Network Terminology:

1. **Electrical Network:**
   An interconnection of electrical elements is defined as an electrical network.

2. **Electrical Circuit:**
   An electrical network with at least one source and a sink and having a closed path for current flow.

   Note: All electrical circuits are networks. But the converse need not be true.

3. **Active Element:**
   An element which supplies or delivers energy in an electrical network is called an active element. For example, Voltage Sources & Current Sources are active elements.

4. **Passive Element:**
   An element which absorbs or stores energy in an electrical network is called a passive element. For example, Resistors, Inductors & Capacitors.

   Note: Resistors dissipate the energy absorbed as heat. Inductors store the absorbed energy in their magnetic field whereas the capacitors store the energy in their electric field.

Basic Definitions:

1. **Electric Current:**

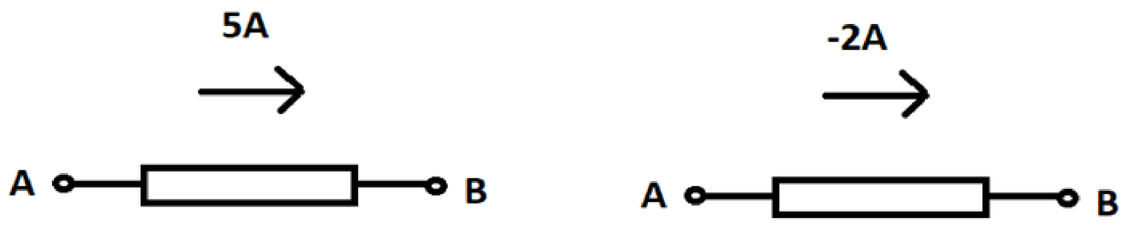
The rate of flow of charges across the cross section of a conductor is defined as the electric current.

It is given by the following equation

$$I = \frac{Q}{t} \text{ (or) } i = \frac{dq}{dt}$$

It is measured in Amperes (A) & 1 Ampere = 1 Coulomb/sec

An electric current is characterised by its magnitude and direction. The direction is conventionally represented in the direction of flow of positive charges even though actually electrons cause current in conductors.



(a) (b)

In figure (a) above, a current of 5A flows from terminal A to terminal B. In figure (b), a negative current is shown. A negative current is one which flows opposite to the direction marked. Hence, in figure (b), a current of 2A flows from terminal B to terminal A.

2. Potential Difference:

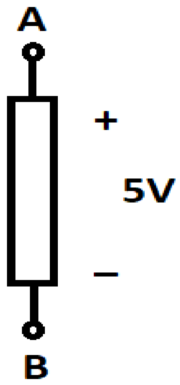
The energy required to move unit positive charge from one terminal to another is defined as the potential difference between the terminals.

It is given by the following equation:

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

It is also termed as voltage. It is measured in Volts (V) & 1 Volt = 1 Joule/Coulomb

An electric voltage is characterised by its magnitude and polarity.

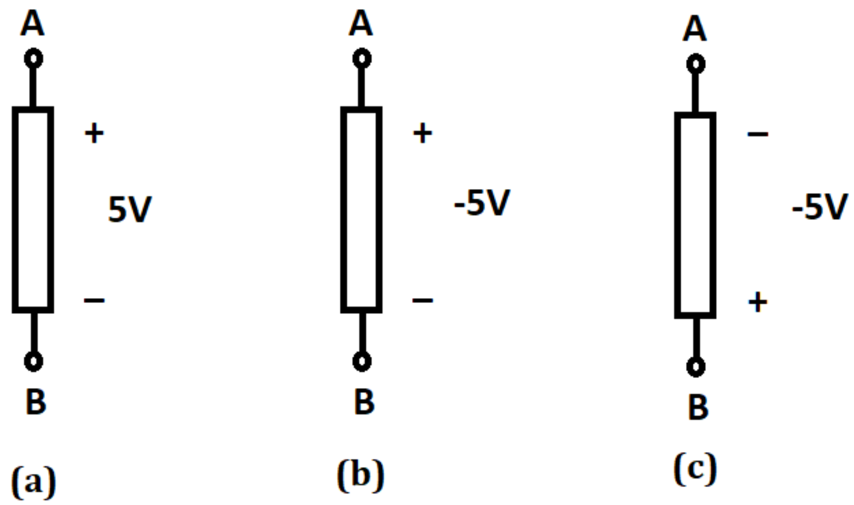


In the figure above, potential difference between A & B is 5V. Here, terminal A is higher in potential with respect to terminal B.

Double Subscript Notation for Voltage:

Since an electric voltage is defined between two terminals, it is represented by double subscript notation.

V_{AB} means relative potential of terminal A with respect to terminal B. If terminal A is higher in potential with respect to terminal B, then V_{AB} is positive. Otherwise, it is negative.



In figure (a) above, terminal A is 5V higher in potential than terminal B. Hence, V_{AB} = 5V in this case.

In figure (b) above, terminal A is -5V higher in potential than terminal B which means that actually terminal B is higher in potential than terminal A. Hence, V_{AB} = -5V in this case.
In figure (c) above, terminal A is marked with a negative sign. Hence, it is -5V lower in potential than terminal B which means that actually terminal A is +5V higher in potential than terminal B. Hence, V_{AB} = 5V in this case.

Also, $V_{BA} = -V_{AB}$.

3. Electric Power:

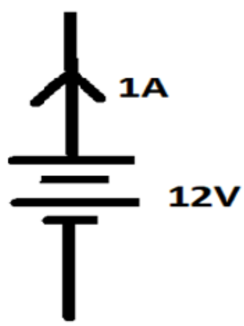
The rate of absorption or delivery of Electrical energy is called Electrical Power.

It is denoted by P and is given by the following equation:

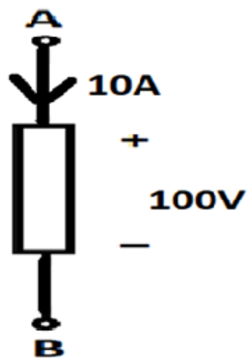
$$P = V*I$$

It is measured in Watts (W) & 1 Watt = (1 Volt)*(1 Ampere)

Conventionally, power absorbed is represented as positive & power delivered is represented as negative.



(a)



(b)

In figure (a) above, a battery delivers a power of (12V*1A) = 12W. Since it is power delivered, it is represented as -12W

In figure (b) above, a passive element such as a resistor is absorbing a power of (100V*10A) = 1000W. Since it is power absorbed, it is represented as +1000W.

Ohm's Law:

At a constant temperature, the potential difference across the terminals of a conductor is directly proportional to the current flowing through it.

i.e., V is proportional to I

Hence, **V = R*I**

where, R is the constant of proportionality called electrical resistance of the conductor.

It is measured in Ohms (Ω) and 1 Ohm = 1 Volt/Ampere

Resistance of a conductor is the opposition offered to the flow of current through it.

It is represented as shown below:

R

It depends on the resistivity of the material & its dimensions.

i.e., R = $\frac{\rho l}{A}$

Where, ρ is the resistivity measured in Ohm-m

l & A are the length and cross sectional area of the conductor in m & m^2 respectively.

Reciprocal of resistance is called Conductance denoted by G and given by

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

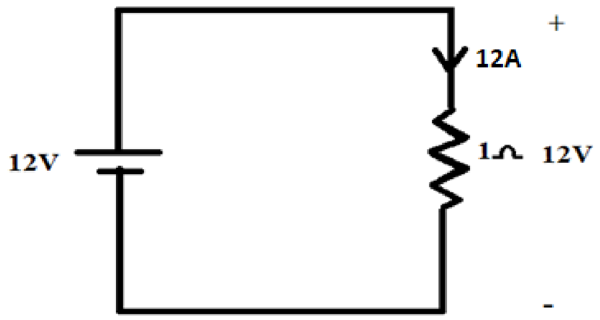
It is the ease with which a conductor allows the flow of current through it.

It is measured in Siemens (S).

Active & Passive sign conventions:

Active Sign Convention is applicable to active elements in an electric network. According to this, “current leaves positive terminal in an active element”.

Passive Sign Convention is applicable to passive elements in an electric network. According to this, “current enter positive terminal in a passive element”.



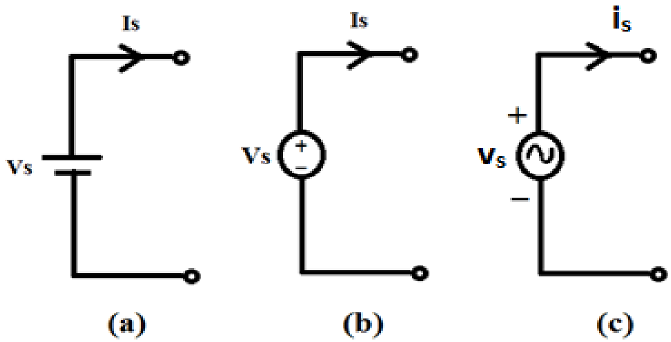
In the circuit shown above, 12V battery is an active element. It satisfies active sign convention i.e., current leaves positive terminal in 12V battery. 1Ω resistor is the passive element. It satisfies passive sign convention i.e., current enters positive terminal in 1Ω resistor.

Ideal Voltage & Current Sources:

Ideal Voltage Source:

An ideal voltage source is a source of EMF in which terminal voltage is independent of the current flowing through it.

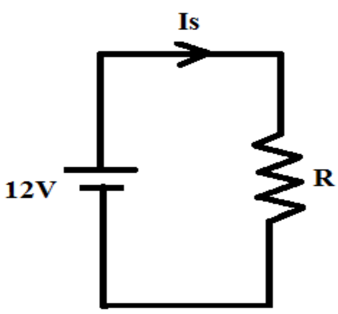
It is represented by one of the following symbols:



Figures (a) & (b) represent a DC Voltage source whereas figure (c) represents an AC voltage source.

However, the current delivered by it can be any finite value & depends on the circuit to which it is connected.

Consider the following example in which an ideal voltage source of EMF 12V is connected across a resistor R.



When R = 10Ω, I_S = 1.2A

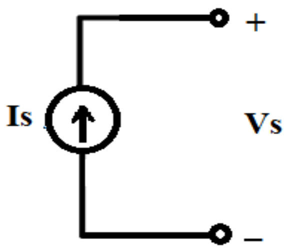
When R = 1Ω, I_S = 12A

As the value of R varies, current delivered by it varies whereas the terminal voltage is fixed at 12V.

Ideal Current Source:

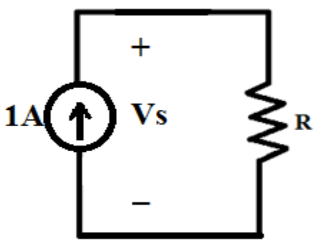
An ideal current source is a source in which terminal current is independent of the voltage across its terminals.

It is represented by the following symbol.



However, the voltage across it can be any finite value & depends on the circuit to which it is connected.

Consider the following example in which an ideal current source of current 1A is connected across a resistor R.



When R = 1Ω, V_S = 1V

When R = 10Ω, V_S = 10V

As the value of R varies, voltage across it varies whereas the terminal current is fixed at 1A.

Kirchhoff's Laws:

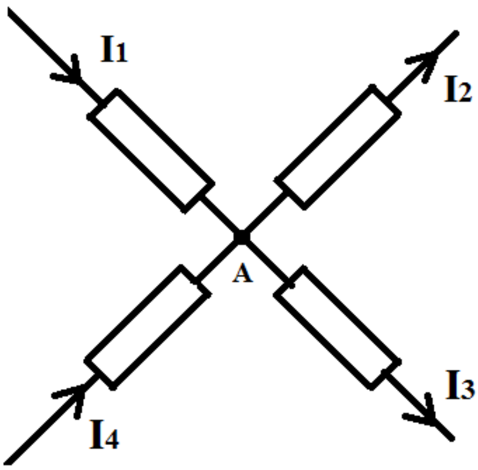
Kirchhoff's Current Law (KCL):

KCL States that

"At every node in an electric network, the algebraic sum of currents is Zero (or) sum of incoming currents is equal to the sum of outgoing currents".

A node is defined as the point of interconnection of two or more elements.

Consider the following example network:



By KCL at node A,

$I_1 + I_4 = I_2 + I_3$

KCL signifies the conservation of charge at every node in an electric network.

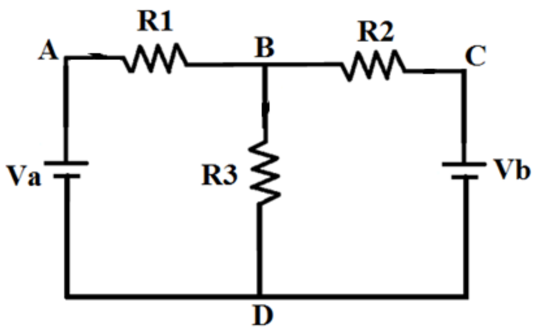
Kirchhoff's Voltage Law (KVL):

KVL States that

"Around every closed path in an electric network, the algebraic sum of voltages is Zero".

Any path which is traversed in an electric network, which starts and ends at the same point is defined as a closed path.

Consider the example network shown below:



ABDA, BCDB & ABCDA represent closed paths in this network.

While writing KVL, if one passes through an element from lower potential terminal to higher potential terminal, it is termed as ‘Voltage Rise’. If an element is traversed from higher potential terminal to lower potential terminal, it is termed as ‘Voltage Drop’.

Conventionally, Voltage drops are considered as negative and voltage rises as positive while writing KVL.

