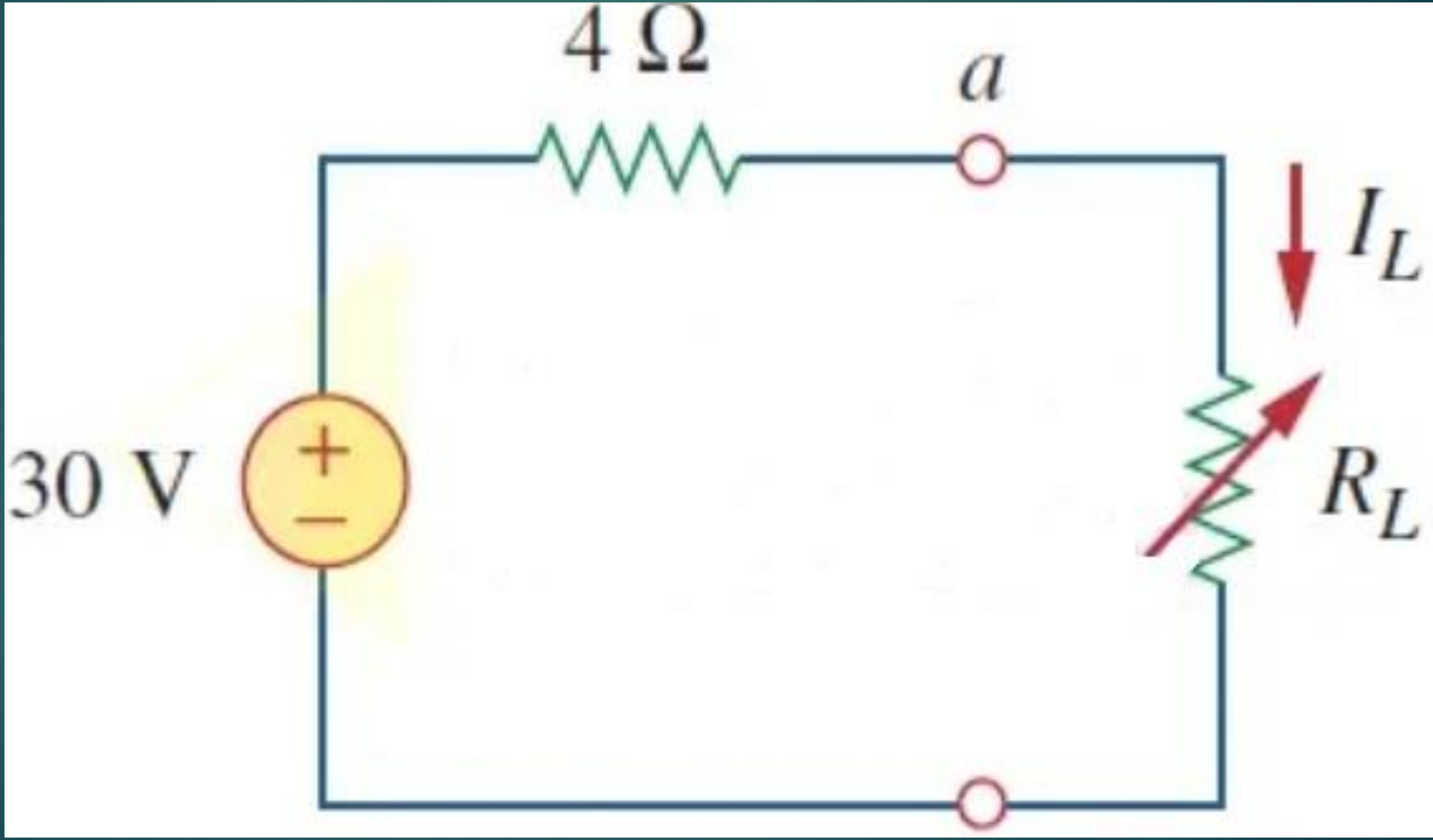
$4i_1 + 12(i_1 - i_2) = 32V$, $i_2 = -2A$

