What do we study in D.C. circuits & D.C Machines?

This unit consists of basic network or circuit parameters : Elementary electrical circuits and measurement of voltage and current, Numerical problems. Fundamental laws and their application in circuit parameter calculation. To introduce the students to fundamental concepts and principles of D.C machines including motors and generators. This unit fundamentally deals with the principles and behavior of electromechanical systems that convert electrical energy into mechanical energy and vice versa

Why do we need to study D.C. circuits & D.C Machines?

The need for D. C. circuit arises to develop an understanding of the fundamental laws and elements of electrical circuits. Also to learn the energy properties of electric elements and the techniques to measure voltage and current and explain the relationship between voltage, current and resistance (Ohm's law). D. C. machines allows faster and more efficient means to do almost everything done in locomotive industry, commercial work.

Where do we use D.C. Circuits & D.C Machines?
D.C. circuits are used to analyze substances DC power is more efficient than AC power. Apply Kirchhoff's laws in solving DC Circuits. List several different circuit components. D.C Machines are used in most of the real-world application, like transportation, and electric traction system.

1.1 Network and Circuit

- **Network:** Any Combination of electrical elements such as Voltage sources, current sources, resistances, Inductance & capacitance is called a **"Network".** It may be opened or closed.
- **Circuit:** Any Closed path formed by the voltage / current sources, resistance, inductance and capacitance that results in a flow of current is known as a "**Circuit**".

NOTE:- Every circuit is a Network but every Network may or may not be a circuit.

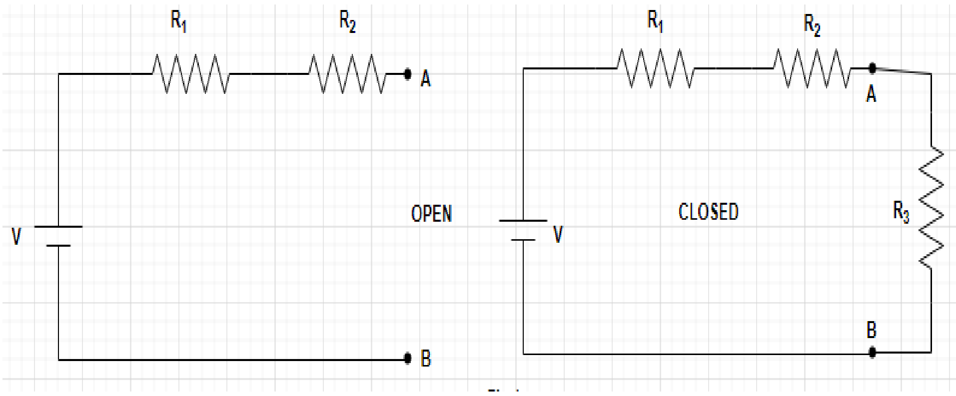

Fig. 1.1.1 Basic open and closed network

1.1.1 Active and passive elements:

Elements that are capable of delivering electrical energy are called "**Active Elements**". Examples: Voltage source, Current source, Battery. Examples are shown in fig.1.1.2

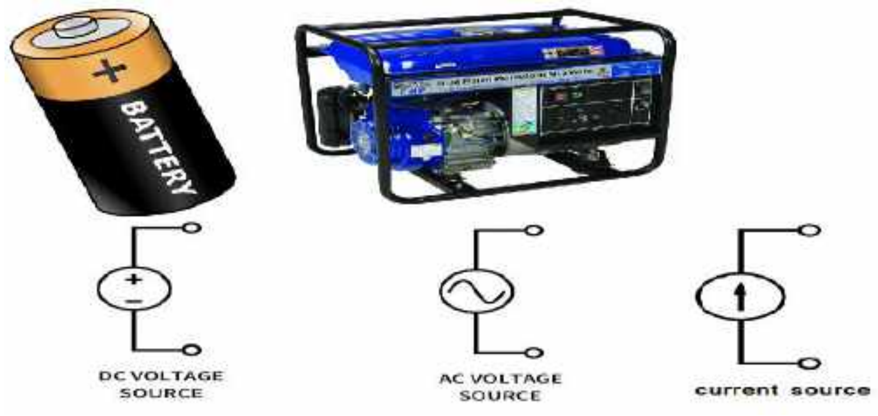

Fig. 1.1.2 Different types of active elements with their symbol

The elements which are Capable of storing or dissipating the electrical energy are called **"Passive elements"**.

Actual Passive elements and their symbol look like as shown in figure 3. Resistor can be measured in ohm(Ω),inductor in Henry (H) and capacitor in Farad(F).

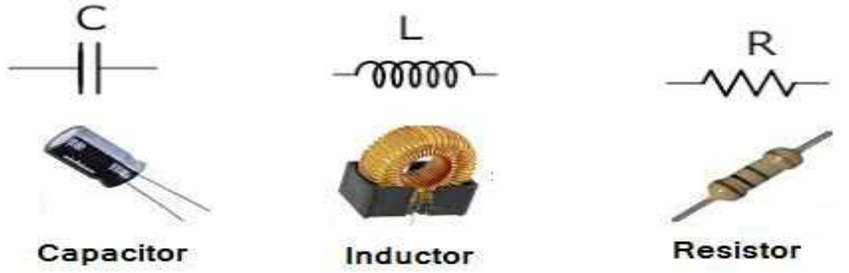

Fig. 1.1.3 Different types of passive elements with their symbols

<u>Short questions</u>

Q1 Distinguish between active and passive elements.

(AKTU 2015-2016)

Q2 Write two characteristics of active elements.

(AKTU 2016-2017)

Q3 Define:
(i) Active and passive elements
(ii) Bilateral and unilateral elements

(AKTU 2017-2018, 2017-2016, 2018-2019)

Q4 Define Active and passive elements

(AKTU 2018-2019, 2020-2021)

Q5 Describe the active and passive elements with examples.

(AKTU 2022-2023)

Q6 Differentiate between ideal voltage source and practical voltage source.

(AKTU 2023-2024)

1.1.2 Unilateral and Bilateral Elements

If the characteristic behavior of elements remains unchanged on Changing the direction of current is known as a **“Bilateral element”.**

Examples:- Resistance, Inductance, Capacitance

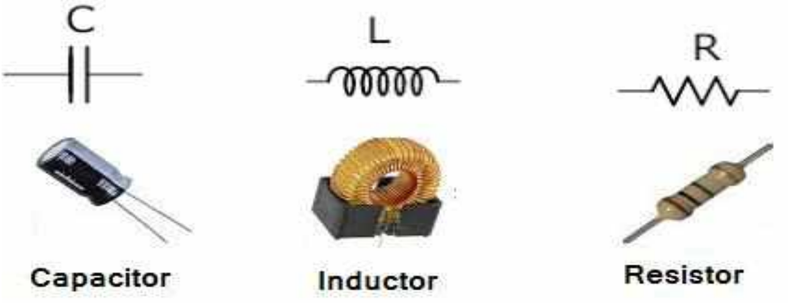

Fig. 1.1.7 Different types of bilateral elements with their symbols

If the characteristics, behaviour of element changes on changing the direction of Current is known as **Unilateral Element"**

Examples:- Diode, Transistors etc

1.1.3 Linear and Non-Linear Elements

Linear elements are those elements whose V-I or I-V characteristics should be linear or we can say they will follow the ohm’s law.

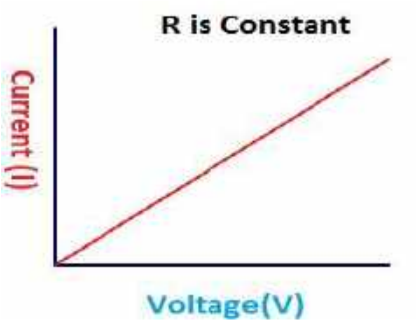

Fig. 1.1.5 V-I curve for Resistance

OR

Linear elements are those elements which provides the same V-I or I-V characteristics after changing the polarity of the supply voltage.

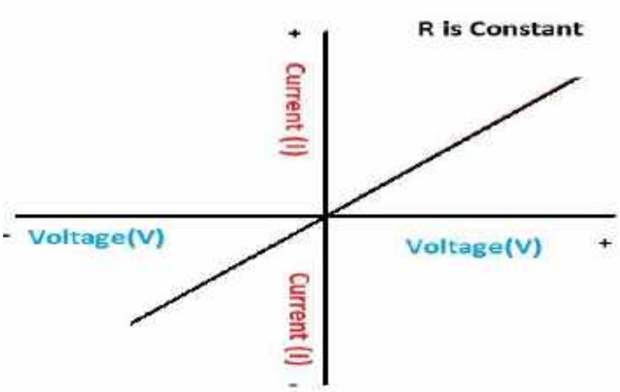

Fig. 1.1.6 V-I curve for Resistance with different polarity

Examples: Resistor (R), Inductor (L), Capacitor (C)

Fig 1.1.7 Symbol of different linear elements

Note: linear circuit obey the homogeneity and additive (superposition) properties

Non-Linear elements are those elements whose V-I or I-V characteristics should be non-linear or we can say they will not follow the ohm's law.

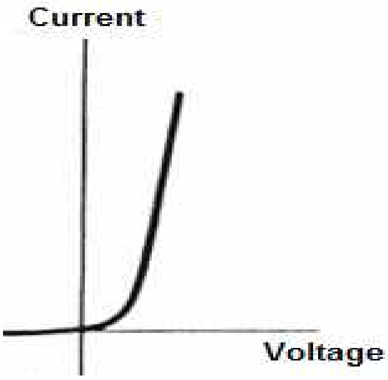

Fig. 1.1.8 V-I curve for Diode

OR

Non-Linear elements are those elements which provides the different V-I or I-V characteristics after changing the polarity of the supply voltage

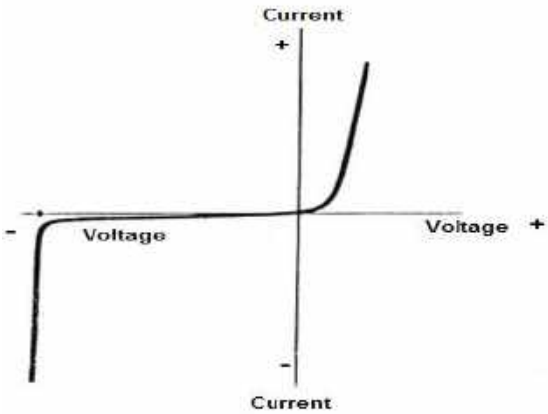

Fig. 1.1.9 V-I curve for diode with different polarity

Note: non-linear circuit does not obey the homogeneity and additive properties

Short questions

Q7 What do you understand by unilateral and bilateral elements? Give examples.

(AKTU 2019-2020)

Q8 Why is linearity important in circuits?

(AKTU 2021-2022)

Soultion: Linearity is an important and desirable feature of an analytical method in a circuit because the point of the calibration function is linear, then it is easier to estimate the equation, and evaluation errors are likely to be small.

Q9 Describe briefly the following elements with examples:
(i) Unilateral & bilateral
(ii) Active & passive

(AKTU 2022-2023, 2023-2024)

1.2 TYPES OF SOURCES

There are two types of sources existing in Electrical Engineering:

- Independent Sources
- Dependent Sources

1.2.1 Independent Sources

There are two types of independent sources:

(a) Voltage source
(b) Current source

1.2.1.1 Ideal and Practical Voltage Sources

- **Ideal Voltage sources:** It gives constant voltage across its terminals irrespective of current drawn through its terminals.

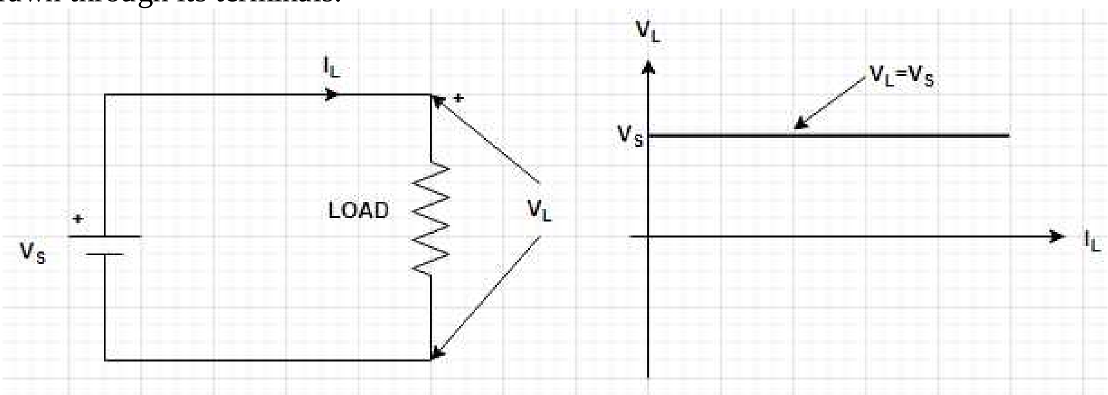

Fig. 1.2.1 Circuit and V-I characteristics for ideal voltage source

Relation between terminal voltage and source voltage is given below

$$V_L = V_S$$

Note:

- **Provides constant voltage independent of current drawn from it**
- **Has zero internal resistance (R_S=0**

- **Practical Voltage sources:** It does not give constant voltage across its terminals irrespective of current drawn through its terminals. Practical voltage source has the following configuration shown in figure:

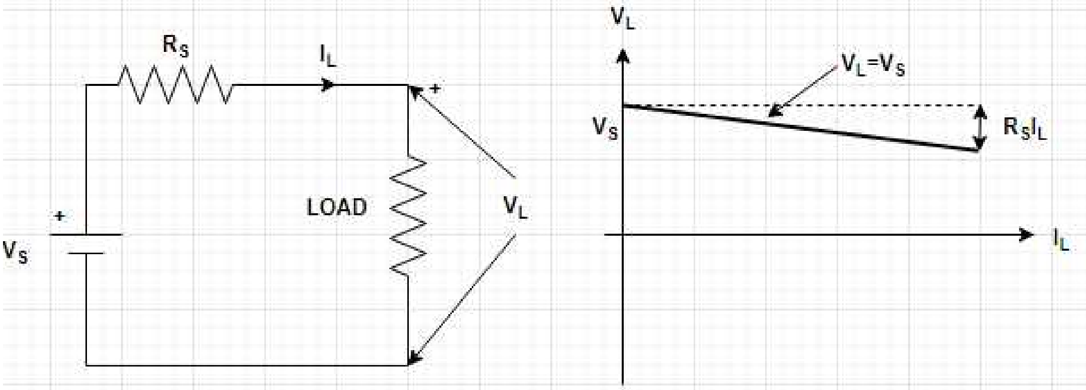

Fig. 1.2.2 Circuit and V-I characteristics for practical voltage source

In this case relation between terminal voltage and source voltage shown below

$$V_L = V_S - I_L.R_S$$

Note:

- **Provides variable voltage dependent of current drawn from it**
- **finite internal resistance (Should be very low)**

1.2.1.2 Ideal and Practical current Sources

- **Ideal current source:-**It is the source which gives constant current at its terminals irrespective of the voltage appearing across its terminals.

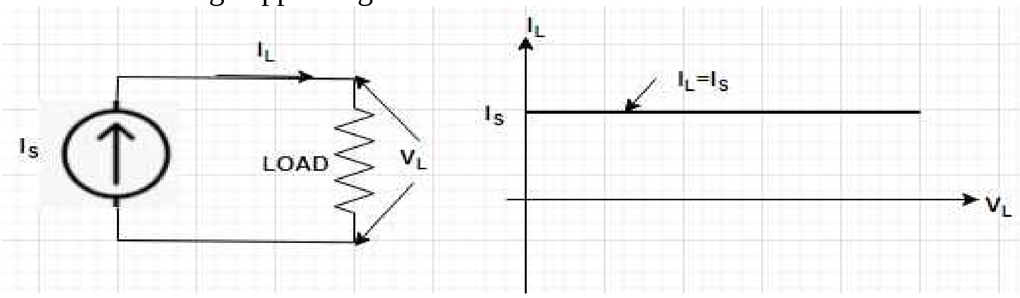

Fig. 1.2.3 Circuit and V-I characteristics for ideal current source

Note:

- **Provides constant current independent of current drawn from it**
- **Infinite internal resistance (R_S=Infinity)**

- **Practical current source:-**It is the source which does not give constant current at its terminals irrespective of the voltage appearing across its terminals.