Hence, KVL in the path ABDA would be

$-V_1-V_3+V_a = 0$

Similarly, KVL in the path BCDB is

$V_2-V_b+V_3 = 0$

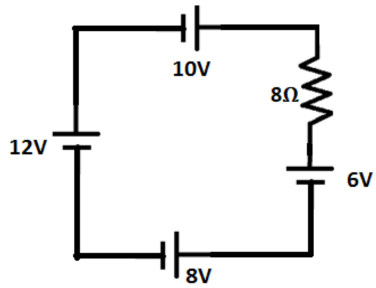
& KVL in the path ABCDA is

$-V_1+V_2-V_b +V_a = 0$

KVL signifies the conservation of energy around every closed path in an electric network.

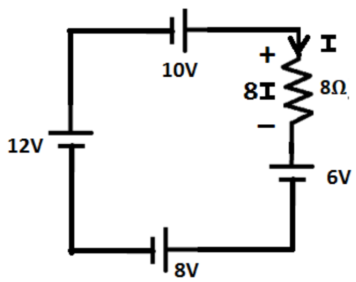
Numerical Examples on KVL:

Example 1: Find the current through 8Ω resistor in the network given.



Solution:

Let the current in the network be I.



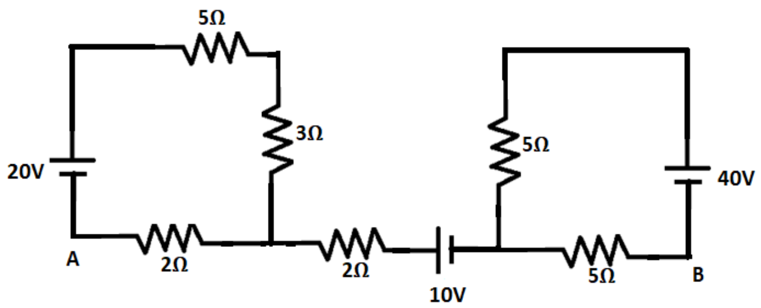
KVL around the path is

+10-8I-6-8+12 = 0

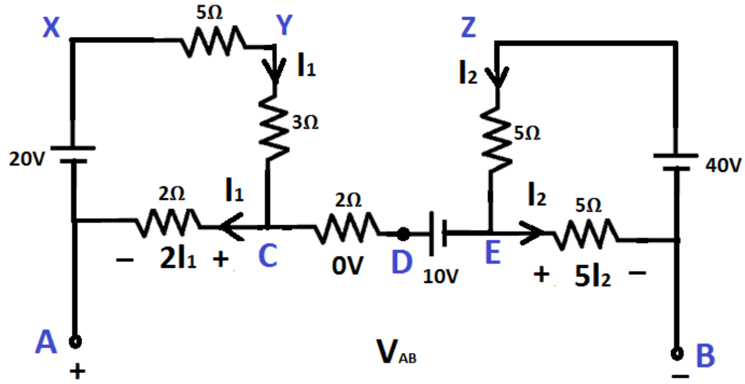
Hence, I = 1A

Example 2:

Find the voltage V_{AB} in the network shown:



Solution:



KVL in the path AXYCA is

$+20-5I_1-3I_1-2I_1 = 0$

Hence, $I_1 = 2A$

KVL in the path BZEB is

$+40-5I_2-5I_2 = 0$

Hence, $I_2 = 4A$

KVL in the path ACDEBA is

$+2I_1-10-5I_2+V_{AB} = 0$

Substituting for I_1 & I_2 in the above equation, $V_{AB} = 26V$

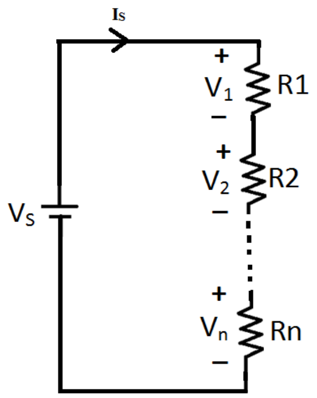
NOTES - CLASS 4

Voltage & Current Division Rules:

Voltage Division Rule:

Voltage Division Rule is applicable to series networks.

Consider the network shown below:



By Ohm's Law across each resistor,

$V_1 = I_S*R_1$

$V_2 = I_S*R_2$

.

.

.

.

$V_n = I_S*R_n$

By KVL around the network,

$V_S = V_1+V_2+\ldots+V_n$

Hence, $I_S = \frac{V_S}{(R_1+R_2+\cdots+R_n)}$

Therefore,

$$V_1 = \frac{V_S * R_1}{(R_1+R_2+\cdots+R_n)} \qquad \text{--------- (1)}$$

.

.

.

.

$$V_n = \frac{V_S * R_n}{(R_1+R_2+\cdots+R_n)} \qquad \text{--------- (N)}$$

Equations (1) to (N) above represent Voltage division rule.

According to it,

"Voltage across any one of the resistors connected in series is equal to the total voltage multiplied by the ratio of that resistance to the sum of all the resistances in series."

Equivalent series resistance:

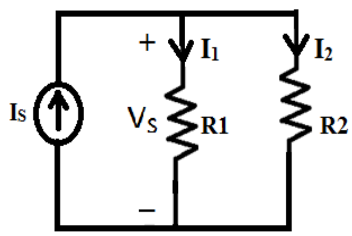
Equivalent resistance of 'n' resistors in series is given by

$\mathbf{R_{eq} = R_1+R_2+\ldots+R_n}$

Current Division Rule:

Current Division Rule is applicable to parallel networks.

Consider the network shown below:



By Ohm's Law,

$I_1 = \frac{V_S}{R_1}$

$I_2 = \frac{V_S}{R_2}$

By KCL,

$I_S = I_1 + I_2$

Hence, $I_S = V_S * (\frac{1}{R_1} + \frac{1}{R_2})$

Therefore,

$V_S = I_S * \frac{R_1 * R_2}{(R_1 + R_2)}$

$I_1 = I_s * \frac{R_2}{(R_1 + R_2)}$ ---------- (1)

$I_2 = I_s * \frac{R_1}{(R_1 + R_2)}$ ----------- (2)

Equations (1) & (2) above represent current division rule.

According to it,

"Current in any one of the two parallel resistors is the total current multiplied by the ratio of opposite resistance to the sum of all parallel resistances."

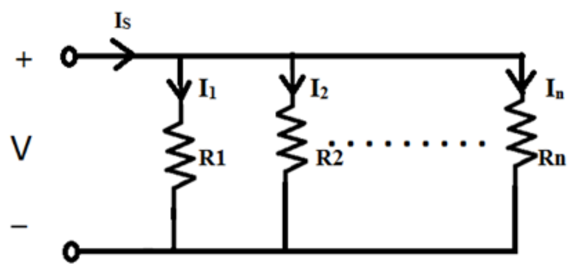
Equivalent parallel resistance (Two resistor case):

Equivalent resistance of two resistors in parallel is given by

$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1} = \frac{R_1 * R_2}{(R_1 + R_2)}$$

Current Division Rule – More than two resistors in Parallel:

When more than two resistors are in parallel, the following steps need to be followed to apply current division:



Step 1: Obtain R_{eq} using the equation, $\frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} + . . . + \frac{1}{R_n}\right).$

Step 2: Find V using the equation, $V = I_S * R_{eq}$.

Step 3: Now, use Ohm's Law to find each branch current.

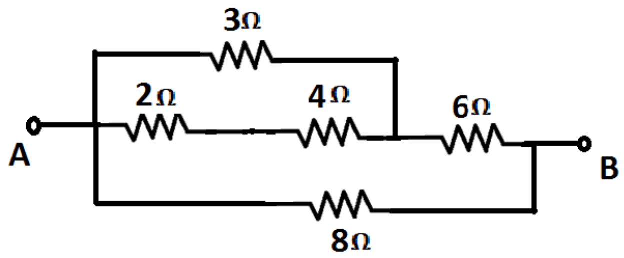
Network Reduction Using Series – Parallel Combinations:

Two elements are said to be in series if they are connected at one terminal and carry the same current through them.

Two elements are said to be in parallel if they are connected at both ends together and have same voltage across them.

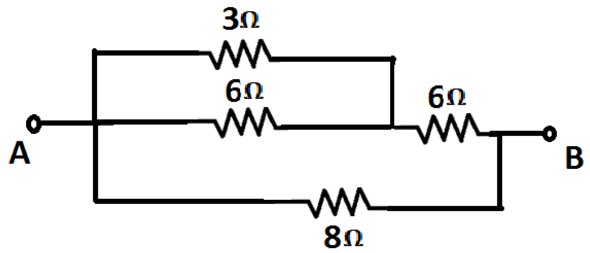
While finding equivalent resistance between two terminals, we usually combine the resistors in series or parallel.

Example: Find the equivalent resistance between A & B in the network shown below

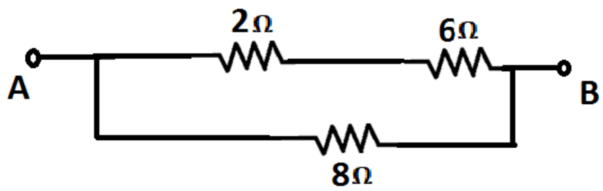


Solution:

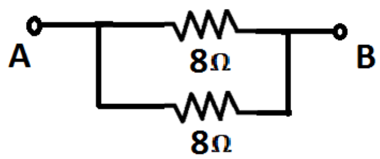
2Ω and 4Ω can be combined in series using R_{eq} = 2Ω + 4Ω = 6Ω



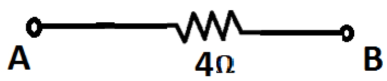
Now, 3Ω and 6Ω can be combined in parallel using $R_{eq} = \frac{R_1 * R_2}{(R_1 + R_2)}$ which gives 2Ω



Now, combine 2Ω and 6Ω in series, which gives 8Ω



Finally, combine both 8Ω resistors in parallel.



Hence, equivalent resistance between A & B is 4Ω.

Concepts of Open Circuit & Short Circuit:

Open Circuit:

An open circuit is characterised by Infinite resistance and hence zero current through it. It is represented as shown below:

Voltage across the Open Circuit can be any finite value.

Short Circuit:

A short circuit is characterised by zero resistance and hence zero voltage across it. It is represented as shown below:

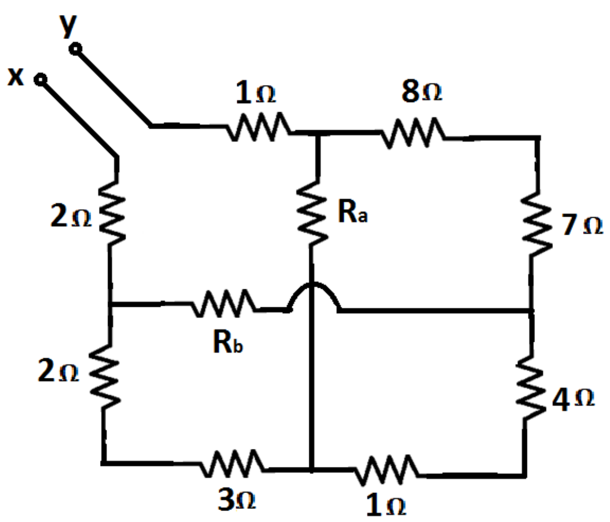
Current through a short circuit can be any finite value.

Current through a Dead Short Circuit is dangerously high.

Numerical Example: Find the equivalent resistance between X & Y if

i) $R_a = \infty$ & $R_b = \infty$ ii) $R_a = 0$ & $R_b = \infty$ iii) $R_a = \infty$ & $R_b = 0$

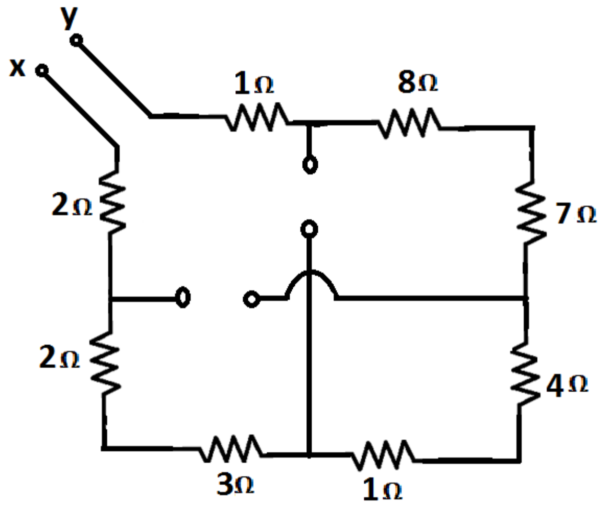
iv) $R_a = 0$ & $R_b = 0$



Solution:

Case i) $R_a = \infty$ & $R_b = \infty$

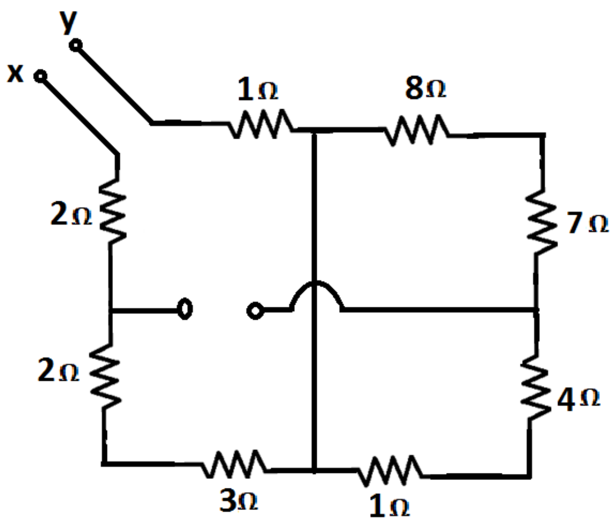
Here, both R_a and R_b have been replaced by infinite resistance i.e., open circuit.



