$\textit{Lecture } 10: \textit{Overhead transmission lines} - \textit{Part } 2$

10.1 Constants of a Transmission Line

A transmission line has resistance, inductance and capacitance uniformly distributed along the whole length of the line.

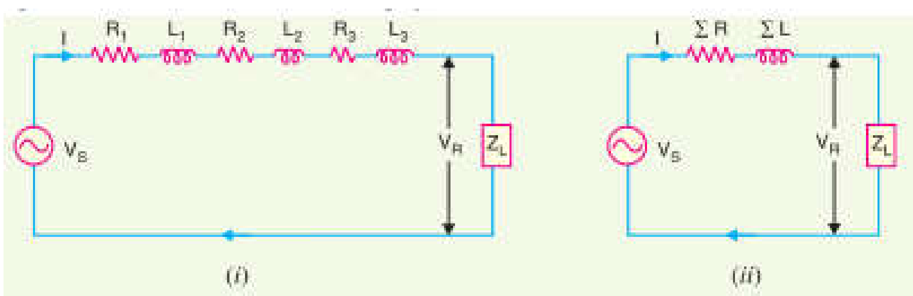

Figure 10.1

(*i*) Resistance. It is the opposition of line conductors to current flow. The resistance is distributed uniformly along the whole length of the line as shown in Fig. 10.1 (*i*). However, the performance of a transmission line can be analyzed conveniently if distributed resistance is considered as lumped as shown in Fig. 10.1(*ii*).

(*ii*) Inductance. When an alternating current flows through a conductor, a changing flux is set up which links the conductor. Due to these flux linkages, the conductor possesses inductance. Mathematically, inductance is defined as the flux linkages per ampere *i.e.,*

$$Inductance, L = \frac{\psi}{I} henry$$

where ψ = flux linkages in weber-turns

I = current in amperes

The inductance is also uniformly distributed along the length of the * line as show in Fig. 10.1(*i*). Again for the convenience of analysis, it can be taken to be lumped as shown in Fig. 10.1(*ii*).

(*iii*) Capacitance. We know that any two conductors separated by an insulating material constitute a capacitor. As any two conductors of an overhead transmission line are separated by air which acts as an insulation, therefore, capacitance exists between any two overhead line conductors. The capacitance between the conductors is the charge per unit potential difference *i.e.,*

$$Capacitance, C = \frac{q}{v} farad$$

where q = charge on the line in coulomb

v = p.d. between the conductors in volts

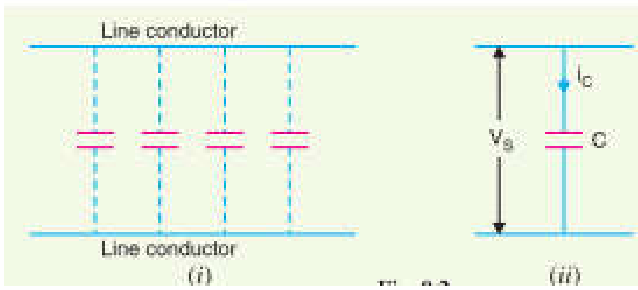

Figure 10.2

10.2 Resistance of a Transmission Line

The resistance of transmission line conductors is the most important cause of power loss in a transmission line. The resistance R of a line conductor having resistivity ρ, length l and area of cross-section a is given by;

$$R = \rho \frac{l}{a}$$

The variation of resistance of metallic conductors with temperature is practically linear over the normal range of operation. Suppose R_1 and R_2 are the resistances of a conductor at t_1ºC and t_2ºC ($t_2 > t_1$) respectively. If α_1 is the temperature coefficient at t_1°C, then,

$$R_2 = R_1[1 + \alpha_1(t_1 + t_1)]$$

Where,

$$\alpha_1 = \frac{\alpha_1}{1 + \alpha_0 t_1}$$

α_0 = temperature coefficient at 0º C (***i***) In a single phase or 2-wire d.c line, the total resistance (known as *loop resistance*) is equal to double the resistance of either conductor.

(***ii***) In case of a 3-phase transmission line, resistance per phase is the resistance of one conductor.

10.3 Skin Effect

When a conductor is carrying steady direct current (d.c), this current is uniformly distributed over the whole X-section of the conductor. However, an alternating current flowing through the conductor does not distribute uniformly, rather it has the tendency to concentrate near the surface of the conductor as shown in Fig. 10.3. This is known as skin effect.

The tendency of alternating current to concentrate near the surface of a conductor is known as skin effect.

Due to skin effect, the effective area of cross-section of the conductor through which current flows is reduced. Consequently, the resistance of the conductor is slightly increased when carrying an alternating current. The cause of skin effect can be easily explained. A solid conductor may be thought to be consisting of a large number of strands, each carrying a small part of the current. The inductance of each strand will vary according to its position. Thus, the strands near the centre are surrounded by a greater magnetic flux and hence have larger inductance than that near the surface. The high reactance of inner strands causes the alternating current to flow near the surface of conductor. This crowding of current near the conductor surface is the skin effect. The skin effect depends upon the following factors:

(***i***) Nature of material

(***ii***) Diameter of wire - increases with the diameter of wire.