Solving the above equations, we get $i_1 = 0.5A$

Therefore $V_{th} = 12(i_1 - i_2) = 12(0.5 + 2) = 30V$

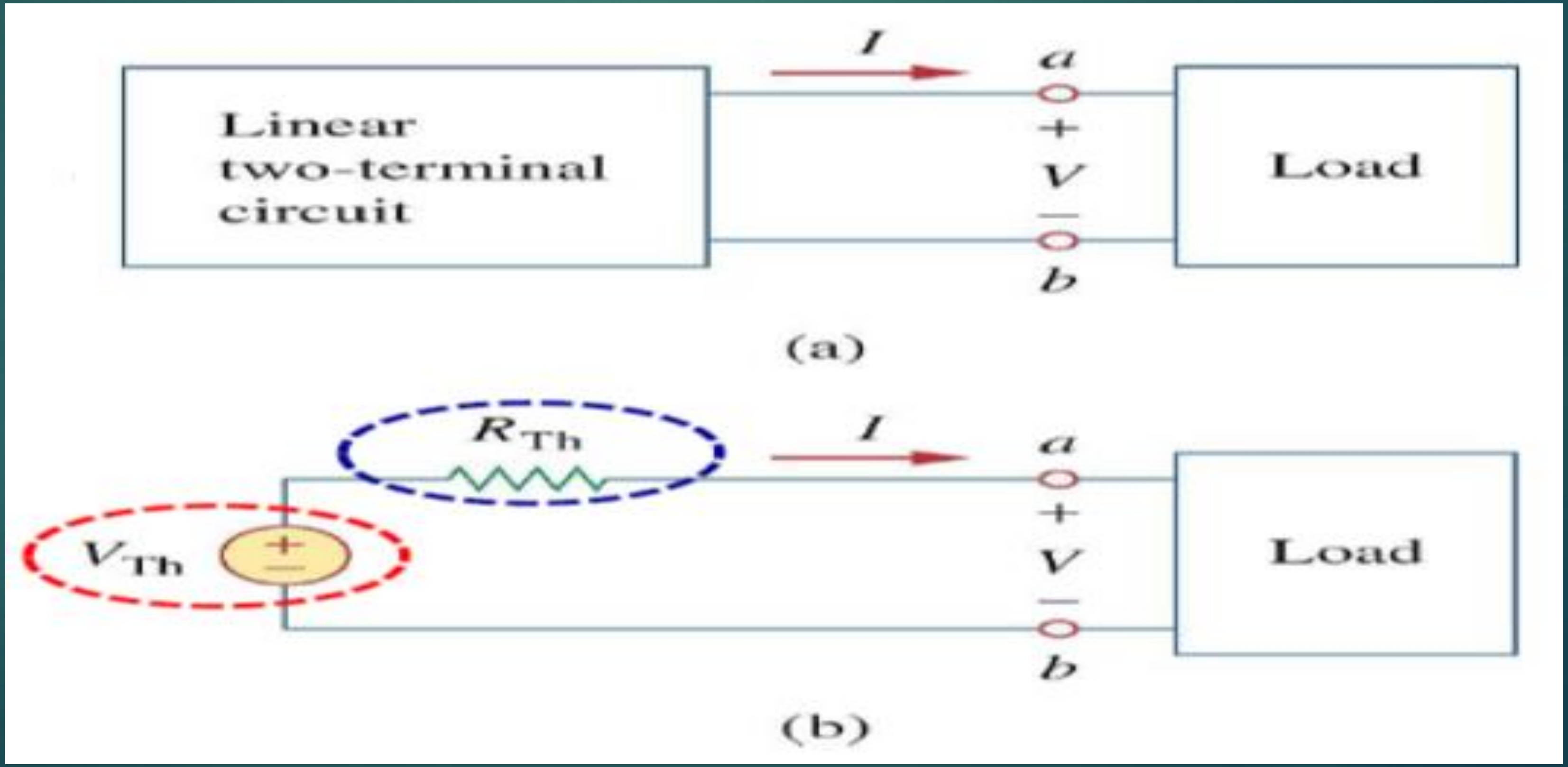
Continued…..

Thevenins equivalent circuit:



Maximum Power Transfer Theorem

- Statement: Its states that in a linear bilateral DC network ,maximum power is delivered to the load, when the load resistance is equal to the internal resistance of a source ,if it is an independent voltage source, then its series resistance is R_S or R_{TH} must equal to the load resistance R_L , i.e $R_S = R_L$ or $R_{TH} = R_L$



