Module 1

D.C. Circuits

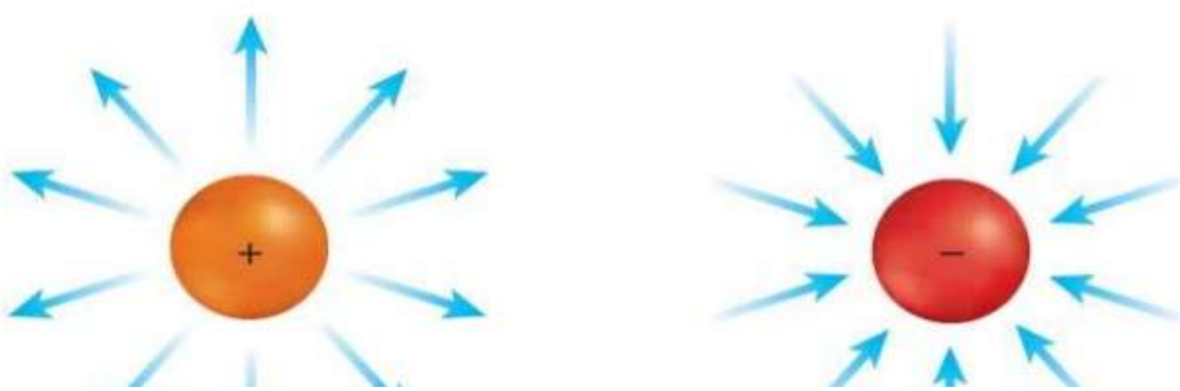
Electricity: Electricity plays an important role in our day to day life.
Electricity is used for

1. Lighting (lamps)
2. Heating(heaters)
3. Cooling
4. Entertainment (T.V. and radio)
5. Transportation
6. Calculations(Calculators)

Now- a- days all the activities are dependent upon electricity.
Electricity: The invisible energy which constitutes flow of electrons in a closed circuit to do work is called electricity.

Nature of Electricity: Every matter is electrical in nature since it contains charged particles like electrons and protons. Therefore

1. Ordinarily, a body is neutral as it contains same number of protons and electrons.
2. If some of electrons are removed from the body, there is a deficit of electrons and the body attains a positive charge.
3. If some of electrons are supplied to the body, there occurs excess of electrons and the body attains a negative charge.



A body is said to be charged +vely or –vely if it has deficit or excess of electrons from its normal due share respectively.

Unit of Charge:
The practical unit of charge is coulomb.
One Coulomb= charge on 6.28×10^{18} electrons.

Free Electrons: The valence electrons which are loosely attached to the nucleus of an atom and free to move when external energy is applied are called free electrons.

Electrical Potential: The capacity of charged body to do work is called electrical potential.

$$\textbf{Electrical Potential} = \frac{\textbf{Workdone}}{\boldsymbol{Charge}} = \frac{\mathbf{W}}{\boldsymbol{Q}}$$

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

Unit of electrical potential is **Vollts or Joules/Coulomb.**

Def: A body is said to have an electric potential of 1 Volt if 1 Joule of work is done to charge the body to 1 coulomb.

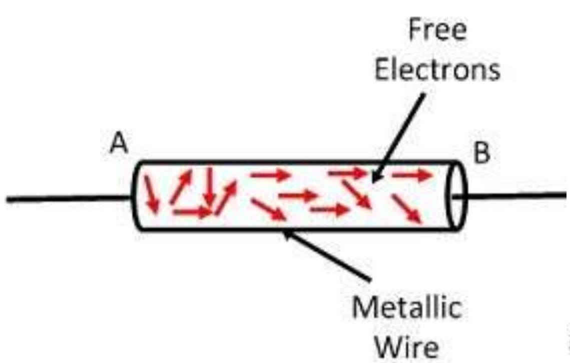
Potential Difference:

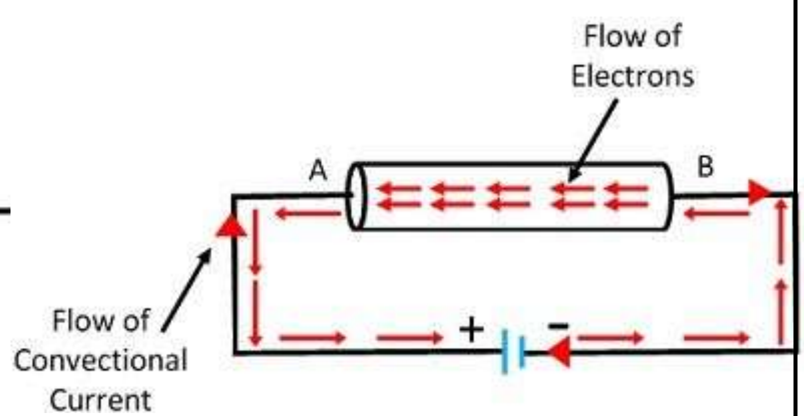
The difference in electrical potential of the two charged bodies is called potential difference.

Unit of potential difference is **Volts.**

Electric Current: In metallic wire, a large number of electrons are available which move from one atom to other at random.

When an electrical potential is applied across a metallic wire, the loosely attached free electron start moving towards positive terminal of the cell.





Thus, continuous flow of electrons in an electric circuit is called electric current

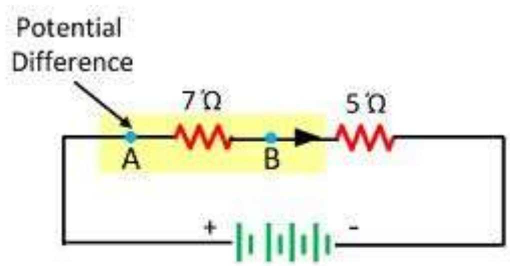
Definition-

Current is rate of flow of electrons i.e. charge flowing per second.

$$\mathbf{I} = \frac{\boldsymbol{Q}}{\boldsymbol{t}}$$

The unit of current is Ampere (A)

E.M.F. (Electromotive force) and potential difference:
E.m.f is the force that causes an electric current to flow in an electric circuit.
Infact it is not a force but it is an energy.
E.m.f: **The electromotive force is the amount of energy supplied by the source to each coulomb of charge.**
Potential Difference: **The potential difference is the amount of energy used by the one coulomb of charge in moving from one point to the other.**
In the following figure battery has emf of 12V and the potential difference between A and B is 7V.



E=12

Ohm's Law

Ohm's laws state that the current through any two points of the conductor is directly proportional to the potential difference applied across the conductor, provided physical conditions i.e. temperature, etc. do not change. It is measured in (Ω) ohm.

Mathematically it is expressed as

$$I \,\alpha\, V$$

$$\frac{V}{I} = constant$$

$$\frac{V_1}{I_1} = \frac{V_2}{I_2} = \cdots = \frac{V_n}{I_n} = constant$$

This constant is also called the resistance (R) of the conductor (or circuit)

R= $\frac{V}{I}$

In a circuit, when current flows through a resistor, the potential difference across the resistor is known as voltage drops across it, i.e., V = IR.

Limitations of Ohm's Law

- Ohm's law is not applicable in unilateral networks. Unilateral networks allow the current to flow in one direction. Such types of network consist of elements like a diode, transistor, etc.
- It is not applicable for the non-linear network (network containing non-linear elements such as electric arc etc). In the nonlinear network, the parameter of the network is varied with the voltage and current. Their parameter likes resistance, inductance, capacitance and frequency, etc., not remain constant with the times. So ohms law is not applicable to the nonlinear network. Ohm's law is used for finding the resistance of the circuit and also for knowing the voltage and current of the circuit.