Practical current source has the following configuration shown in figure:

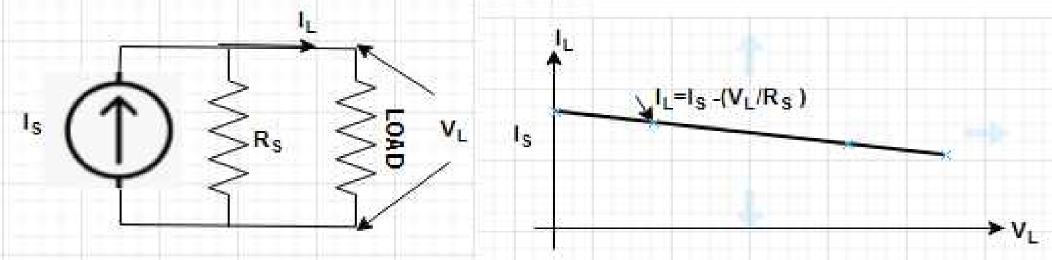

Fig. 1.2.4 Circuit and V-I characteristics for practical current source

In this case relation between load current and source current shown given below

$$I_L = I_S - (V_L/R_S)$$

1.2.2 Dependent Sources

There are four types of dependent sources shown in fig 14

(a) Current dependent current source(CDCS)
(b) Voltage dependent current source(VDCS)
(c) Voltage dependent voltage source(VDVS)
(d) Current dependent voltage source(CDVS)

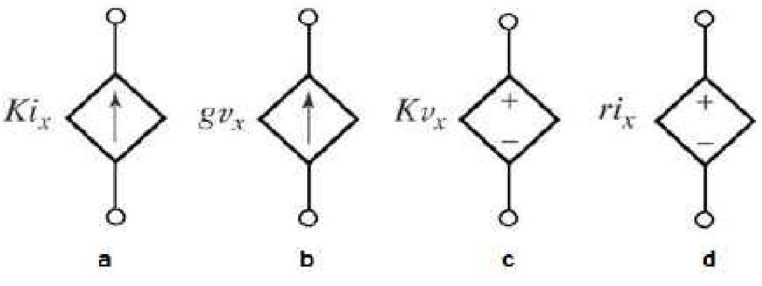

Fig. 1.2.5 Different symbol of dependent source

Note: Application of dependent sources are not in first year Syllabus

Short questions

Question 10 Explain (i) Ideal voltage source (ii) Practical voltage source

(AKTU 2017-2018)

Q11 Explain
(i) Ideal current source
(ii) Ideal voltage source

(AKTU 2018-2019)

Q12 Define ideal voltage and current sources

(AKTU 2018-2019, 020-2021)

Q13 Draw the V-I characteristics for ideal voltage source and ideal current source.

(AKTU 2021-2022)

Q14 Describe the following elements briefly:
(i) Independent ideal voltage source
(ii) Independent ideal current source

(AKTU 2022-2023)

Note:

- **Provides variable current dependents on load voltage**
- **Very-very high amount of internal resistance**

1.3 SOURCE TRANSFORMATION

Source Transformation simply means replacing one source by an equivalent source.

1.3.1 Conversion of Voltage Source into Current Source

A practical voltage source can be transformed into an equivalent practical current source and similarly a Practical current source into voltage source. When the voltage source is connected with the resistance in series and it has to be converted into the current source than the resistance is connected in parallel with the current source as shown in the above figure 1.3.1

Where $\mathbf{I_s = V_s / R}$

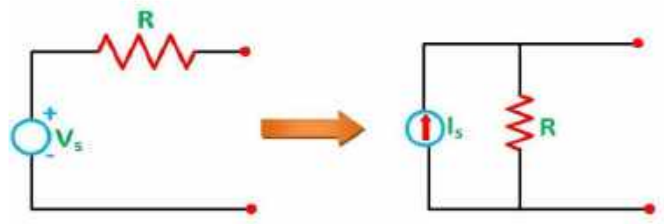

Fig. 1.3.1 Equivalent circuit for voltage source to current source transformation

1.3.2 Conversion of Current Source into Voltage Source

In the above circuit diagram a current source which is connected in parallel with the resistance is transformed into a voltage source by placing the resistance in series with the voltage source.

Where, $\mathbf{V_s = I_s / R}$

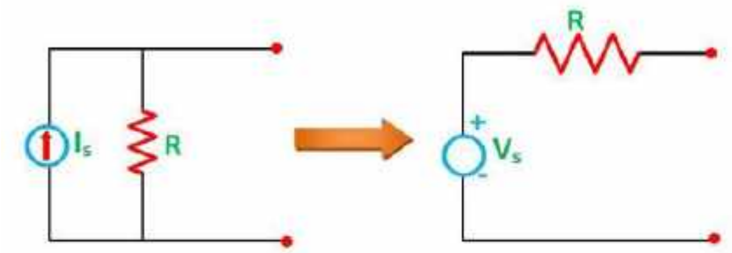

Fig. 1.3.2 Equivalent circuit for current source to voltage source transformation

1.4 KIRCHHOFF'S LAWS

Kirchhoff's laws are basic analytical tools in order to obtain the solutions of currents and voltages for any electric circuit; whether it is supplied from a direct-current system or an alternating current system. But with complex circuits the equations connecting the currents and voltages may become so numerous that much tedious algebraic work is involved in their solutions.

Elements that are generally encountered in an electric circuit can be interconnected in various possible ways. Before discussing the basic analytical tools that determine the currents and voltages at different parts of the circuit, some basic definition of the following terms are considered

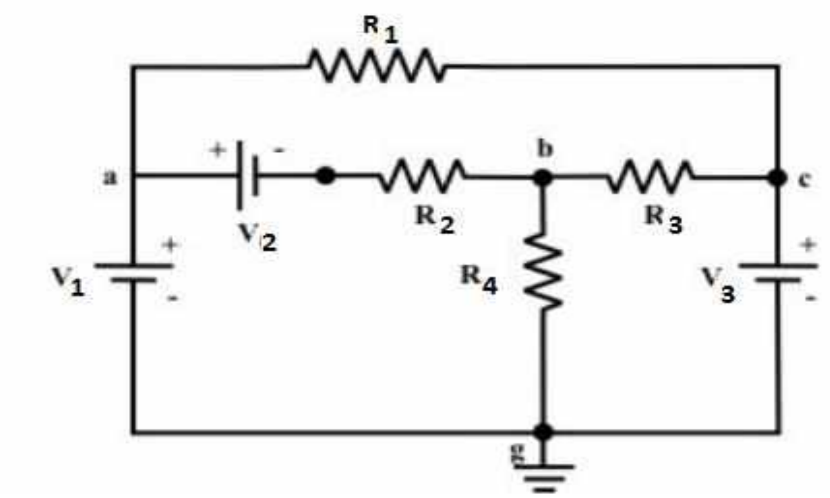

Fig. 1.7.1 Basic electrical circuit

- **Node:** A node in an electric circuit is a point where two or more components are connected together. This point is usually marked with a dark circle or dot. The circuit in fig. 1.7.1 has nodes a, b, c, and g. Generally, a point, or a node in a circuit specifies a certain voltage level with respect to a reference point or node.

- **Branch:** A branch is a conducting path between two nodes in a circuit containing the electric elements. These elements could be sources, resistances, or other elements. Fig. 1.7.1 shows that the circuit has six branches: three resistive branches (a-c, b-c, and b-g) and three branches containing voltage and current sources (a-, a-, and c-g).

- **Loop:** A loop is any closed path in an electric circuit i.e., a closed path or loop in a circuit is a contiguous sequence of branches whose starting and end points for tracing the path are, in effect, the same node and touches no other node more than once. Fig. 1.7.1 shows three loops or closed paths namely, a-b-g-a; b-c-g-b; and a-c-b-a. Further, it may be noted that the outside closed paths a-c-g-a and a-b-c-g-a also form two loops.

- **Mesh:** a mesh is a special case of loop that does not have any other loops within it or in its interior. Fig.1.7.1 indicates that the first three loops (a-b-g-a; b-c-g-b; and a-c-b-a) just identified are also 'meshes' but other two loops (a-c-g-a and a-b-c-g-a) with the introduction of Kirchhoff's laws, various types of electric circuits can be analyzed.

1.4.1 Kirchhoff's Current Law (KCL)

KCL states that at any node (junction) in a circuit the algebraic sum of currents entering and leaving a node at any instant of time must be equal to zero.

$$\sum_{k=1}^{n} I_k = 0$$

Where k=1,2,3........n

Here currents entering(+ve sign) and currents leaving (-ve sign) the node must be assigned opposite algebraic signs (fig.18)hence,

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

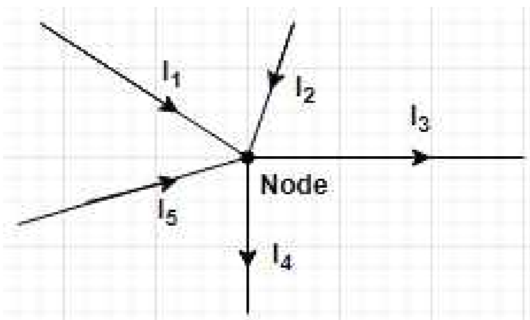

Fig. 1.7.2 Circuit representing node

Note: Charge should be conserved at any node.

1.4.2 Kirchhoff's Voltage Law (KVL)

It states that in a closed circuit, the algebraic sum of all voltages must be equal to zero.

$$\sum_{k=1}^{n} V_k = 0$$

Where k=1,2,3........n

Or we can say that the algebraic sum of all source voltages must be equal to the algebraic sum of all the voltage drops.

Note: Voltage rise should be considered as positive sign(+ive sign)

Voltage drop should be considered as negative sign(-ive sign)

Kirchhoff's voltage law is explained with the help of fig. 1.7.3.

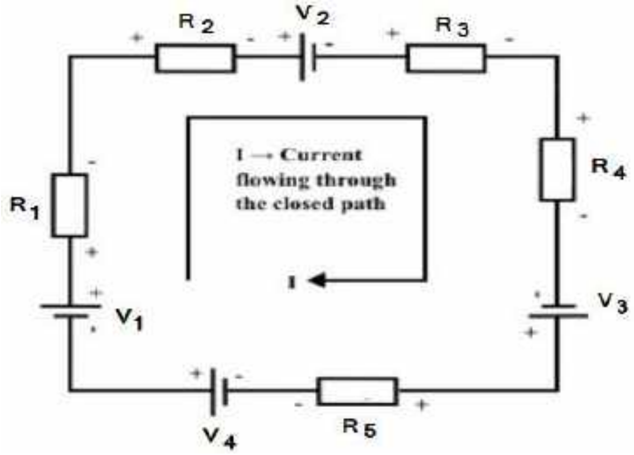

Fig. 1.7.3 Circuit representing mesh or loop to apply KVL

KVL equation for the circuit shown in fig. 1.7.3 is expressed as (we walk in clockwise direction starting from the voltage source and return to the same point)

$$V_1 - I.R_1 - I.R_2 - V_2 - I.R_3 - I.R_4 + V_3 - I.R_5 - V_4 = 0$$

Note: Energy should be conserved in any close loop.

Short questions

Question 15 State Kirchhoff's law.

(AKTU 2021-2022,2023-2024)

Question 16 Describe KCL and KVL with necessary circuit representation.

(AKTU 2022-2023)

1.5 MESH ANALYSIS

It is the application of Kirchhoff's voltage law. Mesh Current Analysis is a technique used to find the currents circulating around a loop or mesh within any closed path of a circuit. There are the following steps for obtaining the responses by using mesh analysis.

Step-1: Draw the circuit on a flat surface with no conductor crossovers.

Step-2: Label the mesh currents (i_I) carefully in a clockwise or anticlockwise direction.

Step-3: Write the mesh equations by inspecting the circuit.

Step-4: Solve the mesh equation for finding the mesh currents as well as the branch current also.

For example, consider the following circuit.

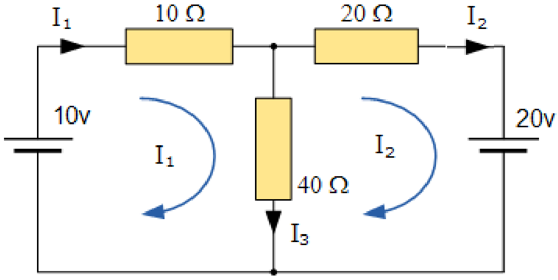

Fig. 1.5.1 Circuit to apply mesh analysis

Mesh 1:

$$50\ I_1 - 40\ I_2 = 10$$

Mesh 2:

$$-40\ I_1 + 60\ I_2 = -20$$

Solving these equation for obtaining mesh currents I_1 and I_2 by using any method
Hence

$$I_1 = -0.413\ A$$
$$I_2 = -0.429\ A$$

Long questions

Q17 Find the current in 2 ohm resistance in the following figure. using loop analysis method. **(AKTU 2015-2016**)

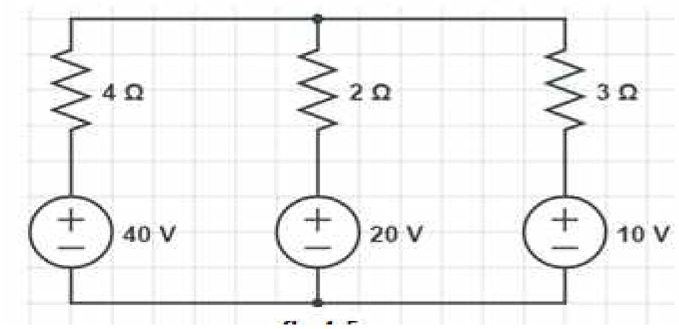

Fig. 1.6.1 Circuit

Solution: The circuit shown in fig. in which mesh currents are indicated,

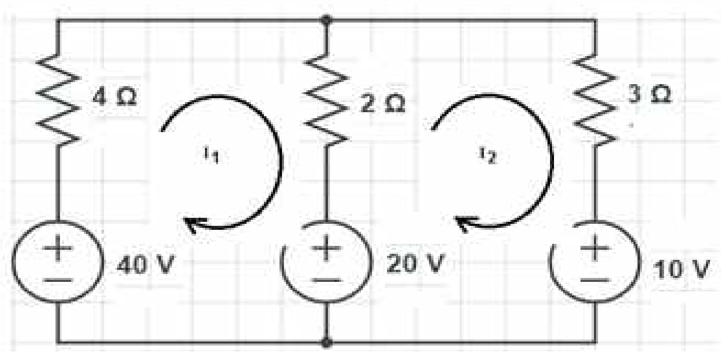

Fig. 1.6.2 Circuit

Applying KVL in mesh 1,

$$-4\,I_1 - 2(I_1 - I_2) - 20 + 40 = 0$$
$$-6I_1 + 2I_2 = -20 \qquad (1)$$

Applying KVL in mesh 2,

$$-3I_2 - 2(I_2 - I_1) - 10 + 20 = 0$$
$$2I_1 - 5I_2 = -10 \qquad (2)$$

By solving Equation (1) and Equation (2) then both mesh current would be

$$I_1 = 4.62\ A,\ \ I_2 = 3.85\ A$$

Current in 2 Ω resistance i.e

$$I_2 - I_1 = 3.85 - 4.62 = -0.77\ A$$

Or Current in 2 Ω resistance i.e

$$I_1 - I_2 = 4.62 - 3.85 = 0.77\ A$$

Q18 Determine current in 4 ohm resistor by using mesh analysis in the circuit shown in figure.

(AKTU 2017-2018)

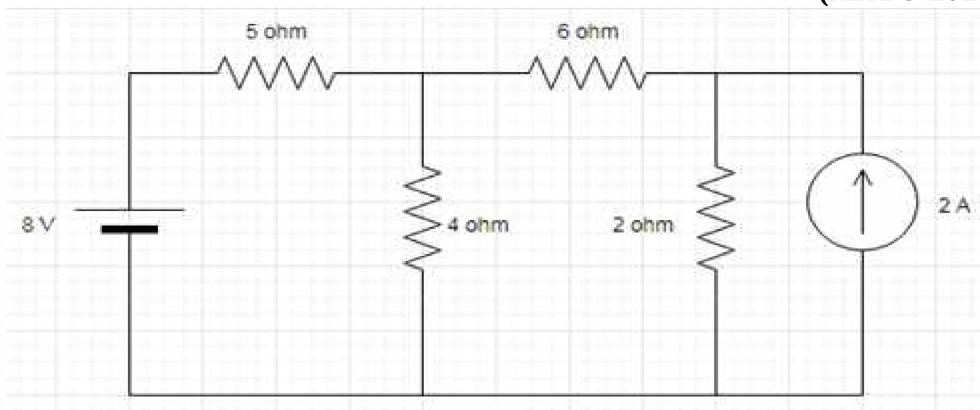

Fig. 1.6.3 Circuit

Solution: The circuit shown in fig. in which mesh currents are given,Now applying KVL in all meshes.

