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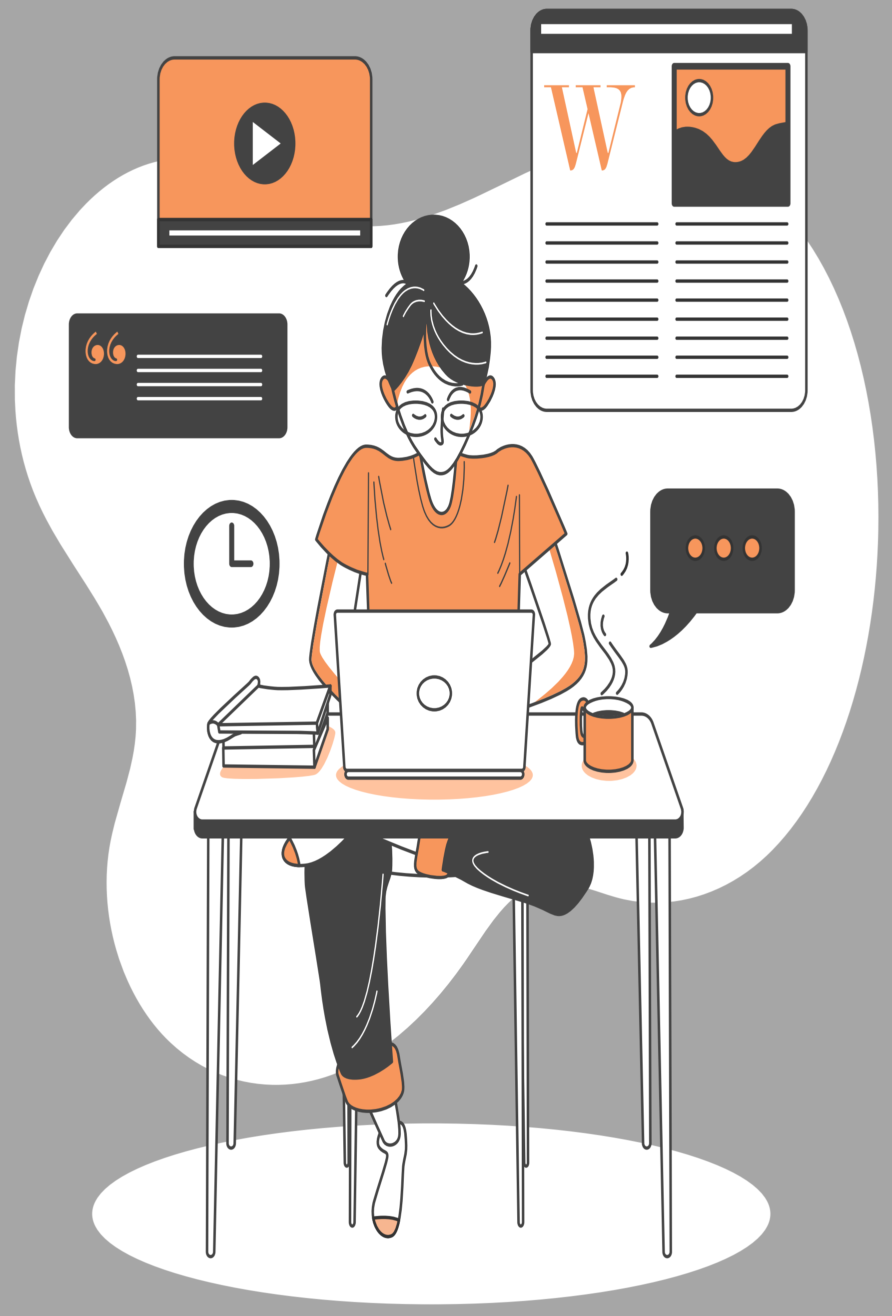

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ELECTRICAL AND ELETRONICS

FIRST YEAR / SECOND SEMESTER

EE8251 – CIRCUIT THEORY

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UNIT 01 – BASIC CIRCUITS ANALYSIS

"You must be the change you wish to see in the world."

—Mahatma Gandhi

Introduction

With increase in population the need for electricity also increases therefore it is necessary to rise number of electrical engineers.
The electrical engineering mainly deals with generation , transmission and distribution of electricity.

Electrical circuits is the basic and fundamental subject which lays path to understand subjects related to generation , transmission and distribution of electricity.

In the first unit we shall deal with what is electrical circuit and formation of electrical circuit

Hence the basic definitions of voltage , current , power and energy are studied here.

CIRCUIT:

The electrical circuit consists of mainly three parts , they are -- source, connecting wire and load or sink.

Source : An source may be battery which forces electrons into the circuit. Connecting wire : This is part which provides path for electrons to flow.

Load : The load may be bulb etc. when electrons flow through it an reaches the Source it glows .

If the electrons are provided closed path to flow, leads to current is called as **electrical circuit**.

BASIC DEFINITIONS:

Voltage(V) : The potential difference between force applied to two oppositely charged particles to bring them as near as possible is called as potential difference .(in electrical terminology it s voltage).

$$V = W / Q \ (v)$$

$$\upsilon = dw / dq \ (v)$$

v- volts , units of voltage.

One Unit volt is defined as 1C of charge developed when 1 J of energy is applied.

Current(I) : The flow of electrons develops the current.

$$I = Q/ t \ (A)$$

$$i = dq / dt \ (A)$$

A = Ampere, units of current.

One Unit ampere of current is constituted when 1C of charge is flowing in 1S.

Power(P): It is defined as product of volateg and power in electrical circuits or Rate of change of energy.

$$P = dw/dt = dw/\ dq\ .$$

$$dq/dt\ =\ \upsilon\ .i\ (W)\ W = \text{watts, units of power.}$$

Unit watt is the 1J of energy is dissipated in 1S.

Enegy : It is the capacity to do work or it is defined as power consumed over Given interval of time.(w)

$$W = \int P\ dt.(J)$$

J = Joules, units of energy 1J = 1 watt-sec.

