ELECTRICAL TECHNOLOGY

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CHAPTER 1

Basic Concepts & Units

1.1 INTRODUCTION

Electricity is so much part and parcel of every human life in civilized world that a world without electricity is unimaginable for us. All the domestic, industrial and commercial activity comes to standstill if the electricity fails. All the scientific, technological and other activities depend today on electricity. Mind boggling progress and development in communication, automation, medicine, computation and numerous branches of science all owe to electricity.

1.2 WHAT IS ELECTRICITY?

Electricity is a natural force due to electric charge naturally available in all the matter in the universe within its every atom, on the elementary particles constituting the atom. The elementary particles are three 1. Electron, 2. Proton, 3. Neutron. The first two particles possess electrical charge. These naturally available charges are of two types 1. Positive charge 2. Negative charge; they are so called because they provide forces opposite of each other i.e., when they are together, the net result is no force i.e., the combination behaves as neutral as if there is no charge. Electrons possess negative charge, protons possess positive charge and the quantity of charge on an electron is equal to that on a proton, it is equal to 1.9×10^{-19} coulomb, where coulomb is a unit of charge. Since the number of electrons is always equal to the number of protons in a normal atom. So, all the atoms and all the matter generally behaves as neutral. The protons and neutrons of an atom are tightly bound in its nucleus while the electrons of the atom are encircling the nucleus in their different orbits. Under certain circumstances one or more of the electrons in the outermost orbit of an atom become free and may move away from the atom, then the charge balance of the atom is lost, there becomes an atom with some positive net charge on it, then the atom is called an ion. Under an electric pressure i.e., electric field or voltage the free electrons or free ions tend to move in the direction of the electric field. In gaseous or liquified matter electrons as well as ions may be free to move but in solids, ions are tightly bound to their surrounding atoms and cannot move, only the free electrons can move. This movement of electrons or ions is actually the movement of electric charge. The rate of movement of electric charge is known as current i. $i = \frac{dq}{dt}$., , where i and q represent current and charge respectively.

The free electrons or free ions are also termed as charge carriers. The free charge carriers have some random motions about their mean positions, the net displacement is zero. Only under the influence of an electric field or electric pressure, they make a net drift in the direction of the field, that makes the current flow:

Example 1.1: There is a drift of 5×10^{19} electrons per second across a cross-section of a conductor. Find the current in the conductor.

Soluti $i = \frac{dq}{dt} = \frac{5 \times 10^{19} \times 1.6 \times 10^{-19}}{1} = 8A.$ n:

1.3 ELECTRIC CONDUCTOR

All the matter or materials are broadly divided into two categories.

1. Conductors.
2. Insulators.

The conductors are those materials which possess large number of free charge carriers, so that, under an electric field a current flows if there is a closed conducting path available to it.

Insulators or bad conductors are those materials in which there are no or insignificant free charge carriers available. So, when an electric field is applied there is no electric current. Table 1.1 and Table 1.2 respectively give some conductors and insulators.

Now a days there is a third type of material very commonly in use in electrical/electronic systems known as semiconductors. These are the few materials which in pure form under normal conditions, are close to be called insulators but can be turned into conductors by certain strategies.

Table 1.1		Table 1.2		
Mat ρ ria mWm	in	Material	Dielectric constant or permittivity	Dielectric strength in kV/mm at 50 Hz
Silver	0.016	Bakelite	5 – 6	3 – 4.5
Copper	0.018	Bitumen	4.5	14
Gold	0.022	Ebonite	2 – 3	10 – 40
Aluminium	0.028	Empire cloth	2	10 – 20
Zinc	0.06	Fibre	4 – 6	5
Brass	0.07	Glass	3 – 8	5 – 12
Iron	0.1	India rubber	10 – 25	2 – 3
Platinum	0.106	Marble	6	8
Tin	0.11			
Lead	0.208	Mica	40 – 150	3 – 8

Contd.