Do not apply KVL in mesh 3 because current source is their so in mesh 3 current would be,

$$I_3 = -2\ A$$

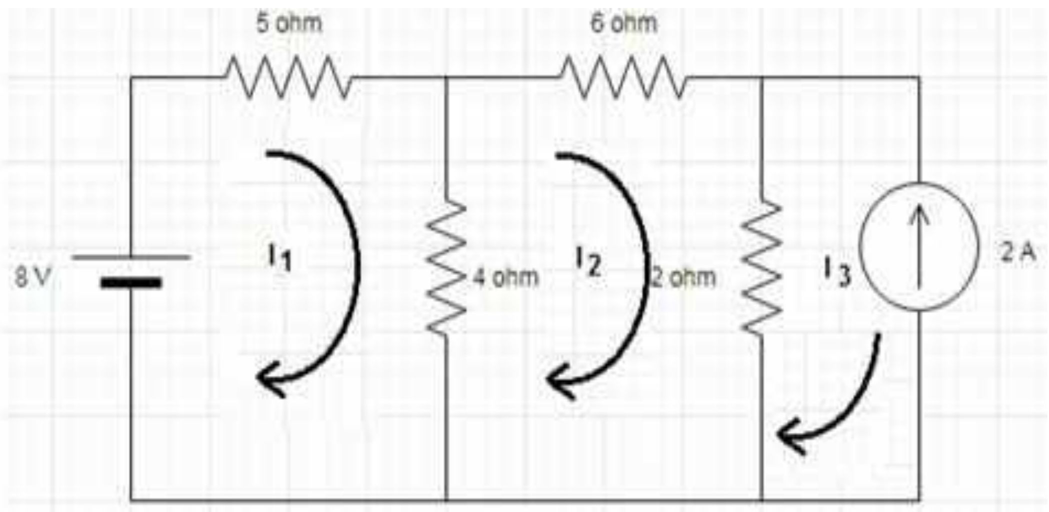

Fig. 1.6.4 Circuit

Now applying KVL in mesh 1,

$$-5\,I_1 - 4(I_1 - I_2) + 8 = 0$$
$$-9I_1 + 4I_2 = -8$$

Mesh 3 is not associated with mesh 1 so the Coefficient of I_3 will be zero.Hence

$$-9I_1 + 4I_2 + 0I_3 = -8$$
$$-9I_1 + 4I_2 + 0.(-2) = -8$$
$$-9I_1 + 4I_2 = -8 \qquad (1)$$

Applying KVL in mesh 2,

$$-6I_2 - 4(I_2 - I_1) - 2(I_2 - I_3) = 0$$

Substitute the value of I_3 then,

$$-6I_2 - 4(I_2 - I_1) - 2(I_2 - (-2)) = 0$$
$$4I_1 - 12I_2 - 4 = 0$$
$$4I_1 - 12I_2 = 4 \qquad (2)$$

By solving Equation (1) and Equation (2) then both mesh current would be

$$I_1 = 0.869\ A,\ \ I_2 = -0.044\ A$$

Current in 4 Ω resistance i.e

$$I_2 - I_1 = -0.044 - 0.869 = -0.913\ A$$

Or Current in 4 Ω resistance i.e

$$I_1 - I_2 = 0.869 - (-0.044) = 0.913\ A$$

Q19 A battery of e.m.f 40 V and internal resistance 2 Ω is connected in parallel with a second source of 44 V and internal resistance 4 Ω. A load resistance of 6 Ω is connected across the ends of parallel circuit shown in fig. Calculate the current in each battery and the by using mesh analysis.

(AKTU 2001-2002)

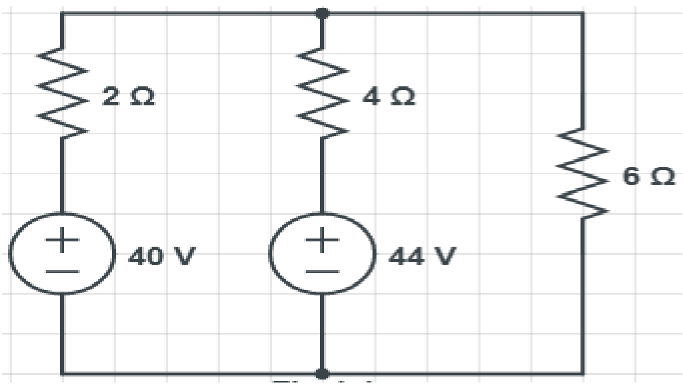

Fig. 1.6.5 Circuit

Answer:

$$I_1 = 3.09\ A,\ \ I_2 = 5.64\ A$$

Current in 40 V battery i.e

$$I_1 = 3.09\ A$$

Current in 44 V battery i.e

$$I_2 - I_1 = 5.64 - 3.09 = 2.55\ A$$

Q20 Using mesh analysis, calculate the currents $I_1 I_1$ and $I_2 I_2$.

(AKTU 2011-2012)

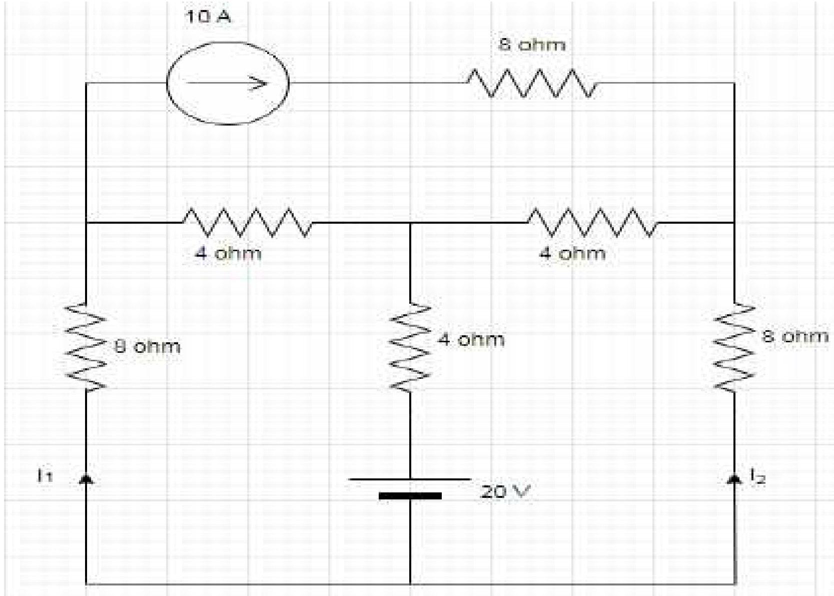

Fig. 1.6.6 Circuit

Answer:

$$I_3 = 10\ A$$
$$I_1 = 2.33\ A,\ \ I_2 = 4.33\ A$$

Q21 Applying mesh analysis, through obtain the current through 5 Ω resistance in the following circuit. **(AKTU 2020-2021)**

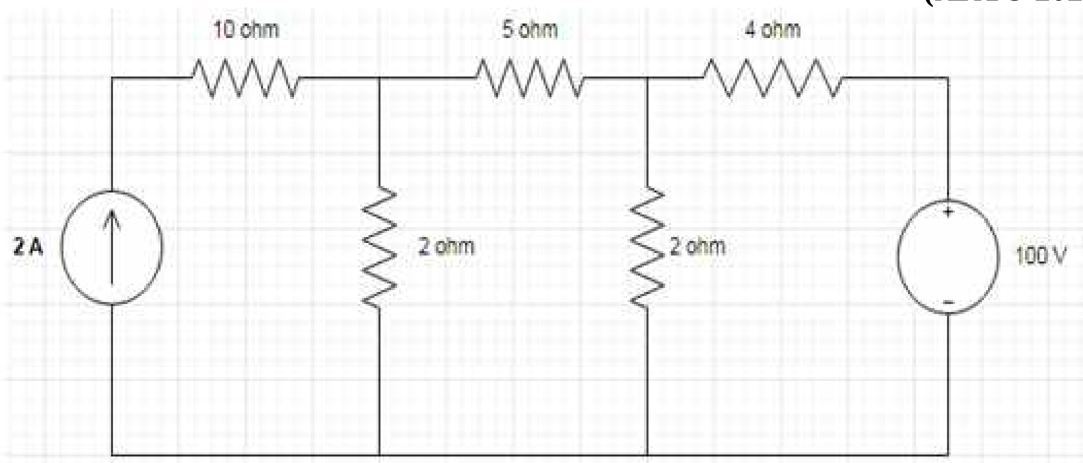

Fig. 1.6.7 Circuit

Solution: The circuit shown in fig. in which mesh currents are given,Now applying KVL in all meshes.

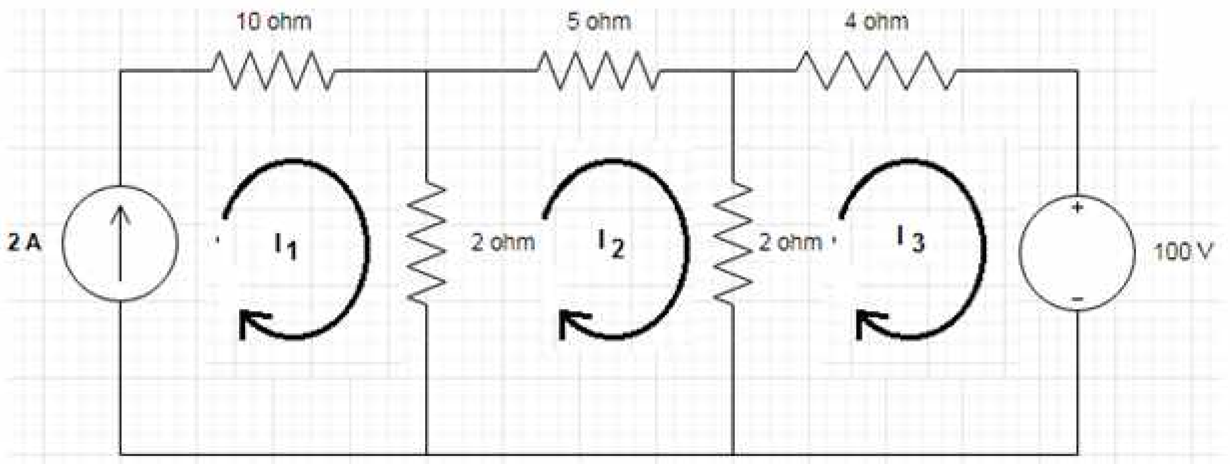

Fig. 1.6.8 Circuit

Do not apply KVL in mesh 1 because current source is their so in mesh 1 current would be,

$$I_1 = 2\ A$$

Now applying KVL in mesh 2,

$$-2(I_2 - I_1) - 5I_2 - 2(I_2 - I_3) = 0$$

Substitute the value of I_1,

$$-2(I_2 - 2) - 5I_2 - 2(I_2 - I_3) = 0$$

$$-9I_2 + 2I_3 = -4 \qquad (1)$$

Applying KVL in mesh 3,

$$-4I_3 - 2(I_3 - I_2) - 100 = 0$$

$$2I_2 - 6I_3 - 100 = 0$$

$$2I_2 - 6I_3 = 100 \qquad (2)$$

By solving Equation (1) and Equation (2) then both mesh current would be

$$I_2 = -3.52\ A,\ \ I_3 = -17.84\ A$$

Current in 5 Ω resistance i.e

$$I_2 = -3.52\ A,$$

Q22 Determine the currents in all branches of the circuit as shown in below figure, using Mesh current method? **(AKTU 2022-2023)**

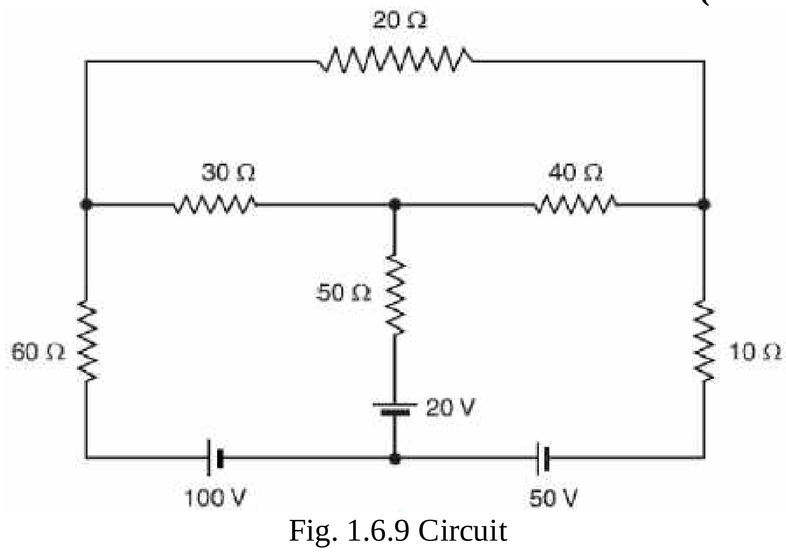

Fig. 1.6.9 Circuit

Solution: The circuit shown in fig. in which mesh currents are given,Now applying KVL in all meshes.

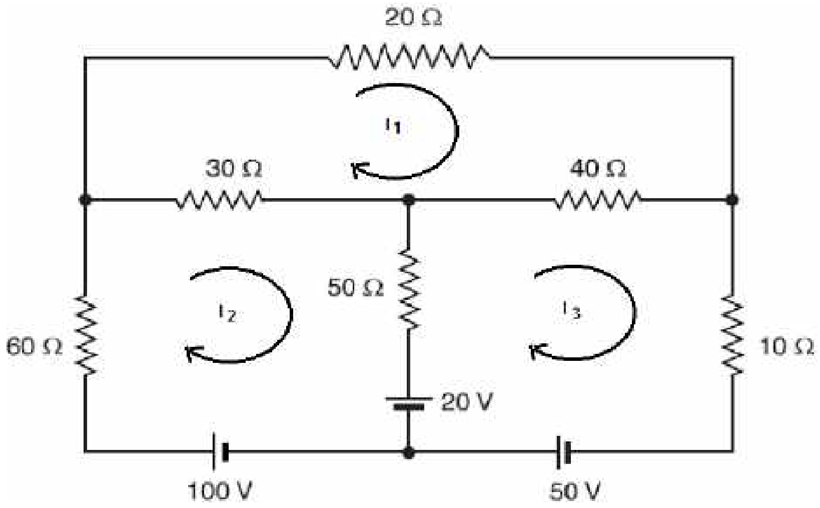

Fig. 1.6.10 Circuit

Applying KVL in mesh 1,

$$-20I_1 - 40(I_1 - I_3) - 30(I_1 - I_2) = 0$$
$$-90I_1 + 30I_2 + 40I_3 = 0 \quad (1)$$

Applying KVL in mesh 2,

$$-60I_2 - 30(I_2 - I_1) - 50(I_2 - I_3) - 20 + 100 = 0$$
$$30I_1 - 140I_2 + 50I_3 = -80 \quad (2)$$

Applying KVL in mesh 3,

$$-10I_3 - 50(I_3 - I_2) - 40(I_3 - I_1) + 50 + 20 = 0$$
$$40I_1 + 50I_2 - 100I_3 = -70 \quad (3)$$

By solving equation (1),equation (2) and equation 3 then all mesh currents would be

$$I_1 = 1.49\ A,\ \ I_2 = 1.65\ A,\ \ I_3 = 2.12\ A$$

Current in 20 Ω resistance,

$$I_1 = 1.49\ A$$

Current in 30 Ω resistance,

$$I_1 - I_2 = 1.49 - 1.65 = -0.16\ A$$

Current in 40 Ω resistance,

$$I_1 - I_3 = 1.49 - 2.12 = -0.63\ A$$

Current in 50 Ω resistance,

$$I_2 - I_3 = 1.65 - 2.12 = -0.47\ A$$

Current in 10 Ω resistance,

$$I_3 = 2.12\ A$$

Current in 60 Ω resistance,

$$I_2 = 1.65\ A$$

Q23 Find the current in 2 ohm resistance in the following figure using loop analysis method.

(AKTU 2015-2016)

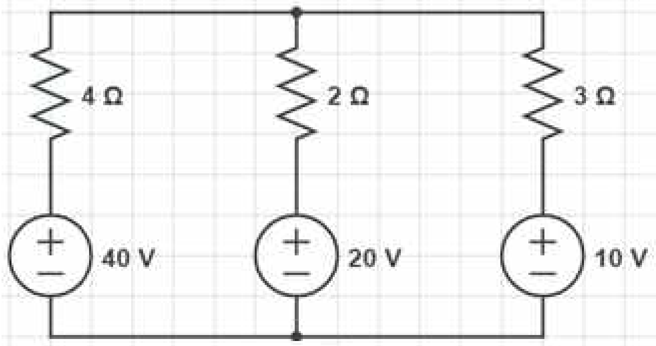

Fig. 1.6.11 Circuit

Answer:

$$I_1 = 4.62\ A,\ \ I_2 = 3.85\ A$$

Current in 2 Ω resistance i.e

$$I_2 - I_1 = 3.85 - 4.62 = -0.77\ A$$

Or Current in 2 Ω resistance i.e

$$I_1 - I_2 = 4.62 - 3.85 = 0.77\ A$$

Q24 Applying mesh analysis, through obtain the current through 5 Ω resistance in the following circuit. **(AKTU 2020-2021)**

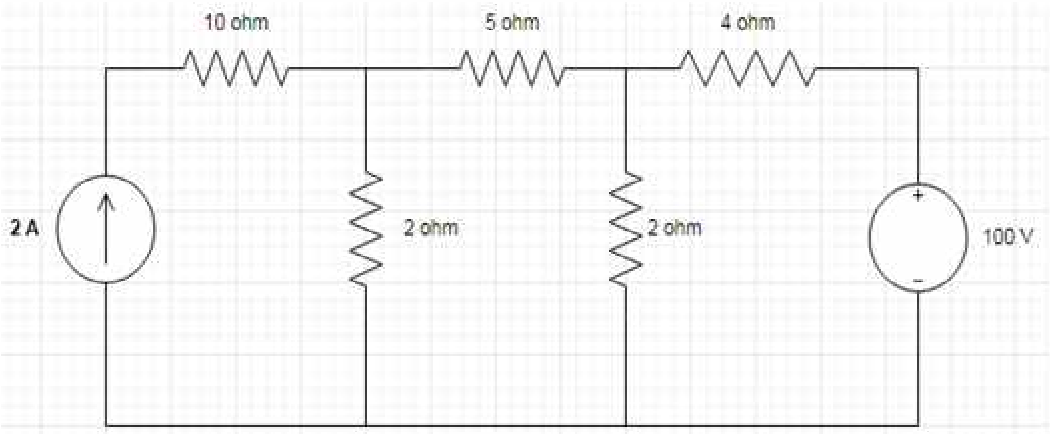

Fig. 1.6.12 Circuit

Answer:

$$I_1 = 2\ A$$
$$I_2 = -3.52\ A,\ \ I_3 = -17.84\ A$$

Current in 5 Ω resistance i.e

$$I_2 = -3.52\ A,$$

1.6 NODAL ANALYSIS

It is the application of Kirchhoff's current law. There are the following steps for obtaining the responses by using nodal analysis.