BASIC PARAMETERS:

Any electrical mainly consists of three important elements , they are resistor, inductor and capacitor. Let us deal these parameters in detail.

Resistor: resistor is the element which restricts flow of electrons and this Property of opposing electrons is called as resistance.

OHM's Law : ohm's law states that current flowing through circuit is Directly proportional to potential difference applied. (at constant temperature)

$I \alpha V$, at constant T.

$I.R = V.$

$R = V / I$, hence resistance can be calculated as ratio of Voltage to current in any element or circuit.OHMS Ω, units of resistance.

Inductor:

An length of wire twisted forms the basic inductor.(L). when Alternating current is allowed through such a element it induces Voltage in it.

Where, e = emf induced

ϕ = flux developed in it for current i.

Hence, e = L di/dt (v).

L= is the inductance of the coil(H)

H = henry units of inductance.

Unit H is the 1v of voltage induced in coil when current changing at arte of 1A/S .

by solving above equation , current flowing through coil is given as, $i = (1/L) \int v\, dt + i(o+)$.

Energy stored in inductor,

$W = \int e.i\, dt = \int L\, di/dt.\, i\, dt. = (1/2)\, L\, i^2$

Properties:

Inductor doesn't allow sudden changes in current.

If DC supply is provided to inductor it acts as short circuit.

Pure inductor is non-dissipative element i.e its internal resistance is zero.

stores energy in the form of magnetic field.

Capacitor : two parallel plates oppositely charged separated by an di-electric medium constitutes an capacitor.

v, i when some voltage v is applied , i is the current flowing through capacitor, given as

$i = c\, dv/dt$

c = capacitance of the capacitor.(F)

Farad is the unit of capacitance, 1F is the when 1A Flow if 1v applied for 1S.

Voltage across capacitor is given as, $v = (1/c) \int i\, dt + v(0+)$.

Energy stored in capacitor is , $w = \int v.i\, dt = \int c\, dv/dt.\, i\, dt. = (1/2)\, cv^2$

Properties:

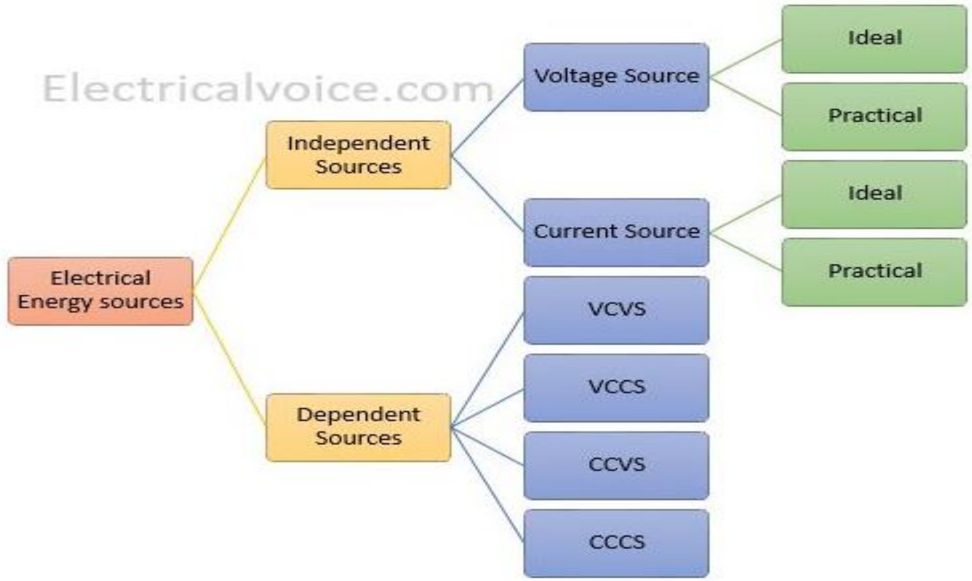
capacitor doesn't allow sudden changes in voltage.

If DC supply is provided to capacitor it acts as open circuit.

Pure capacitor is non-dissipative element i.e its internal resistance is zero.

stores energy in the form of electric field.

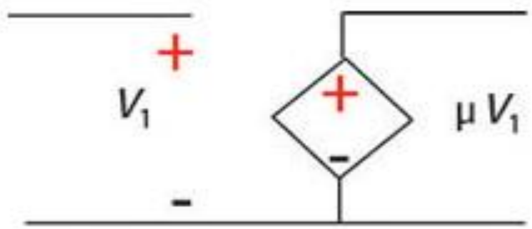
ENERGY SOURCES:



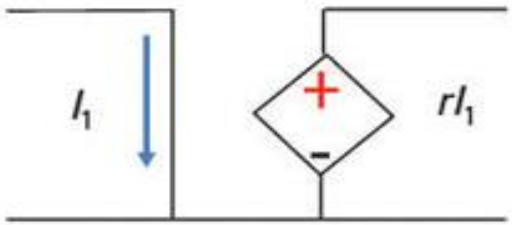
Ideal sources: These are one zero internal resistance their same will appear at
terminals .

Practical sources: These are one with internal resistance and there is a drop at Terminal value than actual value applied.

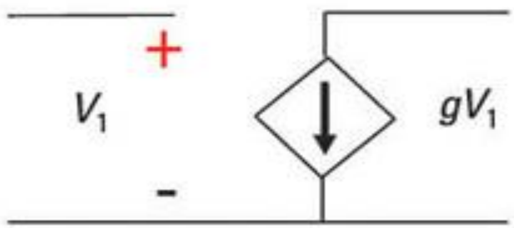
Dependent sources



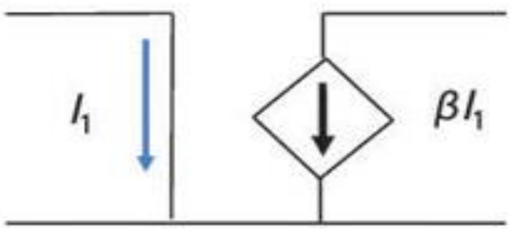
Voltage-controlled
voltage source (VCVS)



Current-controlled
voltage source (CCVS)



Voltage-controlled
current source (VCCS)



Current-controlled
current source (CCCS)

TYPES OF ELEMENTS:

Active and passive elements: Elements which delivers power are active and which receives power are passive.