Resistance: The opposition offered to flow of current is called resistance. It is represented by R. The unit of resistance is ohms (Ω)

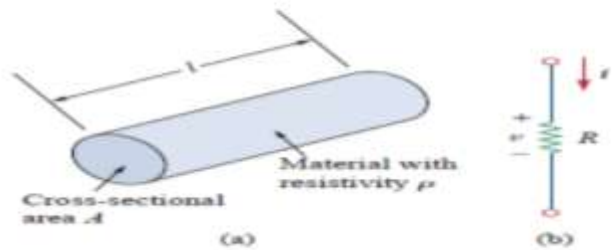


Fig. 1.13 (a) Typical Resistor, (b) Circuit Symbol for Resistor

Law of Resistance: The resistance of a wire depends upon

1. It is directly proportional to its length.
   R α L ………………. 1
2. It is inversely proportional to its area of cross-section.
   R α $\frac{1}{A}$ ………………..2
3. It depends upon the nature of material of which the wire is made.
4. It also depends upon the temperature of the wire.
   Combining 1 and 2
   R α $\frac{L}{A}$
   R = $\frac{\rho L}{A}$

The proportionality constant ρ is called the specific resistance o resistivity of the conductor and its value depends on the material of which the conductor is made.

The inverse of the resistance is called the conductance and inverse of resistivity is called specific conductance or conductivity. The symbol used to represent the conductance is G and conductivity is σ. Thus conductivity $\sigma = 1/\rho$ and its units are Siemens per meter

$$G = \frac{1}{R} = \frac{A}{\rho l} = \frac{1}{\rho} \cdot \frac{A}{l} = \sigma . \frac{A}{l}$$

Numerical on OHM's law

1. A wire of length 1 m has a resistance of 2 ohms. Obtain the resistance if specific resistance is double, the diameter is double and the length is made three times the first.

2. There are two wires A& B of same material. A is 20 times longer than B and has one fifth of the cross-section as that of B. If the resistance of A is 1 ohm. What is the resistance of B?

Electric Circuit:
The close path for flow of electric current is called electric circuit. The electric circuit is an arrangement of electrical energy sources and various circuit elements such as R, L and C are connected in series, parallel or series parallel combinations.

Circuit Elements:
The circuit elements can be categorized as:

1. Active and passive elements
2. Unilateral and bilateral elements
3. Linear and non-linear elements
4. Lumped and distributed elements

1. Active and passive elements:

Active elements are those who supply energy or power in the form of a voltage or current to the circuit or network.

Examples of the active components are batteries or generators etc.

Passive elements are those who receive energy in the form of voltage or current.

Examples of the passive components are resistor, capacitor and inductor.

2. Unilateral and bilateral elements:

Unilateral elements: The elements which conduct the current in one direction only are called unilateral elements such as diodes, transistors, vacuum tubes, rectifiers etc

Bilateral elements: The elements which conduct the current in both the directions are called bilateral elements such as resistors.

3. Linear and non-linear elements

Linear Elements: The elements which follow the linear relation between current and voltage.

e.g. resistors

Non Linear Elements: The elements which don't follow the linear relation between current and voltage. e.g. Diode and transistors

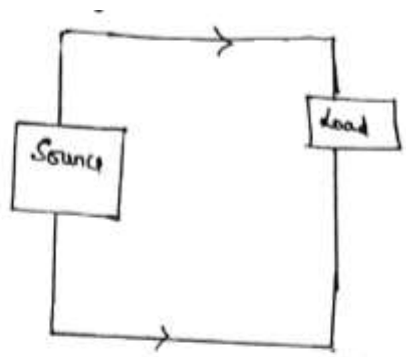
4. Lumped and distributed elements:

Lumped elements: The elements in which action takes place simultaneously are lumped elements such as resistor, capacitor and inductor. These elements are smaller in size.

Distributed elements: The elements in which for a given cause is not occurring simultaneously at the same instant but it is distributed are called distributed elements such as transmission lines.

Voltage and Current Source:

To deliver electrical energy to the electrical circuits, a source is required and a load is connected to source as shown in fig.



The source may be d.c. source or a.c source.

D.C. source:

Any source that produces direct voltage continuously and has ability to deliver direct current is called d.c. source such as batteries and generators etc.

A.C. source:

Any source that produces alternating voltage continuously and has ability to deliver the alternating current is called a.c. source such as alternators, oscillators or signal generators.

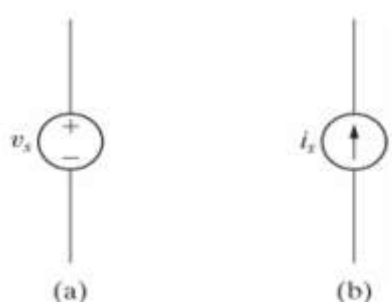
Independent and dependent sources:

There are two types of sources- Voltage source and current source. Sources can be either independent or dependent upon some other quantities.

Independent voltage/ current source:

The voltage (a.c or d.c.) does not dependent on other voltages or current in the circuit.

Symbol for independent voltage and current source



Examples of independent voltage source batteries and generators.
Examples of independent current source semiconductor devices such as Diode and transistors

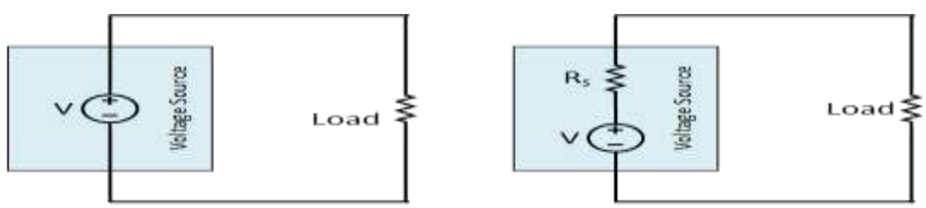
Dependent voltage/ current source:

The voltage does dependent on another voltage or current in the circuit.
Symbol for dependent voltage and current source

(a) Dependent voltage source *(b) Dependent current source*

Ideal and practical voltage sources:

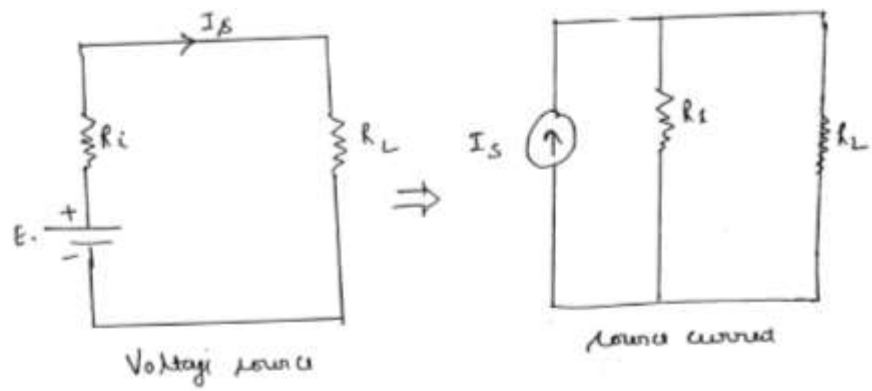
Ideal voltage sources: An imaginary voltage source, which can provide a constant voltage to load ranging from zero to infinity. Such voltage source is having zero internal resistance, Rs and is called Ideal Voltage Source. Practically it is not possible to build a voltage source with no internal resistance and constant voltage for that long range of the load.