Follow these steps while solving any electrical network or circuit using Nodal analysis.

Step 1 − Identify the **principal nodes** and choose one of them as **reference node**. We will treat that reference node as the Ground.

Step 2 − Label the **node voltages** with respect to Ground from all the principal nodes except the reference node.

Step 3 − Mention the all branch current in any direction.

Step 4 − Write **node voltage equations** at all the principal nodes except the reference node. Nodal equation is obtained by applying KCL.

Step 5 − Solve the node voltage equation to get the node voltages.
Step 6 - Finally find the current in any branch of the circuit by using ohm's law.

Long questions

Q25 Using Nodal analysis, find V_{cd} for the circuit Shown below in figure.

(AKTU 2017-2018)

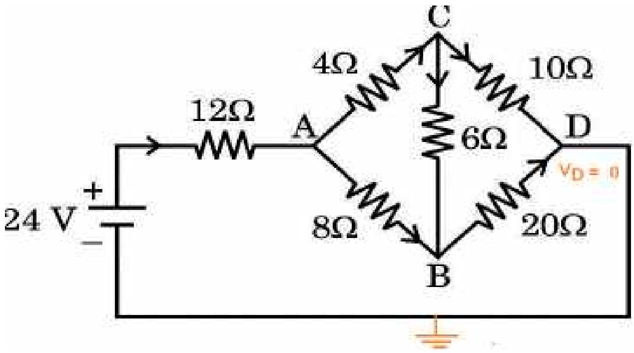

Fig. 1.6.1 Circuit

Ans. Using Nodal Analysis :

$$At\,Node(A) \Rightarrow \frac{24-V_A}{12} = \frac{V_A - V_C}{4} + \frac{V_A - V_B}{8} \quad \ldots(1)$$

$$At\,Node(C) \Rightarrow \frac{V_A - V_C}{4} = \frac{V_C - V_B}{6} + \frac{V_C - V_D}{10} \quad \ldots(2)$$

$$At\,Node(B) \Rightarrow \frac{V_B - V_D}{20} = \frac{V_C - V_B}{6} + \frac{V_A - V_B}{8} \quad \ldots(3)$$

Form equation (1), (2) and (3)

$$11V_A - 3V_B - 6V_C = 48$$
$$15V_A + 10V_B - 31V_C = 0$$
$$15V_A - 41V_B + 20V_C = 0$$
$$V_C = V_B$$

And

$$V_C = \frac{5}{7}V_A$$
$$V_C = 7.5\,V$$

So,

$$V_{CD} = 7.5\,V$$

Q26 Using nodal analysis to find the currents in various resistors of the circuit shown in figure.

(AKTU 2022-2023)

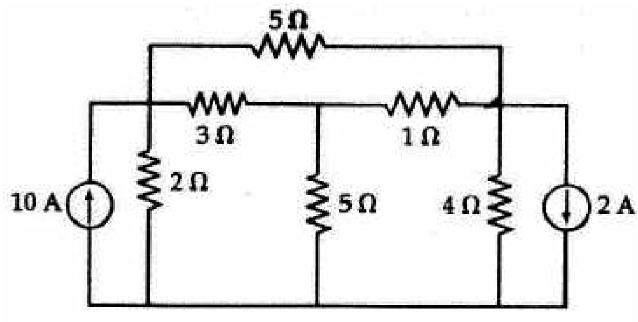

Fig. 1.6.2 Circuit

Solution:

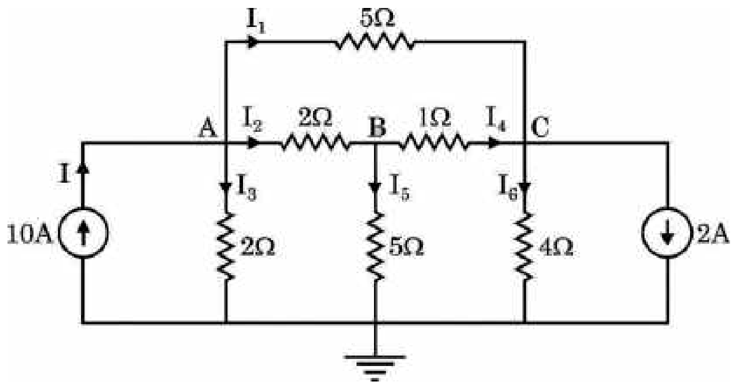

Fig. 1.6.3 Circuit

Applying KCL to node A, B, and C

At node (A)

$$I_1 + I_2 + I_3 = I$$

$$\frac{V_A - V_C}{5} + \frac{V_A - V_B}{3} + \frac{V_A - 0}{2} = 10$$

$$\frac{6V_A - 6V_C + 10V_A - 10V_B + 15V_A}{30} = 10$$

$$31V_A - 10V_B - 6V_C = 300 \qquad \ldots \text{(i)}$$

At node (B)

$$I_2 = I_4 + I_5$$

$$\frac{V_A - V_B}{3} = \frac{V_B - V_C}{1} + \frac{V_B - 0}{5}$$

$$5V_A - 5V_B = 15V_B - 15V_C + 3V_B$$

$$5V_A - 23V_B + 15V_C = 0 \qquad \ldots \text{(ii)}$$

At node (C)

$$I_1 + I_4 = I_6 + 2A$$

$$\frac{V_A - V_C}{5} + \frac{V_B - V_C}{1} = \frac{V_C - 0}{4} + 2$$

$$4V_A + 20V_B - 29V_C = 40 \qquad \ldots \text{(iii)}$$

From equation (i), (ii) and (iii) :

$$I_3 = 6.02A \qquad I_2 = 2.3A$$

$$I_1 = 1.65A \qquad I_4 = 1.29A$$

$I_5 = 1.02A$ $\qquad$ $I_6 = 0.95A$

Q27 Using nodal analysis, find the current through 8 Ω resistor.

(AKTU 2016-2017)

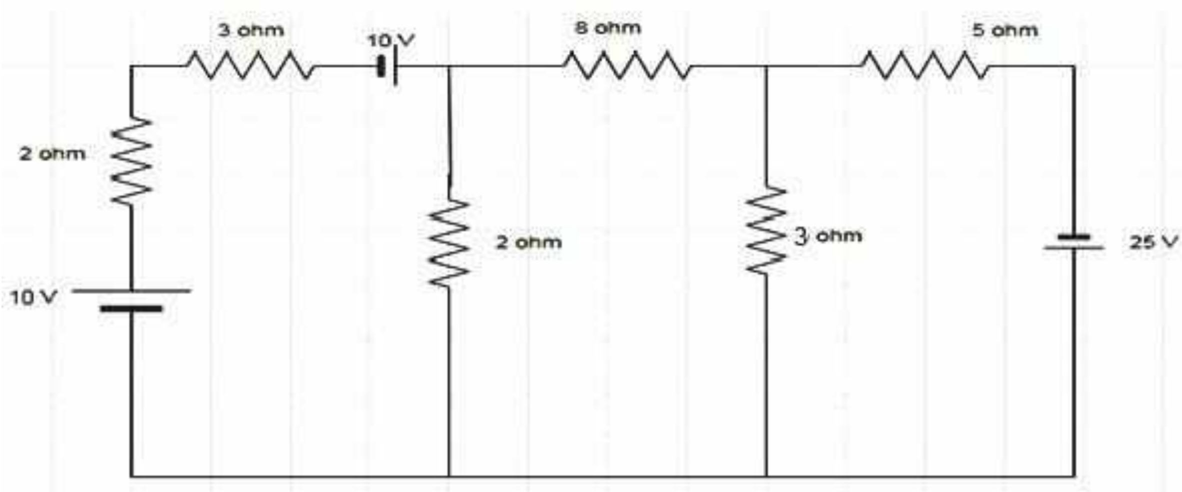

Fig. 1.6.4 Circuit

Answer:

$$V_1 = 3.81\ V, \quad V_2 = -6.87\ V$$

Current in 8 Ω resistance will be,

$$I_3 = \frac{V_1 - V_2}{8} = \frac{3.81 - (-6.87)}{8} = 1.335\ A$$

Q28 Determine current through 15 Ω resistance by node analysis.

(AKTU 2018-2019)

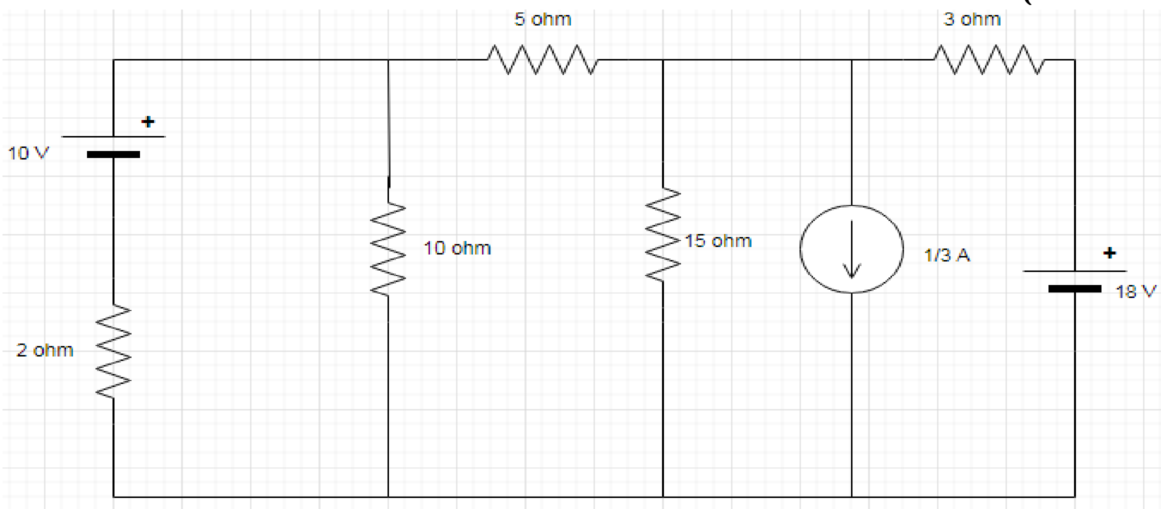

Fig. 1.6.5 Circuit

Answer :

$$V_A = 9.39\ V, \quad V_B = 12.56\ V$$

Current in 15 Ω resistance will be,

$$I_4 = \frac{V_B - V_C}{15} = \frac{9.39 - 0}{15} = 0.626\ A$$

Q29 Determine the current by nodal method, through 2 Ω resistor for the network below.

(AKTU 2022-2023)

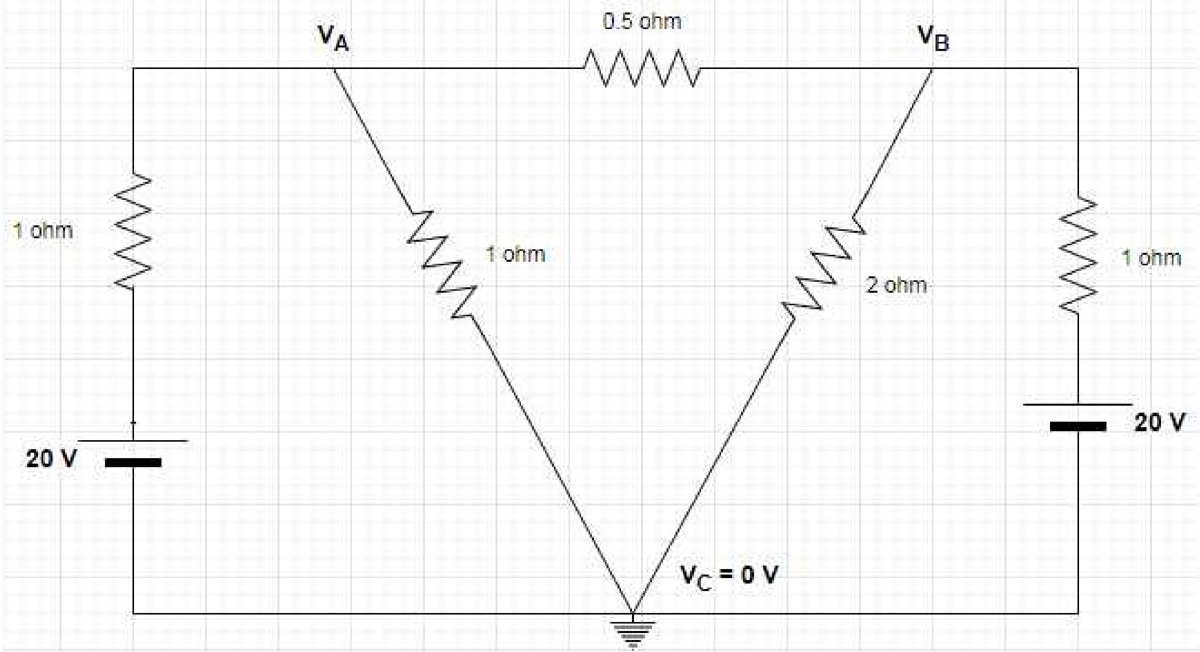

Fig. 1.6.6 Circuit

Solution:

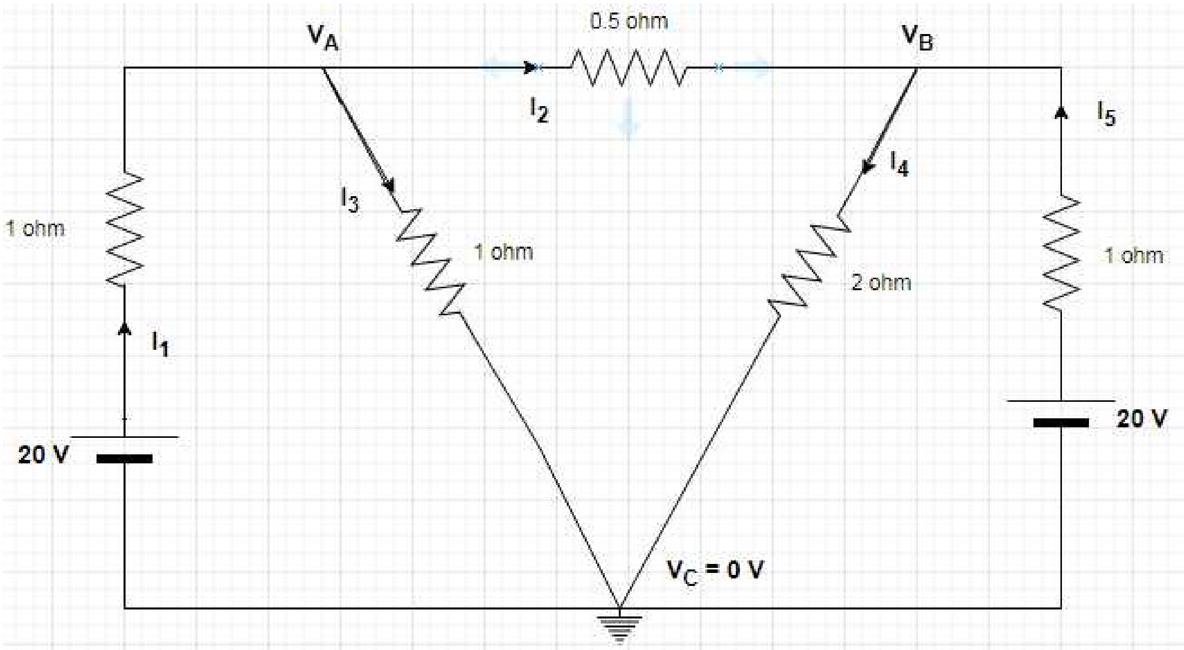

Fig. 1.6.7 Circuit

Applying KCL at node A,

$$I_1 - I_2 - I_3 = 0$$

$$\frac{(V_C - V_A + 20)}{1} - \frac{(V_A - V_B)}{0.5} - \frac{(V_A - V_C)}{1} = 0 \frac{(V_C - V_A + 20)}{1} - \frac{(V_A - V_B)}{0.5} - \frac{(V_A - V_C)}{1} = 0$$

Substitute the value of $V_C = 0 V_C = 0$

$$\frac{(0 - V_A + 20)}{1} - \frac{(V_A - V_B)}{0.5} - \frac{(V_A - 0)}{1} = 0$$

$$\frac{(-V_A+20)}{1}-\frac{(V_A-V_B)}{0.5}-\frac{(V_A)}{1}=0$$

Simplify, then node A voltage equation would be

$$-4V_A+2V_B=-20 \qquad (1)$$

Now applying KCL at node B we have

$$I_2+I_5-I_4=0$$

$$\frac{(V_A-V_B)}{0.5}+\frac{(V_C-V_B+20)}{1}-\frac{(V_B-V_C)}{2}=0$$

Substitute the value of $V_C = 0V_C = 0$ then we have

$$\frac{(V_A-V_B)}{0.5}+\frac{(0-V_B+20)}{1}-\frac{(V_B-0)}{2}=0$$

Simplify, then we will have node B voltage equation,

$4V_A - 7V_B = -40$ $(2)V_A - 7V_B = -40$ (2)

By solving Equation (1) and Equation (2) then node voltages are,

$$V_A = 11\ V, \quad V_B = 12\ V$$

Current in 2 Ω resistance will be,

$$I_4=\frac{V_B-V_C}{2}=\frac{12-0}{2}=6\ A$$

Q30 Determine the currents in the various branches of the circuit shown in figure by nodal analysis.