Eg: voltage and current source for active elements.

R,L,C are passive elements.

Uni-lataeral and bi-lateral elements: If the V-I characteristics are differenrt for different directions of current they are called as uni-lateral otherwise bi-lataeral elements.

Eg: diode, transistor etc for uni-lateral elements.

R for bi-lateral elements.

Linear and non-linear elements: elements which obeys ohms law are called as linear otherwise non-linear.

Eg: R for linear elements.

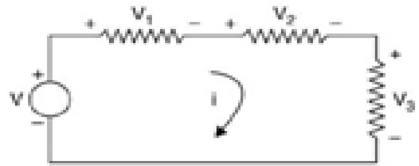
L,C are non-linear elements.

Lumped and distributed: Elements which are small in size are lumped and which distribuited through out the line are distributed elements

Eg: cable wire for distributed elements. R,L,C in lab are lumped elements.

KIRCHOFF'S LAW:

Kirchoff's voltage law(KVL): States that algebraic sum of voltages in an loop is equal to zero.



$\sum v = o.$

V = V1 + V2 + V3

Where, V1 = i.R1, V2 = i.R2, V3 = i.R3,

from which

i = V / (R1 + R2 + R3) = Vs / Rt

V = source voltage i = source current

Rt = equivalent or total resistance of circuit = R1 + R2 + R3

Voltage division rule:

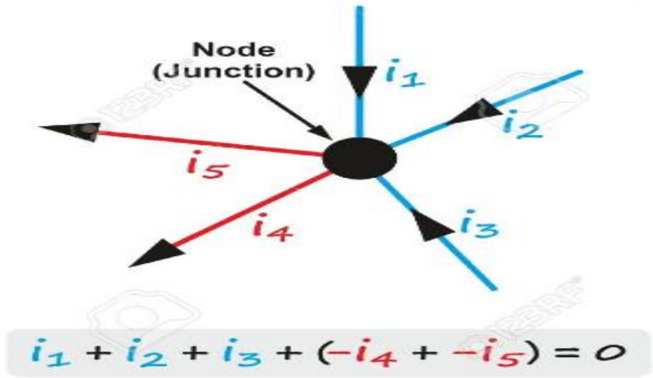
V1 = i.R1

We know that , i = V / (R1 + R2 + R3) = Vs / Rt Substituting i in V1,

V1 = Vs / Rt * R1.

Similarly, V2 = Vs / Rt * R2., V3 = Vs / Rt * R3.

Kirchoff's current law(KCL): States that sum of the current entering junction is equal to sum of the leaving the junction.



Current division rule:

Let Vs be the voltage at node A, I is the source current I1 = Vs / R1

I2 = Vs / R2

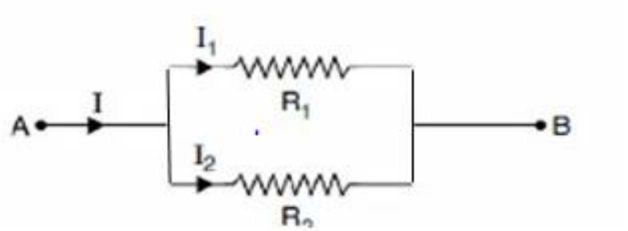
Applying KCL at node A, I = I1 + I2 = Vs / R1 + Vs / R2

Vs = I. [1 / (1/R1) + (1/R2)] = I.Rt

Rt = [1 / (1/R1) + (1/R2)] = R1.R2 / (R1+R2)

I1 = I. R2/ (R1+R2).

I2 = I. R1/ (R1+R2).

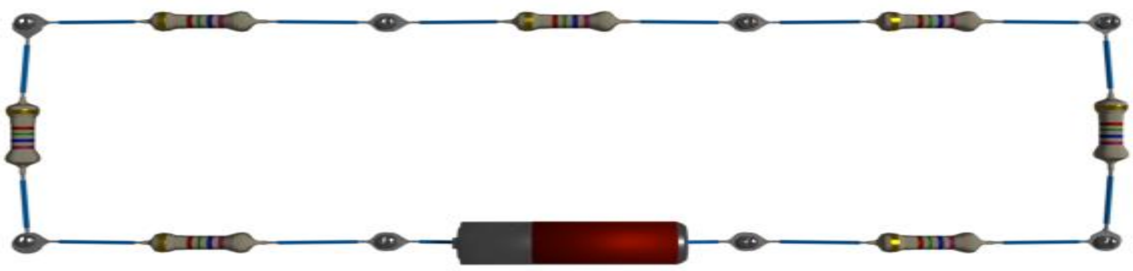


Single and Multi Mesh Analysis

Mesh Analysis is used to find out the voltage, current or power through a particular element or elements. Mesh analysis is based on Kirchhoff Voltage Law. We can use Mesh analysis only on planar circuits. The planar circuit is the one which is possible to draw on a plane surface in such a way that no branch passes over or under any other branch. This circuit does not contain any branch which passes over or under any other branch.

Single Mesh

If in a closed circuit the number of mesh is only one, then that types of circuits are known as single meshed circuits.

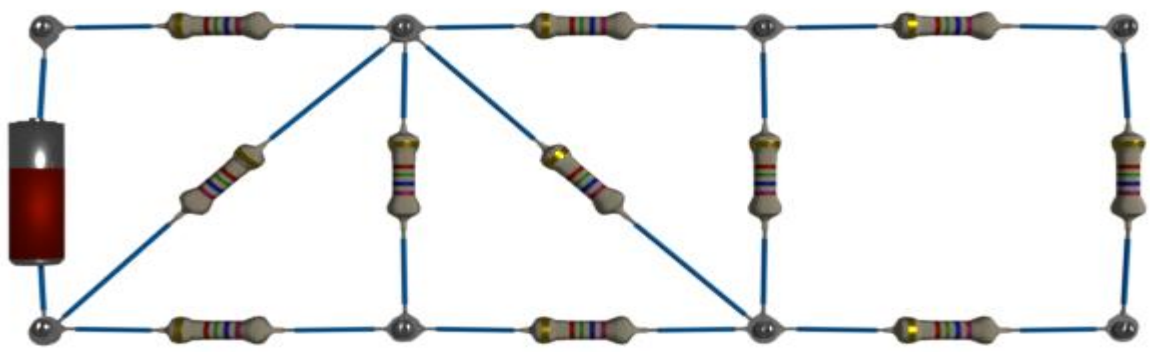


In these types of analysis, the current or voltage across any element can be found out directly by using Ohm's law.