Carbon	66.67	Paper	4 – 10	2
Tungston	0.056	Paraffin wax	8	2
Constantan	0.48	Porcelain	9 – 20	4 – 7
Nichrome	1.00			

It is mostly the solid state materials used in electrical or electronics engineering and conducting, semiconducting or insulating materials are better explained by energy band theory of solids which you learn in the course of basic electronics. The free charge carriers are always the free (quasi free) electrons. So a current means rate of flow of these electrons.

1.4 ELECTRIC TENSION OR POTENTIAL

Whenever there are surplus free charge carriers at any point in a material i.e., the positive and negative charges are not balanced (equal) there. Then, there appears an electric tension, electric pressure, potential or voltage to push the surplus charge carriers towards any other point which has the surplus of the opposite charge carriers. Actually the surplus +ve charge carriers at a point, node or terminal A causes +ve potential at A and the surplus –ve charge carriers at point B causes –ve potential at B. If points A and B are connected through some conducting medium, then the electrons drift from B to A i.e. there is an electronic current from B to A. Since electrons are –ve charged carriers, it means a +ve current flows from A to B. Hence electric potential is a pressure or force which tends to push electric charge carriers towards the points of different potential.

If there is a continuous source of generation of surplus charges of the said polarities at A and B, then the accumulated charges will not exhaust, the generation of charge process continues and current will flow from A to B. Then A and B are the terminals of an electric source or generator. In this process, the electrons actually follow a closed path i.e., they flow from B to A in the external path (circuit) and from A to B in the internal path of the generator. When electrons flow in the external circuit, they may be producing heat energy due to the resistance of the circuit and/or mechanical energy due to some electromagnetic process or some other form of energy. But this energy actually comes from the generator transported by the charge carriers (electrons). When the external circuit is open, the charge carriers can not flow i.e., no current, so no energy is supplied by the generator, so no energy need be generated in the generator except the energy which may go out due to any leakage of charge (current).

1.5 METHODS OF GENERATION OF ELECTRIC TENSION OR VOLTAGE

Some important methods are:

1. By friction (amber, ebonite, glass, etc.).
2. By electrochemical process (electric cell, battery, etc.).
3. By electromagnetic process (generator, dynamo)—Mechanical energy is converted to electrical energy.

4. By heat (thermocouple).
5. By light (solar cell).
6. By pressure (piezoelectricity).

1.6 POTENTIAL AND POTENTIAL DIFFERENCE

Potential of a point is its voltage with reference to a neutral body whose voltage is zero or with reference to earth whose voltage always remains zero, because earth has nearly infinite charge storage capacity without any raise in its potential.

Potential difference between two points A and B, is generally denoted by V_{AB}, potential of point A minus the potential of point B.

1.7 APPLIED VOLTAGE AND VOLTAGE DROP

Applied voltage is an action voltage from a generator source applied to an electric circuit.

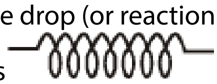
Voltage drop is a reaction voltage produced in the circuit to oppose the applied voltage.

1.7.1 The Law of Action and Reaction in an Electric Circuit

To every action there is an equal and opposite reaction. This law also applies to electric voltages in an electric circuit. It is also known as Kirchhoff's Voltage Law (KVL). It is stated as, "the algebraic sum of all the applied voltages (source voltages) is equal and opposite to the algebraic sum of all the voltage drops in a closed circuit at any instant."

1.7.2 The Reaction Voltages in Electric Circuits

A current can flow in a circuit only when a voltage from a source is applied to it. But the moment the action voltage appears, the same moment the current causes reaction voltages to fully balance the action. There are only three ways in which reaction voltages (voltage drops) occur in electric circuits.

