1.3 OHM'S LAWS

The direct proportionality between the current in a metallic conductor and the potential difference between its terminals was first of all discovered by scientist Simon Ohm and is known as Ohm's law.

According to Ohm's law, if the physical conditions such as temperature remains constant, the current between two points in a conductor is proportional to the potential difference between these two points, i.e.

$$i \propto V \text{ or } V/i = R$$

where the constant of proportionality R is known as resistance of the conductor.

In SI units R is in ohm if i is in ampere and V is in volt. One ohm is the resistance of a conductor in which a current of one ampere exists when the potential difference between its ends is one volt.

Notes

1. The resistance of a conductor is the property which depends on its dimensions, material and temperature determines the current produced in it by a given potential difference across its ends.
2. The conductors which obey Ohm's law are called ohmic conductors. For ohmic conductors (metals and alloys), the graph between current and potential difference is a straight line passing through the origin.
3. For devices exhibiting a nonlinear V-I characteristics (e.g. incandescent lamp) Ohm's law is expressed in differential form, i.e.
   $$dv = Rdi$$
   where R is the slope of the nonlinear curve corresponding to a given point on the curve. If this point is changed, the value of resistance as applied to that point also changes.
4. Ohm's law can be expressed in three different ways, viz.
   $$i = \frac{V}{R}, V = Ri \text{ and } R = \frac{V}{i}$$
   Other relation derived from Ohm's law is
   $$\text{Power } (W) = VI = \frac{V^2}{R} = I^2 R$$
5. **Limitations of Ohm's law:** Ohm's law is not applicable to nonlinear unilateral devices such as diode value, junction diodes, etc. as they exhibit discontinuity and different characteristics in either direction.
6. **Concept of open and short circuits:** By open circuit or simply open, we mean that current is zero regardless of the voltage. Figure 1.4a shows the representation of an open circuit implying that resistance is *infinite* between the two points A and B. From Ohm's law $R = V/I \because I = 0, R = \infty$.
   By short circuit or simply short, we mean that voltage between the two points is zero regardless of the current through it. Fig. 1.4b shows the representation of a short circuit implying that resistance is zero between the two points A and B from Ohm's law $R = V/I \because V = 0, R = 0$.

(a) Representation of open circuit (b) Representation of short circuit

Fig. 1.4: Representation of open and short circuits

Self induced emf is given by

$$V_L \propto di/dt$$

or $$V_L = L\, di/dt$$

where L is coefficient of self inductance or simply inductance. The SI unit of inductance is henry. A coil has an inductance of 1 H if a current changing at a rate 1.8 of 1 A/s causes an emf of 1 V to develop across it.

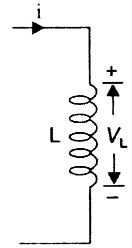

Fig. 1.9

The inductance exists in AC circuits and DC transient circuits only. In AC circuits the current changes continuously and the effect of inductance can be observed. In case of DC transient circuits where emf is suddenly applied to or removed from a network-inductance as well as capacitance, also come into picture.

The important point to note is that inductance parameter stays constant for all values of current if current and flux remain proportional. Such inductances are known as linear inductances (Fig. 1.9). A practical inductance is called an inductor.

Inductances in Series

Figure 1.10 shows three inductances L_1, L_2 and L_3 connected in series. The current through all the inductances is i, and rate of change of current is di/dt.

i. The total inductance L is given by

$$L = L_1 + L_2 + L_3$$

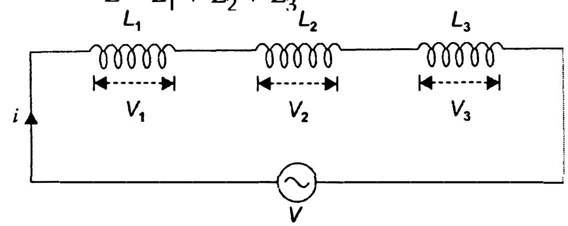

Fig. 1.10

ii. The total voltage across the series combination is the sum of voltages induced across the three inductances

$$V = V_1 + V_2 + V_3$$

$$= L_1 \frac{di}{dt} + L_2 \frac{di}{dt} + L_3 \frac{di}{dt}$$

Inductances in Parallel

Figure 1.11 shows three inductances L_1, L_2 and L_3 connected in parallel. The voltage induced across each inductance is V. It is also assumed that initially there is no current flowing in the circuit which is represented as $i(0) = 0$.