(AKTU 2022-2023, 2022-2023)

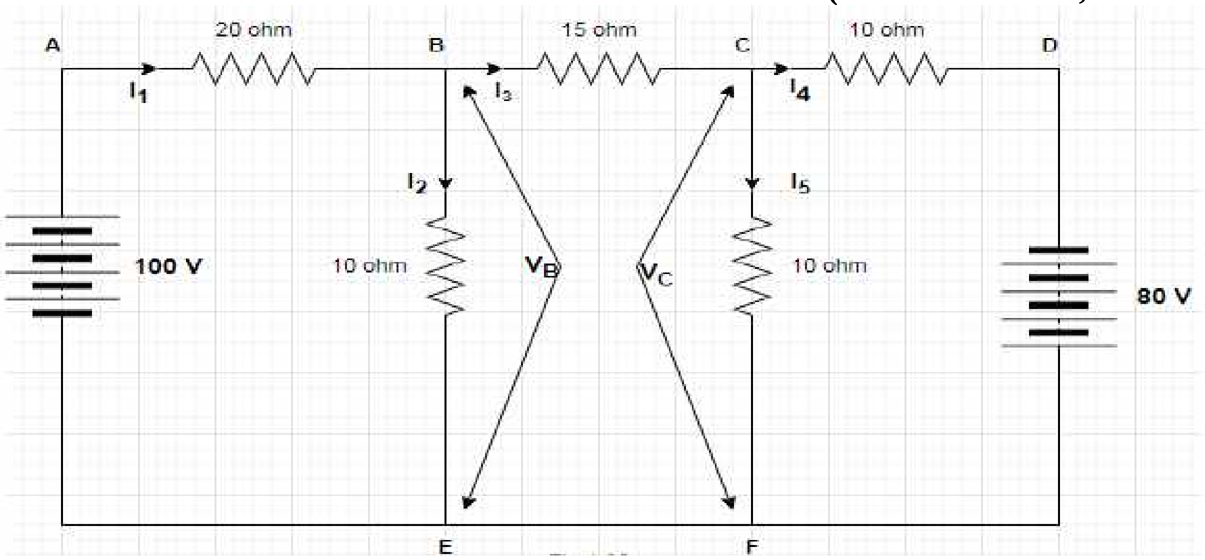

Fig. 1.6.8 Circuit

Solution: Applying KCL at node A,

$$I_1-I_2-I_3=0$$

$$\frac{(V_G-V_B+100)}{20}-\frac{(V_B-V_G)}{10}-\frac{(V_B-V_C)}{15}=0\frac{(V_G-V_B+100)}{20}-\frac{(V_B-V_G)}{10}-\frac{(V_B-V_C)}{15}=0$$

Substitute the value of $V_G = 0V_G = 0$

$$\frac{(0-V_B+100)}{20}-\frac{(V_B-0)}{10}-\frac{(V_B-V_C)}{15}=0$$

$$\frac{(-V_B+100)}{20}-\frac{(V_B)}{10}-\frac{(V_B-V_C)}{15}=0$$

Simplify, then node B voltage equation would be

$$-13V_B+4V_C=-300 \qquad (1)$$

Now applying KCL at node C, we have

$$I_3 - I_4 - I_5 = 0$$

$$\frac{(V_B - V_C)}{15} - \frac{(V_C - V_G + 80)}{10} - \frac{(V_C - V_G)}{10} = 0$$

Substitute the value of $V_G = 0, V_G = 0,$ then we have

$$\frac{(V_B - V_C)}{15} - \frac{(V_C - 0 + 80)}{10} - \frac{(V_C - 0)}{10} = 0$$

Simplify, then we will have node C voltage equation,

$2V_B - 8V_C = 240$ $(2)V_B - 8V_C = 240$ (2)

By solving Equation (1) and Equation (2) then node voltages are,

$$V_B = 15\ V, \quad V_C = -26.25\ V$$

Current in 20 Ω resistance will be,

$$I_1 = \frac{V_G - V_B + 100}{20} = \frac{-(-26.25) + 100}{20} = 6.313\ A$$

Current in 10 Ω resistance will be,

$$I_2 = \frac{V_B - V_G}{10} = \frac{15 - 0}{10} = 1.5\ A$$

Current in 15 Ω resistance will be,

$$I_3 = \frac{V_B - V_C}{15} = \frac{15 - (-26.25)}{15} = 2.75\ A$$

Current in 10 Ω resistance will be,

$$I_4 = \frac{V_C - V_G + 80}{10} = \frac{(-26.25) - 0 + 80}{10} = 5.375\ A$$

Current in another 10 Ω resistance will be,

$$I_5 = \frac{V_C - V_G}{10} = \frac{(-26.25) - 0}{10} = -2.625\ A$$

Super-Node Problem

Q31 Calculate the current in both resistances by using nodal analysis.

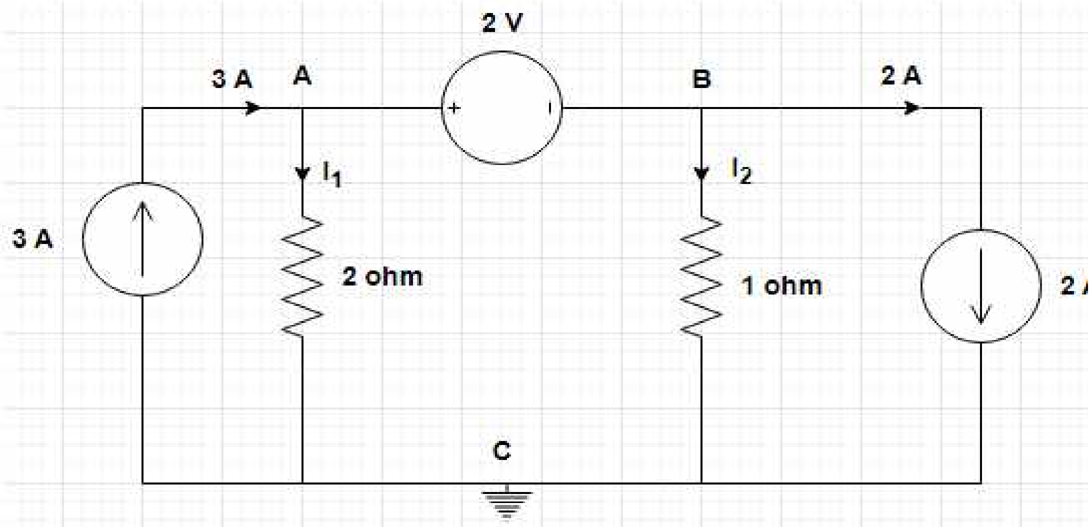

Fig. 1.6.9 Circuit

Solution: We will apply both law's i.e KVL and KCL to solve the problem.

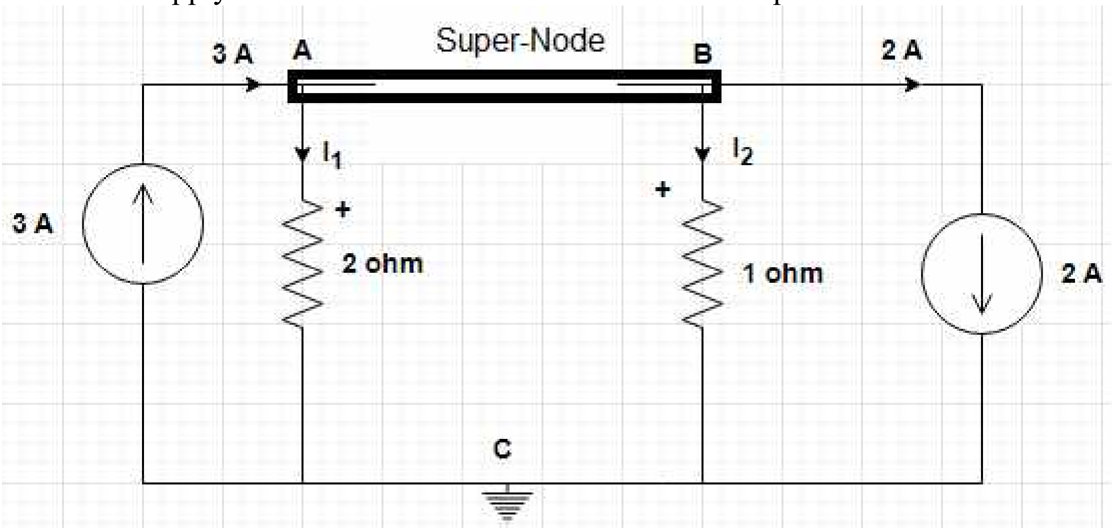

Fig. 1.6.10 Circuit

Applying KCL at super-node,

$$3 - I_1 - I_2 - 2 = 0$$

$$\frac{3}{1} - \frac{(V_A - V_C)}{2} - \frac{(V_B - V_C)}{1} - \frac{2}{1} = 0$$

Substitute the value of $V_C = 0, V_C = 0,$ then we have

$$\frac{3}{1} - \frac{(V_A - 0)}{2} - \frac{(V_B - 0)}{1} - \frac{2}{1} = 0$$

$$\frac{3}{1} - \frac{(V_A)}{2} - \frac{(V_B)}{1} - \frac{2}{1} = 0$$

Simplify, then we will have super-node voltage equation,

$$-V_A - 2V_B = -2 \qquad (1)$$

Now applying KVL in the path of $A \to B \to C \to A$ in the following circuit shown in fig. 1.6.11

$$-2 - (V_B) + (V_A) = 0$$

$$V_A - V_B = 2 \qquad (2)$$

By solving Equation (1) and Equation (2) equation(3) then node voltages are,

$$V_A = 2.0\ V, \quad V_B = 0\ V,$$

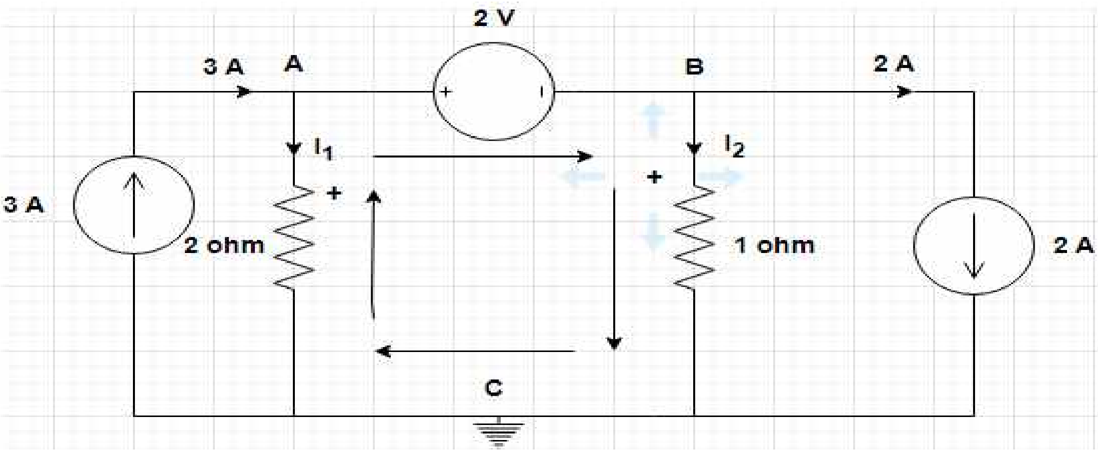

Fig. 1.6.11 Circuit

Current in 2 Ω resistance will be,

$$I_1 = \frac{(V_A - V_C)}{2} = \frac{2-0}{2} = 1.0\ A$$

Current in 1 Ω resistance will be,

$$I_2 = \frac{V_B - V_C}{3} = \frac{0-0}{1} = 0\ A$$

DC MACHINES

Electrical machines are broadly categorized into two types-

1. Generator, which converts Mechanical Energy into Electrical Energy.
2. Motor, which converts Electrical Energy into Mechanical Energy.

The process of converting mechanical energy into electrical energy or electrical energy into mechanical energy is known as Electro-Mechanical Energy Conversion.

1.7 DC Generator

1.7.1 Construction /Basic Structure:-A rotating electric machine has two main parts, Stator & Rotor separated by air gap. The stator of the machine is a stationary part (it does not move). Normally it is the outer frame of the machine.

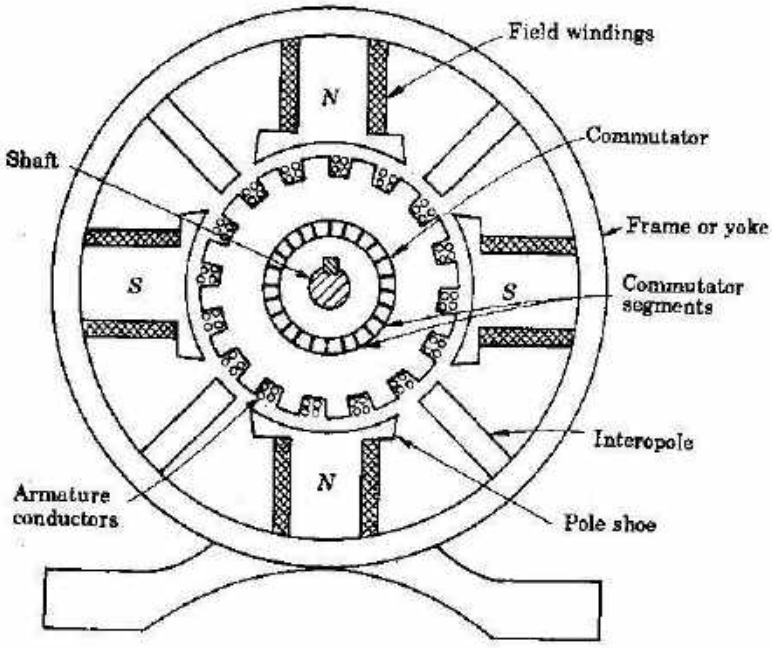

Fig. 1.7.1 Main parts of a 4 Pole DC Machine

Rotor is free to move and normally it is the inner part of the machine. Both stator and rotor are made of Ferromagnetic material. Slots are cut on the inner periphery of the stator and the outer periphery of the rotor. Conductors are placed in the slots of the stator or rotor. The interconnection of conductors forms winding.

The winding in which voltage is induced is called the armature winding. The winding through which a current is passed to produce the main flux is called the field winding. Permanent magnets are used in some machines to provide main flux.

Magnetic Field System:- The object of the field system is to create a uniform magnetic field within which the armature rotates. The magnetic field system is the stationary part of the DC machine.

Yoke or Outer Frame:- The outer frame or yoke is a hollow cylinder of Cast steel or rolled steel. An even number of ***pole cores*** are bolted to the yoke. The yoke serves the following two purposes:-

- **a)** It supports the pole cores and acts as protecting cover to the machine.
- **b)** It forms a part of the magnetic circuit

Poles:- Poles provide the uniform distribution of magnetic flux in the air gap. The projected poles are called "Salient Poles". Each pole core has a pole shoe having curved surface. The function of pole shoes are as follows:-

- **a)** It supports the field coils.
- **b)** It increases the cross-sectional area of the magnetic circuit and reduces the leakage flux

Armature:- The rotating part of the DC machine is called the armature. The armature core has grooves or slots on its outer surface. The insulated conductors are put in the slots of the armature core. The conductors are fastened round the core to prevent them flying under centrifugal forces. The conductors are suitably connected. The connection arrangement of the conductor is called armature winding. Two types of windings used: -

a) Wave wound b) Lap wound

Commutator And Brush Gear:-

- **a)** It is mounted on the shaft. It is made up of a large number of wedge-shaped segments of hard-drawn copper, insulated from each other by a thin layer of mica.
- **b)** The commutator connects the rotating armature conductor to the stationary external circuit through carbon brushes.
- **c) It converts AC emf into DC in case of generator and bidirectional torque into unidirectional torque in case of motor**.

Bearings:- In the small machines ball bearings are used at both ends. For large machines, roller bearings are used at the driving end and ball bearing may be used at the non-driving end i.e. at the Commutator end.

Shaft:- The shaft is made of mild steel with a maximum breaking strength. The shaft is used to transfer mechanical power from or to the machine. The rotating parts such as armature core, Commutator, cooling fan etc. are mounted on the shaft.