It can be observed that all the resistors are in series. Hence, $R_{XY} = 28\Omega$.

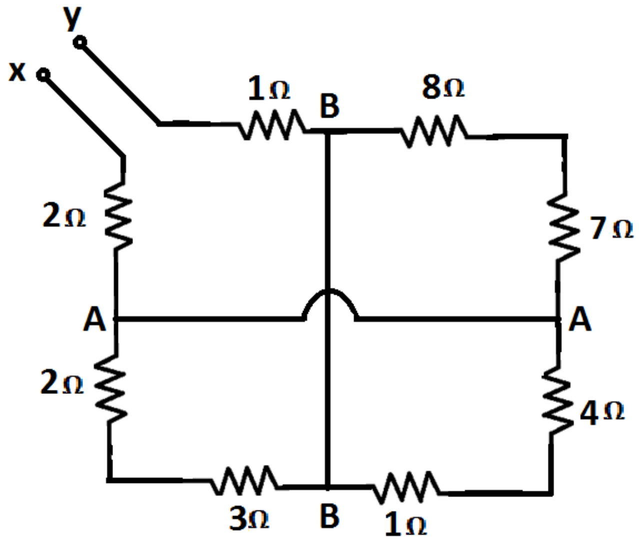
Case ii) $R_a = 0$ & $R_b = \infty$

In this case, replace R_a with zero resistance i.e., short circuit and R_b with infinite resistance, i.e., open circuit.

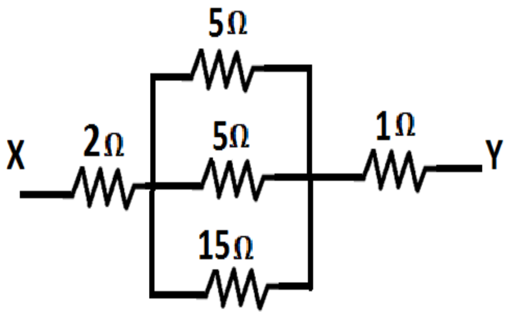


Case iii) can be solved on the similar lines as case ii). By solving, R_{XY} = 18Ω.

Case iv) $R_a = 0$ & $R_b = 0$



Rearranging this network, it looks as shown below:



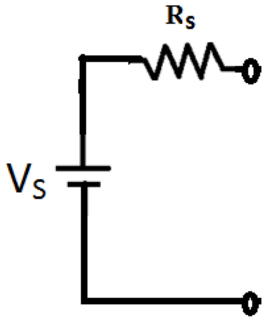
Hence, R_{XY} = (2Ω + (5Ω II 5Ω II 15Ω) + 1Ω) = 5.143Ω.

NOTES – CLASS 6

Practical Voltage & Current Sources:

Practical Voltage Source:

In a practical voltage source, terminal voltage falls as load current increases. It is modelled as an ideal voltage source in series with internal resistance. A practical voltage source is represented as shown below:

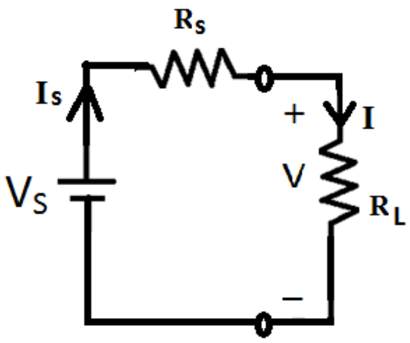


Here, R_S represents its internal resistance.

Internal resistance of a practical voltage source is small, usually few mΩ.

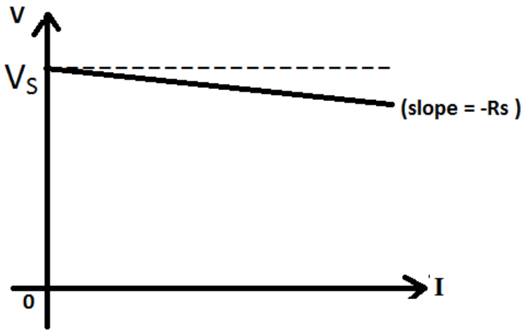
Internal resistance of an ideal voltage source is Zero.

When terminated with a load resistance R_L, the terminal voltage is given by the following equation:



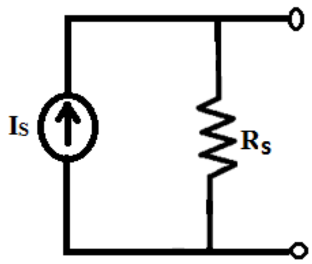
$$V = V_S - I*R_S$$

It exhibits a terminal voltage current characteristic as shown below:



Practical Current Source:

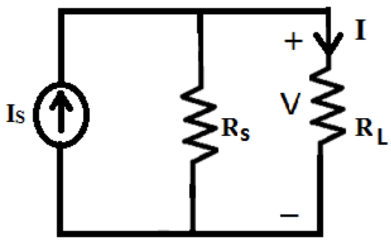
In a practical current source, load current falls as terminal voltage increases. It is modelled as an ideal current source in parallel with internal resistance. A practical current source is represented as shown below:



Here, R_S represents its internal resistance.

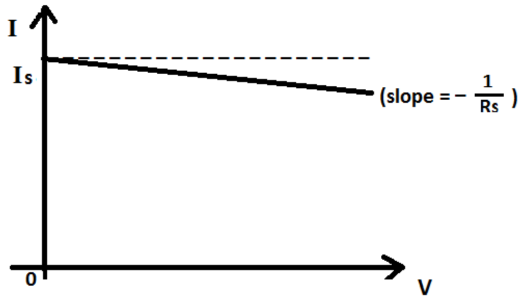
Internal resistance of a practical current source is very high, usually few MΩ.

When terminated with a load resistance R_L, the terminal current is given by the following equation:



$$I = I_S - \left(\frac{V}{R_S}\right)$$

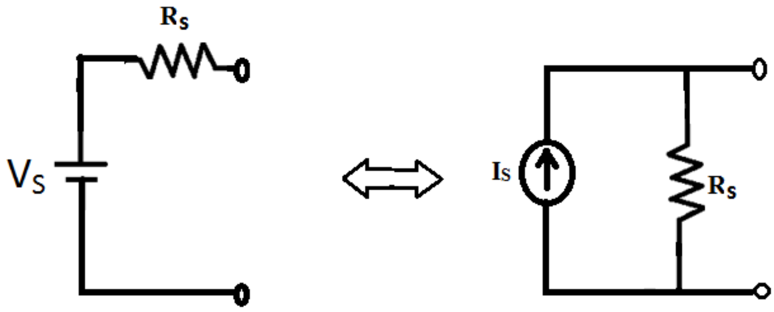
It exhibits a terminal voltage current characteristic as shown below:



Source Transformation:

Source Transformation is applicable to practical sources only.

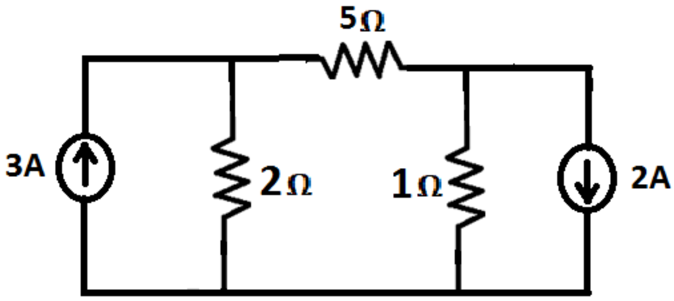
A Practical Voltage Source can be transformed to a Practical Current Source & Vice versa by Source Transformation.



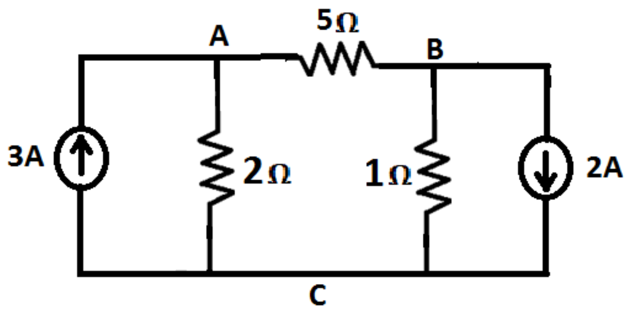
Here, V_S and I_s are related by, $V_S = I_S * R_S$

Numerical Example on Source Transformation:

Find the current through 5Ω resistor in the network shown using source transformation.

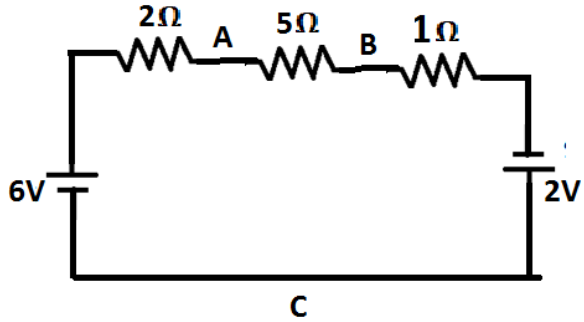


Solution:

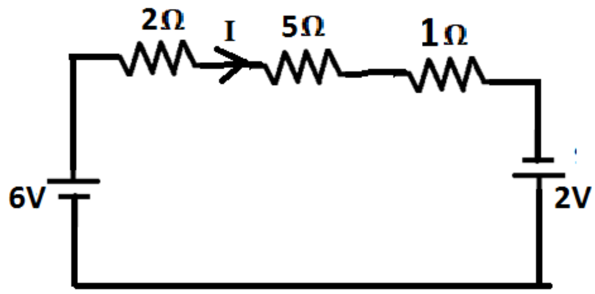


Replace 3A current source & 2Ω resistance with equivalent practical voltage source of EMF = (3A*2Ω) = 6V in series with 2Ω resistance.

Replace 2A current source & 1Ω resistance with equivalent practical voltage source of EMF = (2A*1Ω) = 2V in series with 1Ω resistance.



Consider a current I in this network.



By applying KVL, +6 – 2*I – 5*I – 1*I + 2 = 0

I = 1A

Hence, current through 5Ω resistor is 1A.

NOTES – CLASS 8

Star Delta Transformations:

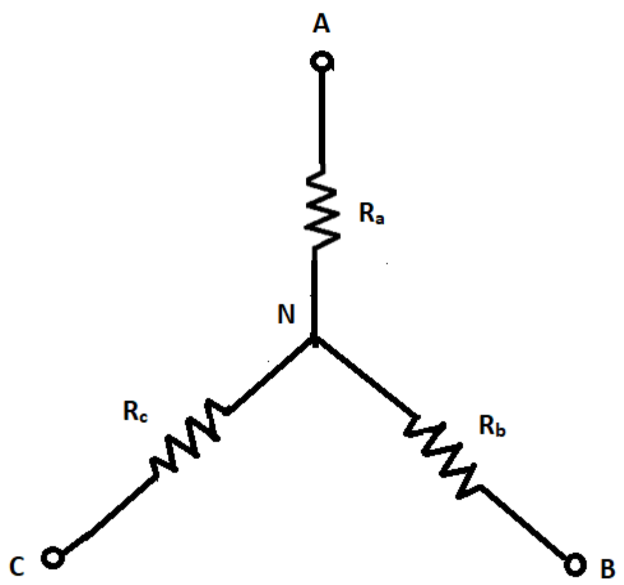
Need for Star Delta Transformation:

Sometimes, we cannot find series or parallel combinations while reducing a given network. In such cases, we can apply star delta transformations to reduce the given network.

Note: Never apply star delta transformation if there exist some series parallel combinations since doing so leads to a lengthy solution.

Star (or) WYE connection:

When three resistors are connected at a common terminal, it makes a star connection of resistors. The common terminal is called 'Neutral' terminal of the star. A star connection is shown below:

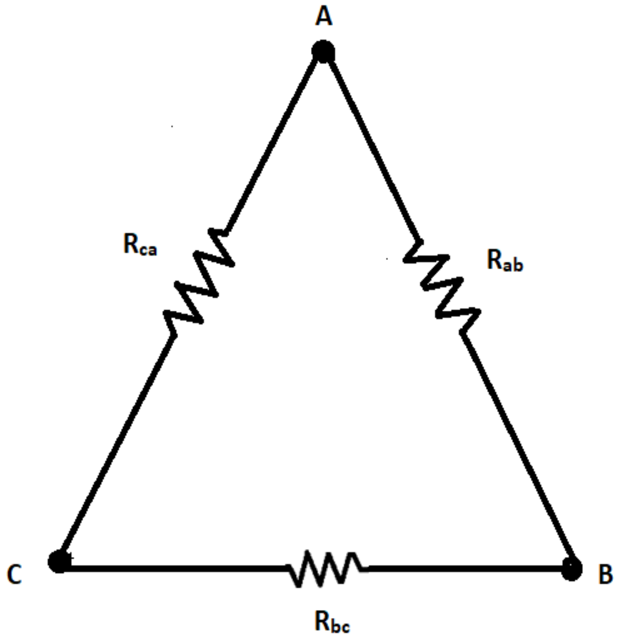


Here, R_a , R_b & R_C represent star resistors and 'N' represents the neutral terminal.