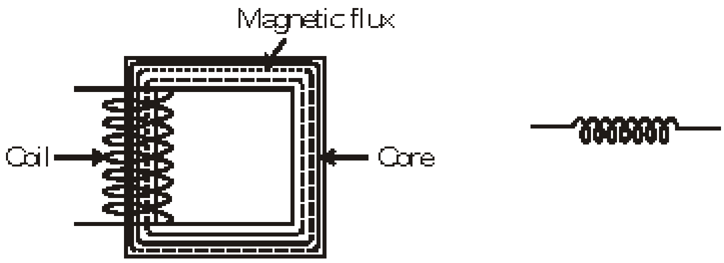
1. Due to Resistance: Free electrons of any material tend to accelerate their motion in the direction of the electric field due to the applied voltage. These electrons would have picked up infinite speed i.e., infinite current would have been there if there was no opposition (resistance). But the electrons move between their atoms and the moving electrons collide with the vibrating atoms here and there. Thus, electrons loose their kinetic energy every now and then, stop and rebuild their motion, the vibration of atoms is increased i.e., heat is generated. This opposition to the current from the vibrating atoms is known as electric resistance represented by R, whose unit is ohm and this opposition is equal to a voltage which is called voltage drop due to resistance or reaction voltage due to resistance. Numerically this voltage is given equal to IR, where I is the current in amperes i.e., voltage drop (or reaction voltage) across a resistance is given as V = IR. This is also referred as Ohm's  lw.

(a) Resistance element (b) Symbol

Fig. 1.1: A Resistance

The reaction voltage to current flow through a resistance is analogous to reaction force produced to a motion of a mechanical body against a friction.

2. Due to Inductance: Whenever there exists a coil in the path of a current, the coil prdouces a flux li $N\phi$ kage = , where N is the number of turns of the co f l and the flux linking with each turn. The flux linkage per ampere is known as inductance L of the $\therefore$ o $L = \frac{N\phi}{I}$ l. ... (1.1)



Unit Henry

(a) Inductor (b) Symbol

Fig. 1.2: Inductance

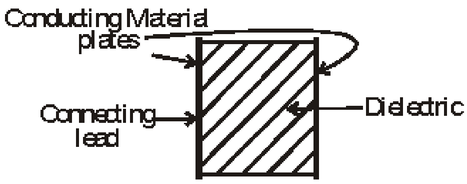
Thus, higher is the magnetic flux linkage per ampere in a coil, higher is its inductance.

If the current through an inductance is constant i.e., DC current, there is no reaction due to the inductance. But if the current tries to change at any moment, there is at once a reaction voltage produced due to Faraday's law of electro-magnetic induction.

This reaction voltage is e $L\frac{di}{dt}.$ ual to This is the voltage drop due to inductance.

Inductance in the path of electric current is analogous to inertia of moving bodies in mechanical system. So, when a body is moving at a constant speed, there is no reaction force produced due to its inertia but the moment the speed of the body tries to change, there is immediately a reaction mechanical force produced to oppose the change. Similarly whenever a current tries to change in a circuit, its inductance produces an opposite voltage to oppose that current change.

3. Due to Capacitance: Whenever there is a capacitance in series with a current path, that means a break in the path, there is a dielectric (insulation) sheet stopping any further passage of the charge, the charges of opposite nature accumulate on the two conducting sheets placed on the two sides of the dielectric. This accumulation of charges on the two plates with an insulation separating them produces a reaction $= \frac{q}{c}$ oltage , where q is the electric charge in coulomb on each plate and c is the capacitance of the capacitor.

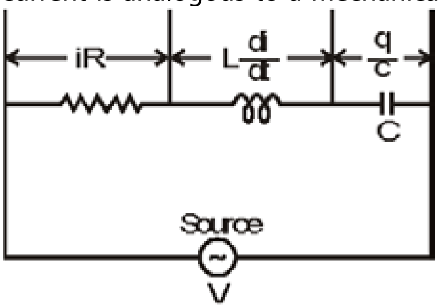


Unit: Far d

(a) Capacitor (b) Symbol

Fig. 1.3

The reaction voltage produced across the capacitor is the voltage drop due to capacitance. The capacitance in Farad is defined as the charge accumulated in coulombs across a capacitor per volt developed between its plates. Capacitance in the path of electric current is analogous to a mechanical spring in the path of the motion of a mechanica



body.