However, if the circuit elements are in parallel then also we can convert them into a **single mesh** by using the law of parallel combinations of the circuit elements.

Multi Mesh

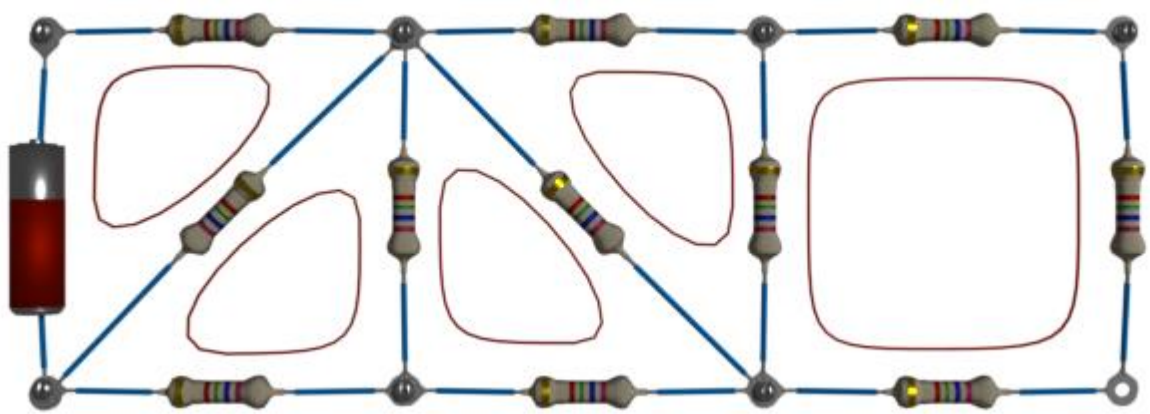
The circuit, which has more than one mesh, is known as **multi meshed circuit**. The analysis of multi meshed circuit is somewhat difficult as compared to that of single meshed circuit

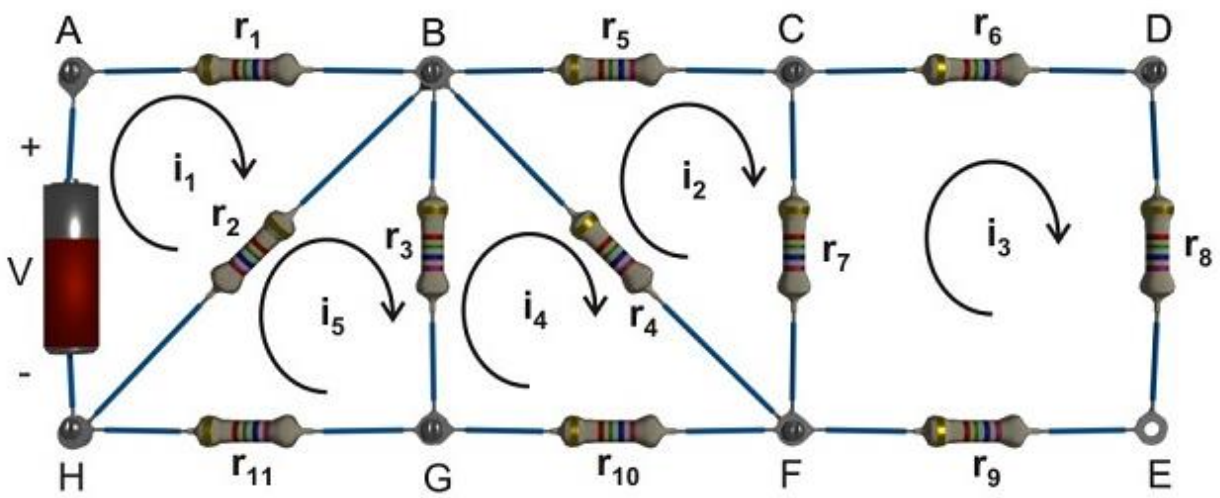


Steps for Mesh Analysis

1.First we have to determine whether the circuit is planar or non planar. If it is a non planar circuit, we have to perform other methods of analysis such as nodal analysis.

2.Then we have to count the number of meshes. The number of equations to be solved is same as the number of meshes.





3.Then we label each of the mesh currents according to the convenience

We write KVL equation for each of the meshes. If the element lies between two meshes then we calculate the total current flowing through the element by considering two meshes.

If the direction of two mesh currents is same then summation of currents is taken as the total current flowing through the element and if the direction is opposite then the difference of mesh currents is taken.

In second case the current in the mesh under consideration is taken as the greatest among all the meshes currents and the procedure is followed.

For mesh ABH, the KVL is

$$V - r_1 i_1 - r_2(i_1 - i_5) = 0 \cdots\cdots (1)$$

For mesh BCF, the KVL is

$$-r_5 i_2 - r_7(i_2 - i_3) - r_4(i_2 - i_4) = 0 \cdots\cdots (2)$$

For mesh CDEF, the KVL is

$$-r_6 i_3 - r_8 i_3 - r_9 i_3 - r_7(i_3 - i_2) = 0 \cdot \cdot \cdot \cdot \cdot (3)$$

For mesh BFG, the KVL is

$$-r_4(i_4 - i_2) - r_{10} i_4 - r_3(i_4 - i_5) = 0 \cdot \cdot \cdot \cdot \cdot (4)$$

For mesh BGH, the KVL is

$$-r_3(i_5 - i_4) - r_{11} i_5 - r_2(i_5 - i_1) = 0 \cdot \cdot \cdot \cdot \cdot (5)$$

Organize the equation according to the mesh currents.
Solve the mesh equations for i_1, i_2, i_3, i_4, and i_5.