Delta (or) Mesh connection:

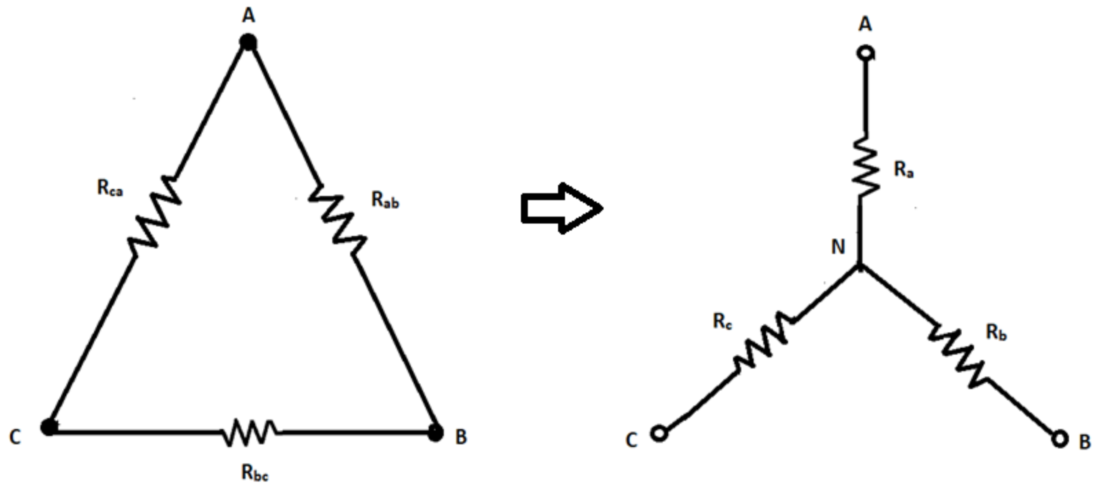
When three resistors are connected end to end, it makes a delta connected system of resistors.

A delta connected system of resistors is shown below:



Here, R_{ab} , R_{bc} & R_{ca} represent delta resistors.

Delta to Star Transformation:



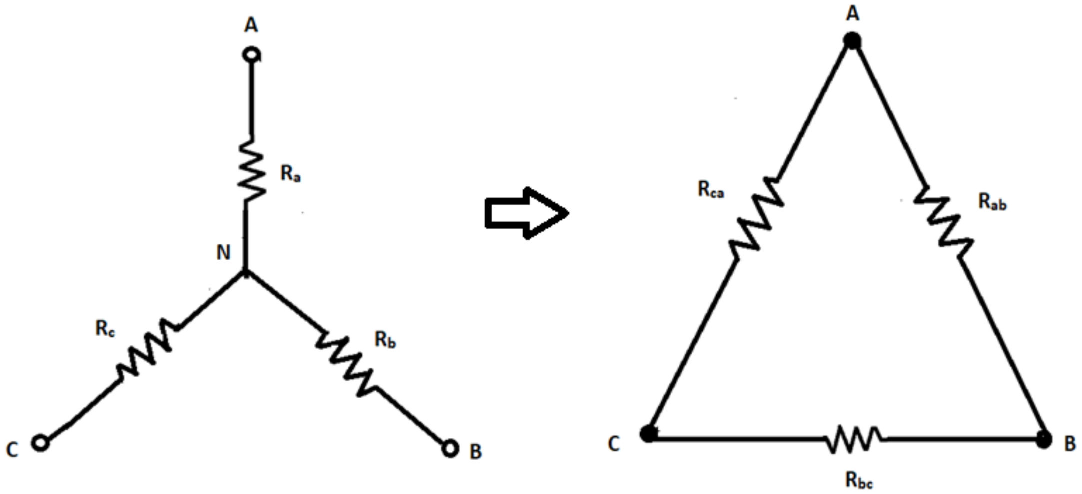
Equations for this transformation are:

$$R_a = \frac{R_{ab}*R_{ca}}{(R_{ab}+R_{bc}+R_{ca})}$$

$$R_b = \frac{R_{bc}*R_{ab}}{(R_{ab}+R_{bc}+R_{ca})}$$

$$R_c = \frac{R_{ca}*R_{bc}}{(R_{ab}+R_{bc}+R_{ca})}$$

Star to Delta Transformation:



Equations for this transformation are:

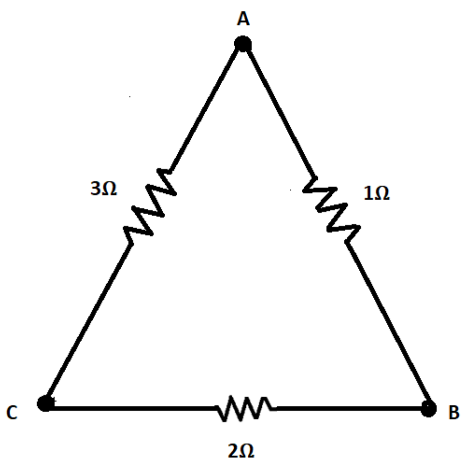
$$R_{ab} = \frac{R_a*R_b+R_b*R_c+R_c*R_a}{R_c}$$

$$R_{bc} = \frac{R_a*R_b+R_b*R_c+R_c*R_a}{R_a}$$

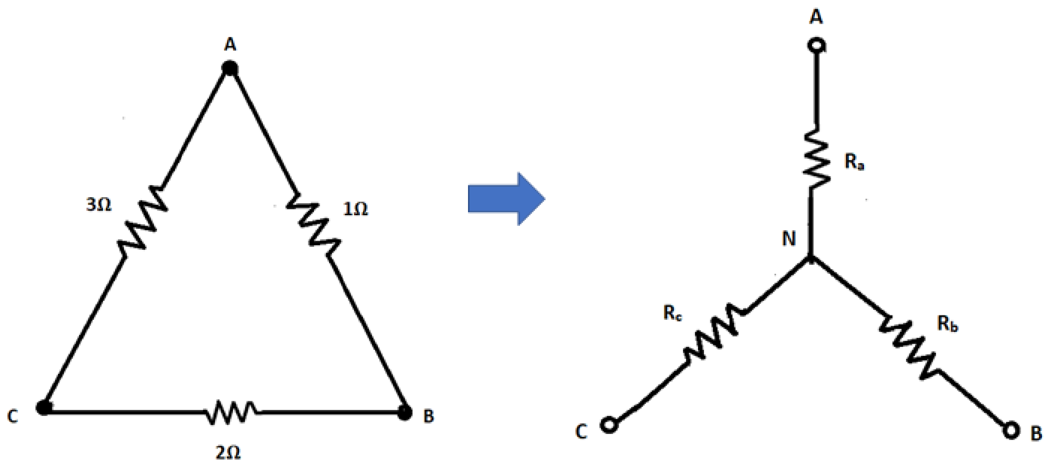
$$R_{ca} = \frac{R_a*R_b+R_b*R_c+R_c*R_a}{R_b}$$

Numerical Examples on Star Delta Transformation:

Example 1: Transform the given delta to equivalent star.



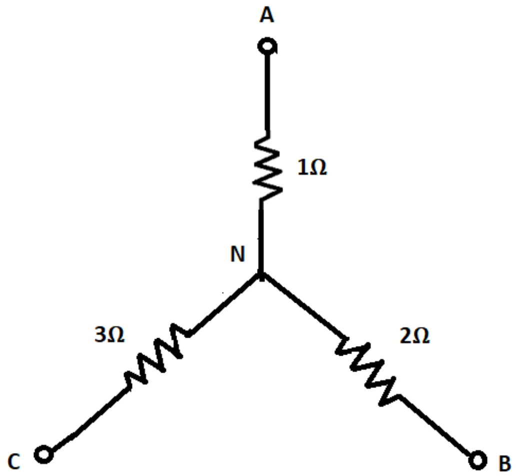
Solution:



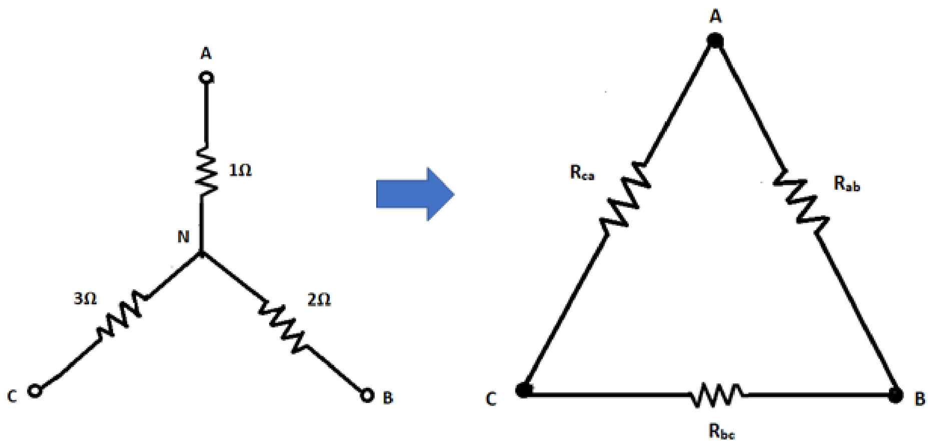
$$R_a = \frac{R_{ab} * R_{ca}}{(R_{ab}+R_{bc}+R_{ca})} = \frac{1*3}{(1+2+3)} = \frac{1}{2}\,\Omega$$

Similarly, $R_b = \frac{1*2}{(1+2+3)} = \frac{1}{3}\,\Omega$ & $R_c = \frac{2*3}{(1+2+3)} = 1\Omega$

Example 2: Transform the given star to equivalent delta.



Solution:



$$R_{ab} = \frac{R_a * R_b + R_b * R_c + R_c * R_a}{R_c} = \frac{1*2+2*3+3*1}{(3)} = \frac{11}{3}\,\Omega$$

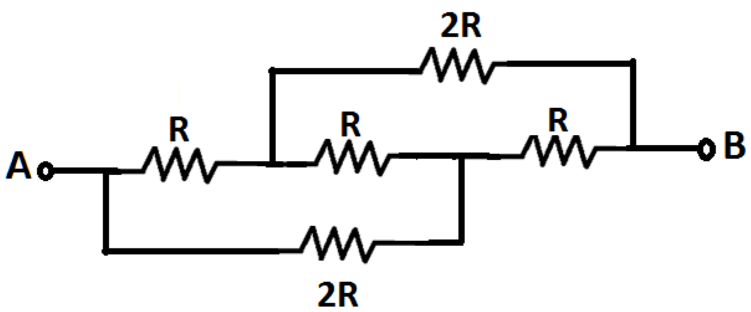
Similarly, $R_{bc} = \dfrac{11}{(R_a)} = 11\,\Omega$ **&** $R_{ca} = \dfrac{11}{(R_b)} = \dfrac{11}{2}\,\Omega$

NOTES – CLASS 9

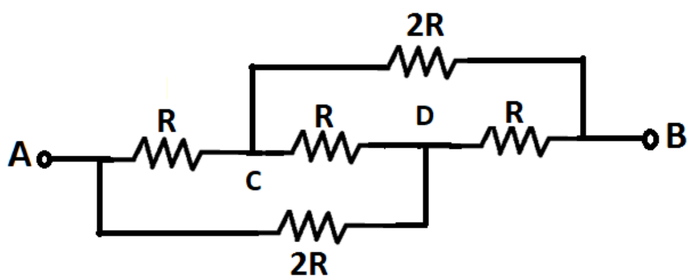
Numerical Examples on Star Delta Transformations:

Numerical Example 3:

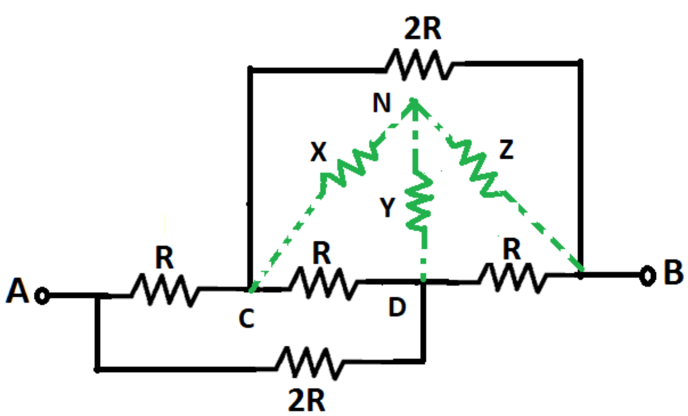
Find the equivalent resistance between the terminals A & B in the given network.