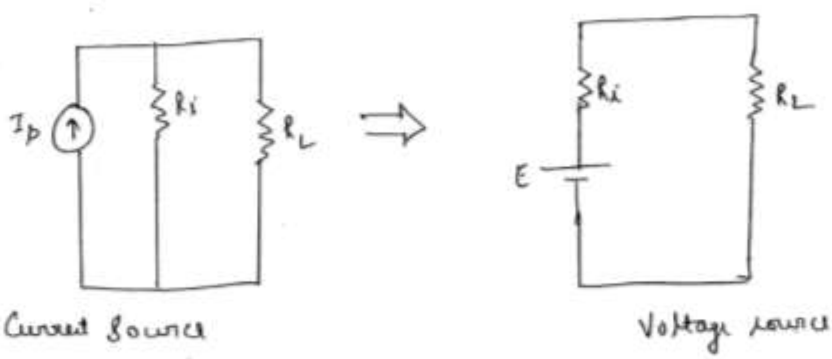


Ideal Voltage Source Practical Voltage Source

Practical voltage sources: Practical voltage sources always have some resistance value in series with an ideal voltage source and because of that series resistance, voltage drops when current passes through it. So, Practical Voltage Source has internal resistance and slightly variable voltage.

Source Transformation:

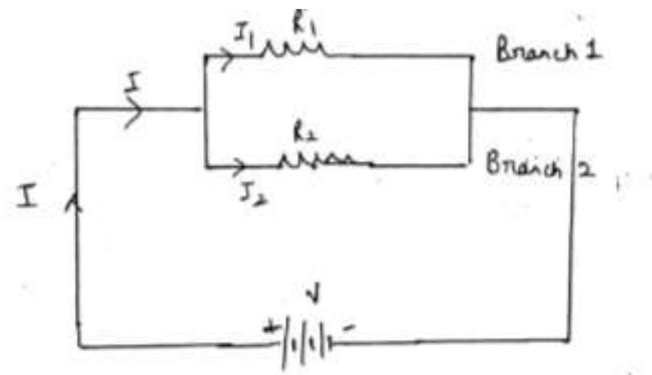




D. C. circuit: The closed path for flow of direct current is called D.C. circuit.

D.C Circuit is of two types:
1. Series Circuit
2. Parallel Circuit

Current in Parallel Circuit:



According to ohm's law

$$V = I_1 R_1 \quad \text{in branch 1}$$

$$V = I_2 R_2 \quad \text{" " 2}$$

$$V = I_1 R_1 = I_2 R_2$$

Total voltage in the circuit is $V = IR$ (ohm's law)

$$IR = I_1 R_1 = I_2 R_2$$

Total resistance in ||el circuit

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

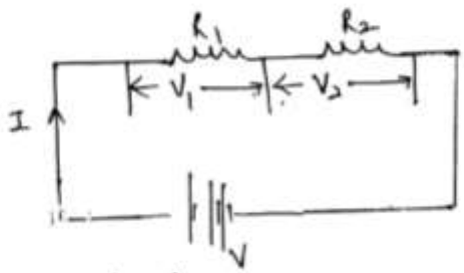
$$I_1 R_1 = I_2 R_2 = I\left(\frac{R_1 R_2}{R_1 + R_2}\right)$$

Then

$$I_1 = \frac{R_2}{R_1 + R_2}(I)$$

$$I_2 = \frac{R_1}{R_1 + R_2}(I)$$

Voltage in Series Circuit:



According to ohm's law

Current in resistance R_1 is

$$I = \frac{V_1}{R_1} \quad \text{—— (1)}$$

Current in resistance R_2 is

$$I = \frac{V_2}{R_2} \quad \text{—— (2)}$$

$$\frac{V_1}{R_1} = \frac{V_2}{R_2} = I \quad \text{—— (3)}$$

Total current in circuit is

$$I = \frac{V}{R} \quad \text{—— (4)}$$

Total resistance of the circuit is $R=R_1+R_2$

Put the values of R in eqn 3 and 4

$$\frac{V_1}{R_1} = \frac{V_2}{R_2} = \frac{V}{R_1+R_2}$$

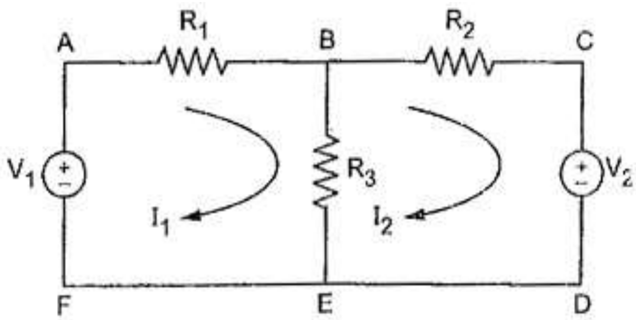
$$V_1 = \frac{R_1}{R_1+R_2}(V)$$

$$V_2 = \frac{R_2}{R_1+R_2}(V)$$

Network Terminology:

1. **Electric Network:**

Electric network is interconnection of electric components. E.g. Batteries, resistors, inductors and capacitors.



2. **Electric Circuit:**

The path for flow of electric current is called electric circuit.

3. **Active Elements:**

The elements which supplies energy to the circuit. In fig V_1 and V_2 are active elements.

4. **Passive Elements:**

The elements which receives energy. In fig R_1, R_2 and R_3 are passive elements.

5. **Node:**

Node is a point where two or more circuit elements are connected together. In Fig. A, B, C and E are nodes.

6. **Junction:**

Junction is a point in the network where three or more circuit elements are connected together. It is a point where current is divided. In Fig. B and E are junctions.

7. **Loop:**

The closed path of a network. E.g. ABEFA, BCDEB and ABCDEFA are loops.

8. **Mesh:**

The elementary form of loop which cannot be further divided is called mesh.
E.g. ABEFA, BCDEB are mesh.

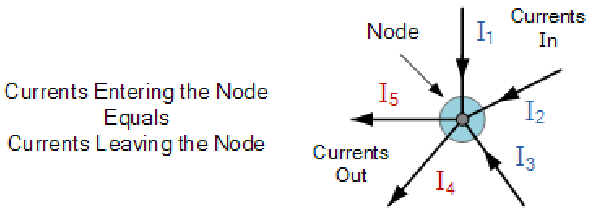
9. **Branch:**

Part of a network which lies between two junction points. In fig. ABEFA, BCDEB AND BE are the three branches.

Kirchhoff's Current Law or KCL

Kirchhoff's Current Law or KCL, states that the "total current or charge entering a junction or node is exactly equal to the charge leaving the node". In other words the algebraic sum of all the currents entering and leaving a node must be equal to zero, I(exiting) + I(entering) = 0.

Kirchhoff's Current Law or KCL



$I_1 + I_2 + I_3 + (-I_4 + -I_5) = 0$

Here, the three currents entering the node, I_1, I_2, I_3 are all positive in value and the two currents leaving the node, I_4 and I_5 are negative in value. Then this means we can also rewrite the equation as;

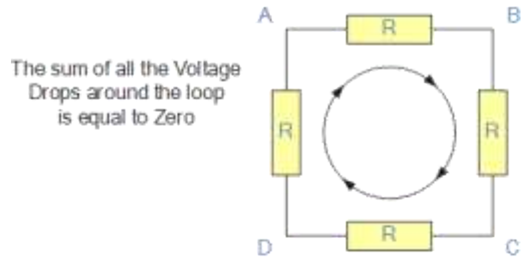
$I_1 + I_2 + I_3 – I_4 – I_5 = 0$

The term Node in an electrical circuit generally refers to a connection or junction of two or more current carrying paths or elements such as cables and components. Also for current to flow either in or out of a node a closed circuit path must exist. We can use Kirchhoff's current law when analyzing parallel circuits.

