MODULE-1

CHAPTER – 1

D.C. CIRCUITS

1.1 Introduction :

An electric circuit is an interconnection of the various elements such as, a voltage source, a current source, resistors, inductors and capacitors. Any Engineering system uses in one way or the other, an electric circuit as a component. The performance of any electrical device or machine is always studied by drawing its electrical equivalent circuit. The fundamental requirement for the understanding of any branch of science is the sound knowledge of electric circuits. Any type of system such as mechanical, hydraulic, thermal, nuclear, traffic flow, weather prediction etc., can always be simulated by an electric circuit. All control systems are studied representing them in the form of electric circuits. When the techniques of circuits theory are mastered, we effectively also learn the analysis of any system.

1.2 D.C. Circuits:

Two types of currents may flow in an electric circuit (i) *direct current* and *(ii) alternating current* and accordingly, we have D.C. circuits and A.C. circuits. The discussion about A.C. circuits is being done in chapter 3. This chapter is restricted to the discussion of only D.C. circuits.

A direct current always remains constant and does not vary with time. The flow of direct current characterizes the flow of electric charge in one particular direction. Fig. 1.1. represents the direct current which does not vary with time.

A D.C. circuit consists of constant voltage sources, constant current sources and their interconnection with resistances only. The study of D.C. circuits necessiates the study of the various elements of an electric circuit.

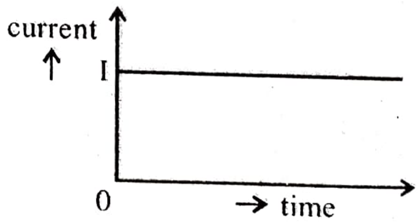

Fig. 1.1 Direct current

1.3 Elements of an Electric Circuit:

An electric circuit consists of two types of elements (i) *Active elements* or *sources* and (ii) *Passive elements* or *sinks.*

Sources are the elements of a circuit which possess energy of their own and can impart it to other elements of the circuit. There are two types of sources. (i) *Voltage source* and (ii) *Current source.*

An ideal voltage source is one, whose terminal voltage remains constant, irrespective of the current delivered by it to the load.

due to the small voltage drop across its internal resistance, as shown in Fig. 1.4. The unit of E.M.F. is also volts.

$$E = E_i - I\,r \tag{1.3}$$

1.11 Ohm's Law:

Statement: *The temperature remaining constant, the current flowing through any conductor is directly proportional to the potential difference between the two ends of the conductor.*

$I \propto V$, when temperature is constant.

i.e. $$I = \frac{V}{R} \tag{1.4}$$

where, R is a constant, known as the resistance of the conductor.

Ohm's law can be applied both for A.C. and D.C. circuits.

Limitations of Ohm's Law:

i) Ohm's law does not hold good for non-metallic conductors such as silicon carbide. The law governing the V–I relation for them is given by

$$V = K\ I^m \tag{1.5}$$

Where, K and m are constants

ii) Ohm's law also does not hold good for non-linear devices such as zener diodes, voltage regulators etc.,

iii) Ohm's law does not hold good to arc lamps because of the non-linear characteristics of the arc produced.

1.12 Power (P) :

Power is defined as the rate at which, the work is done. Its unit is watt (W)

$$P = E\,I = \frac{E^2}{R} = I^2 R \tag{1.6}$$

1.13 Energy (W) :

Energy is the capacity to do work. It is equal to the total work done in a particular time. The unit is Watt Sec.

$$W = E\,I\,t = \frac{E^2}{R}\,t = I^2 R\,t \tag{1.7}$$

Watt Sec. is a very small unit of energy. The practical unit of energy is kilo watt hour (kWH) whose trade name is '**unit**'.

1.14 Resistances in Series:

In Fig. 1.5, three resistances R_1, R_2 and R_3 are connected in series. V is the total voltage applied across the combination and I is the current flowing through them. V_1, V_2 and V_3 are the voltage drops across R_1, R_2 and R_3 respectively.

