MOUDLE- 1

ANALYSIS OF D.C. CIRCUITS

1.1- INTRODUCTION

An atom is the smallest chemical part of an element which is independent and having its own existence. The name is derived from Greek word which means 'A whole, or something which is cannot be broken'.

An atom is consists of a central part called *nucleus* and around the nucleus there are number of *electrons* revolving in different orbits. The nucleus consists of *protons* and *neutrons*. A proton is positively charged and a neutron is electrically neutral as it is not having any charge. Electrons are negatively charged which revolves in an orbit.

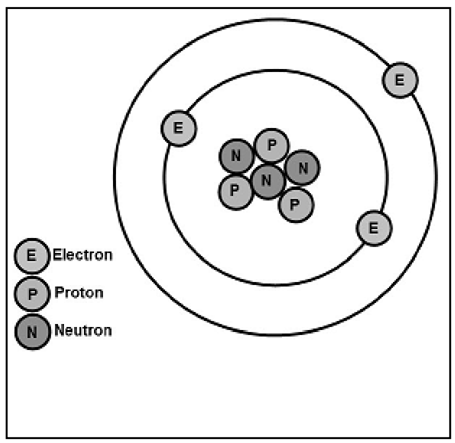


Fig. 1.1 – Atomic structure

1.2- CONCEPT OF CHARGE:

If the number of protons is equal to the number of electrons in a body, the resultant charge is zero and body will be said to be electrically neutral. If from a neutral body , some electrons are removed there will be deficit of electrons in the body and body attains positive charge. On the other hand if body is supplied with electrons there will excess of electrons and the body attains negative charge.

In practice *Coulomb* is used as unit of charge and one coulomb is equal to 625×10^{16} electrons.

1 coulomb = Charge on 625×10^{16} electrons.

1.3- FREE ELECTRONS :

As we have seen that electrons move around the nucleus of an atom in different orbits. The electrons in last orbit are called as *valance electrons*. In metals, the valance electrons are weakly attached to their nuclei so that they can be easily removed or detached. Such electrons are called *free electrons*. Depending upon the metal there will be different number of free electrons available.

1.4- ELECTRIC CURRENT :

The flow of electrons (or charge) in definite direction is called as electric current. As shown in bellow figure, a copper wire is connected to battery and it can be seen from diagram that the electrons which are having negative charge on them attracted towards positive terminal of battery. Hence electrons move from point A towards point B which in turn causes the current to flow.

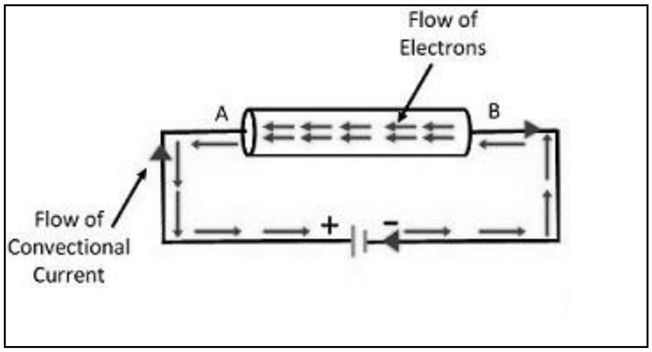


Fig.1.2- Flow of electrons

But the direction of current is opposite to the direction of flow of electrons. Hence, the direction of flow of current is from positive terminal to negative terminal.

Definition: "The flow of electrons or rate of flow of charge in an electric circuit is called as electric current"

If net charge Q flows across any cross section in a conductor in time 't', then current I flowing through cross section of the conductor is given by,

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

SI Unit of Current: The SI unit of charge is Coulomb (C) and SI unit of time is Second (s), hence SI unit of current is Coulomb per second (C/s). This unit is given special name ***Ampere (A)*** which is the name of great scientist Andre Marie Ampere. The device used to measure current is called as Ammeter.

1.5- ELECTRIC POTENTIAL, POTENTIAL DIFFERENCE, AND VOLTAGE :

If a body is raised above the ground, it will have gravitational potential energy. Just like that, a charged body has electric potential energy. When body is charged, work is done in charging the body. Hence, *the electric potential at point is the electric potential energy (W) per unit charge (Q)*. This is also termed as 'Voltage' and denoted as 'V'.

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

The SI unit of work is Joule (J) and that of charge is Coulomb (C), so the **SI unit of electric potential is *Joule/ Coulomb* which is also called as *Volt.***

The difference in the potentials of two charged bodies is called as potential difference (p.d.). Consider two different bodies A and B are joined together as shown in fig bellow. The potential of body A is +6 V and that of body B is +3 V. Clearly, Body A is at higher potential than B.

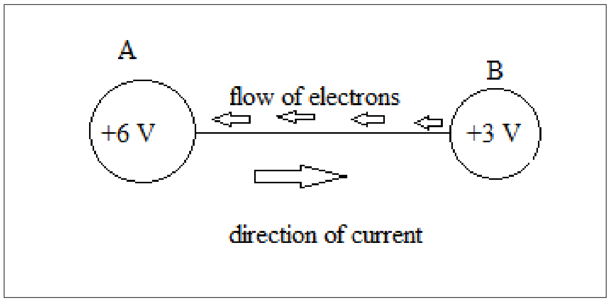


Fig.1.3 – Electric potential

Hence, electrons will flow from lower potential to higher potential i.e. from B to A but as current direction is opposite to that of flow of electrons, current will flow from A to B.(higher potential to lower potential). If these bodies will have same potential on them then there will be no flow of electrons or current.