Short questions

Q1. Why is a commutator needed? **AKTU (2019-2020)**

Q2. What is the function of the commutator in the DC generator? **AKTU (2021-2022)**

1.7.2 Working Principle of a DC Generator:

According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field (or a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor. The magnitude of induced emf can be calculated from the emf equation of DC Generator. If the conductor is provided with a closed path, the induced current will circulate within the path. In a DC generator, field coils produce an electromagnetic field and the armature conductors are rotated into the field. Thus, an electromagnetically induced emf is generated in the armature conductors. The direction of induced current is given by Fleming's right -hand rule.

1.7.3 EMF Equation:-

We know, when armature winding of a DC generator is rotated in any direction by applying a mechanical force, then the flux linkage with armature conductors are changed and hence an emf across armature conductors is induced. This induced emf is also known as "emf of rotation" and given as E_g in generators.

Let

Φ = Flux per pole in Weber

Z = Total No. of armature conductors or coil sides on the armature

P = Number of poles

A = Number of parallel path in the armature

N = Rotational speed in armature

**** Note:-***

A = 2 in case of wave winding

A = P in case of lap winding

Lap winding is used for high current and low voltage requirement.

Wave winding is used for low current and high voltage requirement.

We know that induced emf is proportional to

$$e = \frac{d\emptyset}{dt}$$

Flux cut by one conductor in one revolution = PΦ

Time taken by armature conductor to complete one revolution

$$\frac{N}{60} = dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$e = \frac{P\emptyset N}{60}\text{Volt} \qquad \text{--------} \ldots (3)$$

Number of armature conductor per parallel path $=\frac{Z}{A}$

Therefore, the total emf generated between the terminals is given as:-

$$E_g = e * \frac{Z}{A}$$

$$e = \frac{P\emptyset N}{60} \qquad \text{[from Eq. 2]}$$

$$E_g = \frac{P\Phi NZ}{60A} \text{ volt}$$

This equation is known as EMF equation of Generator.

When the machine is operating as generator this induced EMF is called the "Generated EMF (E_g)" where as in case of the machine operating as a motor it is called the "Counter EMF" or "Back EMF (E_b)".

Short questions

Q 1:What is the generated EMF in the D.C generator? **AKTU(2021-2022)**

Q 2 :A dynamo (DC Generator) has a rated armature current as 250 Amp. What is the current per path of the armature if the armature winding is simplex wave wound or simplex lap wound? The machine has 12 poles.

Solution:-

Rated current

$$I_a = 250Amp$$

No. of poles

$$P = 12$$

A = 2 (for wave winding)

Current per path

$$I_C = \frac{I_a}{A} = \frac{250}{2} = 125Amp$$

A = P (for simplex lap winding)

Current per path

$$I_C = \frac{I_a}{A} = \frac{I_a}{P} = \frac{250}{12} = 20.833Amp$$

Q 3: An 8 pole lap connected armature has 960 conductors and a flux of 40 ×10^{-3} Wb per pole. The speed is 400 rpm. Calculate the emf generated on open circuit.

Solution :- EMF generated on open circuit condition

$$E_g = \frac{P\varphi ZN}{60A} = \frac{8*40*10^{-3}*960*400}{60*8} = 256Volt$$

Q 4: An 8 pole generator has 500 armature conductors and a useful flux of 0.05 Wb. What will be the emf generated. If it is lap connected and runs at 1200 rpm? What must be the speed at which it is to be given to produce the same emf, if it is wave connected?

Solution:- When generator is lap connected

$$E_g = \frac{P\varphi ZN}{60A} = \frac{8*0.05*500*1200}{60*8} = 500 \rightleftarrows\rightleftarrows Volt\{forlapA = P = 8\}$$

Speed of the generator when wave connected to generate 500 Volt

$$E_g = \frac{P\varphi ZN'}{60A}$$

$$N' = \frac{E_g*60*A}{P\varphi Z} = \frac{500*60*2}{8*0.05*500} = 300rpm\{A = 2 \rightleftarrows\rightleftarrows forwavewinding\}$$

Q 5:The armature of a 6 pole DC generator has a wave winding containing 664 conductors. Calculate the generated emf when flux per pole is 0.06 Wb and speed is 250 rpm. At what speed the armature must be driven to generate an emf of 250 Volt if flux per pole is reduced to 0.058 Wb?

Solution:-

Generated emf

$$E_g = \frac{p\varphi ZN}{60A} = \frac{6*0.06*664*250}{60*2} = 498Volt$$

When flux per pole is reduced to Φ'= 0.058 Wb

$$E_g' = \frac{P\varphi' ZN'}{60A} = \frac{250*60*2}{0.058*664*6} = 130rpm$$

1.7.4 Types of DC Generator

1.7.4.1 Separately Excited Generator:- A DC generator whose winding is excited from an independent DC source, such as a battery, is known as a separately excited generator.

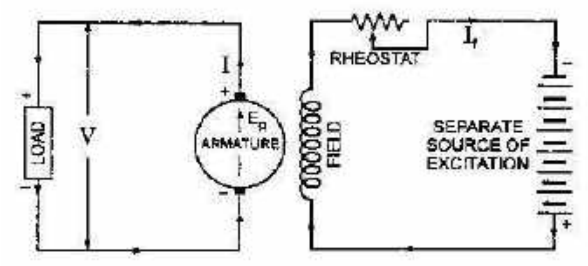

Fig. 1.7.2 Circuit Diagram of Separately Excited Generator

In this case current flowing through the armature I_a and load I_L is the same and the terminal voltage V is equal to the generated emf E_g

The voltage drop in the armature = $I_a R_a$

$I_a = I_L = I$

$V = E_g - IR_a$ (Ra= Armature Resistance)

Power developed = P_g= $E_g I$

Power delivered to external load P_L= VI

1.7.4.2 Self - Excited Generator:- The field winding of the self excited generator is excited by the current supplied by the generator itself. Self -excited generators are classified as:-

a) Series wound generator

b) Shunt wound generator

1.7.4.2.1 Series Wound Generator:- The field winding is connected in series with armature winding so the whole current flows through the field winding as well as load.

Since full load current flows through field winding, it is designed with very low resistance of the order of 0.5 Ω.

$$I_a = I_{se} = I_L = I$$
$$V = E_g = I(R + R_{se})$$

Power developed P_g= $E_g I$

Power delivered P_L=VI

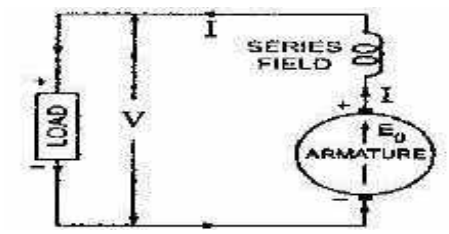

Fig. 1.7.3 circuit diagram of Series Wound Generator

1.7.4.2.2 Shunt Wound Generator:- The field winding is connected in parallel with armature for forming a shunt circuit. The voltage across the field winding is the same as the terminal voltage of the generator.

The armature current Ia is divided into two path:

(i) Load current (ii) Shunt field current

$$I_a = I_L + I_{sh}$$

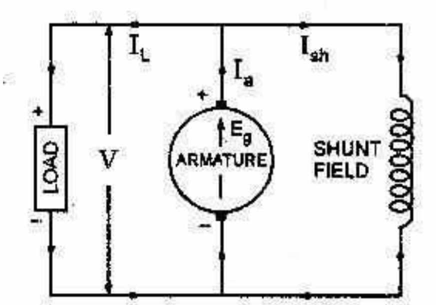

Fig. 1.7.4 Circuit diagram of Shunt Wound Generator

The power of the generator is proportional to current delivered to load. So it is necessary to keep the shunt current as small as possible. It is kept at about 2.5 % of rated armature current. The resistance of the shunt winding is of the order of 100 Ω.

Shunt field current $I_{sh} = \frac{V}{R_{sh}}$

Armature current $I_a = I_L + I_{sh}$

Terminal voltage $V = E_g - I_a R_a$

Power developed $P_g = E_g I_a$

Power delivered $P_L = VI_L$

Armature Resistance:- The resistance offered by armature circuit is known as armature resistance and represented by Ra. It includes

(i) Resistance of armature winding (ii) Brush contact resistance.

Brush Contact Drop:- It is the voltage drop over the brush contact resistance when current flows from the Commutator segment to brushes and finally to external load. It is equal to the product of the values of current and contact resistance.

The voltage drop allowed for all brushes of each polarity shall be 1.0 Volt for Carbon or Graphite brushes and 0.3 Volt for Metal Carbon brushes. This means the total drop of 2 Volt for Carbon or Graphite brush and 0.6 Volt for Metal Carbon brushes.

<u>Long questions</u>

Q 1. A D.C shunt generator delivers 50 kW at 250 V when running at 500 r.p.m The armature and field resistances are 0.05 Ω and 125 Ω respectively. Calculate the speed of the same machine and developed a torque when running as shunt motor and taking 50 kW at 250 V.

AKTU(2016-2017)

Solution:

Given,

$$P = 50 \text{ kW}, \quad N = 500 \text{ r.p.m}, \quad \text{Load voltage} = 250 \text{ V}$$

Armature winding resistance,

$$R_a = 0.05 \ \Omega$$

Shunt field winding resistance,

$$R_{sh} = 125 \ \Omega$$

Generator is shown in fig. 1.7.5

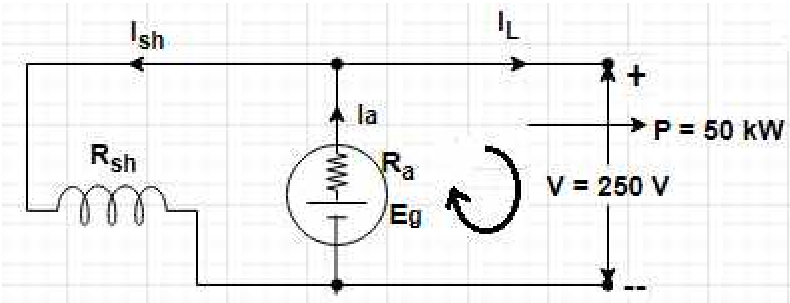

Fig. 1.7.5 Circuit Diagram

Now the load current would be,

$$I_L = \frac{P}{V} = \frac{50\times10^3}{250} = 200 \ A$$

Shunt field winding current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2 \ A$$

So the armature current of the generator,

$$I_a = I_L + I_{sh} = 200 + 2 = 202 \ A$$

Applying KVL in the armature circuit for finding the generated voltage,

$$-V - I_a.R_a + E_g - brush\ drop = 0$$

consider the brush drop is zero so,

$$-V - I_a.R_a + E_g = 0$$

$$E_g = V + I_a.R_a$$

Substitute the value of R_a, V and I_a so,

$$E_g = 250 + 202 \times 0.05 = 260.1 \ V$$

Generator is running with a speed of N_1 so,

$$E_g = \frac{P.\emptyset.N_1.Z}{60.A} \qquad (1)$$

Now same machine is running as shunt motor so its diagram is shown in fig.1.7.6

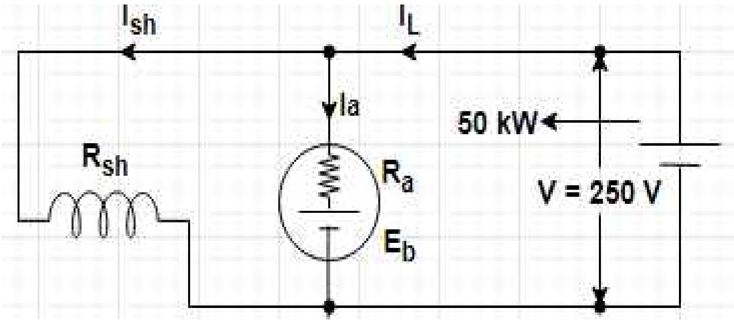

Fig. 1.7.6 Circuit Diagram

Now the supply current would be,

$$I_L = \frac{P}{V} = \frac{50\times10^3}{250} = 200\ A$$

Shunt field winding current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2\ A$$

So the armature current of the motor,

$$I_a = I_L - I_{sh} = 200 - 2 = 198\ A$$

Applying KVL in the armature circuit for finding the back e.m.f in motor,

$$+V - I_a.R_a - E_b - brush\ drop = 0$$

consider the brush drop is zero so,

$$+V - I_a.R_a - E_b = 0$$

$$E_b = V - I_a.R_a$$

Substitute the value of $R_a, V\ and\ I_a\ so,$

$$E_b = 250 - 198 \times 0.05 = 240.1\ V$$

Motor is running with a speed of N_2 so,

$$E_b = \frac{P.\emptyset.N_2.Z}{60.A} \qquad (2)$$

Hence compare equation (1) and equation (2),

$$\frac{E_g}{E_b} = \frac{N_1}{N_2}$$

So,

$$N_2 = \frac{E_b}{E_g} \times N_1 \qquad (3)$$

Substitute the value of $N_2, E_b\ \ and\ E_g\ \ in\ equation\ (3) so\ we\ have,$

$$N_2 = \frac{240.1}{260.1} \times 500 = 461.6\ \ r.m.p$$

Torque developed,

$$T_d = \frac{E_b \times I_a}{\omega} = \frac{E_b \times I_a}{\frac{2.\pi N_2}{60}}$$

$$T_d = \frac{240.1 \times 198 \times 60}{2 \times \pi \times 461.6} = 983.57 \quad N.m$$

Q 2:A 4-pole shunt generator with lap connected armature has field and armature resistance of 50 Ω and 0.1 Ω respectively. If supplying power to 100 W lamp load for 100 V. Calculate the armature current and the generated e.m.f. Consider a contact drop of 1 V per brush. AKTU (2018-2019)

Solution

Given,

$P_L = 100$ W, Load voltage = 100 V, Brush drop = 1 V per brush

$R_a = 0.1 \ \Omega$

$R_{sh} = 50 \ \Omega$

Generator is shown in fig.

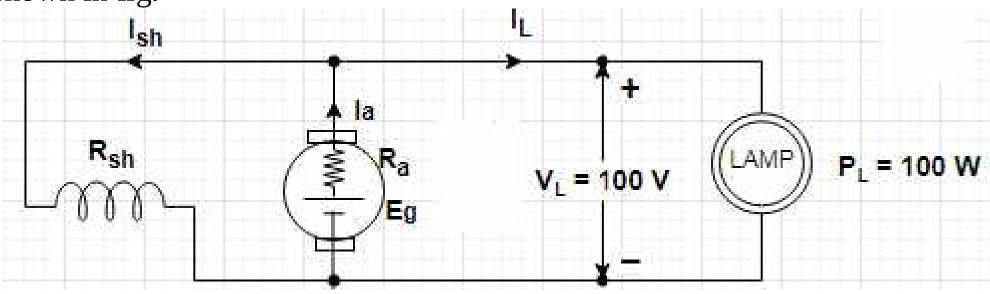

Fig. 1.7.7 Circuit Diagram

Now the load current would be,

$$I_L = \frac{P_L}{V_L} = \frac{100}{100} = 1 \ A$$

Shunt field winding current,

$$I_{sh} = \frac{V_L}{R_{sh}} = \frac{100}{50} = 2 \ A$$

So the armature current of the generator,

$$I_a = I_L + I_{sh} = 1 + 2 = 3 \ A$$

Applying KVL in the armature circuit for finding the generated voltage,

$$-V_L - I_a.R_a + E_g - total\ brush\ drop = 0$$

Substitute the value of $R_a, V\ and\ I_a\ and\ brush\ drop\ so, R_a, V\ and\ I_a\ and\ brush\ drop\ so,$

$$E_g = 100 + 3 \times 0.1 + 2 \times 1 = 102.3 \ V$$

Q 3: Calculate the e.m.f generated by 4 pole wave wound generator having 65 slots with 12 conductors per slot when driven at 1200 r.p.m. The flux per pole is 0.02 Wb.

AKTU(2021-2022)

Solution: Induced e.m.f of the generator would be,

$$E_g = \frac{P.\emptyset.N.Z}{60.A} \qquad (1)$$

Given,

$No. of\ poles,$

$$P = 4$$

$Flux\ per\ pole,$

$$\Phi = 0.02\ Wb.$$

$Speed\ of\ the\ armature,$

$$N = 1200\ r.p.m$$

$No. of\ papallel\ path\ of\ Wave\ connected\ armature\ winding,$

$$A = 2$$

$No. of\ slots\ in\ the\ armature\ winding,$

$$S = 65$$

$No. of\ conductors\ per\ slot\ in\ the\ armature\ winding,$

$$Z_{per\ slot} = 12$$

So,

$No. of\ armature\ conductors\ in\ the\ armature,$

$$Z = Z_{per\ slot} \times S = 12 \times 65 = 780$$

Substitute the value of A,P,N,Z,A and Φ in equation (1),Then

$$E_g = \frac{4 \times 0.02 \times 1200 \times 780}{60 \times 2} = 624\ V$$

Q 4. A 4-pole generator with 400 armature conductor has a useful flux of 0.04 Wb per pole. What is the e.m.f produced if the machine is wave wound and runs at 1200 r.p.m? What must be the speed at which the machine should be driven to generate the same e.m.f if the machine is lap wound?