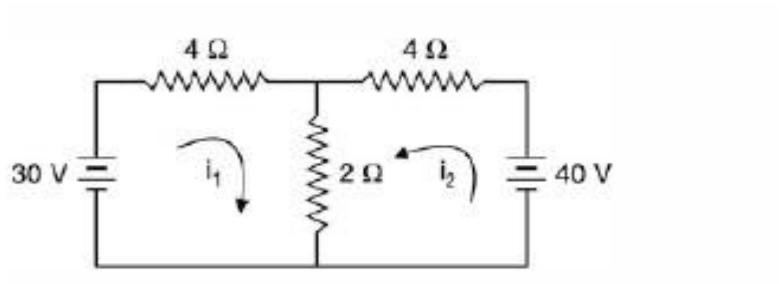
If any dependent source is there in the circuit or any unknown other than mesh currents, express that source in the suitable mesh currents.

Disadvantages of Mesh Analysis

We can use this method only when the circuit is planar, otherwise the method is not useful.

If the network is large then the number of meshes will be large, hence, the total number of equations will be more so it becomes inconvenient to use in that case.

MESH ANALYSIS PROBLEM:



Let V1 = 30v, V2 = 40v, R1 =4 ohms, R2 = 2 ohms and R3 = 4 ohms
i1, i2 are the mesh currents, here positive direction of currents are assumed , but in general we can assume current directions in any fashion and can solve.

Applying KVL to first loop we get, V1 – i1R1 – (i1+i2)R2.
V1 = (R1+R2)i1 + i2.R2. (1)
Applying KVL to second loop we get, V2 – i2R3 – (i1+i2)R2.
V2 = (R1+R2)i1 + i2.R3. (2)

Hence by solving eq. 1 and 2 we can get mesh currents i1 and i2.

Mesh analysis by inspection method:

Inspection method is direct method using mesh currents can be find directly without applying KVL. Let us take same network as above , representing equation 1 and 2 in matrix form.

$$\begin{bmatrix} V1 \\ V2 \end{bmatrix} = \begin{bmatrix} R1 & R1+R2 \\ R1+R2 & R3 \end{bmatrix} \begin{bmatrix} i1 \\ i2 \end{bmatrix}$$

Generally we can write in matrix form as,

$$\begin{bmatrix} V1 \\ V2 \end{bmatrix} = \begin{bmatrix} R11 & R12 \\ R21 & R22 \end{bmatrix} \begin{bmatrix} i1 \\ i2 \end{bmatrix}$$

Where, V1 – sum of all the voltage sources in 1st mesh according current flow. V2 – sum of all the voltage sources in 2nd mesh according current flow. R11- self resistance of first loop, adding total resistance in 1st loop R21= R12- mutual resistance between 1st and 2nd loop ,

+ve if mesh currents are in same direction

-ve if mesh currents are in opposite direction

R22- self resistance of second loop, adding total resistance in 2nd loop

Nodal Analysis in Electric Circuits

Definition of Nodal Analysis

Nodal analysis is a method that provides a general procedure for analyzing circuits using node voltages as the circuit variables. **Nodal Analysis** is also called the **Node-Voltage Method**.

Some Features of Nodal Analysis are as

Nodal Analysis is based on the application of the Kirchhoff's Current Law (KCL).

Having 'n' nodes there will be 'n-1' simultaneous equations to solve.

Solving 'n-1' equations all the nodes voltages can be obtained.

The number of non reference nodes is equal to the number of Nodal equations that can be obtained.

Types of Nodes in Nodal Analysis

Non Reference Node – It is a node which has a definite Node Voltage.

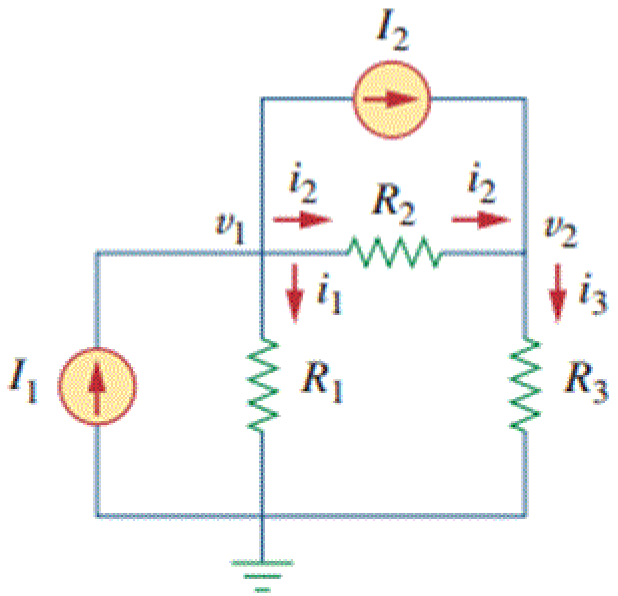
Reference Node – It is a node which acts a reference point to all the other node. It is also called the Datum Node.

Basic Steps Used in Nodal Analysis

1.Select a node as the reference node. Assign voltages V_1, V_2… V_{n-1} to the remaining nodes. The voltages are referenced with respect to the reference node.

2.Apply KCL to each of the non reference nodes.

Use Ohm's law to express the branch currents in terms of node voltages.