Therefore, it is very important to say here that *current will flow if and only the potential difference exists.*

Electro-motive force (EMF) is required for the flow of electrons which is defined as the electrical force or pressure that causes the flow of electrons in an electric circuit. A battery or voltage source is nothing but a source of EMF and it is measured in **Volts (V)**.

1.5.1 – Comparison between E.M.F. and potential difference:

- Emf is the total voltage in the battery while the potential difference is the work done in moving a charge against the electric field between two specific points in the circuit.
- Emf is always greater than the potential difference.
- The concept of emf is applicable only to an electrical field while the potential difference is applicable to magnetic, gravitational, and electric fields.
- Emf is always constant in a circuit while potential difference can be varying due to presence of resistances in the circuit.
- Emf is always greater than potential difference.
- Emf is present in the circuit even if no current flows but potential difference is present only if current is flowing in the circuit.

1.6- RESISTANCE :

Resistance of a conductor can be defined as the property of material due to which it opposes the flow of current through it. In metals such as copper, silver etc, there are large amount of free electrons and hence they have lesser opposition to current (less resistance) and they can be said to have good electrical conductivity.

The SI unit of resistance is Ohm (Ω) and it can be defined as *"A conductor is said to have resistance of 1 ohm, if DC current of one ampere flowing through it produces heat at the rate of 1 Joule per second."*

1.6.1- Factors affecting the resistance of a conductor:

- **Type of material** – Resistance of a material varies according to type of material and it will depend upon the availability of free electrons in that material. For example, silver is best conductor as it offers less resistance whereas iron is having high resistance.
- **Length of conductor** – The resistance of a conductor is directly proportional to its length (l) because as length of a conductor increases its resistance also increases.
- **Area of cross-section** – The resistance is inversely proportional to area of cross-section of that conductor (a).
- **Temperature** – The temperature of the conductor affects its resistance. In conductors, resistance increases with increase in temperature.

So, based on above discussion we can say that,

$$R \; \alpha \; \frac{l}{a} \qquad \text{at given temperature}$$

$$\text{Or,} \quad R = \rho \; \frac{l}{a}$$

Where, ρ is a constant called as *specific resistance* or *resistivity* of material

1.6.2 – Specific resistance or Resistivity:

Consider a cubical piece of a material having length of 1 cm and area of cross-section 1 cm^2 as shown in fig. 1.4

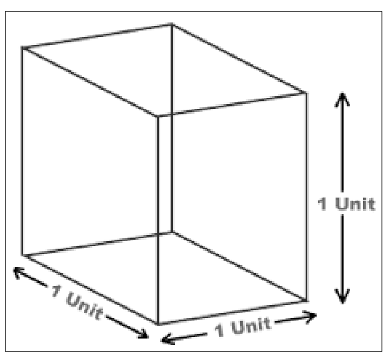


Fig 1.4 – Specific resistance of a material

If we put l= 1 cm and a = 1 cm^2 in above equation, we get, R = ρ

Hence specific resistance can be defined as *"resistance of a specimen piece of a material having unit length and unit cross-sectional area"*.

The unit of specific resistance (ρ) is *Ohm-meter*.

1.7 – OHM'S LAW:

There is relation between voltage (V), current (I), and resistance (R) in a D.C. circuit. In 1827 Dr. Ohm discovered the relation between this quantities and it is known as Ohm's law.

Statement- "***The current flowing through a solid conductor is directly proportional to potential difference (or Voltage) across the conductor and inversely proportional to its resistance, provided the temperature of conductor remains constant.***"

i.e. $$I \propto \frac{V}{R}$$

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

1.7.1 – Limitations of Ohm's law:

i) This law is not suitable for AC circuits with varying frequency voltage sources.

ii) This law has limitations when used in circuits having nonlinear devices such as diodes, transistors, and other semiconductor devices.

1.8 – TERMINOLOGY RELATED TO AN ELECTRICAL CIRCUIT:

1.8.1 – Network:

Any arrangement of various electrical sources along with different circuit elements is called as network. There may be active elements such as voltage or current source, passive elements such as resistor, capacitor, inductor etc. An example of a network is shown in fig. 1.5

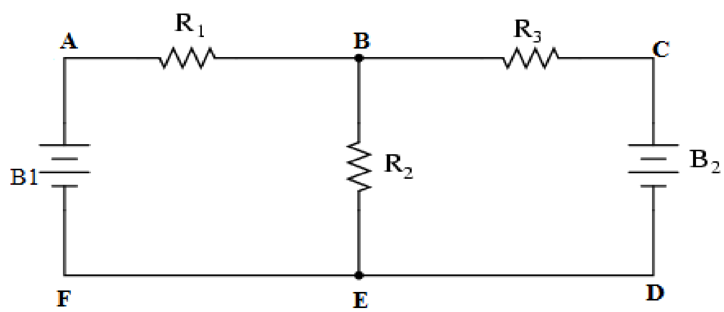


Fig. 1.5 – Electrical network

1.8.2 – Node:

A point at which two or more elements are joined together is called as '*node*'. In above fig there are six nodes namely A, B, C, D, E, F.