Solution:



Transform Delta existing between the terminals C-D-B into its equivalent star



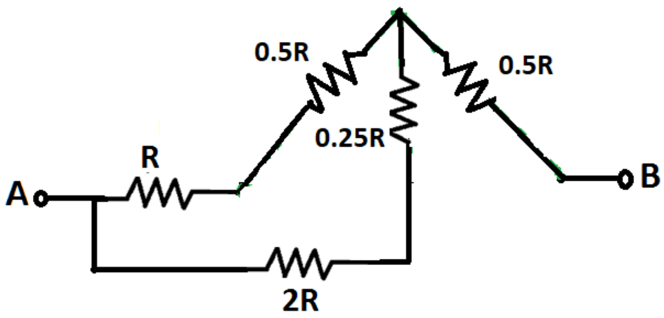
The equivalent star resistors can be obtained as

$$X = \frac{R*2R}{(R+2R+R)} = \frac{R}{2}\,\Omega$$

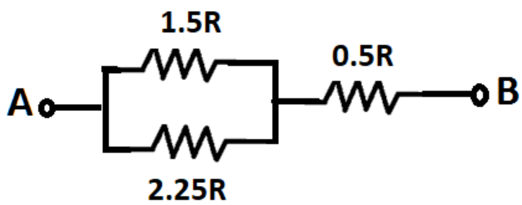
$$Y = \frac{R*R}{(R+2R+R)} = \frac{R}{4}\,\Omega$$

$$Z = \frac{R*2R}{(R+2R+R)} = \frac{R}{2}\,\Omega$$

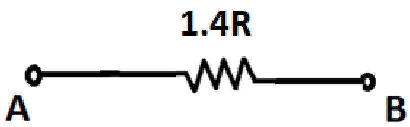
Hence, the network reduces as follows:



Now, combine (R & 0.5R) in series and (2R & 0.25R) in series. It gives



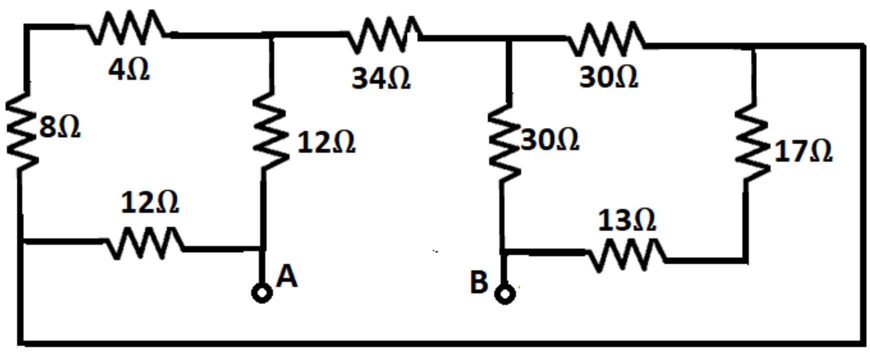
Now, combine (1.5R & 2.25R) in parallel & then, combine its equivalent in series with 0.5R.



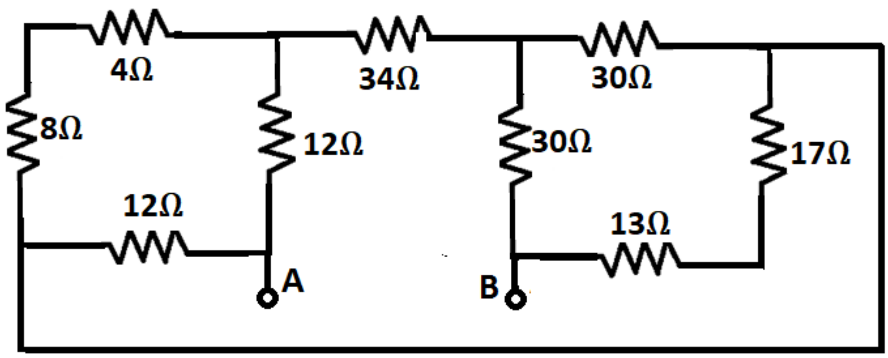
Hence, the equivalent resistance is 1.4R

Numerical Example 4:

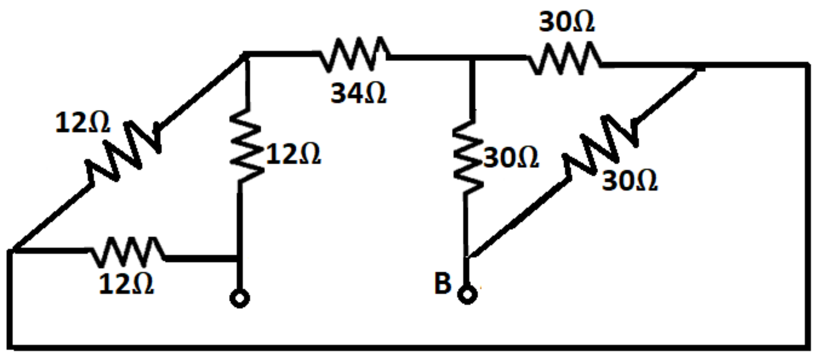
Find the equivalent resistance between the terminals A & B in the network shown.



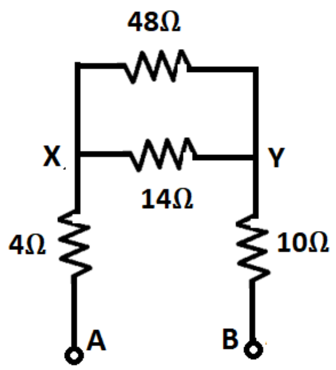
Solution:



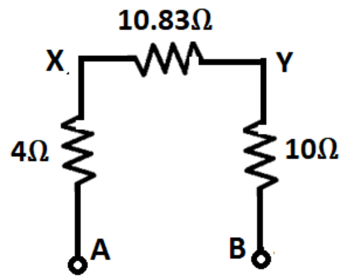
Combining (8Ω & 4Ω) in series and also (13Ω & 17Ω) in series,



Now, transform 12Ω - 12Ω - 12Ω delta into its equivalent star and also 30Ω - 30Ω - 30Ω delta into its equivalent star,



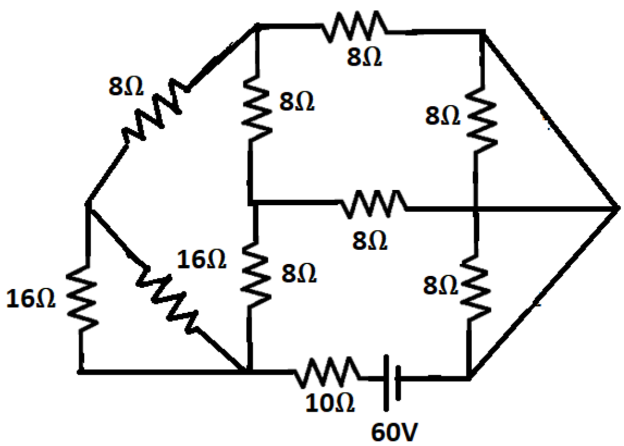
Now, combine 48Ω and 14Ω in parallel



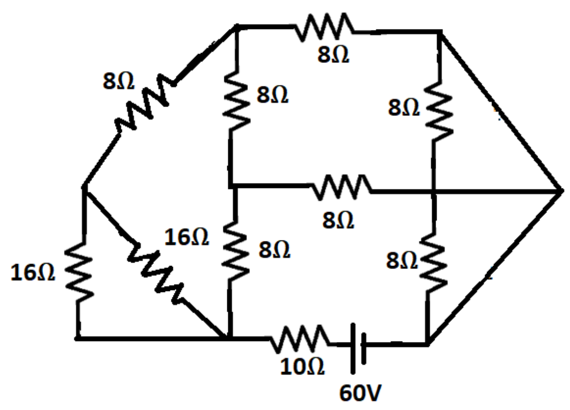
Now, combine all of them in series, which gives R_{AB} = 24.83Ω

Numerical Example 5:

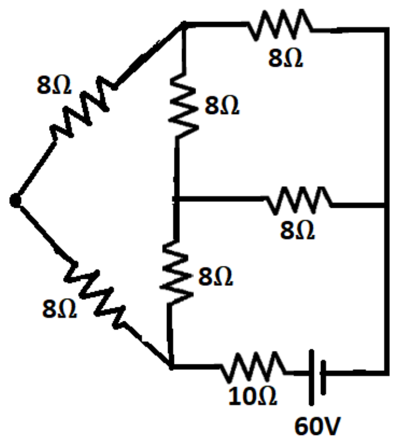
Find the voltage drop across 10Ω resistor in the network shown.



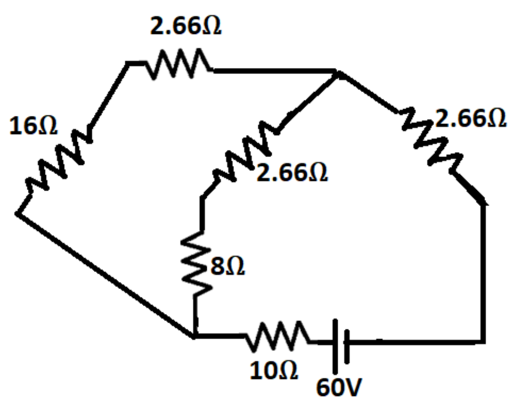
Solution:



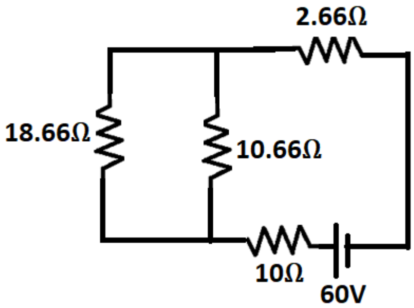
Combine 16Ω & 16Ω in parallel



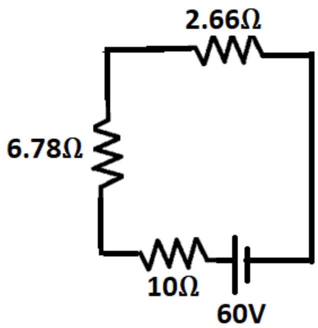
Combine left extreme 8Ω & 8Ω in series. Also, transform top delta (8Ω - 8Ω - 8Ω) into equivalent star



Now, 16Ω and 2.66Ω are in series. Also, 8Ω and 2.66Ω are in series.



Now combine 18.66Ω and 10.66Ω in parallel.



Now, remaining resistors are in series, which gives R_{eq} = 19.44Ω

Current delivered by 60V source, $I_S = \frac{60}{R_{eq}} = \frac{60}{19.44} = 3.086A$

Voltage drop across 10Ω resistor = I_S*10 = 30.86V

NOTES – CLASS 11

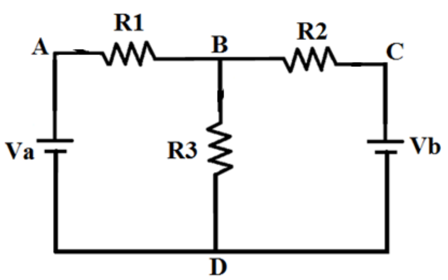
Mesh Analysis:

One of the widely used techniques to solve networks with more number of elements and multiple sources is Mesh Analysis.

A closed path in a network with current flow in every element in that path is defined as a **Loop.**

A mesh is a fundamental loop which does not contain any other smaller loops within itself.

For instance, consider the following network:



In this network, loops are

i) A-B-D-A
ii) B-C-D-B
iii) A-B-C-D-A

Out of these three loops, only (i) & (ii) are Meshes. Third one is just a loop but not a mesh since it loops (i) & (ii) embedded with in itself.

Thus, all meshes are loops but the converse need not be true.

Steps to apply Mesh Analysis:

Step 1: Identify the number of meshes in the network.

Step 2: Assign one mesh current in each mesh preferably in the same direction.

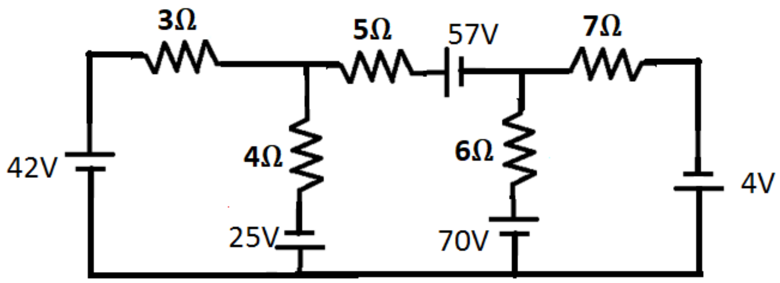
Step 3: Write KVL in every mesh.

Step 4: Solve simultaneous equations to obtain Mesh currents.

Note: After finding current in each mesh, current or voltage or power in any element of choice in the network can be obtained as a function of these mesh currents.

Numerical Example 1:

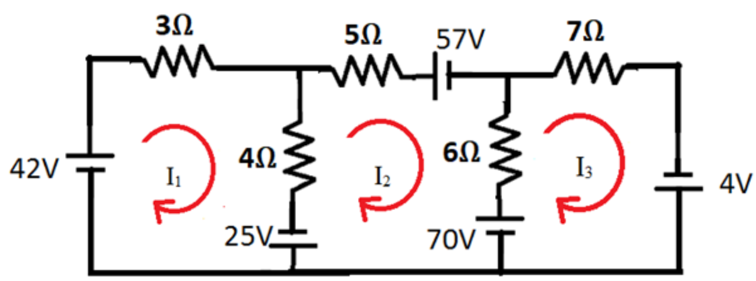
Obtain current through 6Ω resistor using Mesh Analysis.



Solution:

1. Number of Meshes = 3

2. Assign one mesh current in each mesh, all of them preferably either clockwise or anticlockwise.



3. Now, write KVL in every Mesh.

KVL (Mesh 1) : $-3I_1-4(I_1-I_2)+25+42 = 0$ ---- (1)

KVL (Mesh 2) : $-5I_2-57-6(I_2-I_3)-70-25-4(I_2-I_1) = 0$ ---- (2)

KVL (Mesh 3) : $-7I_3+4+70-6(I_3-I_2) = 0$ ---- (3)

4. Solving above equations (1), (2) & (3),

$I_1 = 5A$; $I_2 = -8A$; $I_3 = 2A$

Therefore, current through 6Ω resistor = $(I_2 \sim I_3) = (I_3-I_2) = 10A$

Mesh Analysis – Writing KVLs by Direct Inspection:

KVLs while applying mesh analysis can be written by inspecting the network and following a set of rules. This method is termed as Direct Inspection Method of writing KVLs.