(***iii***) Frequency - increases with the increase in frequency.

(***iv***) Shape of wire - less for stranded conductor than the solid conductor.

It may be noted that skin effect is negligible when the supply frequency is low (< 50 Hz) and conductor diameter is small (< 1cm).

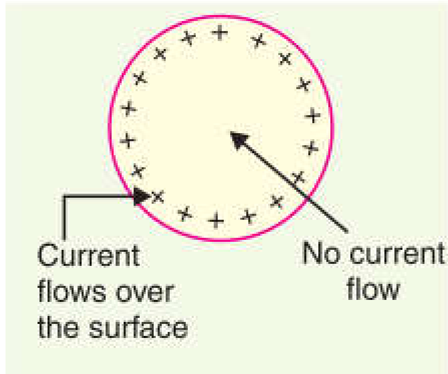

Figure 10.3

10.4 Classification of Overhead Transmission Lines

A transmission line has *three constants *R*, *L* and *C* distributed uniformly along the whole length of the line. The resistance and inductance form the series impedance. The capacitance existing between conductors for 1-phase line or from a conductor to neutral for a 3-phase line forms a shunt path throughout the length of the line. Therefore, capacitance effects introduce complications in transmission line calculations. Depending upon the manner in which capacitance is taken into account, the
overhead transmission lines are classified as :

(*i*) *Short transmission lines.* When the length of an overhead transmission line is up to about 50 km and the line voltage is comparatively low (< 20 kV), it is usually considered as a short transmission line. Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected. Therefore, while studying the performance of a short transmission line, only resistance and inductance of the line are taken into account.

(*ii*) *Medium transmission lines.* When the length of an overhead transmission line is about 50-150 km and the line voltage is moderately high (>20 kV < 100 kV), it is considered as a medium transmission line. Due to sufficient length and voltage of the line, the capacitance effects are taken into account. For purposes of calculations, the distributed capacitance of the line is divided and lumped in the form of condensers shunted across the line at one or more points.

(*iii*) *Long transmission lines.* When the length of an overhead transmission line is more than 150 km and line voltage is very high (> 100 kV), it is considered as a long transmission line. For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line and rigorous methods are employed for solution.

10.5 Important Terms

(*i*) Voltage regulation. When a transmission line is carrying current, there is a voltage drop in the line due to resistance and inductance of the line. The result is that receiving end voltage (V_R) of the line is generally less than the sending end voltage ($V S$). This voltage drop ($V S$ - V_R) in the line is expressed as a percentage of receiving end voltage $V R$ and is called voltage regulation.

*The difference in voltage at the receiving end of a transmission line **between conditions of no load and full load is called* **voltage regulation** and is expressed as a percentage of the receiving end voltage.

$$\%\; age\; voltag\; regulation = \frac{V_S - V_R}{V_R} \times 100$$

It is desirable that the voltage regulation of a transmission line should be low *i.e.*, the increase in load current should make very little difference in the receiving end voltage.

(*ii*) Transmission efficiency. The power obtained at the receiving end of a transmission line is generally less than the sending end power due to losses in the line resistance.
The ratio of receiving end power to the sending end power of a transmission line is known as the **transmission efficiency** *of the line i.e.*

$$\%age\; Transmission\; efficiency, \eta_T = \frac{Receving\; end\; power}{Sending\; end\; power} \times 100$$

$$= \frac{V_R I_R cos\phi_R}{V_S I_S cos\phi_S} \times 100$$

Where V_R, I_R and cos φ_R are the receiving end voltage, current and power factor while VS, IS and cos Φ_s are the corresponding values at the sending end.

Example 10.1

What is the maximum length in km for a 1-phase transmission line having copper conductor of 0·775 cm² cross-section over which 200 kW at unity power factor and at 3300Vare to be delivered? The efficiency of transmission is 90%. Take specific resistance as 1.725 μ Ω*cm.*

Solution.

$$Receiving\ end\ power\ =\ 200\ kW\ =\ 200{,}000\ W$$

$$Transmission\ efficiency\ =\ 0\cdot 9$$

$$Sending\ end\ power = \frac{200{,}000}{0.9} = 222222W$$

$$Line\ losses = 222222 - 200000 = 22222W$$

$$Line\ current, I = \frac{200 \times 10^3}{3{,}300 \times 1} = 60.6A$$

Let R Ω be the resistance of one conductor.

$$Line\ losses = 2I^2R$$

$$22222 = 2(60.6)^6 \times R$$

$$\therefore R = \frac{22222}{2 \times (60.6)^2} = 3.025\Omega$$

$$Now, R = \frac{\rho l}{a}$$

$$\therefore, l = \frac{Ra}{\rho} = \frac{3.025 \times 0.775}{1.725 \times 10^{-6}} = 1.36 \times 10^6 cm = 13.6km$$