1.8.3 – Branch:

A part of a circuit which connects two nodes together is called as '*branch*'. For example, in above fig AB, BC, CD, ED, EF, BE, AF are branches.

1.8.4 – Junction point:

A point or node in the circuit where three or more branches meet together is called as '*junction point*'. In above fig B and E are junction points.

1.8.5 – Mesh or loop:

Mesh or *loop* is set of branches forming a closed path in a network in such a way that if one branch is removed remaining branches does not form a closed loop, e.g. ABEFA, BCDEB, ACDFA are mesh or loops.

1.9 – KIRCHHOFFS CURRENT LAW (KCL)

Statement: "In any electrical network, the algebraic sum of the currents meeting at point or junction is always zero".

Explanation: According to KCL, mathematically it can be written as,

At junction point $\sum I = 0$

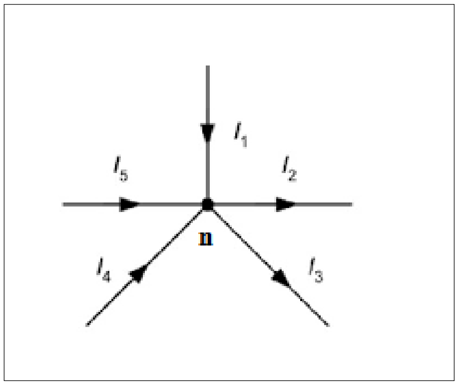


Fig.1.6 – Kirchhoff's Current law

Consider a node or junction point 'n' as shown in above fig. 1.6

Let us assume that currents entering at node are positive whereas current leaving the node are negative. Hence according to KCL,

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

$I_1 - I_2 - I_3+I_4+I_5 = 0$ Or

$I_1 + I_4+I_5 = I_2 + I_3$

So, from above equation it can be also stated as, ***the algebraic sum of currents entering at a node is equal to algebraic sum of currents leaving from that node.***

1.10 – KIRCHHOFF'S VOLTAGE LAW (KVL)

Statement: "The algebraic sum of all branch voltages around any closed loop or mesh is always zero".

This law is also stated as ***"The algebraic sum of the products of currents and resistances in each of the conductors in any closed path (or mesh) in a network plus the algebraic sum of the emf's in that path is zero"***

Mathematically it can be written as,

Σ IR +Σemf = 0 around closed loop

Sign Convention:

A rise in potential should be considered as positive and fall in potential is taken as negative.

- For example, as shown in fig.1.7 (i) below, if we are going from point A towards point B, there is rise in potential hence 'V' is taken *positive*.

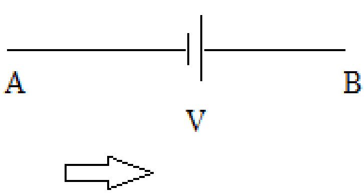


Fig. 1.7 (i)

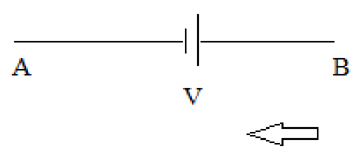


Fig. 1.7 (ii)

- Whereas, if we are going from point B towards point A as shown in fig 1.7 (ii), there is fall in potential because we are going from positive terminal to negative terminal. Hence this time 'V' is taken as '*negative*'
- In case of resistor, when we are going in same direction as of current, there is fall in potential because current always flow from positive terminal to negative terminal. So in case of resistor the first point of resistor is at higher potential and other point is at lower potential. Hence in this case voltage drop (I×R) is taken as 'negative' which is shown in fig. 1.7 (iii) below.

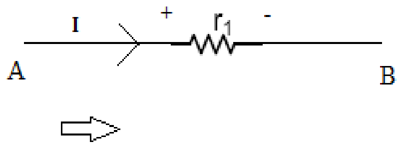


Fig. 1.7 (iii)

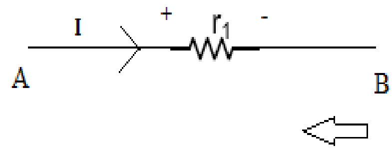


fig. 1.7 (iv)

- As we go from point B towards point A, then there will be rise in potential because we are going opposite to the direction of current. Hence here there is rise in potential and the voltage drop (I× R) is taken as *'positive'*

Explanation with a circuit taken as an example:

Consider a circuit as shown in fig 1.8 below in which there are EMF sources E_1, E_2 and E_3 and current (i) is flowing through resistances.

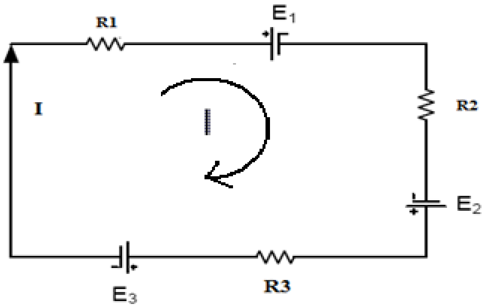


Fig.1.8 – explanation of KVL

We are applying KVL for the above circuit diagram. Here we are going in clockwise direction then the equation will be,

$- I\times R_1 - E_1 - I\times R_2 + E_2 - I\times R_3 - E_3 = 0$ Or

$E_2 - E_1 - E_3 = IR_1 + IR_2 + IR_3$

Current direction:

- We can assume any current direction either clockwise or anticlockwise
- If we get negative value of current after solving the equations then we can conclude that our actual current direction is opposite to the direction that we are assumed
- If we get positive value of current after solving the equation then our assumed direction of current is same as that of actual current direction

1.11 – MESH ANALYSIS (LOOP ANALYSIS):

In mesh analysis or loop analysis method, the number of closed loops in the circuit is identified and corresponding currents are calculated. This method is also called as Maxwell's loop analysis.