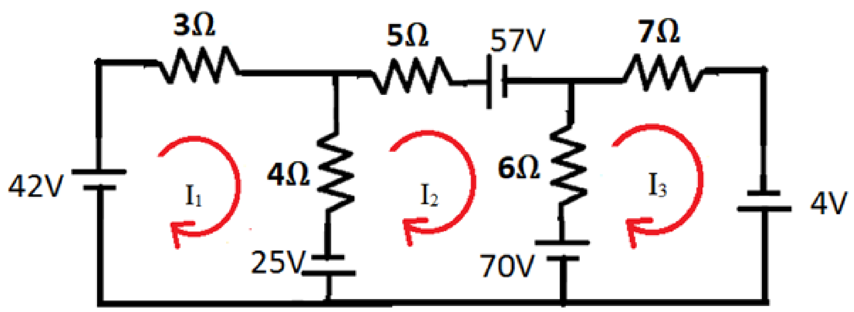
According to this method, while writing a KVL in a particular mesh,

i) Coefficient of same mesh current = Sum of all resistances in that mesh.

ii) Coefficient of other mesh current = Negative of Sum of all common resistances between the meshes.

iii) Constant is written on the right hand side and is algebraic sum of EMFs of all voltage sources in that mesh. These EMF of a voltage source must be taken as positive if that voltage source supports that mesh current (i.e., has a tendency to drive current in the same direction as the marked mesh current direction.). Otherwise, it must be taken as negative.

Let us consider the example we solved above.



KVL in Mesh 1 by direct inspection:

Coefficient of I_1 = Sum of all resistances in that Mesh = $(3\Omega + 4\Omega) = 7$

Coefficient of I_2 = Sum of common resistances between Mesh 1 & Mesh 2 considered with a negative sign = -4 (Since 4Ω is common between Mesh 1 & Mesh 2)

Coefficient of I_3 = Sum of common resistances between Mesh 1 & Mesh 3 considered with a negative sign = 0 (Since nothing is common between Mesh 1 & Mesh 3)

Constant term on Right hand side = +42 + 25 = 67 (Both EMFs are taken with positive sign since they support I_1 direction.)

Thus, KVL (Mesh 1) : $7I_1-4I_2-0I_3 = +25+42$

Similarly, we can write KVLs in Mesh 2 & Mesh 3.

KVL (Mesh 2) : $-4I_1+15I_2-6I_3 = -57-70-25$

KVL (Mesh 3) : $0I_1-6I_2+13I_3 = +4+70$

NOTES – CLASS 12

Mesh Analysis in the networks with current sources:

We cannot write a KVL in the mesh containing current sources since voltage across an ideal current source is unknown. Hence, there is a slight change in step 3 of the Mesh Analysis in the networks with current sources.

Steps to apply Mesh Analysis in the networks with current sources:

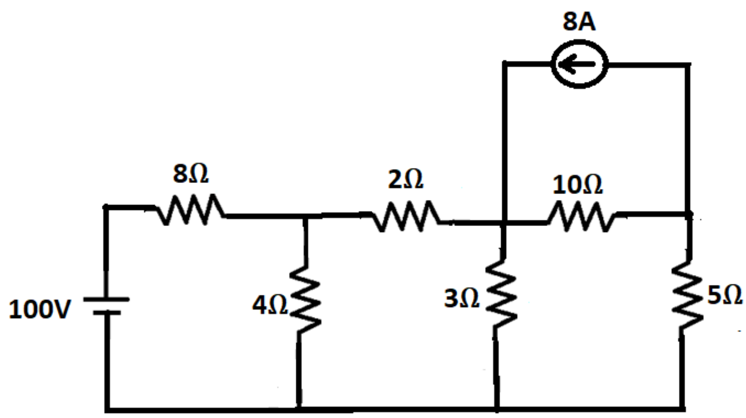
Step 1: Identify the number of meshes in the network.

Step 2: Assign one mesh current in each mesh preferably in the same direction.

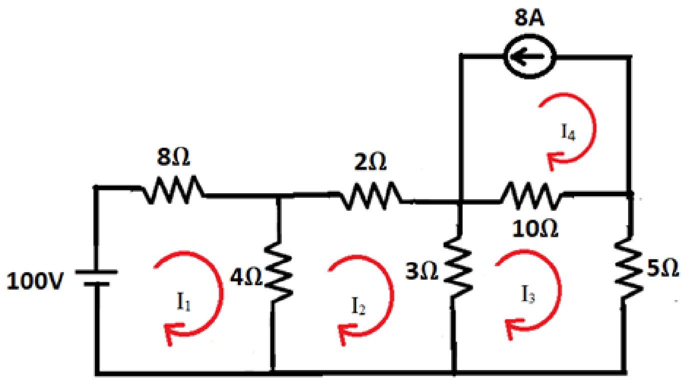
Step 3: Write KVL in the meshes without current sources. Write Current Equation in the Meshes with current sources.

Step 4: Solve simultaneous equations to obtain Mesh currents.

Numerical Example 1: Obtain current through 4Ω resistor using Mesh Analysis.



Solution: Number of Meshes = 4



Meshes 1 , 2 & 3 do not have current sources. Hence, write KVLs in these meshes.

KVL (Mesh 1) : $12I_1-4I_2-0I_3-0I_4 = 100$ ---- (1)

KVL (Mesh 2) : $-4I_1+9I_2-3I_3-0I_4 = 0$ ---- (2)

KVL (Mesh 3) : $0I_1-3I_2+18I_3-10I_4 = 0$ ---- (3)

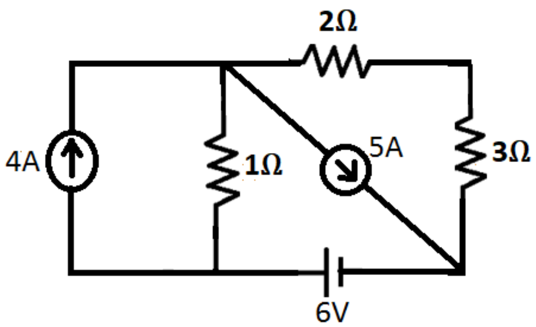
Since Mesh 4 has a current source, we can not write KVL in that mesh. Instead write current equation in that mesh.

Current Equation (Mesh 4) : $I_4 = -8$ ---- (4) (Negative because current source direction is opposite to mesh current direction.)

Solving (1), (2), (3) & (4), $I_1 = 9.26A$; $I_2 = 2.79A$; $I_3 = -3.97A$

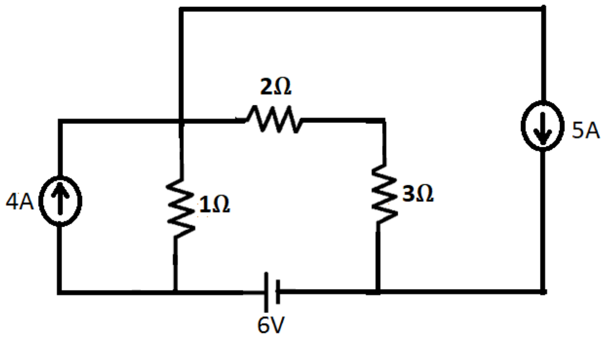
Current through 4Ω resistor = $(I_1 \sim I_2) = (I_1-I_2) = 6.47A$

Numerical Example 2: Obtain voltage across 3Ω resistor using Mesh Analysis.

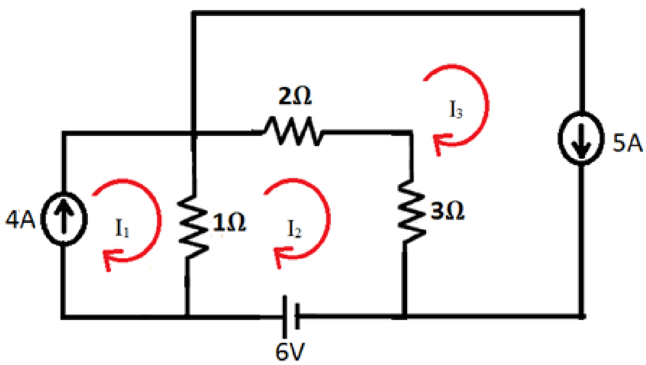


Solution:

In this network, 5A current source is common to two meshes. Rearrange the network such that this common current source is confined to only one mesh before applying Mesh Analysis in such networks.



Now, after rearranging the network, 5A current source is confined to only one mesh.



Current Equation (Mesh 1) : $I_1 = 4$ ---- (1)

KVL (Mesh 2) : $-I_1+6I_2-5I_3- = 6$ ---- (2)

Current Equation (Mesh 3) : $I_3 = 5$ ---- (3)

Solving (1), (2) & (3), $I_2 = 5.83A$

Current through 3Ω resistor = $(I_2 \sim I_3) = (I_2 - I_3) = 0.83A$

Voltage across 3Ω resistor = 2.49V

NOTES – CLASS 14

Concept of Linearity:

A linear element is a passive element with linear voltage-current relationship.

Resistors, Inductors & Capacitors are linear elements.

For instance, resistor obeys Ohm's Law which is a linear voltage current relationship.

Inductors and Capacitors have voltage current relationship which is a linear differential equation. Hence, these elements are linear.

A linear circuit is one which is composed of linear elements, independent sources & linear dependent sources.

One of the major advantages of linear networks is that they satisfy the property of Superposition.

Superposition Theorem:

Statement:

"In a linear network with more than one independent source, the total response in any element is the algebraic sum of the individual responses caused by each independent source acting alone, while all other independent sources are replaced by their internal resistances i.e., all other ideal voltage sources with short circuit and all other ideal current sources with open circuit. "

Procedure to apply Superposition Theorem :

Step 1: Consider one of the independent sources.

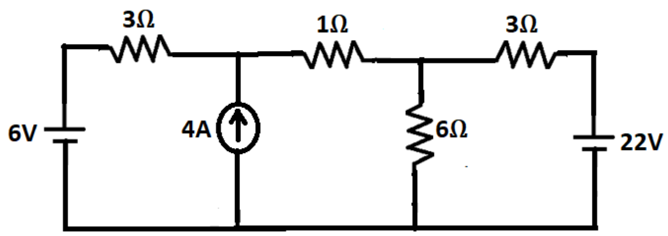
Step 2: Replace all other independent voltage sources with short circuit and all other independent current sources with open circuit.

Step 3: Find the individual response in the desired element due to the considered source acting alone.

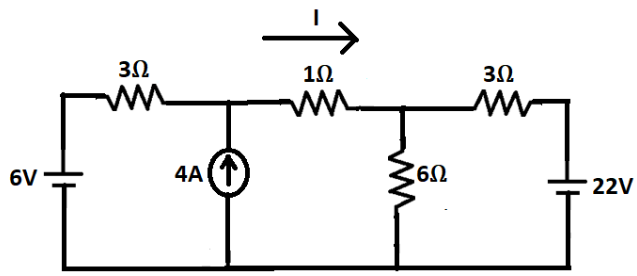
Step 4: Repeat Steps 1, 2 & 3 until all the sources are considered.

Step 5: Add all individual responses algebraically to get the total response.

Numerical Example 1: Obtain current through 1Ω resistor using Superposition Theorem.



Solution: Let I be the current through 1Ω resistor as shown below:

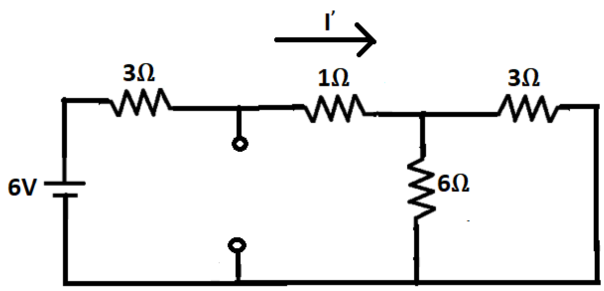


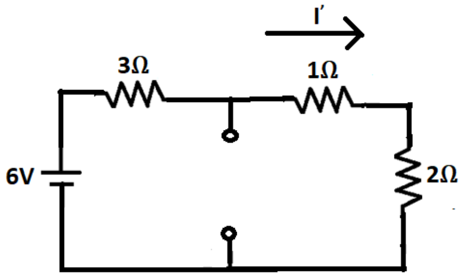
Let us consider individual response due to 6V source acting alone as I'

Let us consider individual response due to 4A source acting alone as I''

Let us consider individual response due to 22V source acting alone as I'''