Continued………

- From the circuit current flowing through the load resistor is I_L

  $I_L = V_{TH}/(R_{TH} + R_L)$

  The Power absorbed by the load is given by

  $P_L = I_L{}^2 \times R_L$

  $P_L = (V_{TH}/(R_{TH} + R_L))^2 \times R_L$

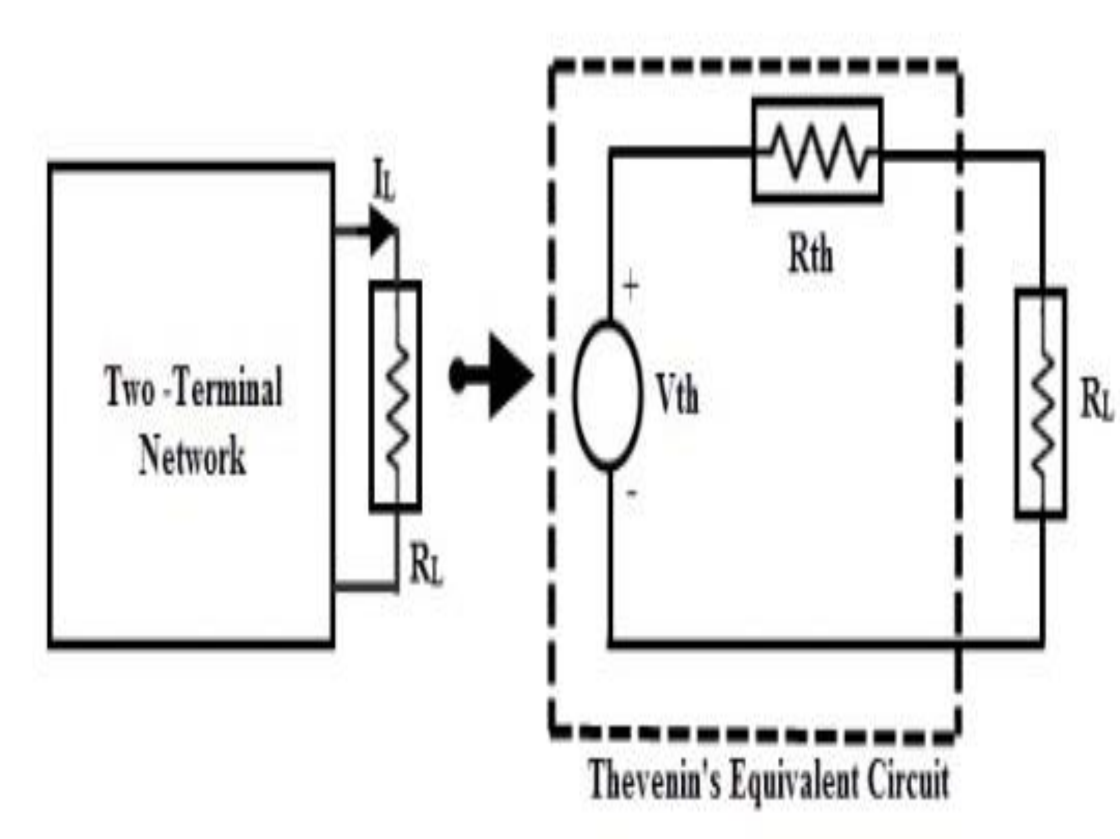
  From the above expression power delivered

  depends on the values of R_{TH} and R_L

  hence Thevenins equivalent is constant

  the power delivered from this equivalent

  source to the load entirely depends on the R_L



- To find the exact value of R_L, we apply differentiation to P_L with respect to R_L and equate to zero

Continued………

$$\frac{dP(R_L)}{dR_L} = V_{Th}^{\ 2}\left[\frac{(R_{Th}+R_L)^2 - 2R_L \times (R_{Th}+R_L)}{(R_{Th}+R_L)^4}\right] = 0$$

$$\Rightarrow (R_{Th}+R_L) - 2R_L = 0$$

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

- therefore this is the condition of matching the load where the maximum power transfer occurs when load resistance is equal to Thevenins resistance of a circuit

Continued……..

- The maximum power delivered to the load is given by

$$P_{\max} = \left[\frac{V_{Th}}{R_{Th} + R_L} \right]^2 \times R_L \Bigg|_{R_L = R_{Th}}$$

$$= \frac{V_{Th}^{\;2}}{4\,R_{Th}}$$

obviously the power transferred by the source is also given by

$$P_{\max} = \left[\frac{V_{Th}}{R_{Th} + R_L} \right]^2 \times R_L \Bigg|_{R_L = R_{Th}}$$