In this method, instead of branch currents, the loop or mesh currents are calculated by solving equation for each loop or mesh.

Procedure to apply loop or mesh analysis:

- Identify number of closed loops in the given circuit and note down their corresponding currents
- Assume the direction of current in each loop as 'clockwise'
- Sign conventions for the IR drops and battery emfs are the same as for Kirchhoff's law.
- This method is easier if all the sources are given as voltage sources. If there is a current source present in a network then convert it into equivalent voltage source.

Explanation: Consider a circuit as shown in fig. 1.9 in which there are two loops. Hence there are two loop currents as I_1 and I_2

As per loop analysis we are assuming both current directions as *clockwise.*

First, KVL is applied to loop -1 i.e. loop ABEFA and equations can be written as

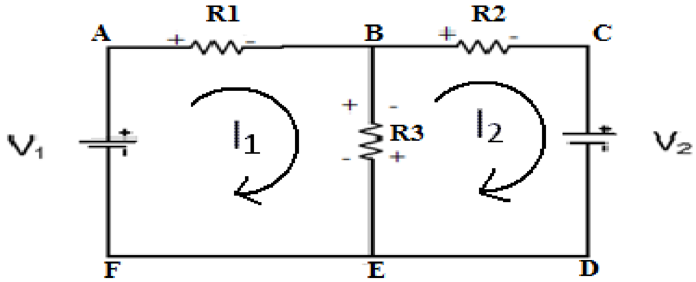


Fig. 1.9 – Loop or mesh analysis

For loop – ABEFA,

$-I_1R_1 – R_3 (I_1- I_2) + V_1 = 0$

i.e. $V_1 = I_1 (R_1+R_3) – I_2R_3$ (1)

For loop – BCDEB,

$-I_2R_2 – V_2 – R_3 (I_2 – I_1) = 0$

i.e. $V_2 = I_1R_3 - I_2(R_2 + R_3)$ (2)

By solving equations (1) and (2) we can calculate values of current I_1 and I_2

Note: *When we consider loop-1, the current I_1 is greater than I_2. So, current through R_3 is (I_1-I_2) similarly, when we consider mesh-2, the current I_2 is greater than I_1. So, current through R_3 is $(I_2 - I_1)$.*

SAMPLE EXAMPLES

<u>Sample Example – 1.2:</u>

For the circuit shown in fig below, find out the current in each resistor by using Mesh analysis.

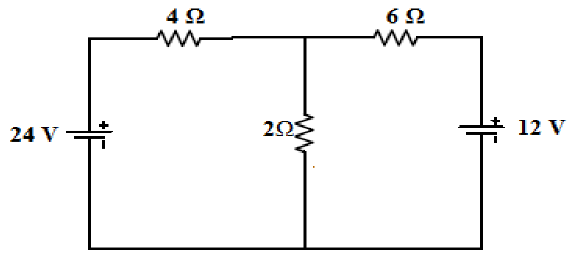


Fig. Ex 1.2

Solution:

In given circuit diagram there are two independent loops hence there must be two equations for two unknown currents.

Let's consider I_1 is the current in loop-1 and I_2 is the current in loop-2 as shown in fig below.

As per mesh analysis, both currents are considered as clockwise direction.

Applying KVL for loop-1

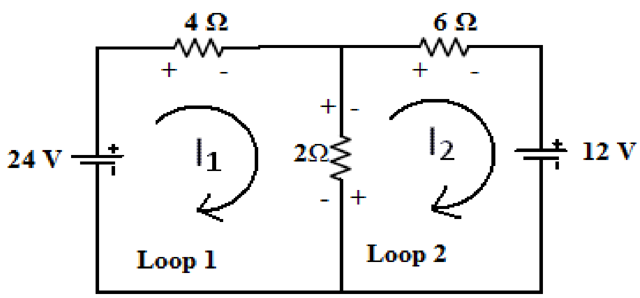


Fig. Ex 1.2 (a)

$$-4I_1 - 2(I_1 - I_2) + 24 = 0$$

$-6I_1 + 2I_2 = -24$

$$6I_1 - 2I_2 = 24 \quad \text{i.e.} \qquad (1.2.1)$$

Applying KVL for loop-2,

$-6I_2 - 12 - 2(I_2 - I_1) = 0$

$$2I_1 - 8I_2 = 12 \quad \text{i.e.} \qquad (1.2.2)$$

To find out the values of I_1 and I_2 we have to solve equations (1.2.1) and (1.2.2)

Multiply equation (1.2.2) by 3, we get

$$6I_1 - 24I_2 = 36 \qquad (1.2.3)$$

Now subtract equation (1.2.3) from equation (1.2.1)

$$\begin{array}{rl} & 6I_1 - 2I_2 = 24 \\ - & \\ & 6I_1 - 24I_2 = 36 \end{array}$$

We get, $22I_2 = -12$

$I_2 = -12/22$ i.e.

