MODULE I

Transmission line

Conductors

Commonly used conductor materials:

The most commonly used conductor materials for over head lines are copper, aluminium, steel-cored aluminium, galvanised steel and cadmium copper. The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions. All conductors used for overhead lines are preferably stranded in order to increase the flexibility.In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24 ...... wires. Thus, if there are n layers, the total number of individual wires is $3n(n + 1) + 1$. In the manufacture of stranded conductors, the consecutive layers of wires are twisted or spiralled in opposite directions so that layers are bound together.

Types of Conductors

1. **Copper**. Copper is an ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength. It is always used in the hard drawn form as stranded conductor. Although hard drawing decreases the electrical conductivity slightly yet it increases the tensile strength considerably.

Copper has high current density i.e., the current carrying capacity of copper per unit of X-sectional area is quite large. This leads to two advantages. Firstly, smaller X-sectional area of conductor is required and secondly, the area offered by the conductor to wind loads is reduced. Moreover, this metal is quite homogeneous, durable and has high scrap value. There is hardly any doubt that copper is an ideal material for transmission and distribution of electric power. However, due to its higher cost and non-availability, it is rarely used for these purposes. Now-a-days the trend is to use aluminium in place of copper.

2. **Aluminium**. Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength. The relative comparison of the two materials is briefed below:

(i) The conductivity of aluminium is 60% that of copper. The smaller conductivity of aluminium means that for any particular transmission efficiency, the X-sectional area of conductor must be larger in aluminium than in copper. For the same resistance, the diameter of aluminium conductor is about 1·26 times the diameter of copper conductor. The increased X-section of aluminium exposes a greater surface to wind pressure and, therefore, supporting towers must be designed for greater transverse strength. This often requires the use of higher towers with consequence of greater sag.

(ii) The specific gravity of aluminium (2·71 gm/cc) is lower than that of copper (8·9 gm/cc). Therefore, an aluminium conductor has almost one-half the weight of equivalent copper conductor. For this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.

(iii) Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.

(iv) Due to lower tensile strength and higher co-efficient of linear expansion of aluminium, the sag is greater in aluminium conductors. Considering the combined properties of cost, conductivity, tensile strength, weight etc., aluminium has an edge over copper. Therefore, it is being widely used as a conductor material. It is particularly profitable to use aluminium for heavy-current transmission where the conductor size is large and its cost forms a major proportion of the total cost of complete installation.

3. **Steel cored aluminium**. Due to low tensile strength, aluminium conductors produce greater sag. This prohibits their use for larger spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanised steel wires. The composite conductor thus obtained is known as steel cored aluminium and is abbreviated as A.C.S.R. (aluminium conductor steel reinforced).

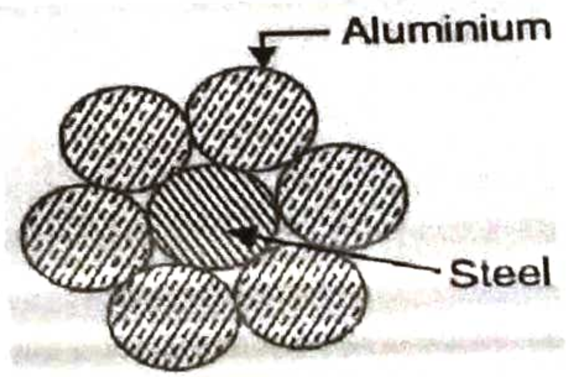

Fig 1.1:ACSR Conductor

Steel-cored aluminium conductor consists of central core of galvanized steel wires surrounded by a number of aluminium strands. Usually, diameter of both steel and aluminium wires is the same. The X-section of the two metals are generally in the ratio of 1 : 6 but can be modified to 1 : 4 in order to get more tensile strength for the conductor. Fig. shows steel cored aluminium conductor having one steel wire surrounded by six wires of aluminium. The result of this composite conductor is that steel core takes greater percentage of mechanical strength while aluminium strands carry the bulk of current. The steel cored aluminium conductors have the following advantages :

(i) The reinforcement with steel increases the tensile strength but at the same time keeps the composite conductor light. Therefore, steel cored aluminium conductors will produce smaller sag and hence longer spans can be used.

(ii) Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.

TRANSMISSION LINE PARAMETER

An electric transmission line has four parameters, namely resistance, inductance, capacitance and shunt conductance. These four parameters are uniformly distributed along the whole line. Each line element has its own value, and it is not possible to concentrate or lumped them at discrete points on the line. For this reason the line parameters are known as distributed parameter, but can be lumped for the purpose of analysis on approximate basis. However, the validity of assumption for the analysis on lumped basis may fail if the line is very long.

Line 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.

$$L = \frac{\psi}{I}$$

where ψ = flux linkage in weber-turns

I = current in turns

Which shows that the self inductance of an electric circuit is numerically equal to the flux linkage of the circuit per unit of current.

Flux Linkages:

As stated earlier, the inductance of a circuit is defined as the flux linkages per unit current. Therefore, in order to find the inductance of a circuit, the determination of flux linkages is of primary importance. We shall discuss two important cases of flux linkages.

1. Flux linkages due to a single current carrying conductor. Consider a long straight cylindrical conductor of radius r metres and carrying a current I amperes (rms) as shown in Fig.1.2(i). This current will set up magnetic field. The magnetic lines of force will exist inside the conductor as well as outside the conductor. Both these fluxes will contribute to the inductance of the conductor.

(i) Flux linkages due to internal flux. Refer to Fig.1.2 (ii) where the X-section of the conductor is shown magnified for clarity. The magnetic field intensity at a point x metres from the centre is given by;

$$H_x = \frac{I_x}{2\pi x}$$

As $$I_x = \frac{\pi x^2}{\pi r^2} I$$

$$H_x = \frac{x}{2\pi r^2} I \text{ AT/m}$$

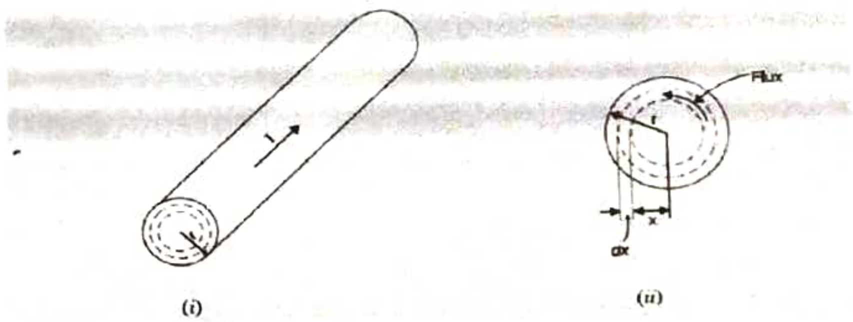

Fig 1.2: Internal flux linkage in a cylindrical conductor

If μ ($=\mu_0\mu_r$) is the permeability of the conductor, then flux density at the considered point is given by

$$B_x = \mu_0 \mu_r H_x$$

$$= \frac{\mu_0 x I}{2\pi r^2} \text{ wb/m}^2 \qquad (\mu_r = 1 \text{ for non magnetic material})$$

Now, flux $d\varphi$ through a cylindrical shell of radial thickness dx and axial length 1 m is given by

$$d\phi = B_x \times 1 \times dx = \frac{\mu_0 x I}{2\pi r^2} dx$$

This flux links with the current I_x only. Therefore the flux linkages per unit length of the conductor is

$$d\psi = \frac{\pi x^2}{\pi r^2} d\phi = \frac{\mu_0 I x^3}{2\pi r^4} dx \text{ weber-turns}$$

Total flux linkages from centre upto the conductor surface is

$$\psi_{int} = \int_0^r \frac{\mu_0 x I^3}{2\pi r^4} dx$$

$$= \frac{\mu_0 I}{8\pi} \text{ weber-turns per meter length}$$

***(ii)* Flux linkages due to external flux**. Now let us calculate the flux linkages of the conductor due to external flux. The external flux extends from the surface of the conductor to infinity. Referring to Fig. 4.5, the field intensity at a distance x metres (from centre) outside the conductor is given by ;