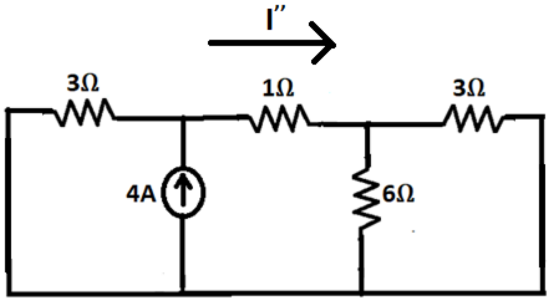
Considering 6V source alone,



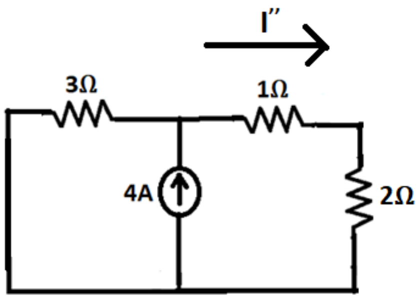


Hence, $I' = \frac{6V}{6\Omega} = 1A$

Now, Considering 4A source alone,

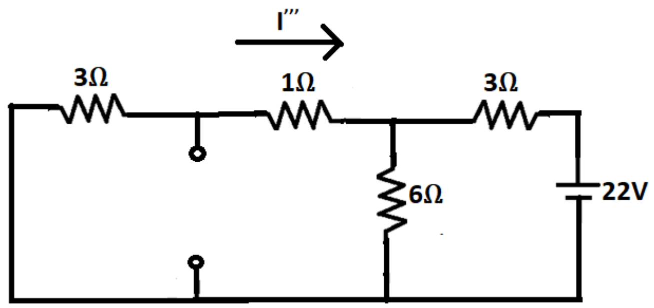


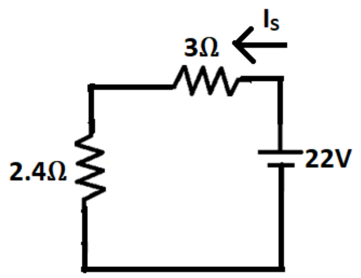
The above network gets simplified as



Hence, $I'' = 4A * \frac{3\Omega}{6\Omega} = 2A$

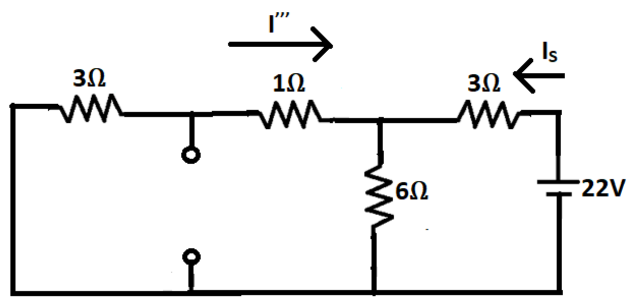
Now, Considering 22V source alone,





$I_S = \frac{22V}{5.4\Omega} = 4.074A$

Therefore, I''' can be obtained as



$I''' = -I_S * \frac{6\Omega}{10\Omega} = -2.44A$

By Superposition Theorem,

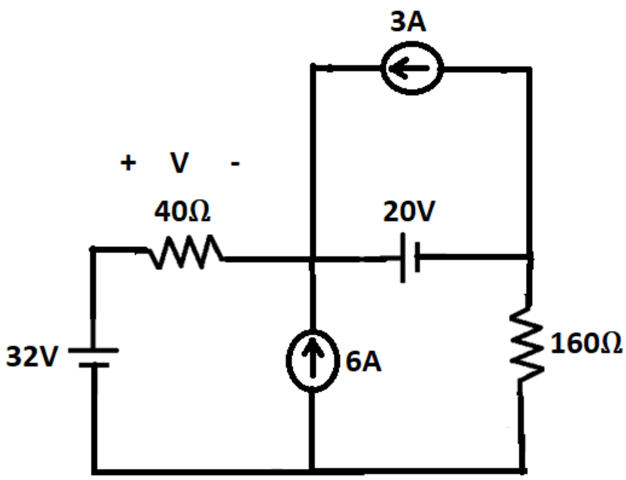
$I = I' + I'' + I'''$

Hence, I = 0.56A

NOTES – CLASS 15

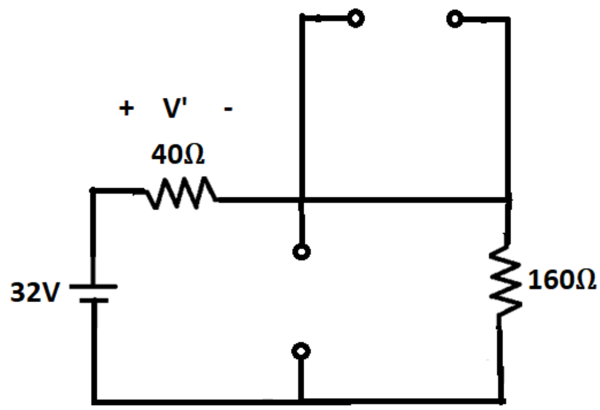
Numerical Examples on Superposition Theorem:

Numerical Example 2: Obtain voltage 'V' using Superposition Theorem.



Solution:

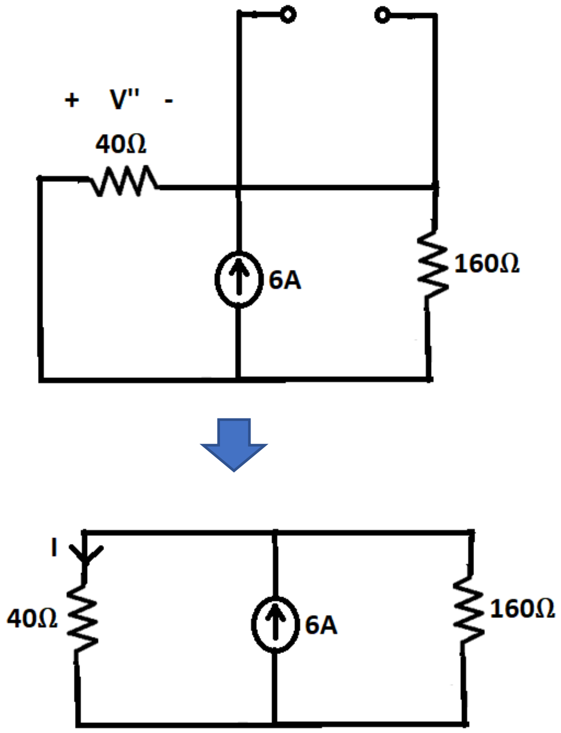
Considering 32V source alone,



Since it is now a simple series network, apply voltage division rule

$V' = 32V * \frac{40\Omega}{200\Omega} = 6.4V$

Considering 6A source alone,



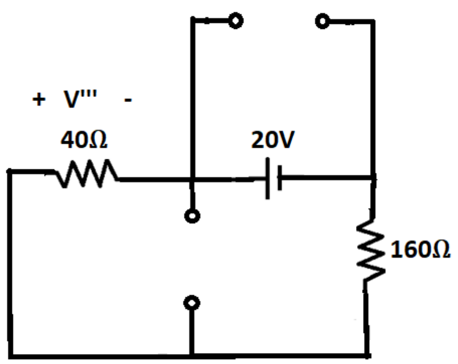
Applying current division rule,

$I = 6A * \frac{160\Omega}{200\Omega} = 4.8A$

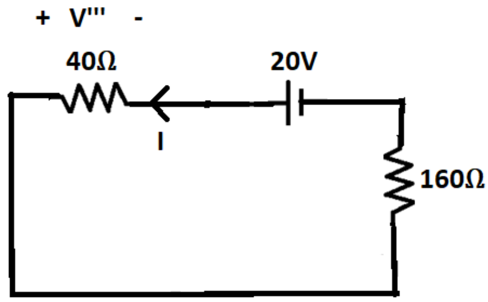
Therefore,

$V'' = -4.8A*40\Omega = -192V$

Considering 20V source alone,



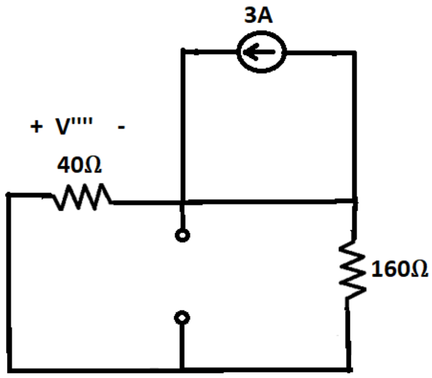
It can be redrawn as,



I = $\frac{20V}{200\Omega}$ = 0.1A

V''' = -0.1A*40Ω = -4V

Considering 3A source alone,



Current from the 3A current source flows through the short circuit. Hence, current through 40Ω resistor is zero.

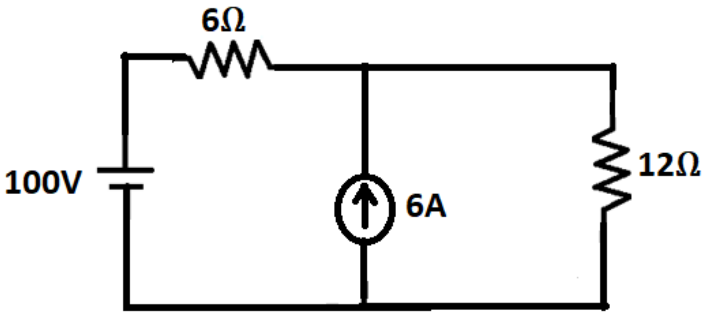
Hence, V'''' = 0

By Superposition Theorem,

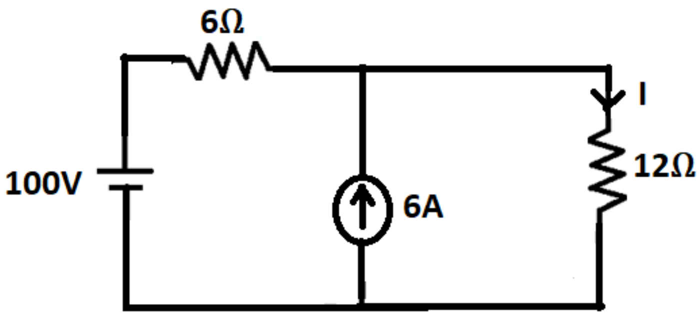
V = V' + V'' + V''' + V'''' = -189.6V

Numerical Example 3:

Find the power absorbed by 12Ω resistor using Superposition Theorem.



Solution:



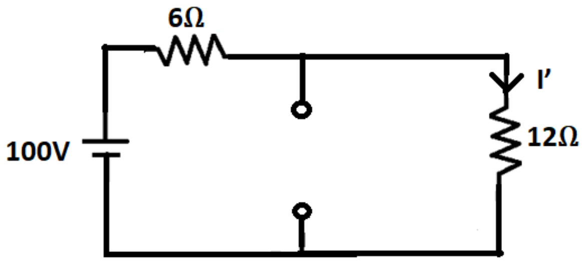
Solution:

Note: Since superposition is applicable to linear elements and linear relationships, it cannot be directly applied to find power since power is a second order variable. Hence, first find either current or voltage response by using superposition. Then, find power using current or voltage thus found.

Let us consider individual current response due to 100V source acting alone as I'

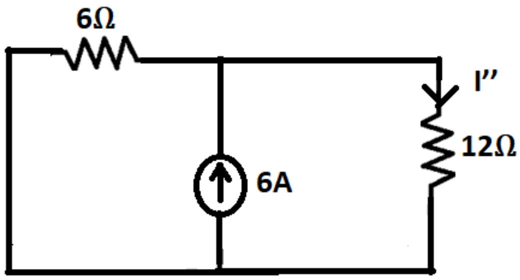
Let us consider individual current response due to 6A source acting alone as I''

Considering 100V source alone,



$I' = \frac{100V}{18\Omega} = 5.56A$

Considering 6A source alone,



Applying current division rule,

$I'' = 6A * \frac{6\Omega}{18\Omega} = 2A$

By Superposition, current in 12Ω resistor = $I = I' + I'' = 7.56A$

Hence, Power absorbed by 12Ω resistor = $I^2 * 12 = 685.84W$

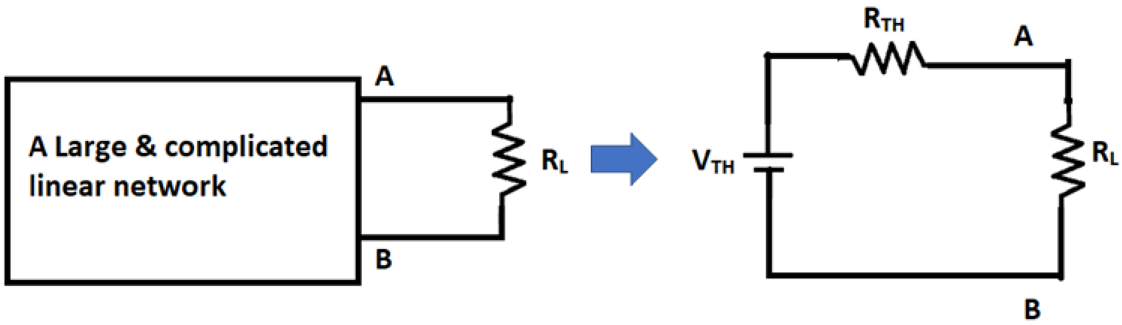
Thus, to get total power response, apply superposition principle to get total current or total voltage & using that find the power.

NOTES – CLASS 16

Thevenin's Theorem:

Statement:

"A linear network with a large number of independent and dependent sources and resistors between two terminals can be replaced with a simple two element series equivalent in which a voltage source called 'Thevenin's Equivalent Voltage'(V_{TH})is in series with a resistance called 'Thevenin's Equivalent Resistance' (R_{TH})."



Steps to find Thevenin's Voltage & Thevenin's Resistance

Steps to find V_{TH} :

Step 1: Remove the load resistance.

Step 2: Mark voltage across open load terminals and designate it as V_{TH}.

Step 3: Find V_{TH} using KVL or any other technique.

Steps to find R_{TH} :

Step 1: Remove the load resistance.