AKTU (2021-2022)

Solution: Given,

$No. of\ poles,$ P=4

$Useflux\ per\ pole,$

$$\Phi = 0.04\ Wb.$$

$$N = 1200\ r.p.m$$

$$A = 2$$

$No. of\ armature\ conductors\ in\ the\ armature,$

$$Z = 400$$

Induced e.m.f of the generator would be,

$$E_g = \frac{P.\emptyset.N.Z}{60.A} \qquad (1)$$

Substitute the value of A,P,N,Z,A and Φ in equation (1),Then

$$E_g = \frac{4 \times 0.04 \times 1200 \times 400}{60 \times 2} = 640\ V$$

Now machine should be driven to generate the same e.m.f if the machine is lap wound, So, No. of parallel path of lap connected armature winding,

$$A = P = 4$$

Speed of the machine would be,

$$N = \frac{60.A.E_g}{P.\emptyset.Z} \qquad (2)$$

Substitute the value of A,P,E_g,Zand Φ in equation (2),Then

$$N = \frac{60 \times 4 \times 640}{4 \times 0.04 \times 400} = 2400 \ r.p.m$$

1.8 DC MOTORS

1.8.1 Construction: - Same as DC Generator:
1.8.2 Operating Principle of DC Motor

When a current carrying conductor is placed in a magnetic field, a force is produced on it. Let us consider one conductor is placed in the slot of armature and suppose that it is acted upon by the magnetic field from the north pole of the motor. By applying fleming's left hand rule it is found that the conductor has a tendency to move the left hand side. Since the conductor is in slot of rotor, the Force Fc in a tangential direction to the rotor conductors. Since the rotor is free to move, it starts rotating.

Consider a single conductor placed in a magnetic field as shown in the figure (a).

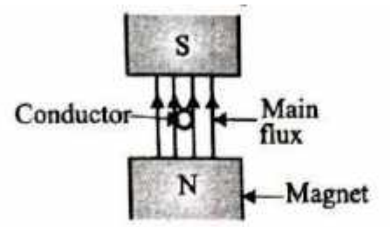

Fig. (a) Conductor in a magnetic field

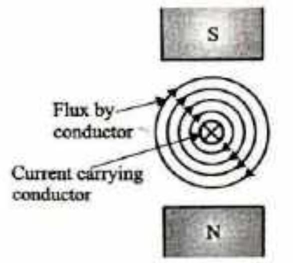

Fig. (b) Flux produced by current carrying conductor

Fig. 1.7.8 Operating Principle of DC Motor

The magnetic field is produces by a permanent magnet but in a practical dc motor it is produced by the field winding when it carries a current.

Now this conductor is excited by a separate supply so that it carries current in a particular direction. Consider that it carries a current away from an observer as shown in the figure (b).

Any current carrying conductor produces its own magnetic field around it, hence this conductor also produces its own flux around. The direction of the flux can be determined by the Right Hand Thumb Rule. For the direction of current considered, the direction of flux around a conductor is clockwise. For simplicity of understanding, the main flux produced by the permanent magnet is not shown in the figure (b).

Now there are two fluxes present:

a) The flux produced by the permanent magnet called main flux.
b) The Flux produced by the current carrying conductor.

In the figure it is clear that on one side of the conductor, both the fluxes are in the same direction.

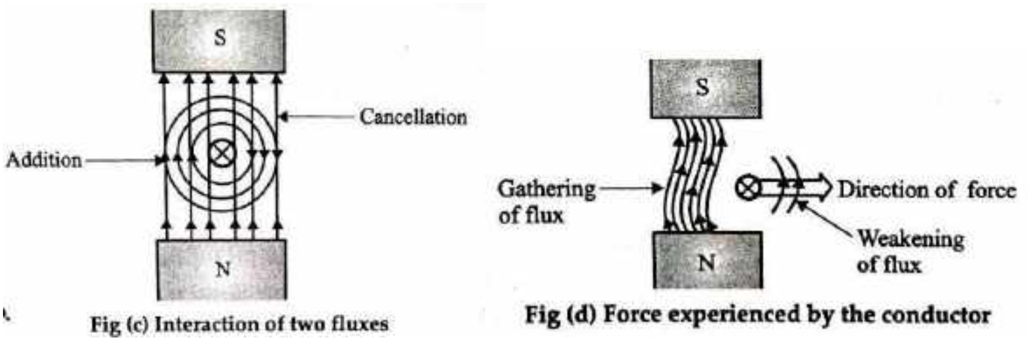

Fig (c) Interaction of two fluxes
Fig (d) Force experienced by the conductor

In this case, on the left of the conductor there is a gathering of the flux lines as two fluxes help each other. As against this, on the right of the conductor, the two fluxes are in opposite directions and hence try to cancel each other. Due to this, the density of the flux lines in this area gets weakened. So on the left, there exists a high flux density area while on the right of the conductor there exists a low flux density area as shown in the figure (d).

This flux distribution around the conductor acts like a stretched rubber band under tension. This exerts a mechanical force on the conductor which acts from high flux density area towards low flux density area i.e. from left to right for the case considered as shown in the figure (e).

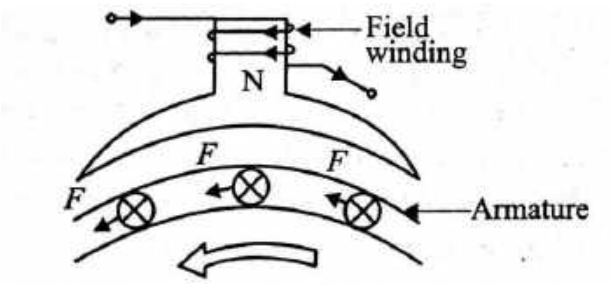

Fig (e) Torque extended on armature

Fig. 1.7.9 (a,b,c,d,e) Operating Principle of DC Motor

1.8.3 Back EMF:

$$E_b = \frac{P\emptyset NZ}{60A}$$

Where P = Number of poles

φ = Flux in Weber

Z = No. of conductors

N = Speed in rpm

A = No. of parallel path (A = 2 for ***Wave*** winding, A = P for ***Lap*** winding)

******Due to rotation of armature during motor action, the conductor cuts the magnetic flux so there is an induced emf in conductors. The direction of this induced EMF is such that it opposes the applied voltage so it is known as*** **Back EMF**.***

As shown in an equivalent circuit of a DC motor the applied voltage V must be large enough to balance both the voltage drop in armature resistance and the back emf all time i.e.

$$V = E_b + I_a R_a$$

$$I_a = \frac{V - E_b}{R_a}$$

Short questions

Q 1. How can we change the direction of rotation of the DC motor. **AKTU(2018-2019)**

Solution: The direction of the torque and the speed can be reversed by changing the direction of either the field winding current or armature current by changing the polarity of the field winding or armature winding terminals.

1.8.4 Types of DC Motors

1.8.4.1 Separately Excited DC Motor:-The armature and field coils of separately excited DC motors are fed from different supply sources as shown in the figure.

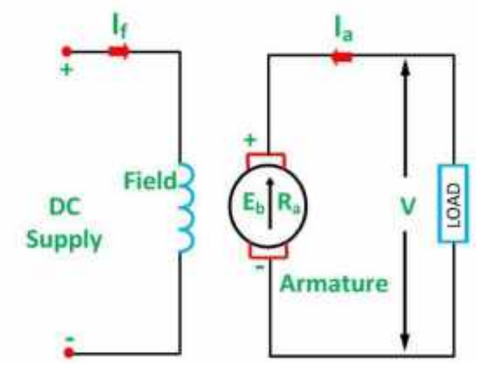

Fig. 1.7.10 Circuit diagram of Separately Excited DC Motor

Armature current$I_a = I_L Line\ Current = I$

Back emf developed $E_b = V - IR_a$

Power is drawn from supply mains P=VI, where V is the supply voltage

Mechanical power developedP_m= Power input to the armature – Power lost in armature

$$= VI - I^2R_a = I(V - IR_a) = E_b I$$

1.8.4.2 Self-Excited DC Motors

1.8.4.2.1 Series Wound DC Motor:

The field coil is connected in series with armature.

Armature currentIa= Series field current I_{se}= Line Current I_L=I

Back emf developed $E_b = V - I(R_a + R_{se})$

Power is drawn from supply = VI

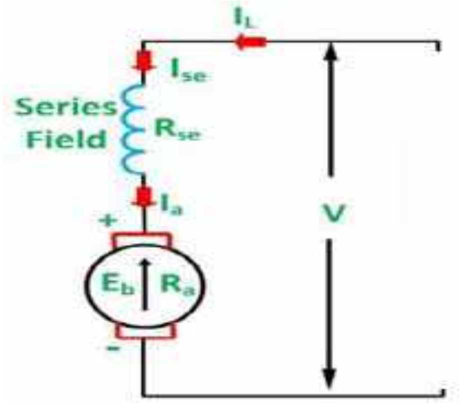

Fig. 1.7.11 Circuit diagram of Series Wound DC Motor

Mechanical power developed

P_m= Power input – Losses in armature and field

$$= VI - I^2(R_a + R_{se})$$
$$= I[V - I(R_a + R_{se})] = IE_b$$

1.8.4.2.2 Shunt Wound Motor: The field coil is connected in parallel with the armature.

Input line current $I_L = I_a + I_{sh}$

$$I_{sh} = \frac{V}{R_{sh}}$$

Back emf

$$E_b = V - I_aR_a$$

Power is drawn from the main supply P= VI_L

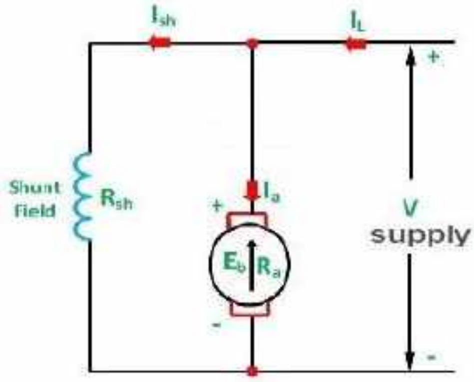

Fig. 1.7.12 Circuit diagram of Shunt Wound Motor

Mechanical power developed P_m= Power input – Losses in armature and shunt field

$$= VI_L - VI_{sh} - I_a^2R_a$$
$$= V(I_L - I_{sh}) - I_a^2R_a$$
$$= VI_a - I_a^2R_a = E_bI_a$$

Short questions

Q 1: What will happen, if the field winding of running DC shunt motor suddenly open?

AKTU(2018-2019)

Solution: Speed of D.C motor can be achieved by the following expression,

$$N = \frac{E_b \times 60 \times A}{P \times \emptyset \times P}\ r.p.m$$

So,

$$N \propto \frac{1}{\emptyset}$$

If the field winding becomes open then flux due to the field winding becomes zero. In this case D.C shunt motor will have residual flux which is very small. So, motor tries to achieve dangerously high speed and may get damaged.

Q 2: A 4 pole, 500 V DC shunt motor has 720 wave connected conductors on its armature. The full load armature current is 60 A and the flux per pole is 0.03 Wb. The armature resistance is 0.2 Ω and contact drop is 1 V per brush. Calculate the full load speed of motor.

Solution :-Back EMF on full load,

$E_b = V - I_a R_a - Brush\ contact\ drop \qquad = 500 - 60 * 0.2 - 2 * 1 = 486V$

Full load speed of motor when armature conductors are wave connected

$$N_f = \frac{E_b}{\Phi} * \frac{60}{Z} * \frac{A}{P} = \frac{486}{0.03} * \frac{60}{720} * \frac{2}{4} = 675rpm$$

Q 3: A DC shunt machine connected to 250 V supply has resistance of armature as 0.1 Ω and field winding resistance as 100 Ω. Find the ratio of speed as a generator to the speed as a motor when line current in each case being 80 Amp.

Solution :- Shunt field current

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{100} = 2.5Amp$$

Line current $I_L = 80Amp$

As generator armature current

$$I_{ag} = I_L + I_{sh} = 80 + 2.5 = 82.5Amp$$

Generated emf

$$E_g = V + I_{ag} R_a = 250 + 82.5 * 0.1 = 258.25Volt$$

As motor armature current

$$I_{am} = I_L - I_{sh} = 80 - 2.5 = 77.5Amp$$

Back emf developed

$$E_b = V - I_{am} R_a = 250 - 77.5 * 0.1 = 242.25Volt$$

Since machine is shunt wound and field current is same so the ratio of speed is given below

$$\frac{Speed\ as\ generator}{Speed\ as\ motor} = \frac{E_g}{E_b} = \frac{258.25}{242.25} = 1.066$$

Q 4:A 220 Volt DC generator supplies 4 KW at a terminal voltage of 220 Volt, the armature resistance being 0.4 Ω. If the machine is now operated as a motor at the same terminal voltage with the same

armature current. Calculate the ratio of generator speed to motor speed. Assume that the flux per pole is made to increase by 10 % as the operation is changed over from generator to motor mode.

Solution:-As Generator

Load current $I_L = \frac{P*1000}{V_L} = \frac{4*1000}{220} = 18.18 Amp$

Generated emf $E_g = V + I_L R_a = 220 + 18.18 * 0.4 = 227.27 Volt$

Neglecting shunt field current and brush contact drop.

As Motor

Armature current

$$I_a = 18.18 Amp,$$

same as generator operation

Back emf

$$E_b = V - I_a R_a = 220 - 18.18 * 0.4 = 212.73 Volt$$

Flux per pole $\emptyset_m = 1.1\emptyset_g$

$$\frac{Speed\ as\ generator}{Speed\ as\ motor} = \frac{E_g}{E_b} * \frac{\varphi_m}{\varphi_g} = \frac{227.27}{212.73} * 1.1 = 1.175 rpm$$

Long questions

Q 5: A 250 V D.C motor takes 41 A at full load. Resistance of motor armature and shunt field winding are 0.1 Ω and 250 Ω respectively. Find the back e.m.f on full load. What will be generated e.m.f, if working as a generator and supplying 41 A to a load at terminal voltage 250 V.

AKTU(2018-2019)

Solution: Motor is running as shunt motor so its diagram is shown in fig.1.7.13

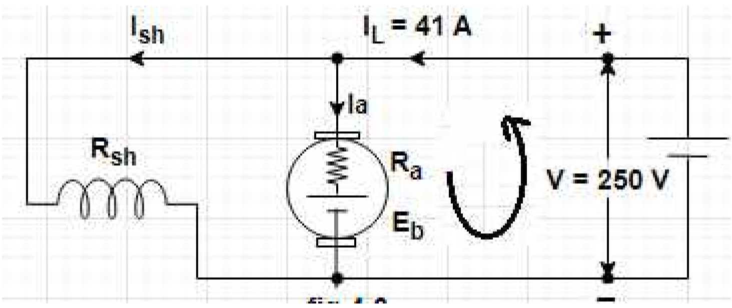

Fig. 1.7.13 Circuit Diagram

The supply current would be,

$$I_L = 41\ A$$

Shunt field winding current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{250} = 1\ A$$

So the armature current of the motor,

$$I_a = I_L - I_{sh} = 41 - 1 = 40\ A$$

Applying KVL in the armature circuit for finding the back e.m.f in motor,

$$+V - I_a.R_a - E_b - brush\ drop = 0$$

consider the brush drop is zero so,

$$+V - I_a.R_a - E_b = 0$$

$$E_b = V - I_a.R_a$$

Substitute the value of $R_a, V\ and\ I_a\ so,$

$$E_b = 250 - 40 \times 0.1 = 246\ V$$

If the machine is working as a generator and its circuit diagram is shown in fig.1.7.14

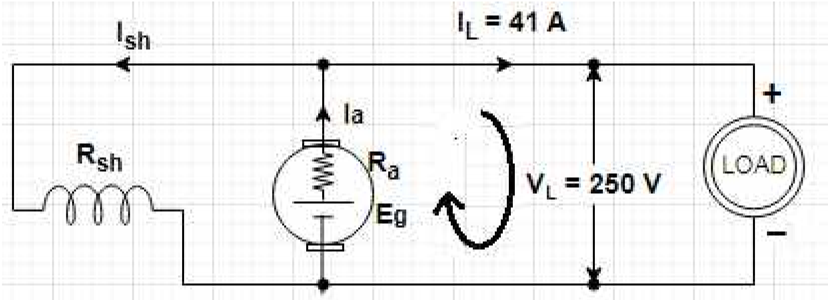

Fig. 1.7.14 Circuit Diagram

Now the load current would be,

$$I_L = 41\ A$$

Shunt field winding current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{250} = 1\ A$$

So the armature current of the generator,

$$I_a = I_L + I_{sh} = 41 + 1 = 42\ A$$

Applying KVL in the armature circuit for finding the generated voltage,

$$-V_L - I_a.R_a + E_g - brush\ drop = 0$$

consider the brush drop is zero so,

$$-V_L - I_a.R_a + E_g = 0$$

$$E_g = V_L + I_a.R_a$$

Substitute the value of R_a ,V and I_a so,

$$E_g = 250 + 42 \times 0.1 = 254.2\ V$$

1.8.5 Torque equation of a DC motor:

Voltage equation of a DC motor

$$V = E + I_a R_a$$

Multiplying both side by I_a

$$VI_a = EI_a + I_a^2 R_a$$

$VI_a =$ Electrical power input to the armature

$I_a^2 R_a =$ Copper loss in armature

Let $\tau_{av} =$ Average electromagnetic torque developed by the armature in N-m

Mechanical power developed by armature

$$P_m = \omega\tau_{av} = 2\pi \frac{N}{60} \tau_{av}$$

$$\because E = \frac{P\varphi ZN}{60A}$$ {N= no. of rev in RPM}

$$\therefore \frac{P\varphi ZN}{60A} * I_a = 2\pi \frac{N}{60} \tau_{av}$$

$$\tau_{av} = \frac{PZ\phi I_a}{2\pi A} \Longrightarrow \frac{PZ}{2\pi A} * \varphi I_a$$

Alternative Method…

Torque is the turning or twisting force about an axis.