$I_2 = -0.545$ A

Putting the value of I_2 in equation (1.2.1) we can get value of I_1

$6I_1 - 2(-0.545) = 24$

$6I_1 = 24 - 1.09 = 22.91$

$I_1 = 22.91/6$ i.e.

$I_1 = 3.81$ A

Hence,

Current through 4Ω resistance is 3.81 A and current through 6Ω resistance is –0.545 A.

Current through 2Ω resistance is (I1–I2) or (I2–I1) which is 3.81– (–0.545) = 3.81+0.545=4.35 A

Answer:

Current through 4Ω resistance is 3.81 A

Current through 6Ω resistance is 0.545 A (In opposite direction)

Current through 2Ω resistance is 4.35 A

Sample Example – 1.3:

Calculate current in 6Ω resistor for the circuit given below by using loop analysis method.

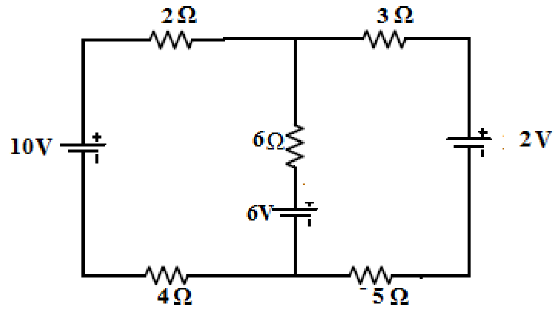


Fig. Ex.1.3

Solution:

Identifying the number of loops in given circuit we can say that there are two loops and current in each loop is I_1 and I_2 as shown in below fig.

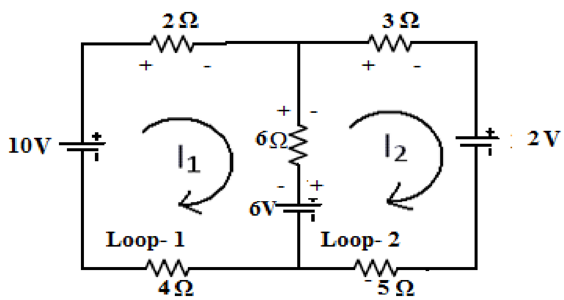


Fig. Ex.1.3(a)

Applying KVL for Loop – 1

$-2I_1 - 6(I_1 - I_2) - 6 - 4I_1 + 10 = 0$

$-12I_1 + 6I_2 = -4$

$$12I_1 - 6I_2 = 4 \quad (1.3.1)$$

Now, applying KVL for Loop – 2,

$-3I_2 - 2 - 5I_2 + 6 - 6(I_2 - I_1) = 0$

$-14I_2 + 6I_1 + 4 = 0$

$$6I_1 - 14I_2 = -4 \quad (1.3.2)$$

Now, we have to solve equations (1.3.1) and (1.3.2) to find out values of I_1 and I_2

Multiplying equation (1.3.2) by 2, we get

$$12I_1 – 28I_2 = - 8 \qquad (1.3.3)$$

Subtracting equation (1.3.3) from equation (1.3.1), we get

$22I_2 = 12$ i.e.

$I_2 = 12/22 =$ **0.545 A**

Putting this value in above equation

$I_1 = 0.605$ A

Hence current in 6 Ω resistor $I_1 – I_2 = 0.605 – 0.545 = 0.06$ A

Current in 6 Ω resistor = 0.06 A

1.12 – NODAL ANALYSIS:

This method determines branch currents in the circuit and also voltages at individual nodes. Following steps are adopted in this method:-

- Identify all the nodes in the network.
- One of these nodes is taken as reference node in at zero potential
- The node voltages are measured with respect to the reference node
- KCL to find current expression for each node
- This method is easier if all the current sources are present. If any voltage source is present, convert it to current source

1.12.1 – Nodal Analysis with voltage source

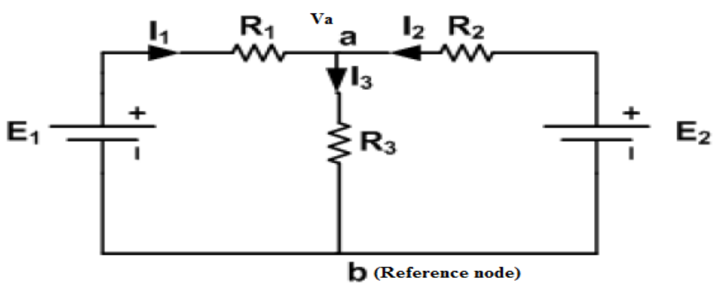


Fig.1.10 – Nodal analysis

In above fig. 1.10, there is one node or junction i.e node ‘a’

Applying KCL at node 'a',

$I_1 + I_2 - I_3 = 0$

$I_1+I_2 = I_3$ (1.12.1)

Let voltage at node 'a' is V_a and voltage at node 'b' is zero because we are taking this node as reference node or zero voltage node.

According to Ohm's law,

$I_1 = (E_1 - V_a) / R_1$ (1.12.2)

$I_2 = (E_2 - V_a) / R_2$ (1.12.3)

$I_3 = V_a / R_3$ (1.12.4)

Putting these values in equation (1.12.1) we get,

$$\frac{(E1 - Va)}{R1} + \frac{(E2 - Va)}{R2} = \frac{Va}{R3}$$

By solving above equation V_a is calculated and putting the value of V_a in equation (1.12.2), (1.12.3), (1.12.4) we can get the values of I_1, I_2, I_3.