Fig. 1.4: *A resistance, inductance and a capacitance connected in series across a source voltage V*

Thus, in an electric circuit when a source voltage is applied, it pushes a current in the circuit overcoming opposition from any one or more of the three sources of opposition viz., resistance, inductance and capacitance. It is analogous to mechanical systems: when a mechanical force is applied to a body which has freedom of movement in the direction of the force applied, then the body moves overcoming any one or more of the three possible oppositions to the motion viz., friction, inertia and spring.

So, $F_{(Applied)} = F_{(Friction)} + F_{(Inertia)} + F_{(Spring)}$ ...(1.2)

In the circuit of Fig. 1.4. At any instant the voltages balancing equation is

$$v = iR + L\frac{di}{dt} + \frac{q}{c}$$ ...(1.3)

wher $q = \int i \, dt$ ...(1.4)

1.8 RESISTANCE, INDUCTANCE AND CAPACITANCE IN TERMS OF

DIMENSIONS AND THE MATERIAL

1.8.1 Resistance $R = \frac{\rho l}{a}$ (R)

...(1.5)

where R is i ρ ohms, is the resistivity in ohm-m of the material of the resistor, l is its length in meters and a is its area of cross-section in m^2.

Power loss P in a resist R W nce of through which a current I ampere flows and the voltage between its terminals is V volt is:

$$P = VI = I^2R = V^2/R \text{ Watts} \qquad ...(1.6)$$

Resistance is also dependent on temperat $R_{t_2} = R_{t_1}\{1 + \alpha_{t_1}(t_2 - t_1)\}$ re:

...(1.7 R_{t_1}

wher R_{t_2} and are the resistances at temperature t_1 and t_2 respectiv a_{t_1} ly and is the resistance temperature coefficient at temperature t_1 $\alpha_t = \frac{\alpha_0}{1 + \alpha_0 t}$

Also ...(1. α_0)

whe α_t e and are the temperature coefficients at temperature 0°C and t°C respectively.

Resistance is a Dissipative Element

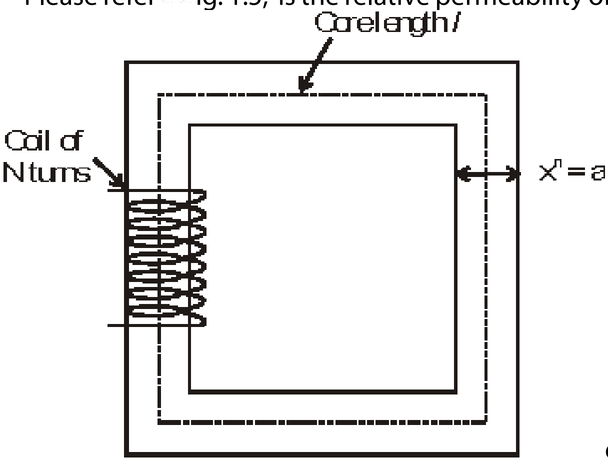
That is, electrical power coming from the source is converted to heat, which is dissipated to the surroundings. It is unidirectional or irreversible conversion. The power taken by the resistance is permanently lost

Electr $\longrightarrow$ c Energy Heat Energy

1.8.2 Inductan $L = \frac{N^2 \mu_0 \mu_r a}{l}$ Henry e (L)

...(1.9)

Please refer μ_r ig. 1.5, is the relative permeability of the core mat μ_0 rial and is the permeability



of fr e space.

Fig. 1.5: An inductor

Magnetic energy stored in the core of the inductor is give $E = \frac{1}{2}LI^2$ by:

...(1.10)

where I is the current in the coil of the inductor.