$$= \frac{V_{Th}^{\;2}}{4\,R_{Th}}$$

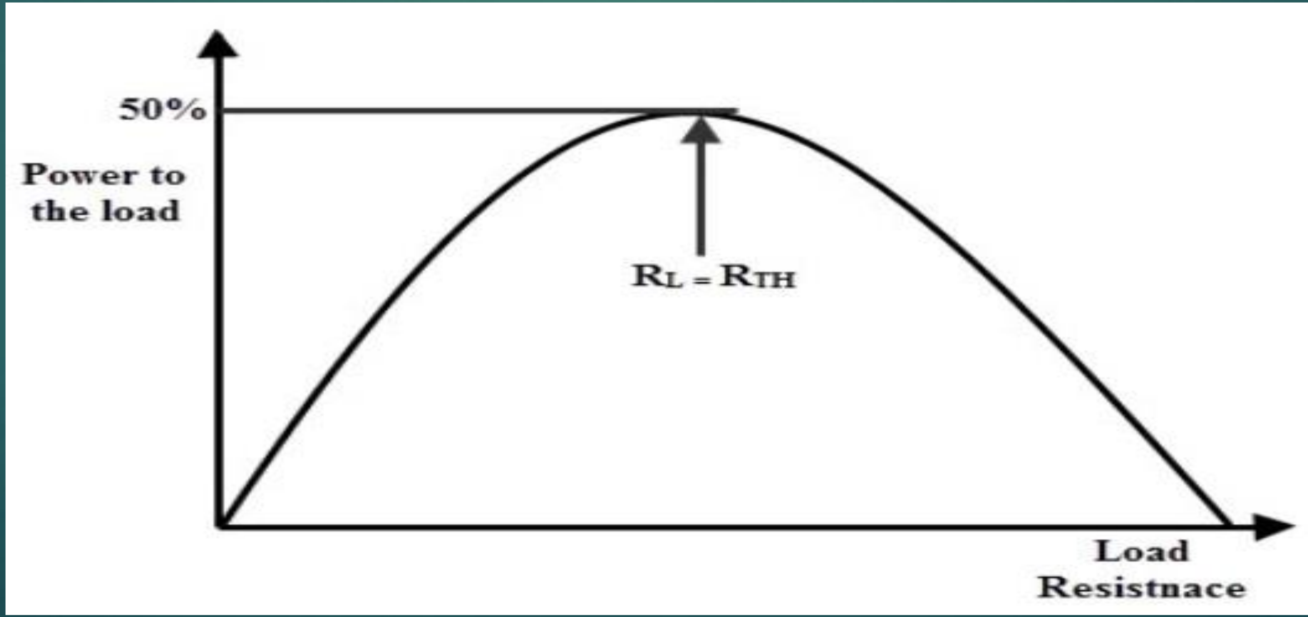
Continued………

- The load power and source power being same
- Total power supplied is thus

$$P_{total} = V_{th}^2 / 4 R_{th} + V_{th}^2 / 4 R_{th} = V_{th}^2 / 2 R_{th} = 0.5 (V_{th}^2 / R_{th})$$