Sample Example – 1.4

Find current through 2Ω resistance of fig shown below by using Nodal analysis.

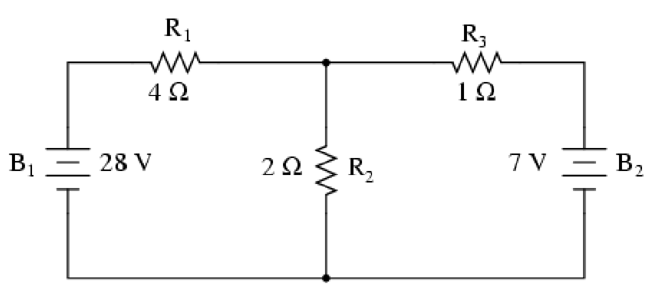


Fig. Ex.1.4

Solution:

Let's mark the currents in given circuit.

Here node 'a' is junction node and its voltage is V_a and node 'n' is taken as reference node or zero voltage node.

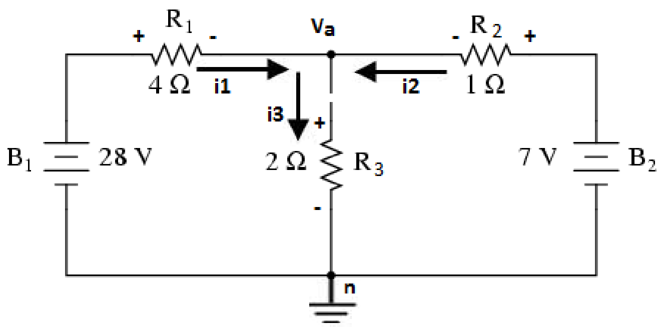


Fig. Ex.1.4 (a)

Applying KCL at node ‘a’ we get’

$i_1 + i_2 - i_3 = 0$

$i_1 + i_2 = i_3$ (1.4.1)

By Ohm’s law,

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

Hence,

$i_1 = \frac{B1-Va}{R1} = \frac{28-Va}{4}$

$i_2 = \frac{B2-Va}{R2} = \frac{7-Va}{1}$

$i_3 = \frac{Va}{2}$

Putting these values in equation (1.4.1)

$\frac{28-Va}{4} + \frac{7-Va}{1} = \frac{Va}{2}$

Solving above equation to find value of Va,

We get,

$28 - V_a + 28 - 4V_a = 2V_a$

$56 = 7V_a$

$V_a = 8$ V

Now, we can calculate value of each current by putting value of V_a in equation of I_1, I_2, I_3

$I_1 = \frac{28-8}{4} = 5$ A

$I_2 = \frac{7-8}{1} = -1$ A

$I_3 = \frac{8}{2} = 4$ A

Hence, current through 2Ω resistance is $I_3 = 4$ A

1.12.2 – Nodal analysis with Current source

Example – 1.5:

Find node voltages V_1 and V_2 and current through 10 Ohm resistance of the circuit shown in below diagram by using Nodal analysis.

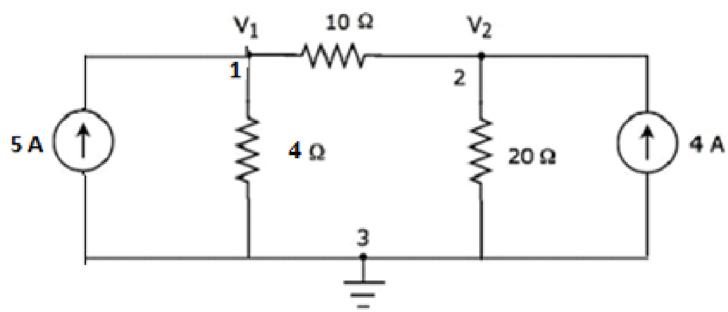


Fig. Ex.1.5

Solution:

There are two independent nodes V_1 and V_2 in given circuit.

Currents are marked in given circuit diagram as shown below.

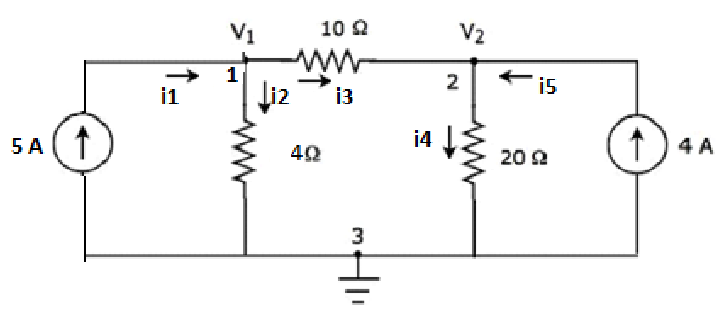


Fig. Ex.1.5 (a)

Now, applying KCL at Node V_1

$i_1 - i_2 - i_3 = 0$

$i_1 = i_2 + i_3$ (1.5.1)

From given circuit diagram value of i_1 is given as 5

Hence, $i_1 = 5$

By ohm's law i_2 and i_3 can be written as

$i_2 = \frac{V1}{4}$, $i_3 = \frac{V1-V2}{10}$

Putting these values in equation (1.5.1) we get

$$\frac{V1}{4} + \frac{V1-V2}{10} = 5$$

Multiplying by 20,

$5V_1 + 2V_1 – 2V_2 = 100$

$7V_1 – 2V_2 = 100$ (1.5.2)

Now, applying KCL at node 'V_2'

$i_3 + i_5 – i_4 = 0$ i.e.