Kirchhoff's Voltage Law

Kirchhoff's Voltage Law or KVL, states that "in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop" which is also equal to zero. In other words the algebraic sum of all voltages within the loop must be equal to zero.

Kirchhoff's Voltage Law or KVL

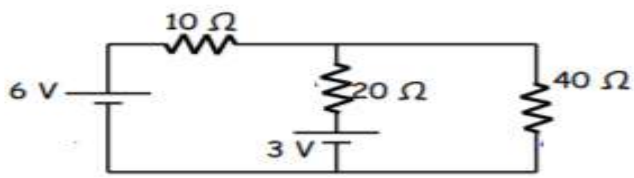


$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$

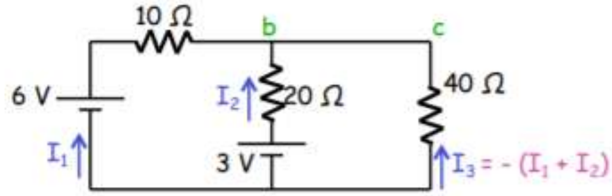
Starting at any point in the loop continue in the same direction noting the direction of all the voltage drops, either positive or negative, and returning back to the same starting point. It is important to maintain the same direction either clockwise or anti-clockwise or the final voltage sum will not be equal to zero. We can use Kirchhoff's voltage law when analyzing series circuits.

Analysis of simple circuits with Kirchhoff's law

Q: Calculate current in given circuit using Kirchhoff's law.



Ans: Firstly we have to mark the direction of current in given circuit.



Junction b: $I_1 + I_2 + I_3 = 0$

So, $I_3 = -(I_1 + I_2)$

Loop abcda: $6\,V - I_1 \cdot 10\Omega + 40\Omega(-I_1 - I_2) = 0$

$\Rightarrow 50I_1 + 40I_2 = 6$ ..... ①

Loop dbcd: $3\,V - 20\Omega \cdot I_2 + 40\Omega(-I_1 - I_2) = 0$

$\Rightarrow 40I_1 + 60I_2 = 3$ ..... ②

4x① - 5x②: $-140\,I_2 = 9$ → $I_2 = -64$ mA

3x① - 2x②: $70\,I_1 = 12$ → $I_1 = 171$ mA

$I_3 = -(171-64) = -107$mA

$I_3 = -107$mA

Superposition theorem

Superposition theorem states that in any linear, active, bilateral network having more than one source, the response across any element is the sum of the responses obtained from each source considered separately and all other sources are replaced by their internal resistance. The superposition theorem is used to solve the network where two or more sources are present and connected. Resulting current in any branch is the algebraic sum of all the currents that would be produced in it.

Procedure for using superposition theorem

Step-1: Retain one source at a time in the circuit and replace all other sources with their internal resistances.

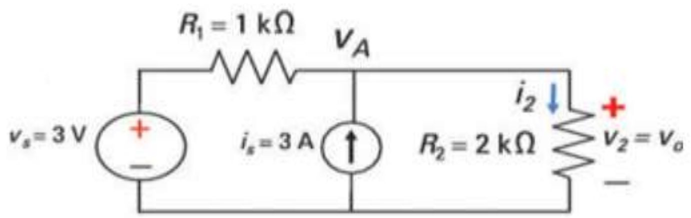
Step-2: Determine the output (current or voltage) due to the single source acting alone using the techniques discussed in lessons 3 and 4.

Step-3: Repeat steps 1 and 2 for each of the other independent sources.

Step-4: Find the total contribution by adding algebraically all the contributions due to the independent sources

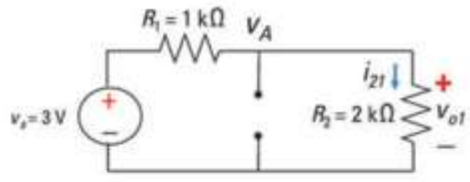
Numerical

Calculate the total voltage in given fig using Superposition theorem



We need to turn off the independent sources one at a time. To do so, replace the current source with an open circuit and the voltage source with a short circuit.

Considering the voltage source

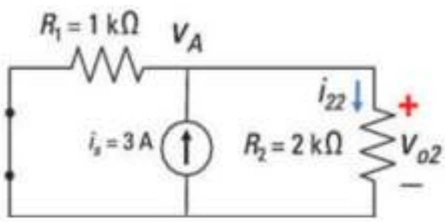


We can use the voltage divider technique because its resistors, R_1 and R_2, are connected in series with a voltage source. So here's the voltage v_{o1} across resistor R_2:

$$v_{o1} = \left(\frac{R_2}{R_1 + R_2}\right) v_s$$

$$v_{o1} = \left(\frac{2\ \text{k}\Omega}{1\ \text{k}\Omega + 2\ \text{k}\Omega}\right)(3\ \text{V}) = 2\ \text{V}$$

Considering Current source



We can use a current divider technique because the resistors are connected in parallel with a current source. The current source provides the following current i_{22} flowing through resistor R_2:

$$i_{22} = \left(\frac{R_1}{R_1 + R_2}\right) i_s$$

$$i_{22} = \left(\frac{1\ \text{k}\Omega}{1\ \text{k}\Omega + 2\ \text{k}\Omega}\right)(3\ \text{A}) = 1\ \text{mA}$$

We can use Ohm's law to find the voltage output v_{o2} across resistor R_2

$$v_{o2} = i_{22} R_2$$

$$v_{o2} = (1\ \text{mA})(2\ \text{k}\Omega) = 2\ \text{V}$$

Now find the total output voltage across R_2 for the two independent sources in Circuit C by adding v_{o1} (due to the source voltage v_s) and v_{o2} (due to the source current i_s). You wind up with the following output voltage.

$v_o = v_{o1} + v_{o2}$

$v_o = 2+2= 4$ V

.

Norton’s Theorem

Statement:

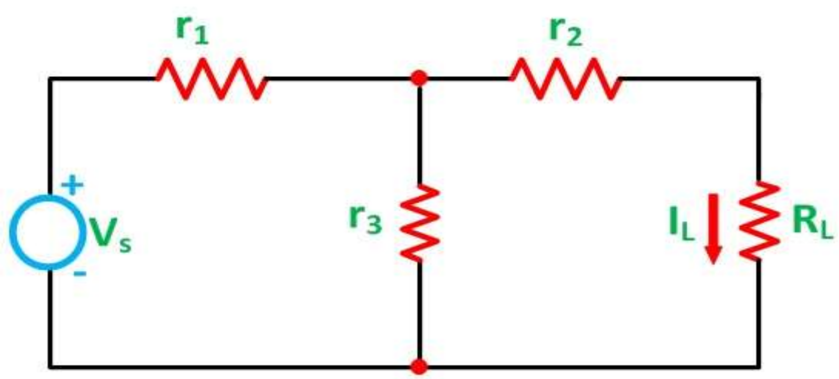
Norton’s Theorem states that – A linear active network consisting of the independent or dependent voltage source and current sources and the various circuit elements can be substituted by an equivalent circuit consisting of a current source in parallel with a resistance.

The current source being the short-circuited current across the load terminal and the resistance being the internal resistance of the source network.

The Norton’s theorems reduce the networks equivalent to the circuit having one current source, parallel resistance and load. Norton’s theorem is the converse of Thevenin’s Theorem. It consists of the equivalent current source instead of an equivalent voltage source as in Thevenin’s theorem.