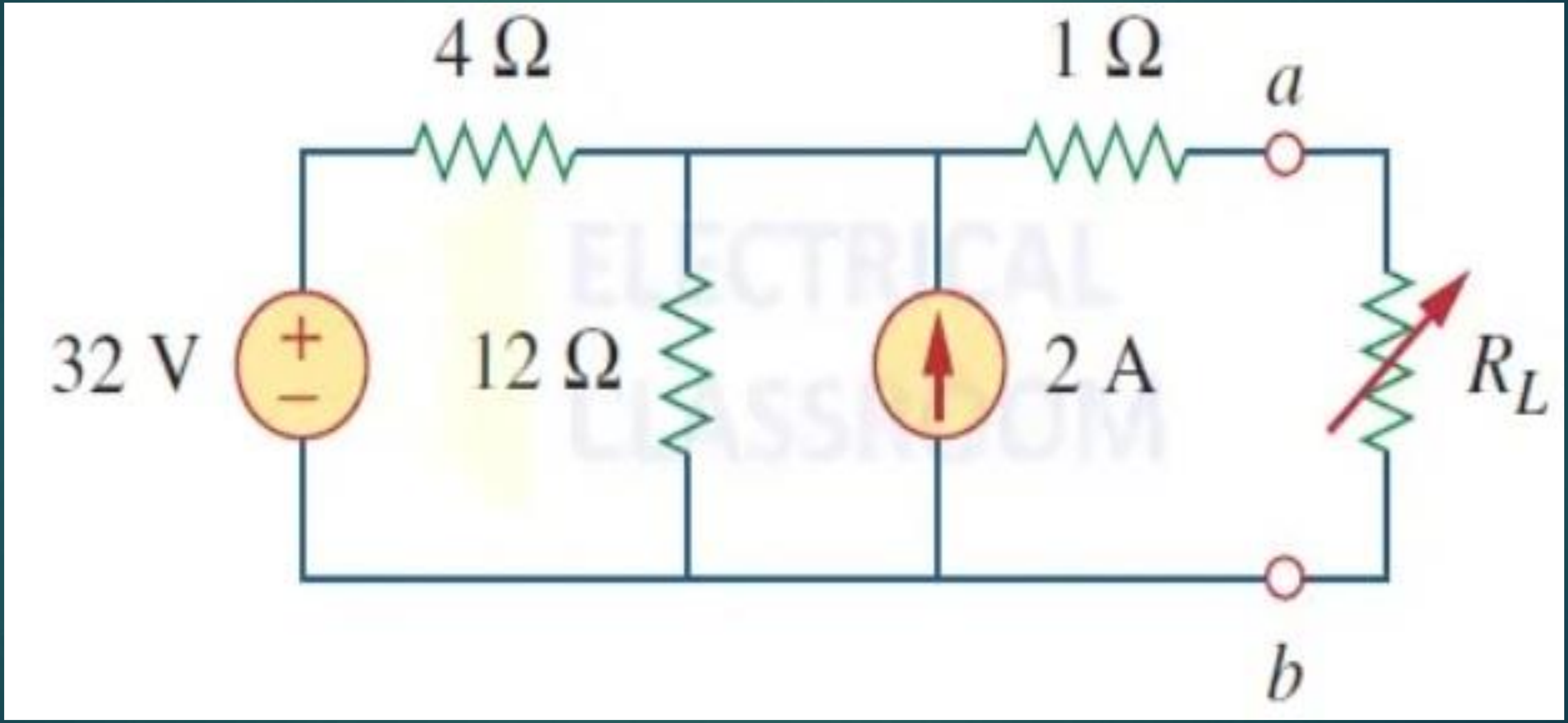
Maximum power transfer the efficiency η is given by η

$$\eta = (P_{max} / P_{total}) \times 100 = 50 \%$$



Maximum Power Transfer Theorem Problem

- Problem: Find the maximum power delivered to the load for the following circuit