Let a wheel having radius R meter.

Circumferential force = F Newton

Speed of rotation of wheel = N rpm

So angular speed of wheel is –

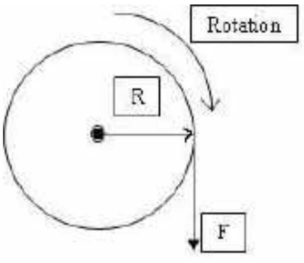

Fig. 1.7.15

Therefore ,

$$\omega = \frac{d\theta}{dt} = \frac{2\pi}{60/N} = \frac{2\pi N}{60}$$ …………………… **(1)**

So work done in one revolution is given by –

$W = F * Distance\ travel\ in\ one\ revolution = F * 2\pi R\ (Joule)$

Now Power Developed,

$P = work\ done/time$

$$\therefore P = \frac{F * 2\pi R}{60/N} = F * R * \left(\frac{2\pi N}{60}\right) = T_a . \omega$$ …………..**(2)**

Let

T_a – Gross torque developed by the armature of the motor.

So gross mechanical power developed by the armature is –

$$P_b = E_b * I_a$$ -------- (3) {from power equation}

Now From equations (2) & (3).

$$E_b * I_a = T_a * \frac{2\pi N}{60}$$

$$\frac{\phi ZNP}{60A} * I_a = T_a * \frac{2\pi N}{60}$$

$$Ta = \frac{1}{2\pi}\frac{\phi ZPI_a}{A} = 0.159\frac{\phi ZPI_a}{A}$$

$$\therefore T_a \propto \Phi * Ia$$

$$T_a = T_f + T_{sh} \ \ (T_{sh} < T_a)$$

T_a = Armature torque

T_f = Lost torque (To overcome stray losses i.e. Friction loss, windage loss)

T_{sh}= Load torque or Shaft torque (available at the shaft for doing useful work)

Long questions

Q 1: A 6-pole lap wound D.C shunt motor has 250 Ω armature conductor, a flux of 0.04 Wb./pole and runs at 1200 r.p.m. The armature and field winding resistances are 1.0 Ω and 220 Ω respectively. It is connected to a 220 V D.C supply. determine: AKTU(2015-2016)

(i) induced e.m.f in the motor
(ii) Armature current
(iii) Input supply current
(iv) Mechanical power developed in the motor
(v) Torque developed

Solution: Given,

$P = 6, \quad Z = 250, \quad \Phi = 0.04\ \frac{\text{Wb}}{\text{pole}}, \quad N = 1200\ \text{r.p.m}, \quad \text{supply voltage} = 220\ V$

$R_a = 1.0\ \Omega$

$R_{sh} = 220\ \Omega$

A, for lap winding it would be,

$$A = P = 6$$

(i) The expression for finding induced e.m.f in the motor would be,

$$E_b = \frac{P\emptyset NZ}{60A}$$

So E_b would be,

$$E_b = \frac{6\times 0.04\times 1200\times 250}{60\times 6} = 200\ V$$

(ii) Circuit diagram is shown in fig.1.7.16

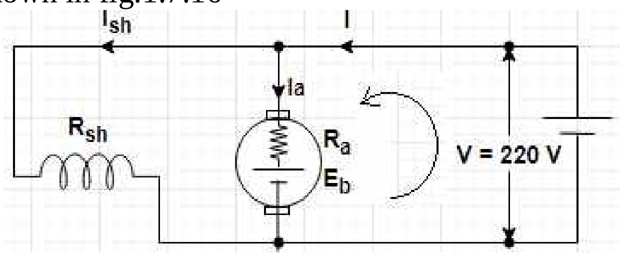

Fig. 1.7.16 circuit diagram

Applying KVL in the armature circuit,

$$V - I_a.R_a - E_b - brush\ drop = 0$$

consider the brush drop is zero so,

$$V - I_a . R_a - E_b = 0$$

Armature current would be,

$$I_a = \frac{V - E_b}{R_a} = \frac{220 - 200}{1} = 20\ A$$

(ii) Applying KCL at the node,

$$I = I_a + I_{sh}$$

Shunt winding field current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{220} = 1\ A$$

So line current would be,

$$I = I_a + I_{sh} = 20 + 1 = 21\ A$$

(iv) Mechanical power developed,
Mechanical Power developed (Pm) = Electrical Power developed in armature (Pe)
So,

$$P_m = P_e = E_b . I_a = 200 \times 20 = 4000\ \frac{J}{Sec.}$$

(v) Torque developed,

$$T_d = \frac{P_m}{\omega} = \frac{P_m}{\frac{2\pi N}{60}} = \frac{P_m \times 60}{2\pi \times N}$$

$$T_d = \frac{4000 \times 60}{2.\pi \times 1200} = 31.83\ \ N - m$$

Q 2: A 8-pole,400 V shunt motor has 960 wave connected armature conductors. The full load armature current is 40 A and flux per pole is 0.02 Wb. The armature resistance is 0.1 Ω and contact drop is 1 V per brush. Calculate the full load speed of the motor.

AKTU(2021-2022)

Solution: Given,

No. of poles,

$$P = 8$$

Flux per pole,

$$\Phi = 0.02\ Wb.$$

Speed of the armature,

$$N = ?$$

No. of papallel path of wave connected armature winding,

$$A = 2$$

No. of wave connected armature conductors ,

$$Z = 960$$

Supply voltage,

$$V = 400\ V$$

Full load armature current,

$$I_a = 40\ A$$

Armature winding resistance,

$$R_a = 0.1\ \ \Omega R_a = 0.1\ \ \Omega$$

Contact drop,

$$Brush\ drop = 1\ V\ per\ brush$$

But we need to calculate the back e.m.f in the shunt motor. Its cicuit diagram is shown in fig.1.7.17

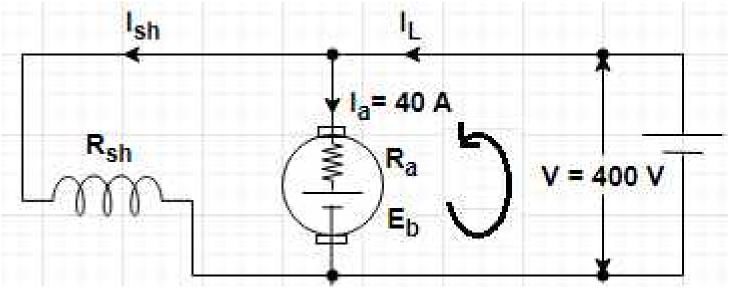

Fig. 1.7.17circuit diagram

The armature current would be,

$$I_a = 40\ A$$

Applying KVL in the armature circuit for finding the back e.m.f in motor,

$$+V - I_a.R_a - E_b - brush\ drop = 0$$

So,

$$E_b = V - I_a.R_a - brush\ drop$$

Substitute the value of $R_a, V\ and\ I_a\ so,$

$$E_b = 400 - 40 \times 0.1 - 2 \times 1 = 394\ V$$

Speed of the shunt motor would be,

$$N = \frac{60.A.E_b}{P.\emptyset.Z} \qquad (1)$$

Hence substitute the value of A,P,Z,$E_b$and Φ in equation (1),Then

$$N = \frac{60 \times 2 \times 394}{8 \times 0.02 \times 960} = 307.81\ \ r.p.m \cong 308\ r.p.m$$

Q 3: A six-pole, 2-circwave-connected armature of a D.C machine has 300 conductors and runs 1000 r.p.m. The e.m.f generated on the open circuit is 400 V. Determine the useful flux per pole.

AKTU(2022-2023)

Solution: Given,

$No.of\ poles,$

$$P = 6$$

$Useflux\ per\ pole,$

$$\Phi =?\ Wb.$$

$Speed\ of\ the\ armature,$

$$N = 1000\ r.p.m$$

$No.of\ papallel\ path\ of\ wave\ connected\ armature\ winding,$

$$A = 2$$

$No.of\ armature\ conductors\ in\ the\ armature,$

$$Z = 300$$

Generated voltage in the generator,

$$E_g = 400\ V$$

Induced e.m.f of the generator would be,

$$E_g = \frac{P.\emptyset.N.Z}{60.A}$$

So useful would be,

$$\emptyset = \frac{E_g.60.A}{P.N.Z} \qquad (1)$$

Substitute the value of A,P,N,Z,A and E_g in equation (1),Then

$$\emptyset = \frac{400 \times 60 \times 2}{6 \times 1000 \times 300} = 0.0267\, Wb.$$

$$\emptyset = 26.7\, mWb$$

Q 4: A 6-pole lap wound D.C shunt motor has 500 conductors in the armature. The resistance of the armature path is 0.05 Ω. The resistance of the shunt field is 25 Ω. Find the speed of the motor when it takes 120 A from D.C mains of 100 V. Flux per pole is 0.02 Wb.

AKTU(2023-2024)

Solution: Circuit diagram of the shunt motor is shown in fig.1.7.18 given below,

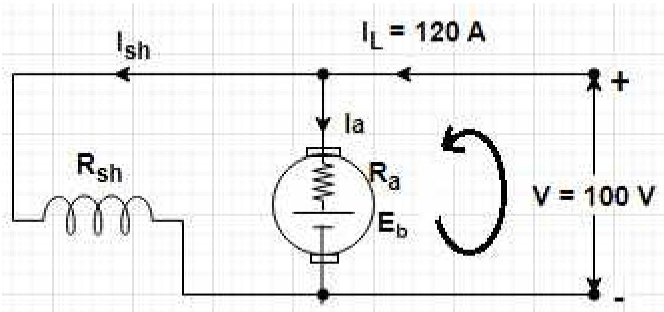

Fig. 1.7.18 circuit diagram

Given,

$P = 6, \quad Z = 500, \quad \Phi = 0.02 \frac{\text{Wb}}{\text{pole}}, \quad N = ?\ \text{r.p.m}, \quad \text{supply voltage} = 100\text{ V}$

Armature winding resistance,

$$R_a = 0.05\ \Omega$$

Shunt field winding resistance,

$$R_{sh} = 25\ \Omega$$

No. of parallel path of the armature winding i.e A, for lap winding it would be,

$$A = P = 6$$

The supply current would be,

$$I_L = 120\ A$$

Shunt field winding current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{100}{25} = 4\ A$$

So the armature current of the motor,

$$I_a = I_L - I_{sh} = 120 - 4 = 116\ A$$

Now applying KVL in the armature circuit for finding the back e.m.f in motor,

$$+V - I_a.R_a - E_b - brush\ drop = 0$$

consider the brush drop is negligible so,

$$+V - I_a.R_a - E_b = 0$$
$$E_b = V - I_a.R_a$$

Substitute the value of Ra, V and Ia so,

$$E_b = 100 - 116 \times 0.05 = 94.2\ V$$

Back e.m.f in the shunt motor would be,

$$E_b = \frac{P.\emptyset.N.Z}{60.A}$$

So, speed of the shunt motor would be,

$$N = \frac{60.A.E_b}{P.\emptyset.Z} \qquad (1)$$

Hence substitute the value of A,P,E_b,Z and Φ in equation (1),Then

$$N = \frac{60 \times 6 \times 94.2}{6 \times 0.02 \times 500} = 565.2\ r.p.m$$
$$N \cong 565\ r.p.m$$

1.8.6 Applications of DC Motor

Shunt Motor:- The characteristics of a shunt motor reveal that it is an approximately constant speed motor. It is therefore used:-

1. Where the speed is required to remain almost constant from no load to full load.
2. Where the load has to be driven at a number of speeds and any one of which is required to remain nearly constant.
3. Some of industrial uses are:- Lather factories, drills, boring machine, shaper, spinning and weaving machines etc.

Series Motor:- It is variable speed motor i.e. speed is low at high torque and vice versa. The motor has a high starting torque. It is therefore used:-

1. Where large starting torque is required e.g. in elevators and electric traction.
2. Where the load is subjected to heavy fluctuations and speed is automatically required to reduce at high torques and vice-versa.
3. Industrial use:Electric traction, cranes, elevators, air compressors, vacuum cleaners, hair dryers, sewing machines.

Compound Motors:
Industrial Use: Press, shear, reciprocating machines etc.

1.9 BLDC Motor

A BLDC Motor is a type of synchronous motor powered by a direct current (DC) voltage supply to generate a magnetic field for rotation. It does not have brushes or a commutator. It commutated electronically to transfer the power to the rotor for movement.

1.9.1 BLDC Motor Components and Construction

A BLDC motor has three main components: the stator, the rotor, and the Hall effect Sensor.

1.9.1.1 Stator

The stator is the stationary part of the motor that contains the windings. These windings are made up of insulated copper wire and are arranged in a specific pattern. The stator provides a magnetic field that interacts with the rotor to produce torque.

Fig.1.9.1 stator

1.9.1.2 Rotor

The rotor is the rotating part of the motor that contains permanent magnets. The magnets are arranged in a specific pattern, opposite to that of the stator. The interaction between the magnetic fields of the stator and the rotor produces rotational movement.

Fig.1.9.2

1.9.1.3 Hall Effect Sensor or Electronic Controller

The Hall effect Sensor is the brain of the motor. It is responsible for controlling the flow of current to the motor windings. The controller also senses the position of the rotor and adjusts the current accordingly to ensure smooth and efficient operation.

1.9.2 Working Principle of BLDC Motor

The working principle of BLDC motors is based on the interaction between the magnetic fields of the stator and the rotor. The stator produces a rotating magnetic field, which interacts with the permanent magnets on the rotor, producing a torque that causes the rotor to rotate.

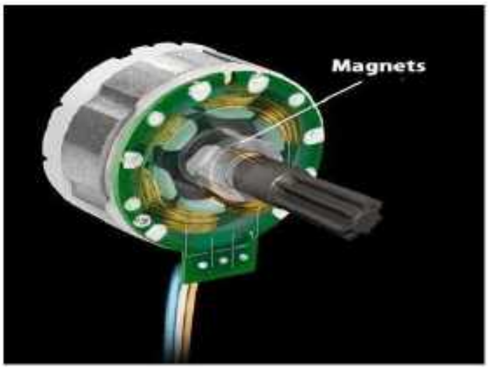

Fig.1.9.3 BLDC motor

The Hall Effect Sensor plays a crucial role in the operation of the motor. It controls the flow of current to the motor windings based on the position of the rotor. The controller senses the position of the rotor using sensors or Hall effect devices mounted on the stator. These sensors detect the position of the magnets on the rotor and send signals to the controller.
Based on the signals from the sensors, the controller adjusts the flow of current to the motor windings to ensure that the magnetic fields of the stator and rotor are properly aligned. This ensures that the motor operates efficiently and smoothly, without any loss of power or vibration.

1.9.3 Advantages of BLDC Motors

BLDC motors offer several advantages over conventional DC motors. Some of the advantages are:
1. Higher Efficiency: BLDC motors are more efficient than conventional DC motors due to the absence of brushes. This results in less friction and lower power loss.
2. Higher Power Density: BLDC motors have a higher power density compared to conventional DC motors. This means that they can produce more power in a smaller size.
3. Longer Lifespan: The absence of brushes in BLDC motors results in less wear and tear, making them more reliable and durable.
4. Low Maintenance: BLDC motors require less maintenance compared to conventional DC motors. This results in lower maintenance costs and longer service life.

1.9.4 Applications of Brushless DC Motors (BLDC)

Brushless DC Motors (BLDC) are used in a wide variety of applications, including varying loads, constant loads, and positioning applications in industrial control, automotive, aviation, automation systems, healthcare equipment, and more. Some specific applications of BLDC motors include:

1. **Electric Vehicles (EVs):** BLDC motors are used in electric and hybrid vehicles for propulsion, providing high efficiency and performance compared to traditional internal combustion engines.
2. **Industrial Automation:** BLDC motors are used in robotics, CNC machines, belt driven systems, and other automated systems for precise motion control and high efficiency.
3. **Consumer Electronics:** BLDC motors are used in appliances like air conditioners, refrigerators, washing machines, compressors, fans, pumps, blowers, and dryers for improved efficiency and reliability.
4. **Aerospace:** BLDC motors are used in aircraft systems for actuation, such as in flight control surfaces, landing gear, and fuel pumps, due to their high power-to-weight ratio and reliability.
5. **Medical Devices:** BLDC motors are used in medical equipment like surgical tools, pumps, and ventilators for precise control and reliability.
6. **Computer Peripherals:** BLDC motors are used in hard disk drives (HDDs), optical disk drives (ODDs), and cooling fans for their reliability and efficiency.

7. **Renewable Energy:** BLDC motors are used in wind turbines and solar tracking systems for their efficiency and ability to operate in harsh environments.

8. **Home Automation:** BLDC motors are used in smart home devices like smart locks, curtains, and HVAC systems for their efficiency and quiet operation.