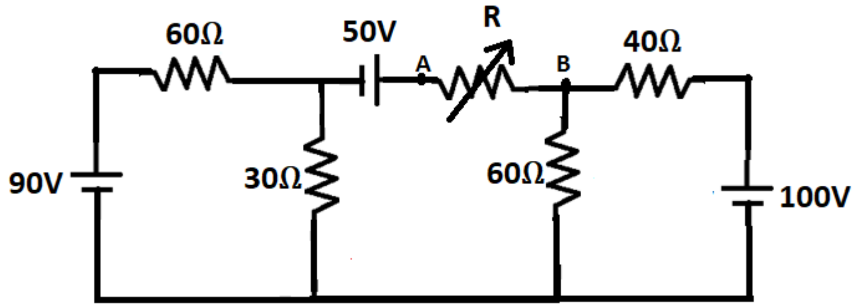
Step 2: Replace all independent voltage sources with short circuit & all independent current sources with open circuit

Step 3: Looking into the open load terminals find the equivalent resistance.

Note: Load resistance is that resistance in which we need to find current or voltage or power response.

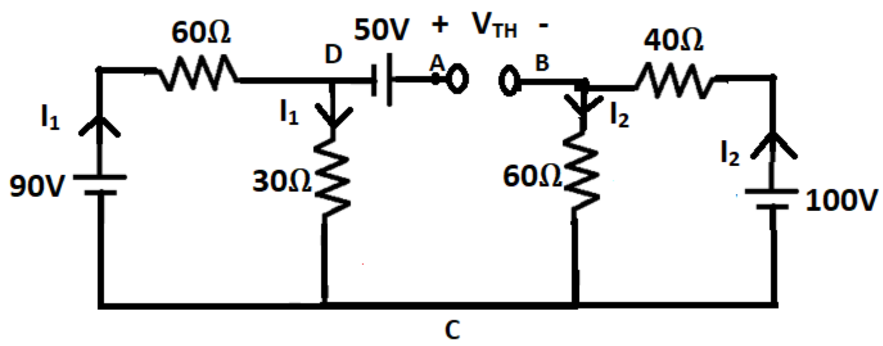
Numerical Example 1:

Using Thevenin's Theorem, calculate the range of current flowing through the resistance R, as it varies from 6Ω and 36Ω.



Solution:

Finding V_{TH} :



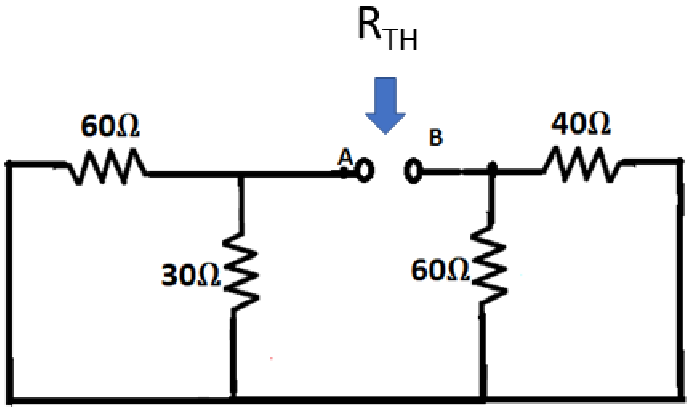
90V - 60Ω - 30Ω makes a simple series path. 100V - 40Ω - 60Ω makes another simple series path.

Hence, $I_1 = \frac{90V}{90\Omega} = 1A$; $I_2 = \frac{100V}{100\Omega} = 1A$

By KVL (DABCD), $+50 - V_{TH} - 60*I_2 + 30*I_1 = 0$

$V_{TH} = 20V$

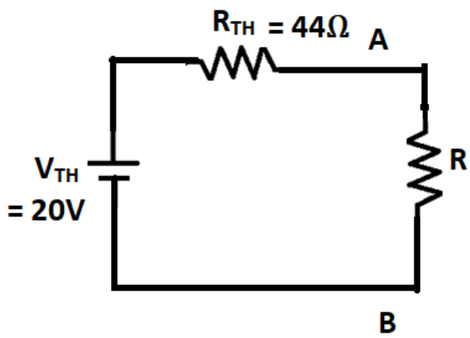
Finding R_{TH} :



Here, (60Ω and 30Ω) are in parallel. Also, (60Ω and 40Ω) are in parallel. These two parallel combinations are in series.

Hence, R_{TH} = (60Ω II 30Ω) + (60Ω II 30Ω) = 44Ω

Let us now replace the original network with its Thevenin's Equivalent i.e.,



Hence, Load current $I_L = \dfrac{V_{TH}}{R_{TH}+R}$

When R = 6Ω, I_L = 0.4A

When R = 36Ω, I_L = 0.25A

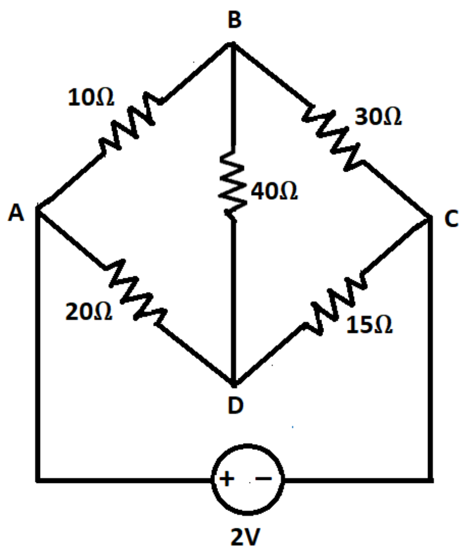
Hence, current through 'R' ranges from 0.25A to 0.4A.

NOTES – CLASS 17

Numerical Example on Thevenin's Theorem:

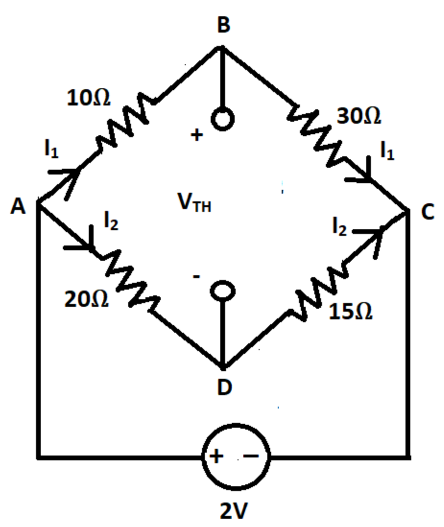
Numerical Example 1:

Using Thevenin's Theorem, find the magnitude and direction of current in the branch BD in the network shown.



Solution:

Finding V_{TH} : Here 40Ω resistor is the load resistor.



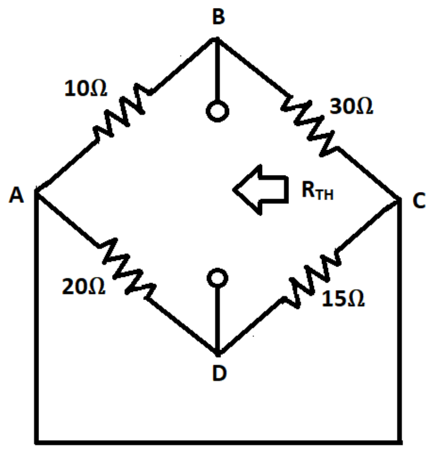
Here, 10Ω and 30Ω are in series. Hence, $I_1 = \frac{2V}{40\Omega} = 0.05A$

Also, 20Ω and 15Ω are in series. Hence, $I_2 = \frac{2V}{35\Omega} = 0.057A$

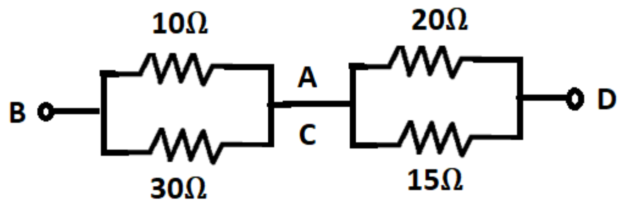
By KVL (ACDA), $-10*I_1 - V_{TH} + 20*I_2 = 0$

Hence, $V_{TH} = 0.64V$

Finding R_{TH} :

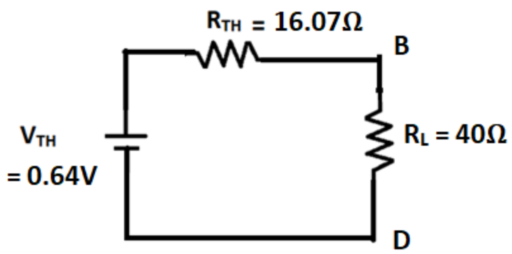


The above network can be rearranged as follows:



Hence, R_{TH} = (10Ω II 30Ω) + (20Ω II 15Ω) = 16.07Ω.

Thevenin's Equivalent Circuit:

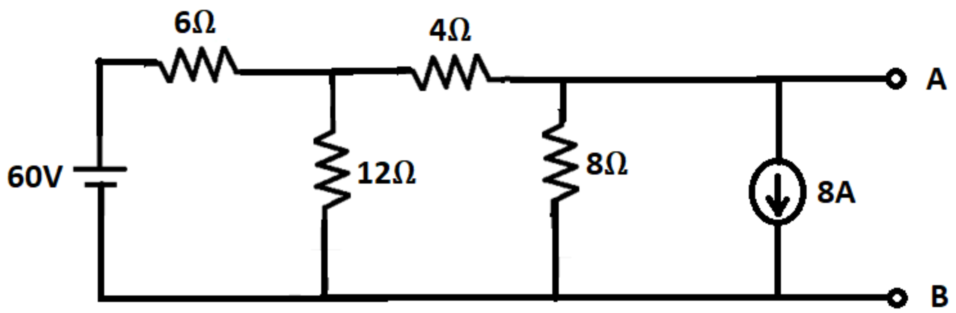


$$I_L = \frac{V_{TH}}{R_{TH}+R_L}$$

Hence, current through the branch BD is 11.41mA and flows from terminal B to terminal D.

Numerical Example 2:

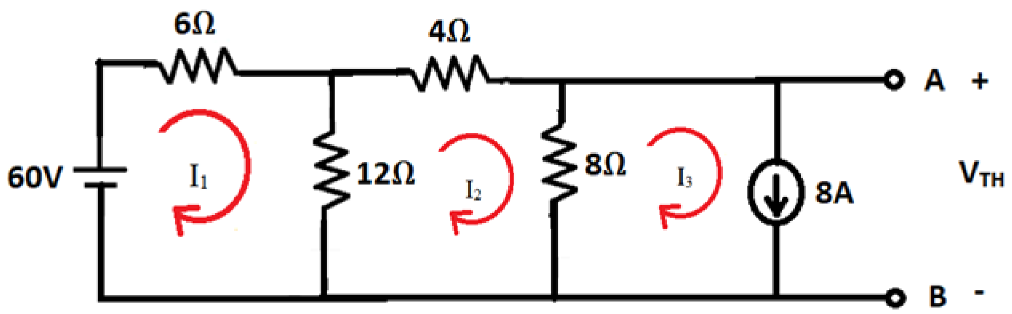
Obtain the Thevenin's Equivalent across the terminals A & B for the network given.



Solution:

Note: In this network, there is no load resistance. Entire network needs to be replaced with its Thevenin's Equivalent i.e., V_{TH} in series with R_{TH}.

Finding V_{TH} :



KVL (Mesh 1) : $18I_1-12I_2-0I_3 = 60$ ---- (1)

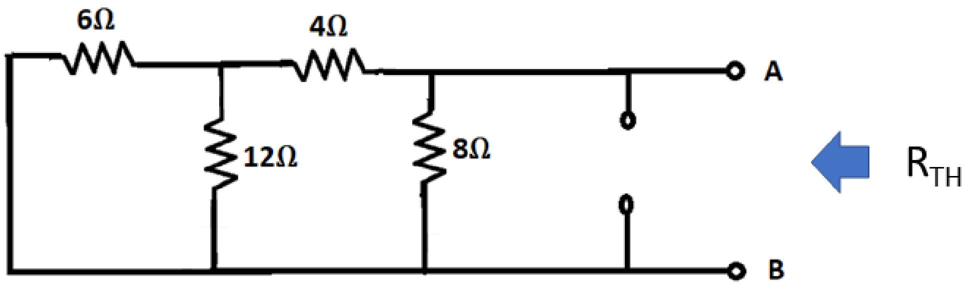
KVL (Mesh 2) : $-12I_1+24I_2-8I_3 = 0$ ---- (2)

Current Equation(Mesh 3) : $I_3 = 8$ ---- (3)

Solving (1), (2) & (3), $I_1 = 7.66A$; $I_2 = 6.5A$

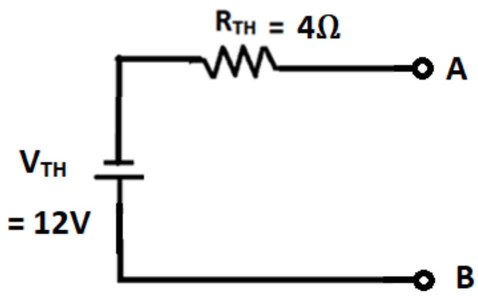
Hence, $V_{TH} = (I_2\text{-}I_3)*8\Omega = -12V$

Finding R_{TH} :



Hence, $R_{TH} = \{(6\Omega \text{ II } 12\Omega) + 4\Omega) \text{ II } 8\Omega\} = 4\Omega$

Thevenin's Equivalent Circuit:



Here, since V_{TH} has turned out to be negative, it can be represented in the equivalent network with battery polarity reversed.