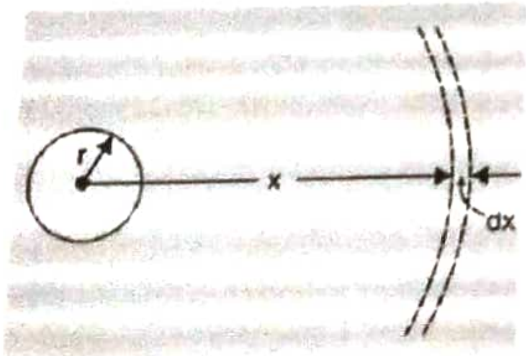

Fig 1.3: External flux linkage in a conductor

$$H_x = \frac{I}{2\pi x} \text{ AT/m}$$

$$\text{Flux density, } B_x = \mu_0 H_X = \frac{\mu_0 I}{2\pi X} \text{ wb/m}^2$$

Now, flux $d\varphi$ through a cylindrical shell of radial thickness dx and axial length 1 m is given by

$$d\phi = B_x \times 1 \times dx = \frac{\mu_0 I}{2\pi x} dx$$

The flux $d\varphi$ links all the current in the conductor once and only once.

$$d\psi = d\phi = \frac{\mu_0 I}{2\pi x} dx \quad \text{Weber-turns}$$

Total flux linkage of the conductor from surface to infinity

$$\psi_{ext} = \int_r^{\infty} \frac{\mu_0 I}{2\pi x} dx \quad \text{Weber-turns}$$

Over all flux linkage $\psi = \psi_{int} + \psi_{ext} = \frac{\mu_0 I}{8\pi} + \int_r^{\infty} \frac{\mu_0 I}{2\pi x} dx$

$$= \frac{\mu_0 I}{2\pi}\left[\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right] \quad \text{weber-turns/m length}$$

Inductance of Single Phase Two Wire Line

A single phase line consists of two parallel conductors which form a rectangular loop of one turn. When an alternating current flows through such a loop, a changing magnetic flux is set up. The changing flux links the loop and hence the loop possesses inductance. It may appear that inductance of a single phase line is negligible because it consists of a loop of one turn and the flux path is through air of high reluctance. But as the X -sectional area of the loop is very large, even for a small flux density, the total flux linking the loop is quite large and hence the line has appreciable inductance.

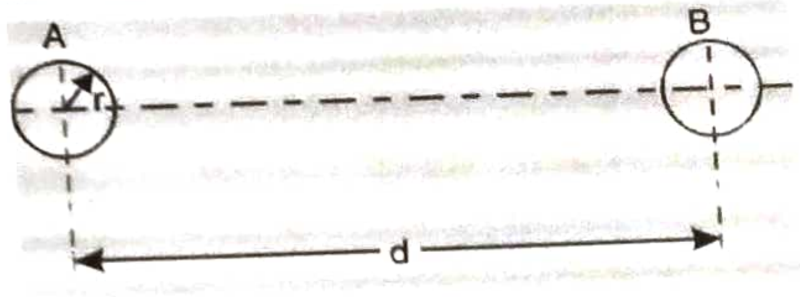

Fig 1.4: Single phase two wire transmission line

Consider a single phase overhead line consisting of two parallel conductors A and B spaced d metres apart as shown in Fig. 4.7. Conductors A and B carry the same amount of current (i.e. $I_A = I_B$), but in the opposite direction because one forms the return circuit of the other.

As we can see here, V_S and V_R is the supply and receiving end voltages respectively, and

I_s is the current flowing through the supply end.

I_R is the current flowing through the receiving end of the circuit.

I_1 and I_3 are the values of currents flowing through the admittances. And

I_2 is the current through the impedance Z.

Now applying KCL, at node P, we get

$$I_S = I_1 + I_2 \qquad (1)$$

Similarly applying KCL, to node Q.

$$I_2 = I_3 + I_R \qquad (2)$$

Now substituting equation (2) to equation (1)

$$I_S = I_1 + I_3 + I_R$$

$$= \frac{Y}{2}V_S + \frac{Y}{2}V_R + I_R \qquad (3)$$

Now by applying KVL to the circuit,

$$V_S = V_R + ZI_2$$

$$= V_R + Z(V_R\frac{Y}{2} + I_R)$$

$$= (Z\frac{Y}{2} + 1)V_R + ZI_R \qquad (4)$$

Now substituting equation (4) to equation (3), we get

$$I_s = \frac{Y}{2}[(\frac{Y}{2}Z + 1)V_R + ZI_R] + \frac{Y}{2}V_R + I_R$$

$$= Y(\frac{Y}{4}Z + 1)V_R + (\frac{Y}{2}Z + 1)I_R \qquad (5)$$

Comparing equation (4) and (5) with the standard ABCD parameter equations we derive the parameters of a medium transmission line as:

Insulating Material

The main cause of failure of overhead line insulator, is flash over, occurs in between line and earth during abnormal over voltage in the system. During this flash over, the huge heat produced by arcing, causes puncher in insulator body. Viewing this phenomenon the materials used for electrical insulator, has to posses some specific properties.

Properties of Insulating Material

The materials generally used for insulating purpose is called **insulating material.** For successful utilization, this material should have some specific properties as listed below-

1. It must be mechanically strong enough to carry tension and weight of conductors.
2. It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.
3. It must possesses high Insulation Resistance to prevent leakage current to the earth.
4. The **insulating material** must be free from unwanted impurities.
5. It should not be porous.
6. There must not be any entrance on the surface of electrical insulator so that the moisture or gases can enter in it.
7. There physical as well as electrical properties must be less affected by changing temperature.

There are mainly three **types of insulator** used as **overhead insulator** likewise

1. **Pin Insulator**
2. **Suspension Insulator**
3. **Strain Insulator**

In addition to that there are other two **types of electrical insulator** available mainly for low voltage application i.e. **Stray Insulator** and **Shackle Insulator**.

Pin Insulator

Pin Insulator is earliest developed **overhead insulator**, but still popularly used in power network up to 33KV system. Pin type insulator can be one part, two parts or three parts type, depending upon application voltage. In 11KV system we generally use one part type insulator where whole pin insulator is one piece of properly shaped porcelain or glass. As the leakage path of insulator is through its surface, it is desirable to increase the vertical length of the insulator surface area for lengthening leakage path. In order to obtain lengthy leakage path, one, tower or more rain sheds or petticoats are provided on the insulator body. In addition to that rain shed or petticoats on an insulator serve another purpose. These rain sheds or petticoats are so designed, that during raining the outer surface of the rain shed becomes wet but the inner surface remains dry and non-conductive. So there will be discontinuations of conducting path through the wet pin insulator surface.

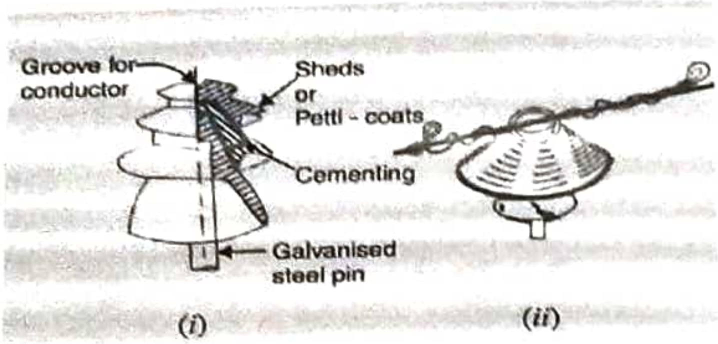

Fig 2.1- Pin Insulator

In higher **voltage** like 33KV and 66KV manufacturing of one part porcelain pin insulator becomes difficult. Because in higher voltage, the thickness of the insulator become more and a quite thick single piece porcelain insulator cannot manufactured practically. In this case we use multiple part pin insulator, where a number of properly designed porcelain shells are fixed together by Portland cement to form one complete insulator unit. For 33KV tow parts and for 66KV three parts pin insulator are generally used.

Designing Consideration of Electrical Insulator

The live conductor attached to the top of the pin insulator is at a potential and bottom of the insulator fixed to supporting structure of earth potential. The insulator has to withstand the potential stresses between conductor and earth. The shortest distance between conductor and earth, surrounding the insulator body, along which electrical discharge may take place through air, is known as flash over distance.

1. When insulator is wet, its outer surface becomes almost conducting. Hence the flash over distance of insulator is decreased. The design of an electrical insulator should be such that the decrease of flash over distance is minimum when the insulator is wet. That is why the upper most petticoat of a pin insulator has umbrella type designed so that it can protect, the rest lower part of the insulator from rain. The upper surface of top most petticoat is inclined as less as possible to maintain maximum flash over voltage during raining.

2. To keep the inner side of the insulator dry, the rain sheds are made in order that these rain sheds should not disturb the voltage distribution they are so designed that their subsurface at right angle to the electromagnetic lines of force.

Suspension Insulator

In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of the insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming these difficulties, **suspension insulator** was developed. In **suspension insulator** numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their disc like shape.

Advantages of Suspension Insulator

(i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.

(ii) Each unit or disc of suspension type insulator is designed for low voltage,usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.

(iii) If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

(iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

(v) In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

(vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

Disadvantages of Suspension Insulator

1. Suspension insulator string costlier than pin and post type insulator.
2. Suspension string requires more height of supporting structure than that for pin or post insulator to maintain same ground clearance of current conductor.
3. The amplitude of free swing of conductors is larger in suspension insulator system, hence, more spacing between conductors should be provided.

Strain Insulator

When suspension string is used to sustain extraordinary tensile load of conductor it is referred as **string insulator**. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A **strain insulator** must have considerable mechanical strength as well as the necessary electrical insulating properties.

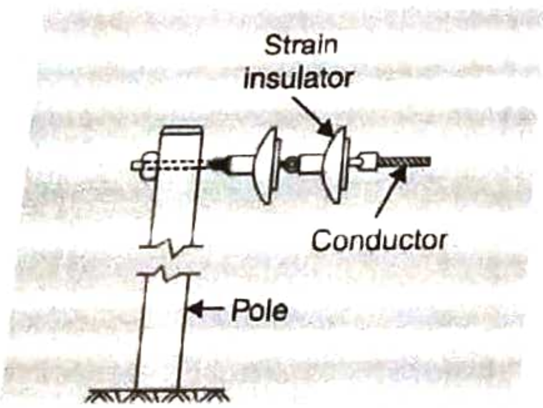

Fig 2.2- Strain Insulator

And the receiving end current

$$I_R = \frac{2(V_M - V_R)}{Z/2} \quad (7)$$

Now substituting V_M from equation (6) to (7) we get

$$V_S = \left(\frac{Y}{2}Z + 1\right)V_R + Z(\frac{Y}{4}Z + 1)I_R \quad (8)$$

Now the sending end current is,

$$I_S = YV_M + I_R \quad (9)$$

Substituting the value of V_M to equation (9) we get,

$$I_S = YV_R + (\frac{Y}{2}Z + 1)I_R \quad (10)$$

Again comparing equation (8) and (10) with the standard ABCD parameter equations, the parameters of the **T** network of a medium transmission line are

$$A = (\frac{Y}{2}Z + 1)$$

$$B = Z(\frac{Y}{4}Z + 1)$$

$$C = Y$$

$$D = (\frac{Y}{2}Z + 1)$$

Long Transmission Line

A power transmission line with its effective length of around 250 ms or above is referred to as a **long transmission line**. Calculations related to circuit parameters (ABCD parameters) of such a power transmission is not that simple, as was the case for a short transmission line or medium transmission line. The reason being that, the effective circuit length in this case is much higher than what it was for the former models (long and medium line) and, thus ruling out the approximations considered there like.