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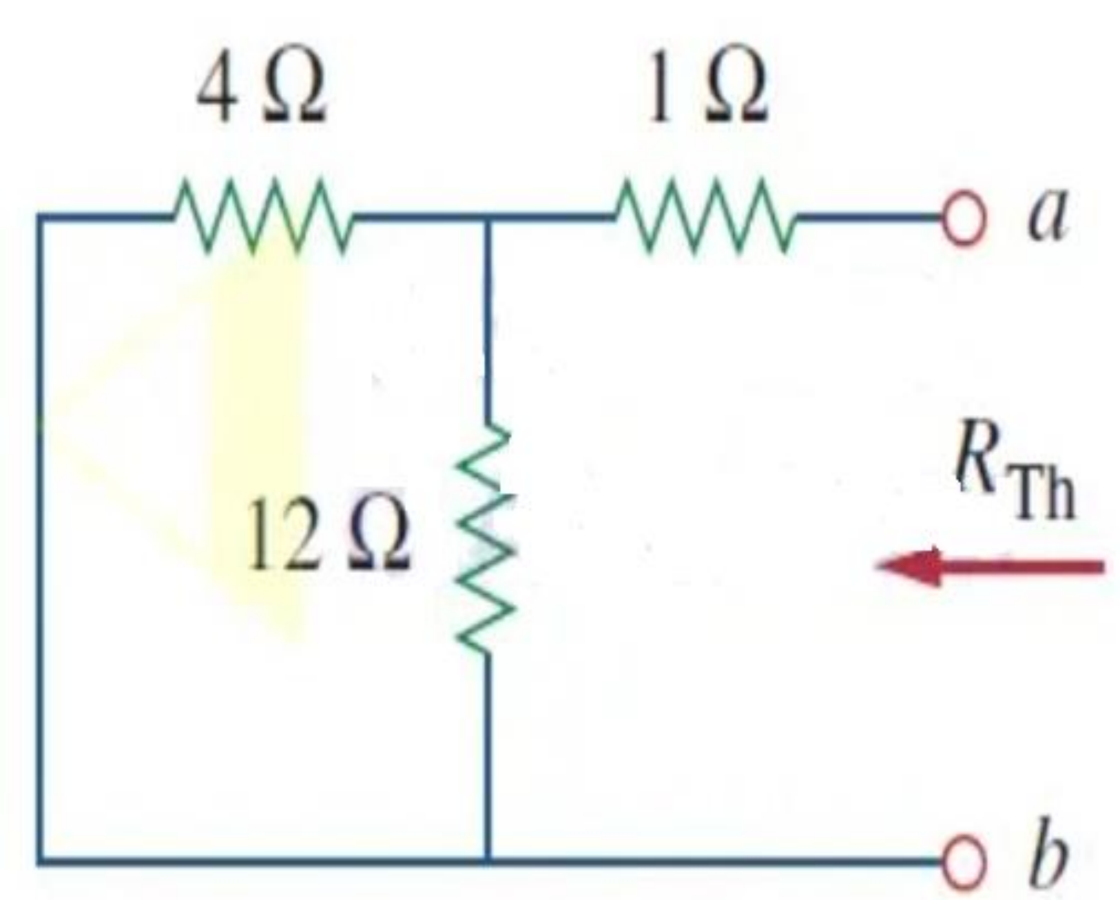
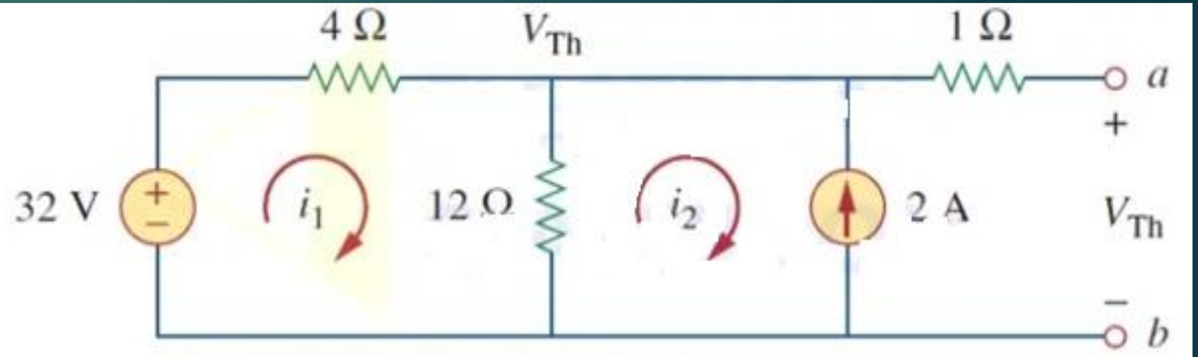
- Solution: Rth = 4 ohms



Thevenins voltage V_{TH} : 30 V



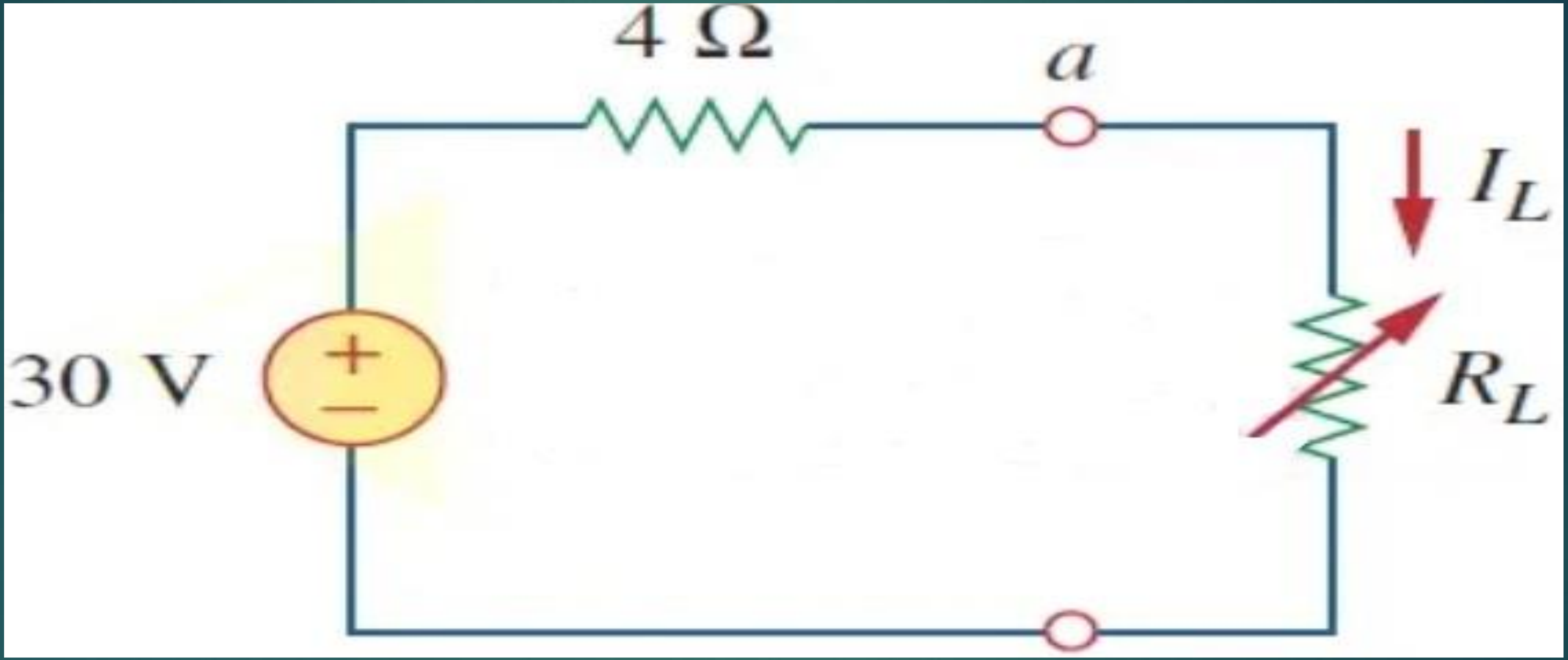
$4i_1 + 12(i_1 - i_2) = 32V$, $i_2 = -2A$