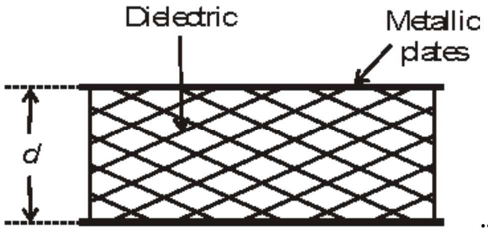
An Inductance is a Non-dissipative Element

That is, no electric energy from the source is lost in the inductance. As the current increases in the coil more electrical energy comes from the source, gets converted and stored as magnetic energy in the core. When the current decreases, the magnetic energy of the core also decreases as per the equation (1.10). The decrease in the stored magnetic energy actually is reconverted to electric energy and goes back to source.

$$\text{Electri} \xrightleftharpoons{\text{reversible}} \text{al energy Magnetic energy}$$

If due to some reason the source is not able to receive back the electric energy from the inductor, it may be lost as heat in the form of spark in the switch etc. (which is a current jumping through the high resistance of the air-gap)

1.8.3 Capacita $C(\text{in Faradays}) = \frac{e_0 e_r A}{d}$, ce (C)



...(1.11)

Fig. 1.6: A capacitor

where A is the area of X_n of each e_r plate and is the relative permittivity of the dielectric e_0 material, is the permittivity of free space.

Electrostatic energy stored in the dielectric of a capacitor is g $E = \frac{1}{2}CV^2$ ven by

...(1.12)

where V is the voltage across the capacitor.

A Capacitor is Also a Non-dissipative Element

That is, no electric energy from the source is lost in the capacitor. Whatever energy comes and gets stored in the capacitor goes back to the source as the voltage across the capacitor decreases to zero.

Electri $\xrightarrow{\text{reversible}}$ al energy Electrostatic energy

If the source does not receive back the energy stored in the dielectric of the capacitor, the energy may be dissipated as heat by discharging the capacitor through some resistance.

Example 1.2: An electric heater has an element of nichrome wire of length 1 metre and uniform circular cross-section of diameter 0.2 mm. If the resistivity of nichrome is giv $m\Omega m.$ n as 1.02 Find the resistance of the element and its power rating if the voltage rating is 230 V.

$$R = \frac{\rho l}{a} = \frac{1.02 \times 10^{-6} \times 1}{\frac{\pi \times (0.2)^2}{4} \times 10^{-6}} = \frac{1.02 \times 4}{\pi \times 0.04} = \frac{1.02 \times 100}{\pi}$$

S lution:

$$\boxed{R = 32.48\ \Omega} \qquad \therefore\ P = \frac{V^2}{R} = \frac{(230)^2}{32.48} = 1628.7W$$

$$\boxed{P = 1.63\,\text{kW.}}$$

Example 1.3 : A coil of copper conductor has a res $0.1\ \Omega$ stance of at 20°C. Find the temperature when its resistance be Ω omes 0.12 α_{20}. Assume for copper to be 0.004°C.

Sol $R_{t_2} = R_{t_1}\{1 + a_{t_1}(t_2 - t_1)\} = 0.1\{1 + 0.004(t_2 - 20)\} = 0.12$ ti∴n:

1 + 0.004(t_2 – ∴0) = 1.2

0.004(t_2 –∴20) =0.2

t_2 – 20∴= $\frac{200}{4}$ = 5 $\boxed{t_2 = 70°}$

Example 1.4: A coil of 200 turns is wound on an iron core of uniform cross-section of 4 cm² and length 10 cm. Relative permeability of the iron is 1000. Find the inductance of the coil.

$$L = \frac{N^2 \mu_0 \mu_r a}{l} = \frac{(200)^2 \times 4\pi \times 10^{-7} \times 1000 \times 4 \times 10^{-4}}{10 \times 10^{-2}} = 64\pi \times 10^{-3}$$ oluti $\boxed{L = 0.2\ \text{H}}$ n: H

Example 1.5: A parallel plate capacitor has aluminium foils acting as the plates of cross-sectional area of 20 cm². These foils are separated by a 10 micron thickness of a die $\varepsilon_r = 5.$ ectric of Find its capacitance. When a c μ arge of 1 coulomb collects across the foils, determine the voltage across the foils.

$C = \varepsilon_0 \varepsilon_r A / d =$ olution:

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