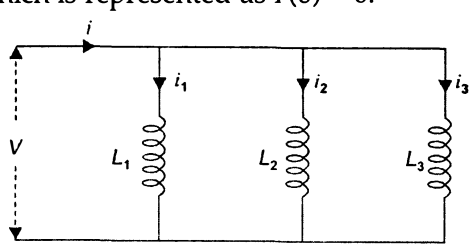

Fig. 1.11

known as a *capacitor or condenser*. A condenser has a capacitance of one farad if the addition of one coulomb of charge to it raises its potential by one volt.

$$1\ \mu F = 10^{-6}\ \text{farad}$$

and $$1\ \text{pF (pico farad)} = 10^{-12}\ \text{farad}$$

An arrangement which is capable of changing the capacitance of a conductor is called condenser or capacitor. It consists of two plates placed close together and insulated from one another by air or some dielectric medium. In other words, a device or arrangement which can store considerable amount of charge is called a condenser or capacitor.

Capacitors in Series

When a number of capacitors having capacities C_1, C_2, C_3, etc. are connected in series, then the resultant capacitance C is given by

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

Capacitors in Parallel

When a number of capacitors having capacities C_1, C_2, C_3 ... etc. are connected in parallel, then the resultant capacitance C is given by

$$C = C_1 + C_2 + C_3 + \ldots$$

Concept of Capacitance as a Circuit Parameter

We have already seen that

$$Q = CV$$

As $i = dQ/dt$, we may also write

$$i = C\frac{dV}{dt} \qquad \ldots(1.2)$$

From Eq. (1.2) it follows that capacitor is a circuit element which has the property of yielding a current directly proportional to the rate of change of voltage across its terminals. In case of two parallel plates separated by a distance d metre, the capacitance is equal to

$$C = \varepsilon\frac{A}{d}$$

where A is the area of plates in m^2, d is the distance of separation of plates, and E is the permittivity of the material (medium).

If the capacitor is given a charge q coulomb so that its potential is raised by V volt, then the energy W joule stored is given by

$$W = \frac{1}{2}qV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{q^2}{C}$$

where C is in farad.

1.4.4 Capacitance in Series

In Fig. 1.13, three capacitors of capacitance C_1, C_2 and C_3 are connected in series across a DC supply of potential difference V through a switch K. On closing the switch, the

If a flux of ϕ weber (Wb) links with a coil of N turns, the induced emf in the coil is given by

$$e \propto \frac{d(\phi N)}{dt} = k\frac{d(\phi N)}{dt}$$

In SI the proportionality constant $k = 1$ and

$$e = N\frac{d\phi}{dt} \quad ...(1.3)$$

Lenz's law: Faraday's law, that gives the magnitude of induced emf. The polarity of the induced emf is determined by Lenz's law. It states that the polarity of the induced emf is such as to opposes the change which produces it.

Remembering Lenz's law, Faraday's law is written as

$$e = -N\frac{d\phi}{dt} \quad ...(1.4)$$

If ϕ_1 be the magnitude of the flux linked with a circuit initially and ϕ_2 be the flux after t second, then

$$\text{rate of change of flux} = \frac{\phi_1 - \phi_2}{t}$$

$$\text{The induced emf, } e = -N\frac{\phi_1 - \phi_2}{t}$$

1.7 KIRCHHOFF'S LAWS

Ohm's law is unable to give current in complicated circuits. Kirchhoff in 1842, gave two general laws which are extremely useful in electrical circuits. These are:

i. The algebraic sum of the currents at any junction in a circuit is zero, i.e.

$$\Sigma i = 0$$

This means that there is no accumulation of electric charge at any point in the circuit. The currents which flow towards a point are taken as positive while those flowing away from the point are taken as negative. From Fig. 1.20, we have

$$i_1 - i_2 - i_3 + i_4 - i_5 + i_6 = 0$$

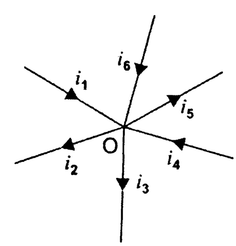

Fig. 1.20

ii. In any closed circuit, the algebraic sum of the products of the current and resistance of each part of the circuit is equal to the total emf in the circuit, i.e.

$$\Sigma iR = \Sigma E$$

The product of current and resistance is taken as positive when we traverse in the direction of current. The emf is taken positive when we traverse from negative to positive electrode through electrolyte.

Before discussing Kirchhoff's law, we shall now define certain basic terms associated with electrical circuits.

i. *Node* is a junction where two or more elemental points meet.
ii. *Path* is the route through elements from one node to another without going through the same node twice.
iii. *Branch* is a path between two adjoining nodes.
iv. *Loop* is a closed path where the route ends upon the starting node.
v. *Mesh* is a loop that does not contain any other loop within it.