$i_3 - i_4 = -i_5$ (1.5.3)

By ohm's law,

Putting value of i_3, i_4 and i_5 is given as 4A,

$$\frac{V1-V2}{10} - \frac{V2}{20} = -4$$

$2(V_1-V_2) - V_2 = - 80$

$2V_1 – 3V_2 = -80$ (1.5.4)

Solving equations (1.5.2) and (1.5.3) we get values of V_1 and V_2

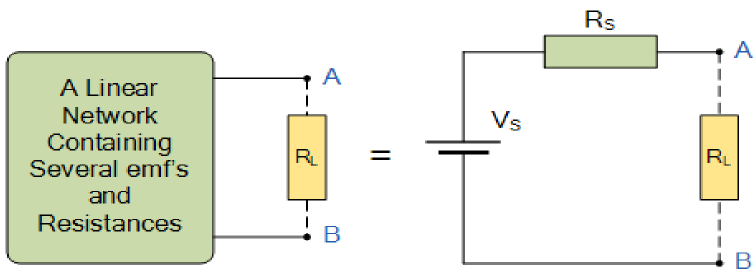
$V_1 = 27.05$ V and $V_2 = 44.7$ V

Hence current through each resistance is

Current through 10Ω (i_3) = $\frac{V1-V2}{10} = \frac{(27.05)-(44.7)}{10} =$ **-** 1.765 A or 1.765 A in opposite direction

1.13 - Thevenin’s Theorem:

Statement: “*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.

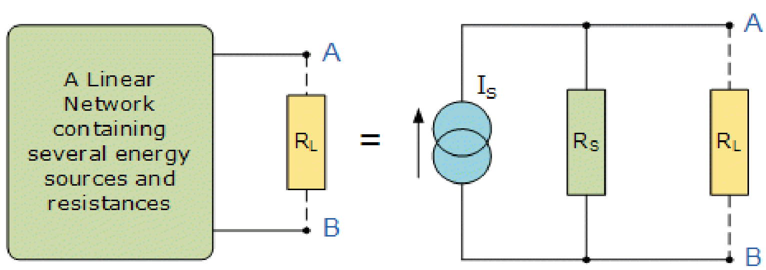


The basic procedure for solving a circuit using Thevenin’s Theorem is as follows:

- 1. Remove the load resistor R_L or component concerned.
- 2. Find R_{TH} (R_s) by shorting all voltage sources or by open circuiting all the current sources.
- 3. Find V_{TH} (V_s) by the usual circuit analysis methods.
- 4. Replace the network with V_{TH} in series with R_{TH} across the load.

1.14 - Norton’s Theorem:

Statement - “*Any linear circuit containing several energy sources and resistances can be replaced by a single Constant Current source in parallel with a Single Resistor***”**



The basic procedure for solving a circuit using Norton’s Theorem is as follows:

- 1. Remove the load resistor R_L or component concerned.
- 2. Find R_N (or R_s) by shorting all voltage sources or by open circuiting all the current sources.
- 3. Find I_N (or I_s) by the usual circuit analysis methods.
- 4. Replace the network with I_N in parallel with R_N across the load.

1.15 - Magnet and it's properties

A magnet is as solid material that possesses the property of attracting the iron pieces. When a magnet is rolled into iron pieces it will attract the iron pieces towards the end points.

The points at which the iron pieces accumulate maximum are called poles of the magnet while imaginary lines joining these poles called axis of the magnet. There are two poles called North pole (N-pole) and South pole (S-pole).There are two types of magnets.

1. Natural magnet
2. Electro-magnet

The natural magnets have the property of magnetism naturally present whereas the electromagnets are formed by passing an electric current around a certain material. The material then acts as magnet as long as the current is present. But it loses its magnetic properties as soon as the current stops.

Properties of magnet: -

1. A magnet attracts the iron pieces of iron.

2. A freely suspended magnet aligns itself in north-south direction.

3. Like poles of the magnet repel & unlike pole of the magnet attracts each other.

4. Magnetic induction.

5. Magnetic lines of force/ magnetic field/magnetic flux.

1.16 - Magnetic field and Magnetic lines of force.

Magnetic Field: - The magnetic field is defined as the region near a magnet within which the effect or influence of the magnet is felt.

Magnetic Lines of Force: - A line of force is defined as a line along which an isolated N-pole would travel if it is allowed to move freely in a magnetic field.

Properties of Magnetic Lines of Forces: -

1. The magnetic lines of force always form a closed loop. They originate from N-pole & terminate in S-pole.

2. The magnetic lines of force do not cross or intersect each other.

3. The magnetic lines of force which are parallel to each other & are acting in the same direction tend to repel each other.

4. The magnetic lines of force behave like stretched elastic band & always try to contract in length.

5. The magnetic lines of force always try to follow the minimum opposition path.

1.17- Magnetic circuit

A magnetic circuit is defined as the closed path followed by the magnetic lines of force i.e. flux.

This is very similar to an electric circuit which states that the electric circuit is the closed path provided for the electric circuit. The quantities associated with magnetic circuits are MMF, flux, reluctance permeability etc.

1. **Magnetic flux:** The magnetic flux is defined as the total number of magnetic lines of force in a magnetic field. It is denoted by 'φ' & is measured in *Weber (Wb)*. One Webber is defined as the flux radiated out by a unit N-pole
   1Wb = 10^8 lines of force

2. **Magnetic flux density (B):** The flux per unit area (a), measured in a plane perpendicular to the flux is called as the flux density. It is measured in *Tesla (T)* or *(Wb/m^2).*

   B = flux / area = φ/ a

3. **Magnetic Field Strength or Magnetic Field Intensity (H):** The magnetic field strength at a point in the magnetic field is defined as the force experienced by a unit North Pole placed at that point in the magnetic field. It is measured in *Newton per Weber* (N/Wb).

4. **Magneto Motive Force (MMF): -** The Magneto Motive Force is defined as the force responsible for the generation of the flux. It is nothing but the work done on a unit magnetic pole to take it around a closed magnetic circuit.

   The MMF is the driving force behind the magnetic circuit. It is given by the product of the number of turns of the magnetizing coil & the current passing through the coil.
   Mathematically, MMF= N.I
   Where, N = number of turns of the magnetizing coil, I = current passing through the coil
   The SI unit of the MMF is *Ampere-turn (AT)*

5. **Reluctance (S):** The reluctance of a material is the opposition offered by that material for passage of magnetic lines of force (magnetic flux) through it. It is denoted by 'S'.

   The reluctance of a material is directly proportional to the length (l) of the magnetic circuit & inversely proportional to the area of cross section (a).

S α l/a

S = l / μ.a , Where μ = absolute permeability
Its SI unit is *Ampere per Wb*.
Reluctance is also defined as ratio of MMF and flux.

S = MMF / Flux
S = N.I / φ

1.18 - Comparison Of Magnetic circuit and Electric circuit

Sr.No	Electrical Circuit	Magnetic Circuit
Similarities		
1.	It is the combination of paths through which electric current can pass.	It is the combination of paths through which magnetic flux can pass.
2.	EMF is driving force	MMF is driving force
3.	Resistance(R) is opposing factor	Reluctance (S) is opposing factor
4.	I = V/ R	Φ = MMF / S
5.	DC battery gives constant EMF	Permanent magnet gives constant MMF
6.	DC current passes from positive to negative polarity	Flux passes from N- pole to S -pole
Differences		
1.	Electrical energy is continuously require to produce electric current	Magnetic energy is required only to set up the flux. Once flux sets up no energy required
2.	The current actually flows in circuit	Flux actually not flows in circuit but they sets up
3.	Resistance is temperature dependent	Reluctance does not depend upon temperature
4.	It may be open or close	It is always closed
5.	Electrical insulation is required	Magnetic insulation does not exist

1.19 - Magnetic leakage and magnetic fringing

- In many electromagnetic devises like generators, motors, transformers, measuring instruments etc. are having air gap in their magnetic circuits.
- Hence magnetic flux passing through the air gap can be utilized to produce desired effect.
- So, the flux passing through the air gap and used for the desired result is known as ‘ *useful flux’*
- But practically, some part of total flux always leaks out taking short paths through air and it doesn’t contribute in desired results. This is shown in fig below.
- This flux which is not following the intended path for it is known as *‘ Leakage flux’*
- Since this flux is not passing through the air gap, it is cannot be utilized for desired purpose.

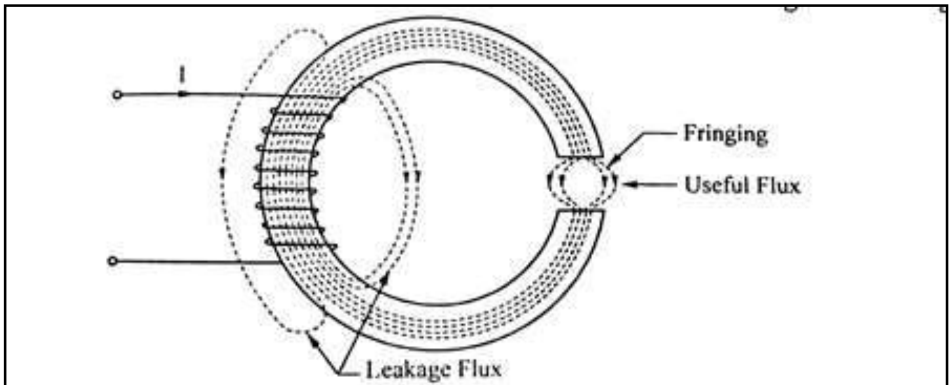


Fig. 4.16 : Magnetic leakage and fringing

- Hence total flux = Useful flux + leakage flux
- The ratio of Total flux to the useful flux is called as *' Leakage factor'(λ)*
- Hence *, λ = Total flux / Useful flux*
- When the magnetic lines of force are passing through the air gap, they are not in straight line but they have the tendency to *spread out* at the edge s of air gap as shown in above fig.
- This effect of bulging or spreading of magnetic flux at the edges of air gap is called as '*fringing'*
- Fringing increases the effective cross-sectional area of air gap and reduces the flux density in the air gap.
- Hence fringing can be reduced by reducing the air gap of magnetic circuit.