3.Node Always assumes that current flows from a higher potential to a lower potential in resistor. Hence, current is expressed as follows

$$I = \frac{V_{high} - V_{low}}{R}$$

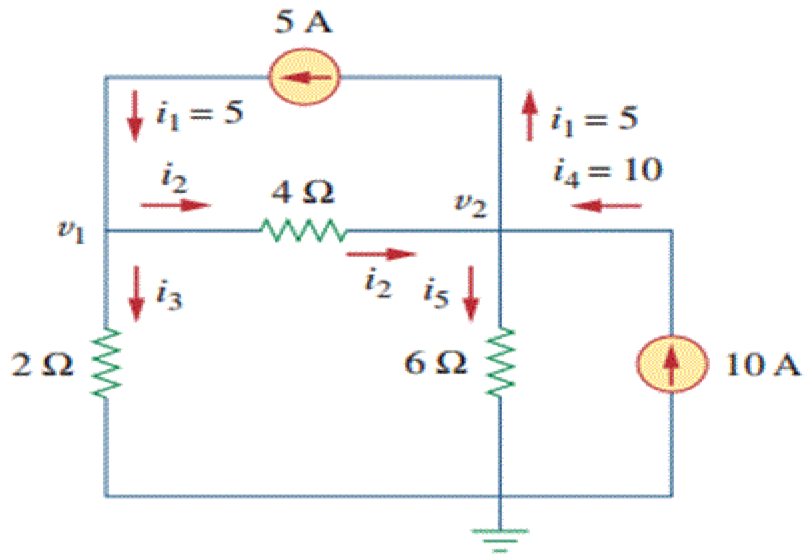
4. After the application of Ohm's Law get the 'n-1' node equations in terms of node voltages and resistances.

5. Solve 'n-1' node equations for the values of node voltages and get the required node Voltages as result.

Nodal Analysis with Current Sources

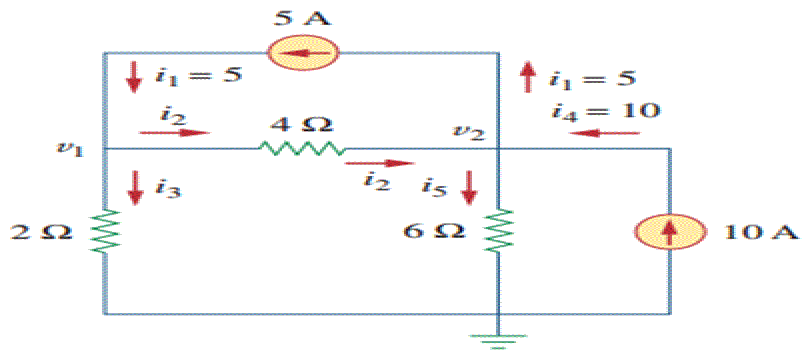
Nodal analysis with current sources is very easy and it is discussed with a example below.

Example: Calculate Node Voltages in following circuit



In the following circuit we have 3 nodes from which one is reference node and other two are non reference nodes – Node 1 and Node 2.

Step I. Assign the nodes voltages as v_1 and $_2$ and also mark the directions of branch currents with respect to the reference nodes



Step II. Apply KCL to Nodes 1 and 2
KCL t node 1

$$i_1 = i_2 + i_3 \cdots\cdots(1)$$

KCL at node 2

$$i_2 + i_4 = i_1 + i_5 \cdots\cdots(2)$$

Step III. Apply Ohm's Law to KCL equations

- Ohm's law to KCL equation at Node 1

$$i_1 = i_2 + i_3 \Rightarrow 5 = \frac{v_1 - v_2}{4} + \frac{v_1 - 0}{2}$$

Simplifying the above equation we get

$$-3v_1 + 5v_2 = 60 \cdots\cdots(4)$$

Step IV. Now solve the equations 3 and 4 to get the values of v_1 and v_2 as,
Using elimination method

$$3v_1 - v_2 = 20$$
$$-3v_1 + 5v_2 = 60$$
$$\Rightarrow 4v_2 = 80 \Rightarrow v_2 = 20\ Volts$$

And substituting value v_2 = 20 Volts in equation (3) we get-

$$3v_1 - 20 = 20 \Rightarrow v_1 = \frac{40}{3} = 13.333\ Volts$$

Hence node voltages are as v_1 = 13.33 Volts and v_2 = 20 Volts.

Nodal Analysis with Voltage Sources

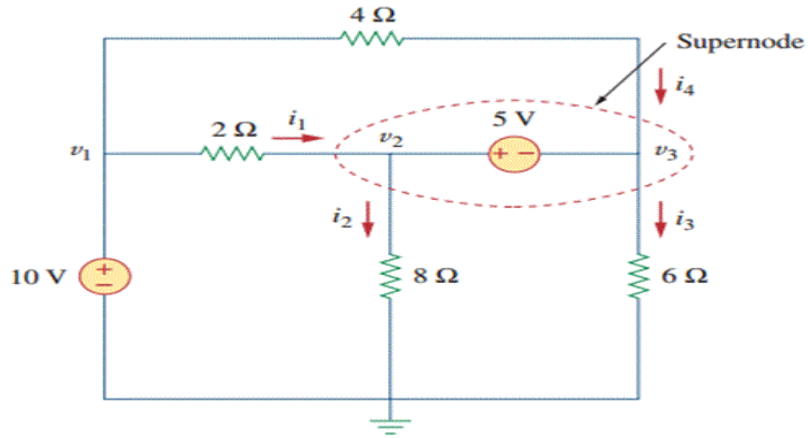
Case I. If a voltage source is connected between the reference node and a non reference node, we simply set the voltage at the non-reference node equal to the voltage of the voltage source and its analysis can be done as we done with current sources. $v_1 = 10$ Volts.

Case II. If the voltage source is between the two non reference nodes then it forms a supernode whose analysis is done as following

Supernode Analysis

Definition of Super Node

Whenever a voltage source (Independent or Dependent) is connected between the two non reference nodes then these two nodes form a generalized node called the Super node. So, Super node can be regarded as a surface enclosing the voltage source and its two nodes.



In the above Figure 5V source is connected between two non reference nodes Node – 2 and Node – 3. So here Node – 2 and Node – 3 form the Super node.

Properties of Super node

Always the difference between the voltage of two non reference nodes is known at Super node.