Solving the above equations, we get $i_1 = 0.5A$

Therefore $V_{th} = 12(i_1 - i_2) = 12(0.5 + 2) = 30V$

Continued…..

Thevenins equivalent circuit:



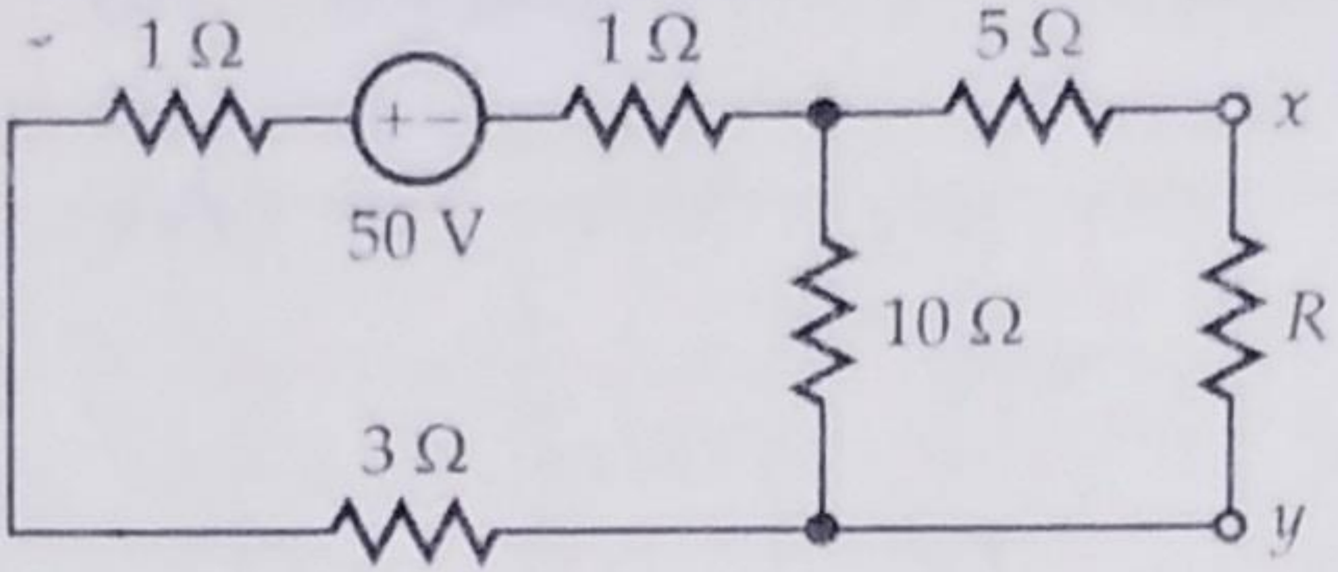
According to maximum power transfer theorem $R_{th} = R_L = 4$ ohms

$$P_{max} = V_{th}^2 / 4 R_{th} = (30)^2 /4 \times 4 = 56.26 \text{ watts}$$

Maximum Power Transfer Theorem Problems

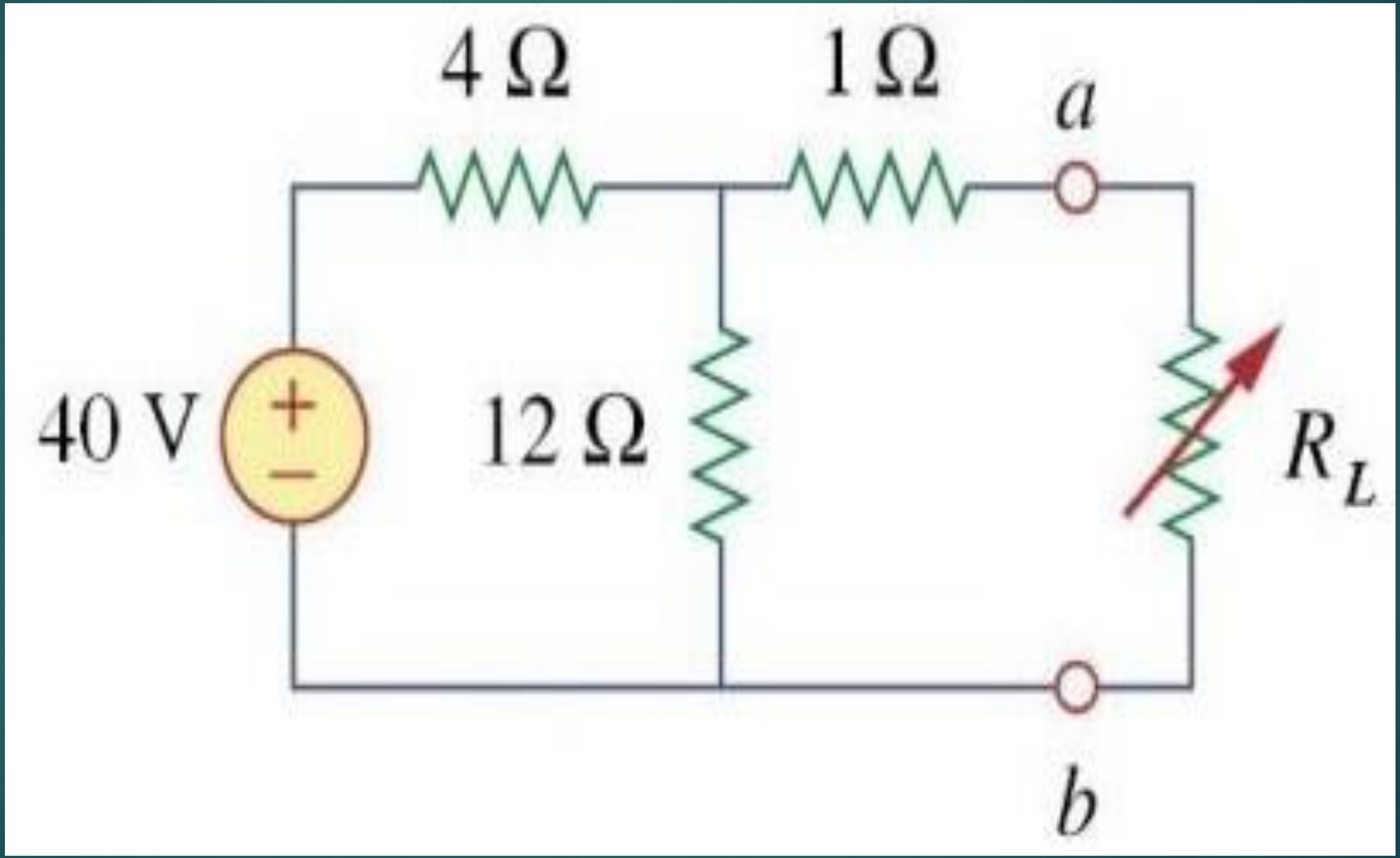
- Problem:

EXAMPLE 3.49 *Assuming maximum power transfer from the source to R, find the value of this amount of power in the circuit of Fig. E3.49.*



Continued………..

- Problem: Find the maximum power delivered to the load for the following circuit



RLC Circuits