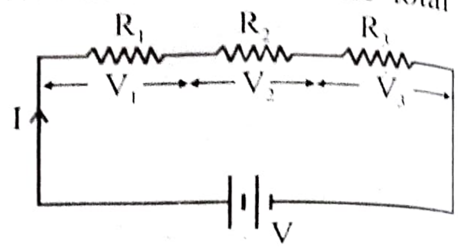

Fig. 1.5 Resistances in Series

Then, $V = V_1 + V_2 + V_3$

$$IR = IR_1 + IR_2 + IR_3$$

or $$R = R_1 + R_2 + R_3 = \text{Total resistance.} \tag{1.8}$$

If there are **n** resistances connected in series, then the total resistance is given by

$$R = R_1 + R_2 + R_3 + \text{- - -} + R_n \tag{1.9}$$

1.15 Resistances in parallel:

In figure.1.6, three resistances R_1, R_2 and R_3 are connected in parallel across a voltage of V volts. I is the total current I_1, I_2 and I_3 are currents flowing through R_1, R_2 and R_3 respectively.

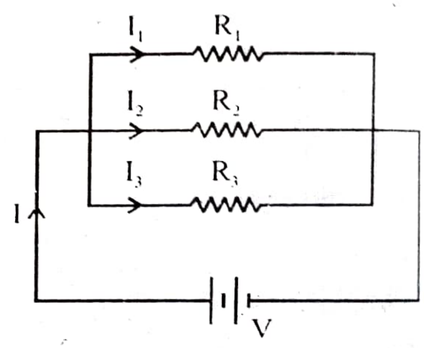

Fig. 1.6 Resistances in Parallel

$$I = I_1 + I_2 + I_3$$

$$\therefore \quad \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}, \qquad \therefore \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \tag{1.10}$$

Where, R = Total resistance

If there are **n** resistances connected in parallel, the total resistance is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n} \tag{1.11}$$

If there are only two resistances connected in parallel, then the total resistance is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2}, \qquad \therefore R = \frac{R_1 R_2}{R_1 + R_2} \tag{1.12}$$

Equation (1.12) is more convenient to use, when only two resistances are connected in parallel.

1.16 Current in a Parallel Branch:

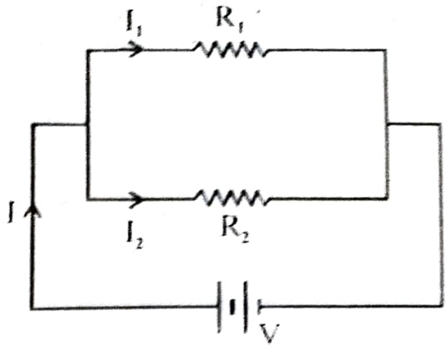

Fig. 1.7

$$I = I_1 + I_2$$

$$V = I_1R_1 = I_2R_2$$

i.e. $$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

i.e. $$\frac{I_1 + I_2}{I_2} = \frac{R_2 + R_1}{R_1}$$

i.e. $$\frac{I_1}{I_2} = \frac{R_1 + R_2}{R_1} \quad \text{or} \quad I_2 = I\,\frac{R_1}{R_1 + R_2} \qquad (1.13)$$

Similarly, $$I_1 = I\,\frac{R_2}{R_1 + R_2}$$

Hence, the branch current is given by,

$$\text{Branch current} = \text{Total current x } \frac{\text{The other resistance}}{\text{Sum of the two resistances}}$$

$P_3 = I_3^2 \times 4 = 0.8575^2 \times 4 = 2.94$ W

1.17 Kirchoff's Laws:

Gustav Robert Kirchhoff (1824–1887), a German Physicist enunciated two laws which enables us to find the currents flowing in an electric circuit and voltages across the various elements of the circuit. These laws form the basis for the study of electrical circuits. The two laws are (i) *current law* and (ii) *voltage law*.