A super node has no voltage of its own

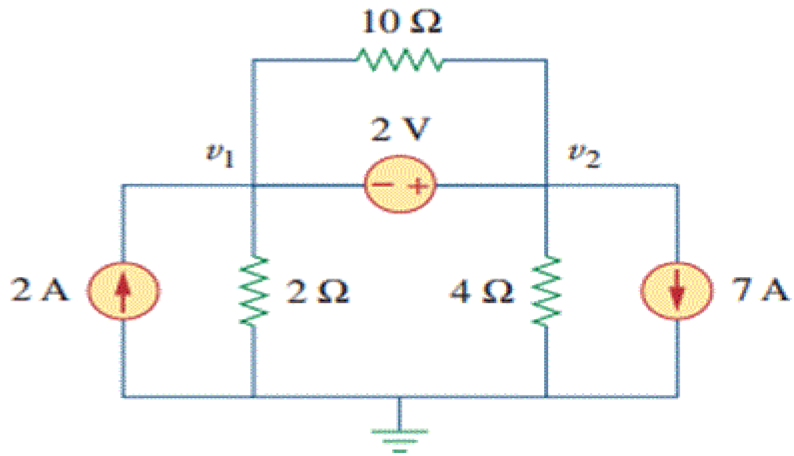
A super node requires application of both KCL and KVL to solve it.

Any element can be connected in parallel with the voltage source forming the super node.

A Super node satisfies the KCL as like a simple node.

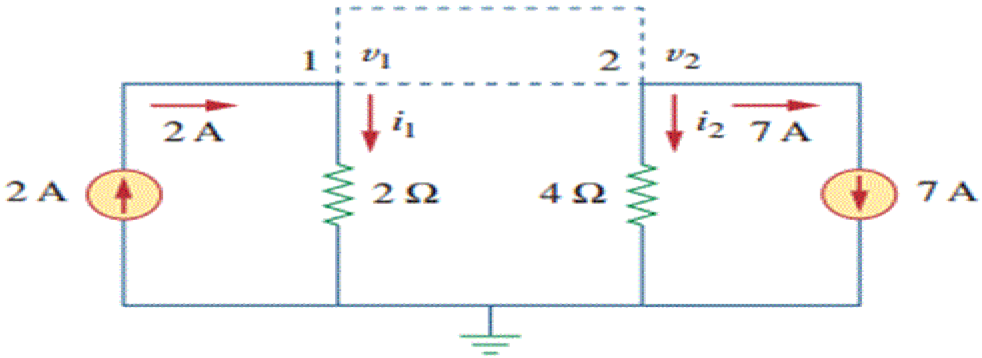
Circuit Containing Super node

Let's take a example to understand how to **solve circuit containing Super node**



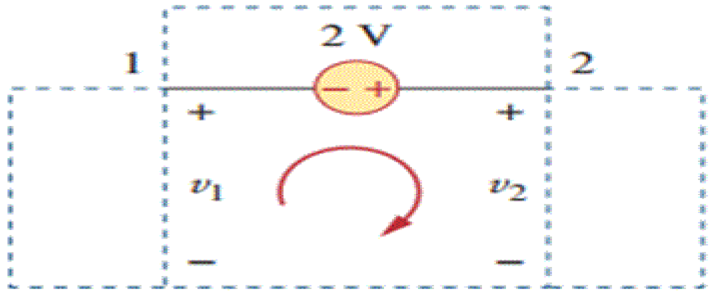
Here 2V voltage source is connected between Node-1 and Node-2 and it forms a Super node with a 10Ω resistor in parallel.

Note – Any element connected in parallel with the voltage source forming Super node doesn't make any difference because $v_2 - v_1 = 2V$ always whatever may be the value of resistor. Thus 10 Ω can be removed and circuit is redrawn and applying KCL to the super node as shown in figure gives,



Expressing and in terms of the node voltages.

$$2 = \frac{v_1 - 0}{2} + \frac{v_2 - 0}{4} + 7 \Rightarrow 8 = 2v_1 + v_2 + 28 \Rightarrow v_2 = -2v_1 - 20 \cdots\cdots(5)$$



$$v_1 + 2 - v_2 = 0 \Rightarrow v_2 = v_1 + 2 \cdots\cdots(6)$$

From Equation 5 and 6 we can write as

$$v_2 = v_1 + 2 = -2v_1 - 20 \Rightarrow 3v_1 = -22$$
$$\Rightarrow v_1 = -7.333\ V \ \&\ v_2 = v_1 + 2 = -7.333 + 2 = -5.333\ V$$

Hence, v_1 = – 7.333V and v_2 = – 5.333V which is required answer.

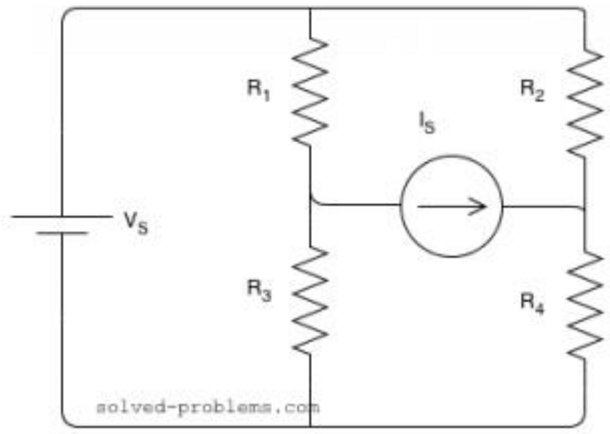
SUPERMESH

Super mesh Analysis is a better technique instead of using **Mesh analysis** to analysis such a complex electric circuit or network, where two meshes have a current source as a common element.

In super mesh circuit analysis technique, the current source is in the inner area of the super mesh. Therefore, we are able to reduce the number of meshes by one (1) for each current source which is present in the circuit.

The single mesh can be ignored, if current source (in that mesh) lies on the perimeter of the circuit. Alternatively, KVL (Kirchhoff's Voltage Law) is applied only to those meshes or super meshes in the renewed circuit.

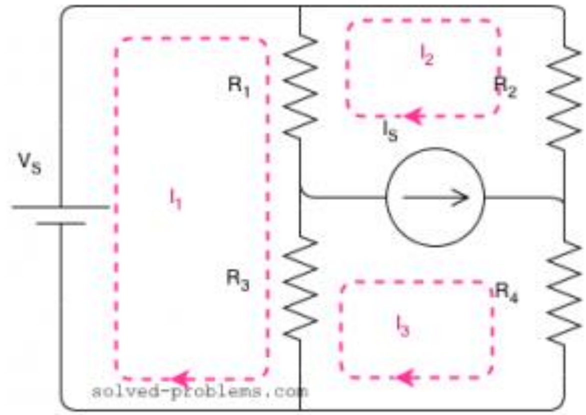
Solve the circuit and find the power of sources:



$V_S=10V$, $I_S=4A$, $R1=2\Omega$, $R2=6\Omega$, $R3=1\Omega$, $R4=2\Omega$.

Solution:

There are three meshes in the circuit. So, we need to assign three mesh currents. It is better to have all the mesh currents loop in the same direction (usually clockwise) to prevent errors when writing out the equations.



If one assume the inverse direction, i.e. from bottom to top, it would be I2−I1I2−I1.

Now, lets write the equation for mesh of I1I1 (Mesh I). A mesh equation is in fact a KVL equation using mesh currents. We start from a point and calculate algebraic sum of voltage drops around the loop:

First the voltage source:

−VS+...−VS+...

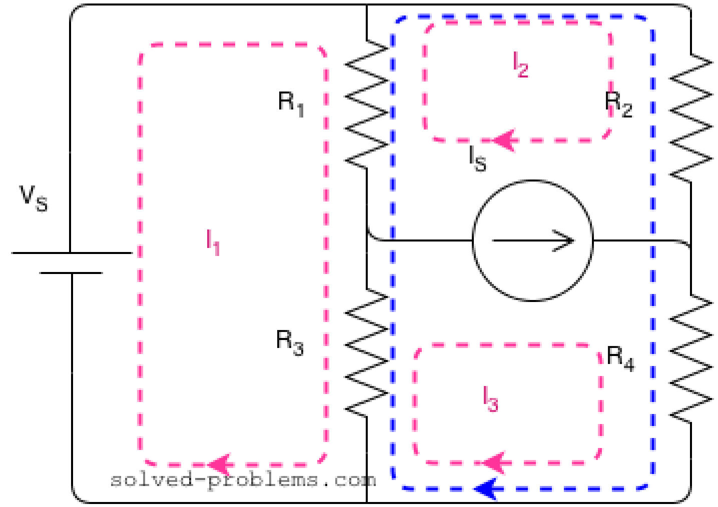
Now we have reached R1R1 from its upper node. So its current is I1−I2I1−I2 and we have:

−VS+R1×(I1−I2)+...−VS+R1×(I1−I2)+...

A supermesh is a larger loop which has both meshes inside.
Let's try both methods.
1) Using VIS
Mesh II:
$R1\times(I2-I1)+R2\times(I2)-VIS=0R1\times(I2-I1)+R2\times(I2)-VIS=0$
Note that for R1R1, unlike the equation for Mesh I, the current is $I2-I1I2-I1$. This is because we are walking around the loop with the direction of I2I2, or briefly it is because we are writing the equation for mesh of I2I2.
Mesh III:
$R3\times(I3-I1)+VIS+R4\times(I3)=0R3\times(I3-I1)+VIS+R4\times(I3)=0$.
Let's add two equations:
$R1\times(I2-I1)+R2\times(I2)-VIS+R3\times(I3-I1)+VIS+R4\times(I3)=0+0R1\times(I2-I1)+R2\times(I2)-VIS+R3\times(I3-I1)+VIS+R4\times(I3)=0+0$
Simplifying:
$R1\times(I2-I1)+R2\times(I2)+R3\times(I3-I1)+R4\times(I3)=0R1\times(I2-I1)+R2\times(I2)+R3\times(I3-I1)+R4\times(I3)=0$

2) Supermesh

Here is the supermesh:



Around the loop clockwise:

R1×(I2−I1)+R2×(I2)+R4×(I3)+R3×(I3−I1)=0R1×(I2−I1)+R2×(I2)+R4×(I3)+R3×(I3−I1)=0.

As you can see, we were able to write the equation in one shot. That is why the supermesh method is preferred.

Now, we have two equations: one for Mesh I and one for the supermesh. But there are three unknowns: I1I1, I2I2 and I3I3. So we need another equation. Note that the current of R2R2 and R4R4 are I2I2 and I3I3,

$-I2-IS+I3=0-I2-IS+I3=0$

Now we have all three equations:

$-VS+R1\times(I1-I2)+R3\times(I1-I3)=0$

$R1\times(I2-I1)+R2\times(I2)+R4\times(I3)+R3\times(I3-I1)=0-I2-IS+I3=0$

$-VS+R1\times(I1-I2)+R3\times(I1-I3)=0$

$R1\times(I2-I1)+R2\times(I2)+R4\times(I3)+R3\times(I3-I1)=0-I2-IS+I3=0$

Let's substitute values:

VS=10VVS=10V, IS=4AIS=4A, R1=2ΩR1=2Ω, R2=6ΩR2=6Ω, R3=1ΩR3=1Ω, R4=2ΩR4=2Ω.

$2(I1-I2)+(I1-I3)=10$

$2(I2-I1)+6I2+2I3+I3-I1=0$

$-I2+I3=4$

$3I1-2I2-I3=10$

$-3I1+8I2+3I3=0$

$-I2+I3=4$

By solve this equation

I1=4.92A

I2=0.25A

I3=4.25A

For the current source, the voltage V and IS can be calculated by KVL equation of mesh II:

$R1\times(I2-I1)+R2\times(I2)-VIS=0$

$VIS=2\times(0.25-4.92)+6\times0.25=-7.84V$

Here, the current is entering from the positive terminal. So, the passive sign convention should be used:

$P_{IS}=V\ I_S\times IS=-7.84\times4=-31.36W<0$ (supplying power).

Now, it is on you to find the power of all resistors and validate that the power conservation law is satisfied.