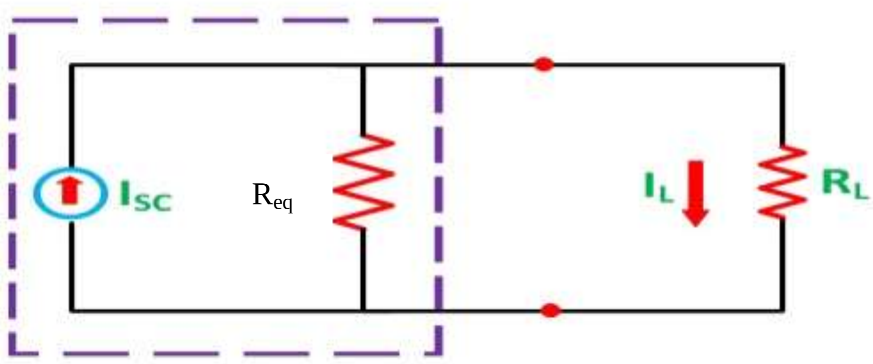
Explanation of Norton’s Theorem

To understand Norton’s Theorem in detail, let us consider a circuit diagram given below



In order to find the current through the load resistance I_L as shown in the circuit diagram above

Step 1:



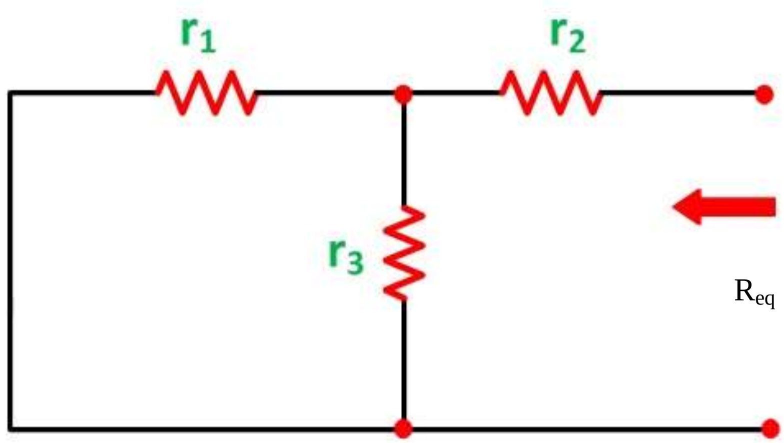
$I_L = I_{SC}\,\frac{Req}{Req + RL}$

Where, I_L is the load current, I_{sc} is the short circuit current

R_{eq} is the equivalentl resistance of the circuit, R_L is the load resistance of the circuit

Step 3: To find Req

Now the short circuit is removed, and the independent source is deactivated as shown in the circuit diagram below and the value of the equivalent resistance is calculated by:

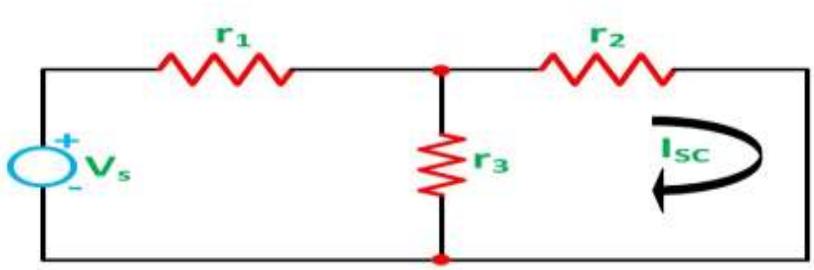


So,

$Req = r_1 \| r_3 + r_2$

$Req = \frac{r1r3}{r1+r3} + r_2$

Step 2: To find Isc



Now, the value of current I flowing in the circuit is found out by the equation

$$I = \frac{V_S}{r_1 + \frac{r_2 r_3}{r_2 + r_3}}$$

And the short-circuit current I_{SC} is given by the equation shown below:

$$I_{sc} = I \frac{r_3}{r_3 + r_2}$$

Steps for Solving a Network Utilizing Norton's Theorem

Step 1 – Norton's equivalent circuit is drawn by keeping the equivalent resistance R_{eq} in parallel with the short circuit current I_{SC}.

Step 2 – Find the internal resistance R_{eq} of the source network by deactivating the constant sources.

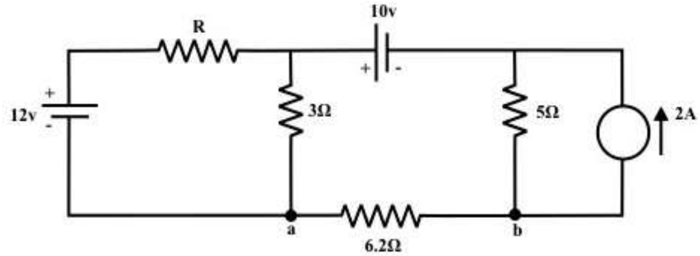
Step 3 – Now short the load terminals and find the short circuit current I_{SC} flowing through the shorted load terminals using conventional network analysis methods.

Step 4 – Reconnect the load resistance R_L of the circuit across the load terminals and find the current through it known as load current I_L.

This is all about Norton's Theorem.

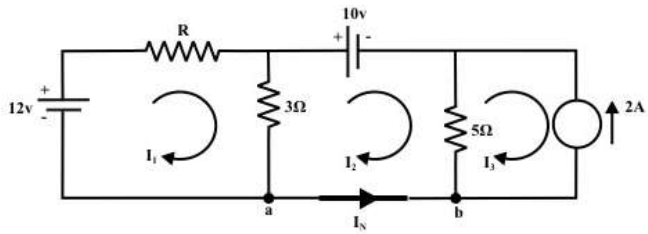
<u>Numerical</u>

Applying Norton's theorem, find the maximum power dissipated by the resistor 6.2Ω under that situation



Solution of numerical

Step-1: Short the terminals ‘a’ and ‘b’ after disconnecting the 6.2 resistor. The Norton’s current I_N for the circuit shown in fig. is computed by using ‘mesh-current’ method.



Loop-1:

$$12 - I_1 R - 3(I_1 - I_2) = 0$$

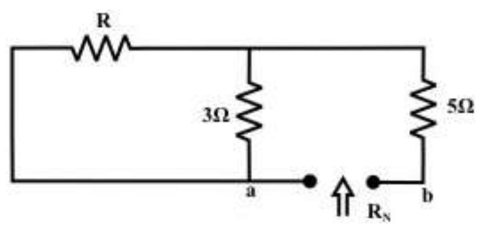
Loop-2:

$$-10 - 5(I_2 - I_3) - 3(I_2 - I_1) = 0\ ,\ \ note\ \ I_3 = -2\,A$$

Solving equations

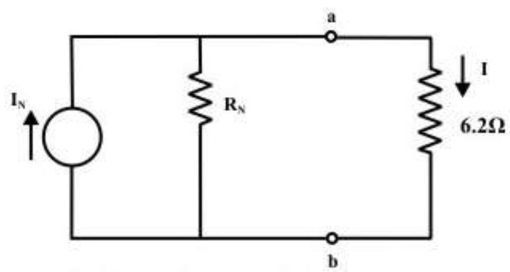
$I_1 = \dfrac{36}{15+8R}\ ;\ I_2 = -\dfrac{24+20R}{15+8R}$ (-ve sign implies that the current is flowing from ‘b’ to ‘a’) and Norton’s current $I_N = -I_2 = \dfrac{24+20R}{15+8R}$

Norton’s resistance R_N is computed by replacing all sources by their internal resistances while the short-circuit across the output terminal ‘a’ and ‘b’ is removed. From the circuit diagram fig. the Norton’s resistance is obtained between the terminals ‘a’ and ‘b’.



$$R_N = (R \| 3) + 5 = \frac{3R}{3+R} + 5$$

Note that the maximum power will dissipate in load resistance when load resistance = Norton’s resistance $R_N = R_L = 6.2\Omega$. To satisfy this condition the value of the resistance can be obtained from equation of R_N we get $R = 2\Omega$. The circuit now replaced by an equivalent Norton’s current source.



Norton's equivalent circuit

The maximum power delivered by the given network to the load R_L=6.2Ω is thus given by

$$P_{max} = \frac{1}{4} \times I_N^2 R_L = \frac{1}{4} \times \left(\frac{24+20R}{15+8R} \right)^2 \times R_L = 6.61\, watts$$

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**.
In Node-Voltage Method, we can solve for unknown voltages in a circuit using KCL.

Some Features of Nodal Analysis:

- **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

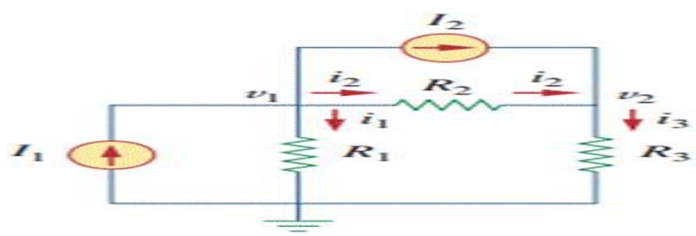
- Non Reference Node – It is a node which has a definite Node Voltage. e.g. Here Node 1 and Node 2 are the Non Reference nodes

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

Solving of Circuit Using Nodal Analysis

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



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

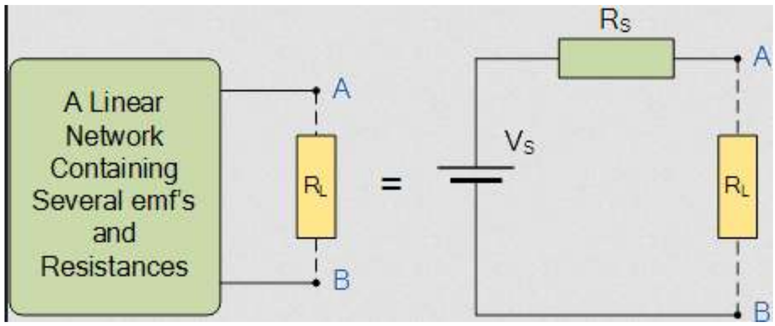
5. Solve 'n-1' node equations for the values of node voltages and get the required node Voltages as result.

Thevenin's Theorem

Thevenin's Theorem states that *"*Any linear circuit containing several voltages and resistances can be replaced by just one single voltage in series with a single resistance connected across the load*"*. In other words, it is possible to simplify any electrical circuit, no matter how complex, to an equivalent two-terminal circuit with just a single constant voltage source in series with a resistance (or impedance) connected to a load as shown below.

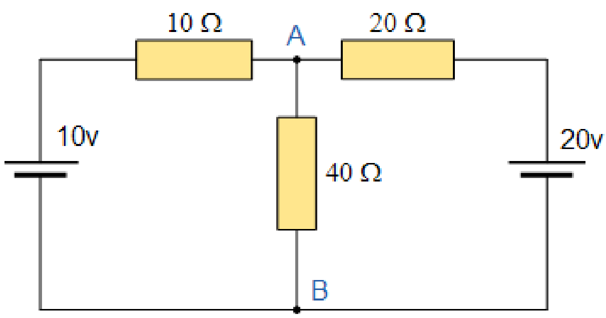
Thevenin's Theorem is especially useful in the circuit analysis of power or battery systems and other interconnected resistive circuits where it will have an effect on the adjoining part of the circuit.

Thevenin's equivalent circuit



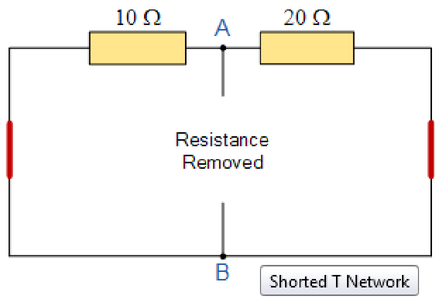
As far as the load resistor R_L is concerned, any complex "one-port" network consisting of multiple resistive circuit elements and energy sources can be replaced by one single equivalent resistance R_s and one single equivalent voltage V_s. R_s is the source resistance value looking back into the circuit and V_s is the open circuit voltage at the terminals.

Find the load current in 40 Ω in given fig using Thevenin's theorem



Firstly, to analyze the circuit we have to remove the centre 40Ω load resistor connected across the terminals A-B, and remove any internal resistance associated with the voltage source(s). This is done by shorting out all the voltage sources connected to the circuit, that is v = 0, or open circuit any connected current sources making i = 0. The reason for this is that we want to have an ideal voltage source or an ideal current source for the circuit analysis.

The value of the equivalent resistance, Rs is found by calculating the total resistance looking back from the terminals A and B with all the voltage sources shorted. We then get the following circuit.



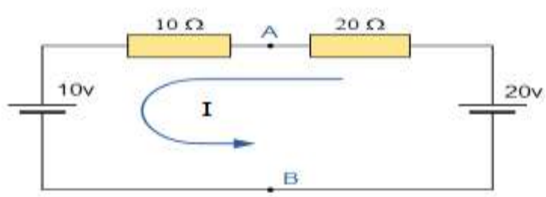
Find the Equivalent Resistance (Rs)

10Ω resistor in parallel with 20Ω resistor

R_s = 10*20/10+20= 200/30= 6.67Ω

The voltage Vs is defined as the total voltage across the terminals A and B when there is an open circuit between them. That is without the load resistor R_L connected.

Find the Equivalent Voltage (Vs)



We now need to reconnect the two voltages back into the circuit, and as $V_S = V_{AB}$ the current flowing around the loop is calculated as:

$$I = \frac{V}{R} = \frac{20v - 10v}{20\Omega + 10\Omega} = 0.33\ amps$$

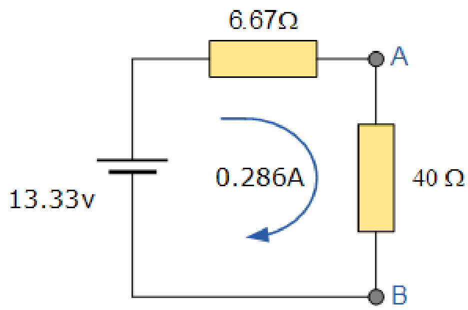
This current of 0.33 amperes (330mA) is common to both resistors so the voltage drop across the 20Ω resistor or the 10Ω resistor can be calculated as:

$$V_{AB} = 20 - (20\Omega \times 0.33\text{amps}) = 13.33 \text{ volts.}$$

or

$$V_{AB} = 10 + (10\Omega \times 0.33\text{amps}) = 13.33 \text{ volts, the same.}$$

Then the Thevenin's Equivalent circuit would consist or a series resistance of 6.67Ω and a voltage source of 13.33v. With the 40Ω resistor connected back into the circuit we get:



and from this the current flowing around the circuit is given as:

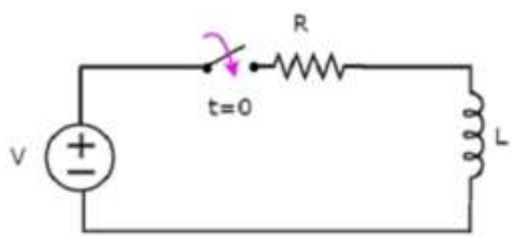
$$I = \frac{V}{R} = \frac{13.33\,v}{6.67\Omega + 40\Omega} = 0.286\ amps$$

Time-domain analysis of first-order RL circuit(Transient Response)

The short timed electrical phenomenon that occurs in a system due to sudden change in voltage, current of load is called transient response. Transients occur in the response due to sudden change in the sources that are applied to the electric circuit and / or due to switching action. The transient part occurs in the response of an electrical circuit or network due to the presence of energy storing elements such as inductor and capacitor.

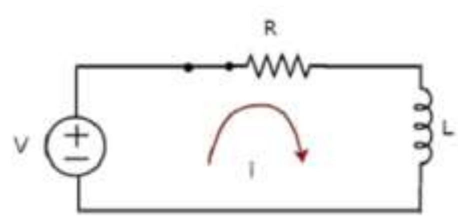
- The transient part will not present in the response of an electrical circuit or network, if it contains only resistances. Because resistor is having the ability to adjust any amount of voltage and current.
- The transient part occurs in the response of an electrical circuit or network due to the presence of energy storing elements such as inductor and capacitor. Because they can't change the energy stored in those elements instantly.

Consider the following series RL circuit diagram.



In the above circuit, the switch was kept open up to t = 0 and it was closed at t = 0. So, the DC voltage source having V volts is not connected to the series RL circuit up to this instant. Therefore, there is no initial current flow through inductor.

The circuit diagram, when the switch is in closed position is shown in the following figure.



Now, the current ***i*** flows in the entire circuit, since the DC voltage source having ***V*** volts is connected to the series RL circuit.

Now, apply KVL around the loop.

$$V = Ri + L\frac{di}{dt}$$

$$\frac{di}{dt} + (\frac{R}{L})i = \frac{V}{L}$$ **Equation 1**

The above equation is a first order differential equation and it is in the form of

$$\frac{dy}{dt} + Py = Q$$ **Equation 2**

By comparing Equation 1 and Equation 2, we will get the following relations.

$$x = t \text{ , } y = i$$

$$P = \frac{R}{L} \text{ , } Q = \frac{V}{L}$$

The **solution** of Equation 2 will be

$$ye^{\int pdx} = \int Qe^{\int pdx} dx + k$$ **Equation 3**

Where, **k** is the constant.

Substitute, the values of x, y, P & Q in Equation 3.

$$ie^{\int (\frac{R}{L})dt} = \int (\frac{V}{L})(e^{\int (\frac{R}{L})dt})dt + k$$

$$\Rightarrow ie^{(\frac{R}{L})t} = \frac{V}{L} \int e^{(\frac{R}{L})t} dt + k$$

$$\Rightarrow ie^{(\frac{R}{L})t} = \frac{V}{L} \{ \frac{e^{(\frac{R}{L})t}}{\frac{R}{L}} \} + k$$

$$\Rightarrow i = \frac{V}{R} + ke^{-(\frac{R}{L})t}$$ **Equation 4**

We know that there is no initial current in the circuit. Hence, substitute, $t = 0$ and $i = 0$ in Equation 4 in order to find the value of the constant ***k***.

$$0 = \frac{V}{R} + ke^{-(\frac{R}{L})(0)}$$

$$0 = \frac{V}{R} + k(1)$$

$$k = -\frac{V}{R}$$

Substituting the value of k in Equation 4.

$$i = \frac{V}{R} + (-\frac{V}{R})e^{-(\frac{R}{L})t}$$

$$i = \frac{V}{R} - \frac{V}{R}e^{-(\frac{R}{L})t}$$

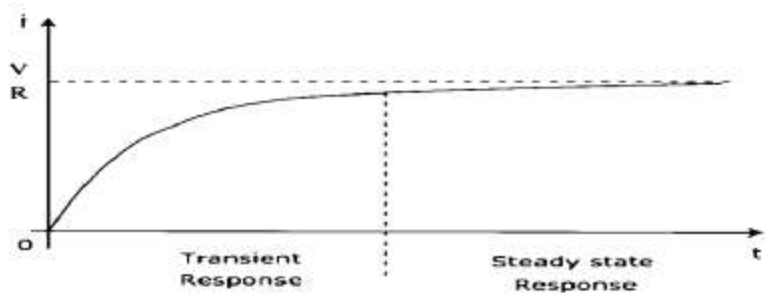
Therefore, the current flowing through the circuit is

$$i = -\frac{V}{R}e^{-(\frac{R}{L})t} + \frac{V}{R} \qquad \textbf{Equation 5}$$

So, the response of the series RL circuit, when it is excited by a DC voltage source, has the following two terms.

The first term $-\frac{V}{R}e^{-(\frac{R}{L})t}$ corresponds with the **transient response**.

The second term $\frac{V}{R}$ corresponds with the **steady state response**. These two responses are shown in the following figure.



We can re-write the Equation 5 as follows

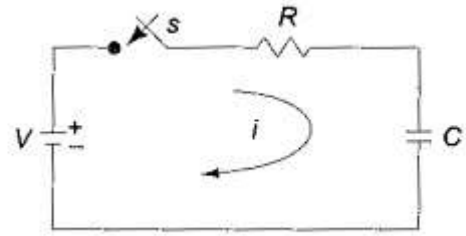
$$i = \frac{V}{R}(1 - e^{-(\frac{R}{L})t})$$

$$\Rightarrow i = \frac{V}{R}(1 - e^{-(\frac{t}{\tau})}) \qquad \textbf{Equation 6}$$

Where, τ is the time constant and its value is equal to L/R

Transient Response of RC Circuit:

Consider a Transient Response of RC Circuit consisting of resistance and capacitance as shown in fig.



The capacitor in the circuit is initially uncharged, and is in series with a resistor. When the switch S is closed at t = 0, we can determine. the complete solution for the current. Application of the Kirchhoff's voltage law to the circuit results in the following differential equation.

$$V = Ri + \frac{1}{C}\int i\,dt$$

By differentiating the above equation, we get

$$0 = R\frac{di}{dt} + \frac{i}{C}$$

$$\frac{di}{dt} + \frac{1}{RC}i = 0$$

$$P = \frac{1}{RC}, \qquad Q = 0$$

- $I.F = e^{\int P\,dt} = e^{\int \frac{1}{RC}dt} = e^{\frac{t}{RC}}$

Solution

$$i \times I.F = \int Q \times I.F\,dt + A$$

$$i\,e^{\frac{t}{RC}} = \int 0 \times e^{\frac{t}{RC}}\,dt + A$$

$$i\,e^{\frac{t}{RC}} = A$$

$i(t) = A\, e^{-\frac{t}{RC}}$ A is a constant

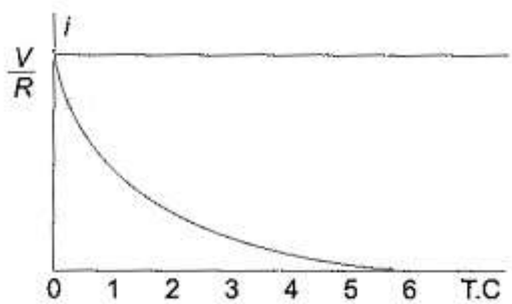
As at $t = 0^+ = i(0^+) = \frac{V}{R}$ since capacitor behaves as a short circuited at $t = 0^+$

$\frac{V}{R} = A$

The current equation becomes

$$i = \frac{V}{R}\, e^{-t/RC}$$

When switch S is closed, the response decays with time as shown in Fig.



In the solution, the quantity RC is the time constant, and is denoted by τ,

where τ = RC sec

After 5 TC, the curve reaches 99 per cent of its final value. In. Fig. , we can find out the voltage across each element by using the current equation. Voltage across the resistor is

$$v_R = Ri = R \times \frac{V}{R}\, e^{-(1/RC)t}\,;\ v_R = Ve^{-\frac{t}{RC}}$$

Similarly, voltage across the capacitor is

$$v_C = \frac{1}{C}\int i\,dt$$
$$= \frac{1}{C}\int \frac{V}{R}\,e^{-t/RC}\,dt$$
$$= -\left(\frac{V}{RC} \times RC\,e^{-t/RC}\right) + c = -Ve^{-t/RC} + c$$

At t = 0, voltage across capacitor is zero

$$c = V$$
$$v_C = V(1 - e^{-t/RC})$$

The responses are shown in Fig. 12.8.

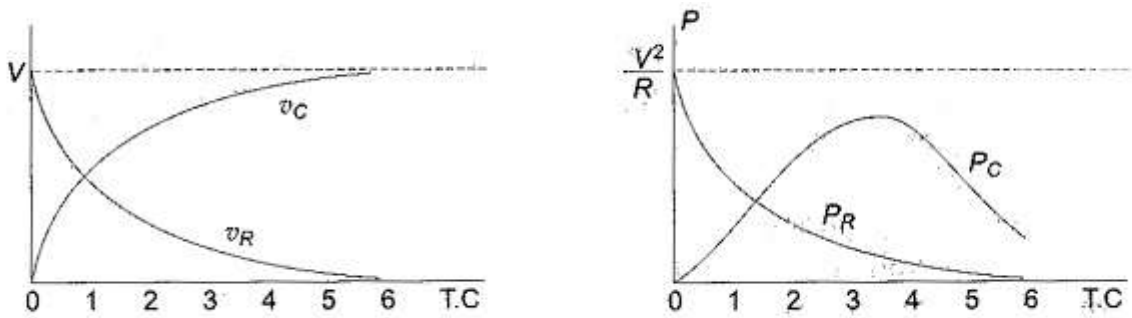
Power in the resistor

$$p_R = v_R i = Ve^{-t/RC} \times \frac{V}{R}\,e^{-t/RC} = \frac{V^2}{R}\,e^{-2t/RC}$$

Power in the capacitor

$$p_C = v_C i = V(1 - e^{-t/RC})\,\frac{V}{R}\,e^{-t/RC}$$
$$= \frac{V^2}{R}\,(e^{-t/RC} - e^{-2t/RC})$$

The responses are shown in Fig.



Short Questions with answers

Module 1

Q1. State Ohm’s law and its limitations.

Ans. Ohm’s laws state that the current through any two points of the conductor is directly proportional to the potential difference applied across the conductor, provided physical conditions i.e. temperature, etc. do not change. It is measured in (Ω) ohm.

Mathematically it is expressed as

$$I \, \alpha \, V$$

$$\frac{V}{I} = constant$$

$$\frac{V_1}{I_1} = \frac{V_2}{I_2} = \cdots = \frac{V_n}{I_n} = constant$$

This constant is also called the resistance (R) of the conductor (or circuit)

R= $\frac{V}{I}$

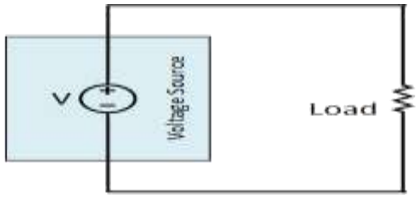
In a circuit, when current flows through a resistor, the potential difference across the resistor is known as voltage drops across it, i.e., V = IR.

Limitations of Ohm’s Law

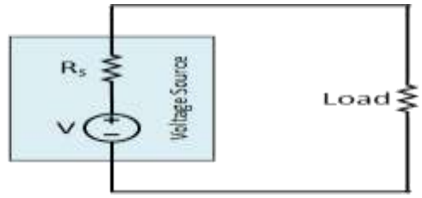
- Ohm’s law is not applicable in unilateral networks. Unilateral networks allow the current to flow in one direction. Such types of network consist elements like a diode, transistor, etc.
- It is not applicable for the non-linear network. In the nonlinear network, the parameter of the network is varied with the voltage and current. Their parameter likes resistance, inductance, capacitance and frequency, etc., not remain constant with the times. So ohms law is not applicable to the nonlinear network. Ohm’s law is used for finding the resistance of the circuit and also for knowing the voltage and current of the circuit.

Q2. Differentiate between Ideal and practical voltage sources.

Ans. Ideal voltage sources: An imaginary voltage source, which can provide a constant voltage to load ranging from zero to infinity. Such voltage source is having zero internal resistance, Rs and is called Ideal Voltage Source. Practically it is not possible to build a voltage source with no internal resistance and constant voltage for that long range of the load.



Ideal Voltage Source



Practical Voltage Source

Practical voltage sources: Practical voltage sources always have some resistance value in series with an ideal voltage source and because of that series resistance, voltage drops when current passes through it. So, Practical Voltage Source has internal resistance and slightly variable voltage

Q3. How will you differentiate between Linear and Non Linear elements?

Ans. In Electrical Circuits Linear Elements are the devices that follow the linear relation between current and voltage. e.g. an ideal Resistance.

Non Linear Elements are devices which don't follow the linear relation between current and voltage. e.g. Diode.

Q4. Differentiate between active and passive elements.

Ans. Active components are those who deliver or supply energy or power in the form of a voltage or current. Passive components are those who utilizes or store energy in the form of voltage or current.

Examples of the active components are Diodes, transistors, SCR, integrated circuits, etc.

Examples of the passive components are resistor, capacitor and inductor.

Q5. State superposition theorem.

Ans. Superposition theorem states that in any linear, active, bilateral network having more than one source, the response across any element is the sum of the responses obtained from each source considered separately and all other sources are replaced by their internal resistance. The superposition theorem is used to solve the network where two or more sources are present and connected

Q6. What do you mean by time domain analysis? Discuss

Ans. The solution of the linear differential equation gives the response of the system. The representation of a electrical system by a linear differential equation of functions of time and its solution is collectively called time domain analysis of electrical system

Q7.State Thevenin's Theorem

Ans. Thevenin's Theorem states that "Any linear circuit containing several voltages and resistances can be replaced by just one single voltage in series with a single resistance connected across the load". In other words, it is possible to simplify any electrical circuit, no matter how complex, to an equivalent two-terminal circuit with just a single constant voltage source in series with a resistance (or impedance) connected to a load .

Q8.If a 30 V source can force 1.5 A through a certain linear circuit, how much current can10 V force through the same circuit?

Ans. R= $\frac{V}{I}$

R=$\frac{30}{1.5}$

R= 20 Ω

V=IR

I=$\frac{V}{R}$, I = $\frac{10}{20}$

I= 0.5 A

Q9. State Norton's Theorem.

Ans. Norton's Theorem states that a linear active network consisting of independent or dependent voltage source and current sources and the various circuit elements can be substituted by an equivalent circuit consisting of a current source in parallel with a resistance. The current source being the short-circuited current across the load terminal and the resistance being the internal resistance of the source network.

Q10. State Kirchhoff's law.

Ans. Kirchhoffs Current Law or KCL, states that the "total current or charge entering a junction or node is exactly equal to the charge leaving the node". In other words the algebraic sum of all the currents entering and leaving a node must be equal to zero, I(exiting) + I(entering) = 0.

Kirchhoffs Voltage Law or KVL, states that "in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop" which is also equal to zero. In other words the algebraic sum of all voltages within the loop must be equal to zero.