(i) Current Law:

Statement: *The algebraic sum of all the currents meeting at any junction of an electrical circuit is zero.*

i.e. $\sum I = 0$ (1.19)

Fig. 1.20 shows the junction A of an electric circuit at which four currents I_1, I_2, I_3 and I_4 meet. All the currents flowing towards the junction are taken as +ve and all the currents flowing away from the junction are taken as –ve. Then, according to Kirchhoffs current law,

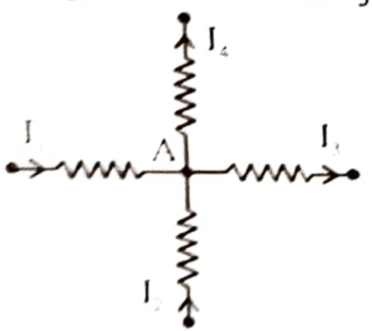

Fig. 1.20

$$I_1 + I_2 - I_3 - I_4 = 0 \quad \text{or} \quad I_1 + I_2 = I_3 + I_4 \qquad (1.20)$$

From equation (1.20), Kirchhoffs current law can also be stated as "*At any junction of an electric circuit, the sum of all the currents entering the junction is equal to the sum of all the currents leaving the junction*".

(ii) Voltage Law:

Statement: *In any closed electrical circuit, the algebraic sum of all the e.mfs and the resistive drops is equal to zero.*

$$\text{i.e.,} \quad \sum E + \sum IR = 0 \tag{1.21}$$

All the voltage rises are taken as +ve and all the voltage drops are taken as –ve.

Fig. 1.21 represents a battery of e.m.f. E volts connected between two points a and b, which can be traced either from a to b or from b to a. When it is traced from a to b, the battery is traced from –ve terminal to +ve terminal. It is a voltage rise. Hence, the e.m.f. is +ve.

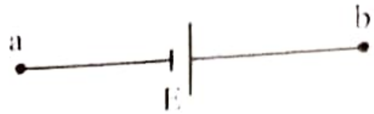

Fig. 1.21

$\therefore \quad E_{(ab)}$ is positive

When the battery is traced from b to a, it is traced from +ve terminal to –ve terminal. It is a voltage fall and hence the e.m.f. is –ve.

$\therefore \quad E_{(ba)}$ is –ve

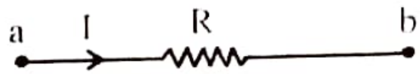

Fig. 1.22

Consider a resistance R connected between two points a and b, through which, a current I is flowing as shown in Fig. 1.22. The voltage drop $(I\,R)_{ab}$ is along the direction of the current. It is a voltage fall and hence –ve.

$\therefore \quad (I\,R)_{ab}$ is –ve

The voltage drop $(I\,R)_{ba}$ is against the direction of the current. It is a voltage rise and hence +ve.

$\therefore \quad (I\,R)_{ba}$ is +ve

Consider a circuit is as shown in Fig. 1.23.

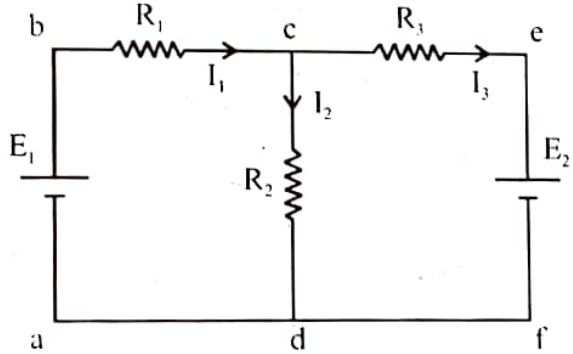

Fig. 1.23

The directions of currents I_1, I_2 and I_3 flowing in the various branches of the circuit are arbitrarily assumed. For the closed loops in the circuit, using Kirchhoffs voltage law, the equations are,

For loop abcda : $\quad E_1 - I_1R_1 - I_2R_2 = 0$

For loop dcefd : $\quad I_2R_2 - I_3R_3 - E_2 = 0$

1.18 Cramer's Rule: