POWER SYSTEMS-II
(B.Tech, Electrical and Electronics Engineering)

Prepared
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UNIT-I
Transmission Line Parameters

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1. Types of conductors

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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

2. Aluminium:

Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength

3. 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

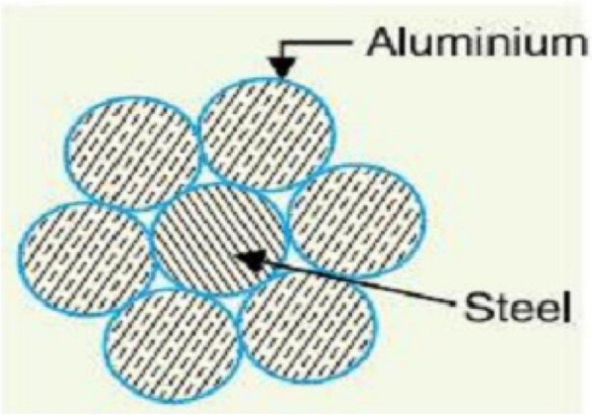


Fig 1.1:ACSR Conductor

Inductance of Single Phase Two Wire Line

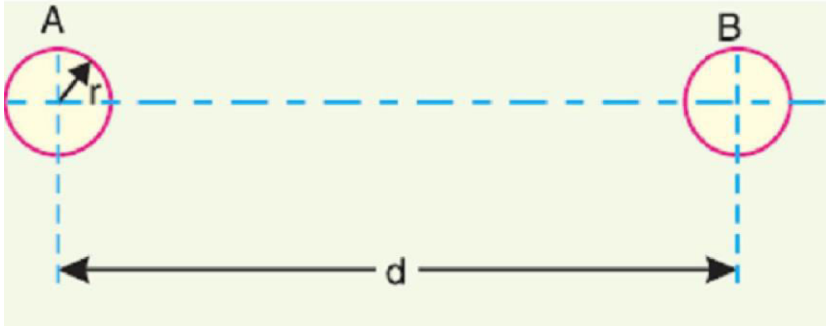


Fig 1.4: Single phase two wire transmission line

Flux linkages with conductor A due to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right]$$

Flux linkages with conductor A due to current I_B

$$= \frac{\mu_0 I_B}{2\pi}\left[\int_d^{\infty} \frac{dx}{x}\right]$$

Total flux linkage with the with conductor A is

$$\psi_A = \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty} \frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_d^{\infty}\frac{dx}{x}$$

On solving above equation, we get

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \ln\frac{d}{r}\right]$$

Inductance of conductor A is

$$L_A = \frac{\psi_A}{I_A}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \ln\frac{d}{r}\right] \text{ H/m}$$

$$= 2\times10^{-7}\left[\ln e^{\frac{1}{4}} + \ln\frac{d}{r}\right]$$

The radius r′ is that of a fictitious conductor assumed to have no internal flux but with the same inductance as the actual conductor of radius r. The quantity $e^{-1/4}$= = 0·7788 so that r′ = r $e^{-1/4}$= 0·7788 r

The term r′ (= r $e^{-1/4}$) is called geometric mean radius (GMR) of the conductor. Loop inductance = 2 L_A = 2 × 2 × 10−7 log d/r′ H/m

Note that r′ = 0·7788 r is applicable to only solid round conductor.

Inductance of Three phase Overhead line:

Fig. 1.4 shows the three conductors A, B and C of a 3-phase line carrying currents I_A, I_B and I_C respectively. Let d_1, d_2 and d_3 be the spacing between the conductors as shown.

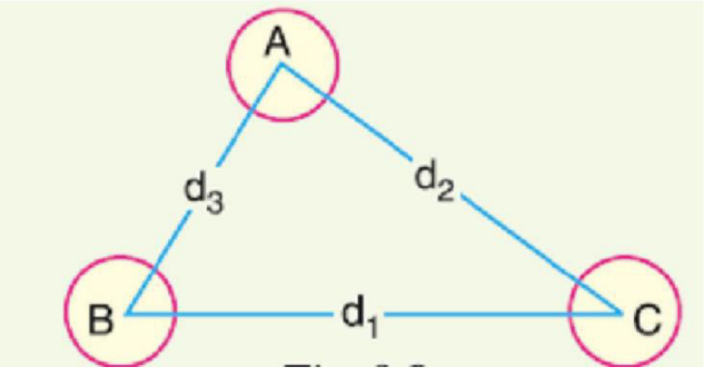


Fig 1.4 Three phase Overhead line

Flux linkages with conductor A due to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_r^{\infty}\frac{dx}{x}\right)$$

Similarly. Flux linkages with conductor A due to current I_B

x linkages with conductor A due to current I_c

The total Flux linkages with conductor A is

$$\psi_A = \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\left(\frac{1}{4} + \int_{d_1}^{\infty}\frac{dx}{x}\right) + \frac{\mu_0 I_C}{2\pi}\left(\frac{1}{4} + \int_{d_2}^{\infty}\frac{dx}{x}\right)$$

$I_A + I_B + I_C = 0$

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \ln r\right) I_A + I_B \ln d3 + I_C \ln d_2\right]$$

Symmetrical Spacing:

If the three conductors A, B and C are placed symmetrically at the corners of an equilateral triangle of side d, then, $d_1 = d_2 = d_3 = d$. Under such conditions, the flux linkages with conductor A become:

Inductance of conductor A, $L_A = \frac{\psi_A}{I_A} = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \ln\frac{d}{r}\right)\right]$ H/m

putting the value of $\mu_0 = 4\pi \times 10^{-7}$ in the above equation

$$L_A = 2\times 10^{-7}\left[\left(\ln\frac{d}{r'}\right)\right] \quad \text{H/m}$$

Unsymmetrical spacing

When 3-phase line conductors are not equidistant from each other, the conductor spacing is said to be unsymmetrical. Under such conditions, the flux linkages and inductance of each phase are not the same.

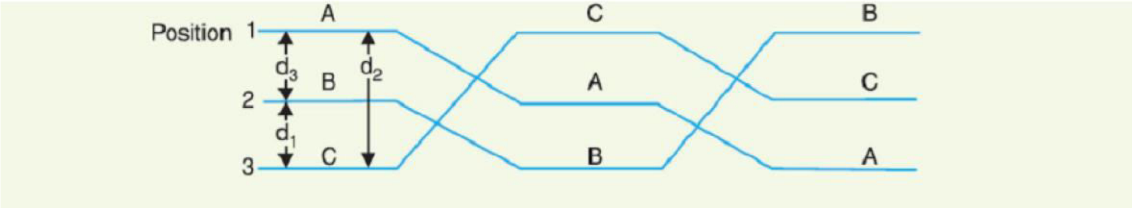


Fig 1.5: Transposition of three phase conductor

The inductance per phase can be

$$L_A = 2\times 10^{-7}\left[\left(\ln \frac{\sqrt[3]{d_1 d_2 d_3}}{r'}\right)\right] \text{ H/m}$$

Capacitance of Single Phase Two Wire Line

Consider a single phase overhead transmission line consisting of two parallel conductors A and B spaced d metres apart in air. Suppose that radius of each conductor is r metres. Let their respective charge be + Q and − Q coulombs per metre length.

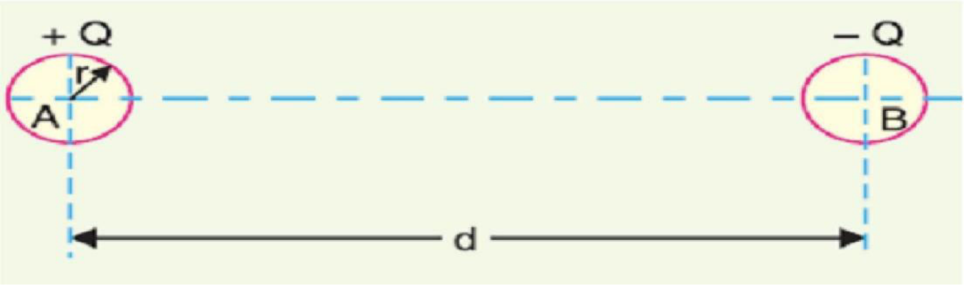


Fig 1.7: Single phase two wire transmission line

The total p.d. between conductor A and neutral "infinite" plane is

$$V_A = \frac{Q}{2\pi\varepsilon_0}\int_r^{\infty}\frac{dx}{x} - \frac{Q}{2\pi\varepsilon_0}\int_d^{\infty}\frac{dx}{x}$$

$$= \frac{Q}{2\pi\varepsilon_0}\ln\frac{d}{r} \text{ Volts}$$

Similarly, p.d. between conductor B and neutral "infinite" plane is

$$= \frac{-Q}{2\pi\varepsilon_0} \ln \frac{d}{r} \text{ Volts}$$

Both these potentials are w.r.t. the same neutral plane. Since the unlike charges attract each other, the potential difference between the conductors is

$$V_{AB} = 2V_A = \frac{2Q}{2\pi\varepsilon_0} \ln \frac{d}{r}$$

$$C_{AB} = \frac{Q}{V_{AB}} = \frac{\pi\varepsilon_0}{\ln \frac{d}{r}} \text{ F/m}$$

Capacitance to neutral:

$$C_N = C_{AN} = C_{BN} = 2C_{AB} = \frac{2\pi\varepsilon_0}{\ln \frac{d}{r}}$$

Capacitance of a 3-Phase Overhead Line

Capacitance of a 3-Phase Overhead Line

Symmetrical Spacing. Fig. 1.8 shows the three conductors A, B and C of the 3-phase overhead transmission line having charges Q_A, Q_B and Q_C per metre length respectively. Let the Conductors be equidistant (d metres) from each other. We shall find the capacitance from line conductor to neutral in this symmetrically spaced line

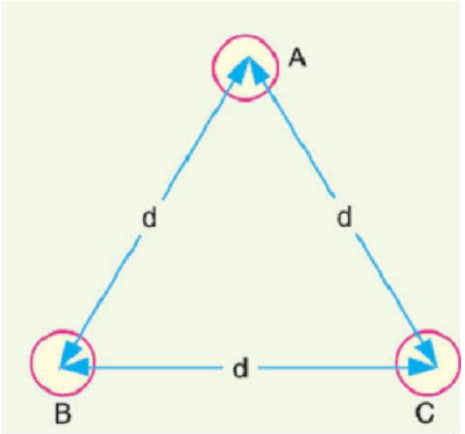


Fig 1.8 Three phase symmetrically spaced transmission line

$$V_A = \int_r^{\infty} \frac{Q_A}{2\pi\varepsilon_0 x} dx + \int_d^{\infty} \frac{Q_B}{2\pi\varepsilon_0 x} dx + \int_d^{\infty} \frac{Q_c}{2\pi\varepsilon_0 x} dx$$

Assuming $Q_A+Q_B+Q_C=0$

$$V_A = \frac{Q_A}{2\pi\varepsilon_0} \ln \frac{d}{r}$$

Capacitance of conductor A with respect to neutral

$$C_A = \frac{Q_A}{V_A} = \frac{2\pi\varepsilon_0}{\ln\frac{d}{r}} \quad \text{F/m}$$

Note that this equation is identical to capacitance to neutral for two-wire line. Derived in a similar manner, the expressions for capacitance are the same for conductors B and C.

Unsymmetrical spacing

Fig.1.9 shows a 3-phase transposed line having unsymmetrical spacing. Let us assume balanced conditions i.e. $Q_A + Q_B + Q_C = 0$.

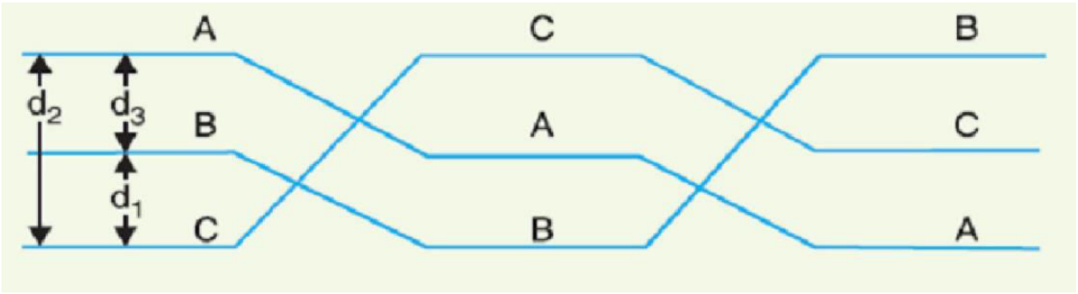


Fig 1.9: Unsymmetrical spaced transposed three phase line

$$V_A = \frac{Q_A}{2\pi\varepsilon} \ln \frac{\sqrt[3]{d_1 d_2 d_3}}{r}$$

Capacitance from conductor to neutral is

$$C_A = \frac{Q_A}{V_A} = \frac{2\pi\varepsilon_0}{\ln \frac{\sqrt[3]{d_1 d_2 d_3}}{r}}$$

$$C_A = \frac{Q_A}{V_A} = \frac{2\pi\varepsilon_0}{\ln \frac{\sqrt[3]{d_1 d_2 d_3}}{r}}$$

UNIT-II

Performance of shot, Medium and Long Length Transmission Lines

1. Short Transmission Line:

The transmission lines which have length less than 80 km are generally referred as **short transmission lines**.

$V_s = V_R + I_R.R.\cos\varphi_R + I_R.X.\sin\varphi_R$

As there is no capacitance, during no load condition the current through the line is considered as zero, hence at no load condition, receiving end voltage is the same as sending end voltage. As per definition of voltage regulation of power transmission line,

$$\%regulation = \frac{V_s - V_R}{V_R} X100\%$$

$$= \frac{I_R R\cos\Phi_R + I_R X\sin\Phi_R}{V_R} X100\%$$

Efficiency of Short Transmission Line

The efficiency of short line as simple as efficiency equation of any other electrical equipment, that means

$$\%\text{efficiency} = \frac{\text{Power received at receiving end}}{\text{Power received at receiving end} + 3I_R^2 R} X100$$

Medium Transmission Line:

The transmission line having its effective length more than 80 km but less than 250 km, is generally referred to as a **medium transmission line**

These lumped parameters of a medium length transmission line can be represented using two different models, namely

1. Nominal **Π** representation.

2. Nominal **T** representation.

Nominal Π Representation of a Medium Transmission Line

In case of a nominal **Π** representation, the lumped series impedance is placed at the middle of the circuit where as the shunt admittances are at the ends. As we can see from the diagram of the Π network below, the total lumped shunt admittance is divided into 2 equal halves, and each half with value Y / 2 is placed at both the sending and the receiving end while the entire circuit impedance is between the two

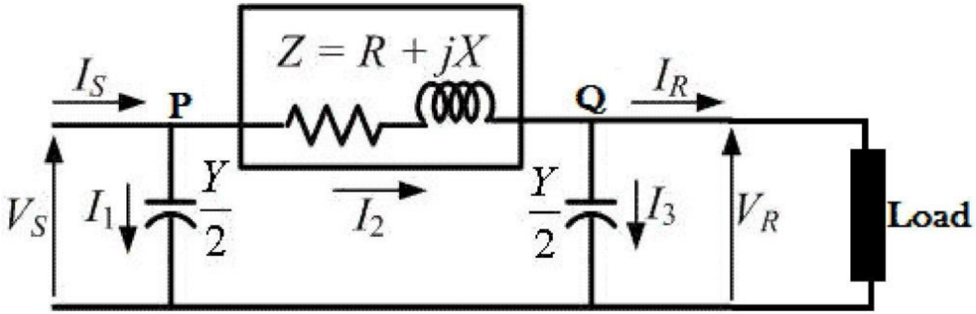


Fig.1.12: Nominal Π Representation of a Medium Transmission Line

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

$$B = Z$$

$$C = Y\left(\frac{Y}{4}Z + 1\right)$$

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

Nominal T Representation of a Medium Transmission Line

In the **nominal T** model of a medium transmission line the lumped shunt admittance is placed in the middle, while the net series impedance is divided into two equal halves and placed on either side of the shunt admittance.

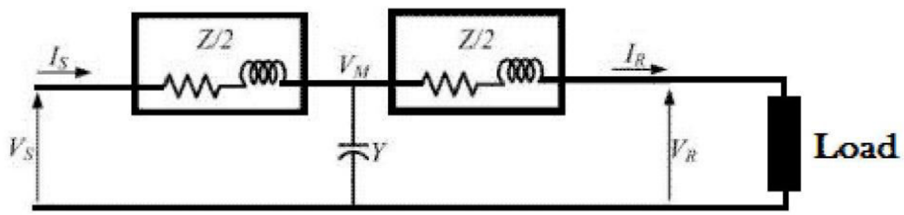


Fig.1.13: Nominal T representation of medium transmission line

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

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

$$C = Y$$

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

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**

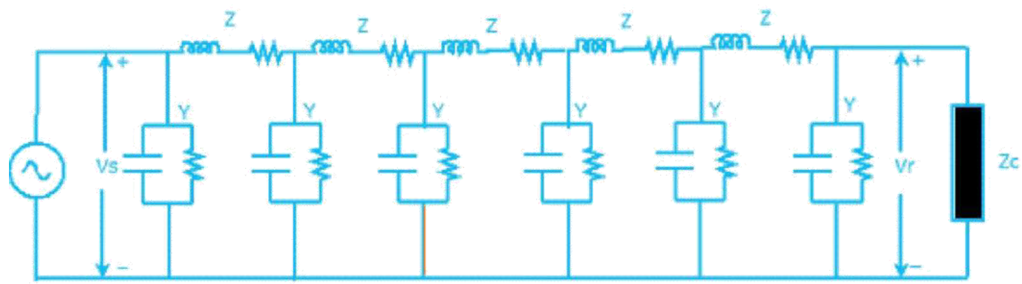


Fig.1.14: Long line model

For accurate modeling to determine circuit parameters let us consider the circuit of the **long transmission line** as shown in the diagram below.

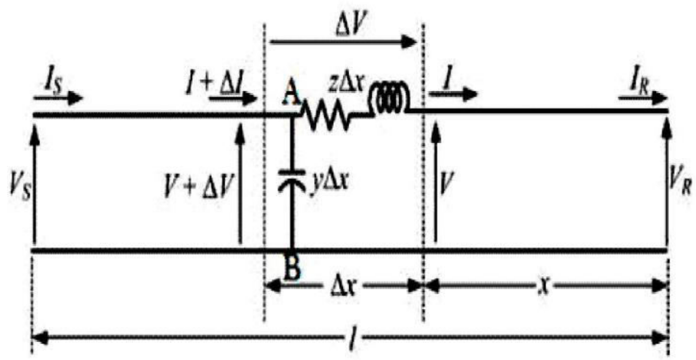


Fig.1.15: Modeling of long transmission line

ABCD parameters of a long transmission line as,

$A = \cosh \delta l$

$B = Z_C \sinh \delta l$

$C = \sinh \delta l / Z_C$

$D = \cosh \delta l$

UNIT-III

POWER SYSTEM TRANSIENTS&FACTORS GOVERING THE PERFORMANCE OF TRANSMISSION LINES

Skin Effect: The phenomena arising due to unequal distribution of current over the entire cross section of the conductor being used for long distance power transmission is referred as the skin effect in transmission lines.

Factors Affecting Skin Effect in Transmission Lines

The skin effect in an ac system depends on a number of factors like:-

Shape of conductor.

Type of material.

Diameter of the conductors.

Operational frequency.

Proximity Effect:

Proximity means nearness in space or time, so as the name suggests, proximity effect in transmission lines indicates the effect in one conductor for other neighbouring conductors. When the alternating current is flowing through a conductor, alternating magnetic flux is generated surrounding the conductor.

Corona

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called corona.

Factors Affecting Corona Effect in Power System

As mentioned earlier, the line voltage of the conductor is the main determining factor for corona in transmission lines, at low values of voltage (lesser than critical disruptive voltage) the stress on the air is too less to dissociate them, and hence no electrical discharge occurs.

Atmospheric Conditions for Corona in Transmission Lines

It has been physically proven that the voltage gradient for di-electric breakdown of air is directly proportional to the density of air.

Hence in a stormy day, due to continuous air flow the number of ions present surrounding the conductor is far more than normal, and hence its more likely to have electrical discharge in transmission lines on such a day, compared to a day with fairly clear weather. The system has to designed taking those extreme situations into consideration.

Condition of Cables for Corona in Transmission Line.

This particular phenomena depends highly on the conductors and its physical condition. It has an inverse proportionality relationship with the diameter of the conductors. i.e. with the increase in diameter, the effect of corona in power system reduces considerably.

Also the presence of dirt or roughness of the conductor reduces the critical breakdown voltage, making the conductors more prone to corona losses. Hence in most cities and industrial areas having high pollution, this factor is of reasonable importance to counter the ill effects it has on the system.

Spacing between Conductors

As already mentioned, for corona to occur effectively the spacing between the lines should be much higher compared to its diameter, but if the length is increased beyond a certain limit, the dielectric stress on the air reduces and consequently the effect of corona reduces as well. If the spacing is made too large then corona for that region of the transmission line might not occur at all.

Important Terms:

The phenomenon of corona plays an important role in the design of an overhead transmission line. Therefore, it is profitable to consider the following terms much used in the analysis of corona effects

Critical Disruptive Voltage:

It is the minimum phase-neutral voltage at which corona occurs. Consider two conductors of radii r cm and spaced d cm apart. If V is the phase-neutral potential, then potential gradient at the conductor surface is given by:

$$g_0 = \frac{V_c}{r \ln \frac{d}{r}}$$

The value of g_o is directly proportional to air density. Thus the breakdown strength of air at a barometric pressure of b cm of mercury and temperature of t°C becomes δg_0 where

$$\boldsymbol{\delta = \text{air density factor}} = \frac{3.92}{273+t}$$

Under standard conditions, the value of $\delta = 1$.

Visual critical voltage

It is the minimum phase-neutral voltage at which corona glow appears all along the line conductors.

It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage Vc but at a higher voltage V_v, called **visual critical voltage**. The phase-neutral effective value of visual critical voltage is given by the following empirical formula

$$V_v = m_v g_0 \delta r \left(1 + \frac{0.3}{\sqrt{\delta r}}\right) \ln \frac{d}{r} \text{ kV/phase}$$

where m_v is another irregularity factor having a value of 1·0 for polished conductors and 0·72 to 0·82 for rough conductors.

Power loss due to corona

Formation of corona is always accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action. When disruptive voltage is exceeded, the power loss due to corona is given by:

$$P = 241 \times 10^{-5} \left(\frac{f + 25}{\delta} \right) \sqrt{\frac{r}{d}} (V - V_c)^2 \text{ kw/km/phase}$$

Advantages and Disadvantages of Corona

Corona has many advantages and disadvantages. In the correct design of a high voltage overheadline, a balance should be struck between the advantages and disadvantages. Below are the Advantages and disadvantages of Corona.

Disadvantages

Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.
Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.

Methods to reduce Corona Discharge Effect

By minimizing the voltage stress and electric field gradient.:
This is accomplished by using utilizing good high voltage design practices, i.e., maximizing the distance between conductors that have large voltage differentials, using conductors with large radii, and avoiding parts that have sharp points or sharp edges.

Surface Treatments: Corona inception voltage can sometimes be increased by using a surface treatment, such as a semiconductor layer, high voltage putty or corona dope.

Homogenous Insulators: Use a good, homogeneous insulator. Void free solids, such as properly prepared silicone and epoxy potting materials work well.
Using Bundled Conductors: on our 345 kV lines, we have installed multiple conductors per phase. This is a common way of increasing the effective diameter of the conductor, which in turn results in less resistance, which in turn reduces losses.
By increasing the spacing between the conductors: Corona Discharge Effect can be reduced by increasing the clearance spacing between the phases of the transmission lines. However increase in the phase's results in heavier metal supports. Cost and Space requirement increases.
By increasing the diameter of the conductor: Diameter of the conductor can be increased to reduce the corona discharge effect. By using hollow conductors corona discharge effect can be improved.

UNIT-IV

Overhead Line Insulators & Sag Tension Calculations

Electrical Insulator must be used in electrical system to prevent unwanted flow of current to the earth from its supporting points. The **insulator** plays a vital role in electrical system.

Electrical Insulator is a very high resistive path through which practically no current can flow. In transmission and distribution system, the overhead conductors are generally supported by supporting towers or poles. The towers and poles both are properly grounded. So there must be **insulator** between tower or pole body and current carrying conductors to prevent the flow of current from conductor to earth through the grounded supporting towers or poles

Properties of Insulating Material

It must be mechanically strong enough to carry tension and weight of conductors.
It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.
It must possesses high Insulation Resistance to prevent leakage current to the earth.
The **insulating material** must be free from unwanted impurities.
It should not be porous.

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

1.Pin Insulator

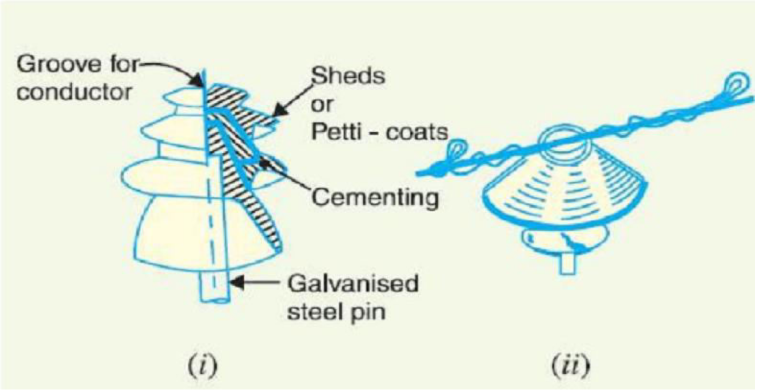
2.Suspension Insulator

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 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.

Designing Consideration of Electrical Insulator

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.

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

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

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.

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

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.

Disadvantages of Suspension Insulator

Suspension insulator string costlier than pin and post type insulator.

Suspension string requires more height of supporting structure than that for pin or post insulator to maintain same ground clearance of current conductor.

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.

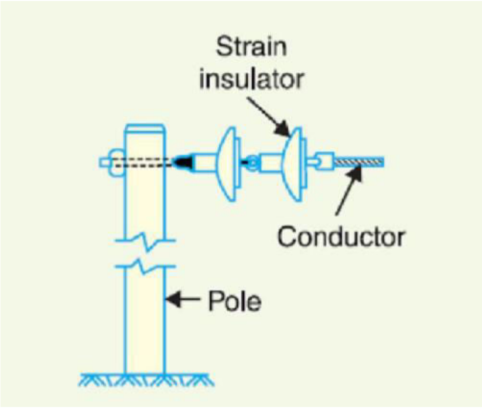


Fig 2.2- Strain Insulator

Shackle Insulator or Spool Insulator

The **shackle insulator** or **spool insulator** is usually used in low voltage distribution network. It can be used both in horizontal and vertical position. The use of such insulator has decreased recently after increasing the using of underground cable for distribution purpose. The tapered hole of the **spool insulator** distributes the load more evenly and minimizes the possibility of breakage when heavily loaded. The conductor in the groove of **shackle insulator** is fixed with the help of soft binding wire.

Potential distribution overa string of suspension insulators:

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links.

The following points may be noted regarding the potential distribution over a string of suspension insulators:
The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.

The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalize the potential across each unit.

The presence of stray capacitance causes unequal potential distribution over the string. The end unit of the string (which is the closest to the line) takes maximum potential difference and the upper units have a gradually decreased potential difference until the uppermost unit which has the lowest potential difference.

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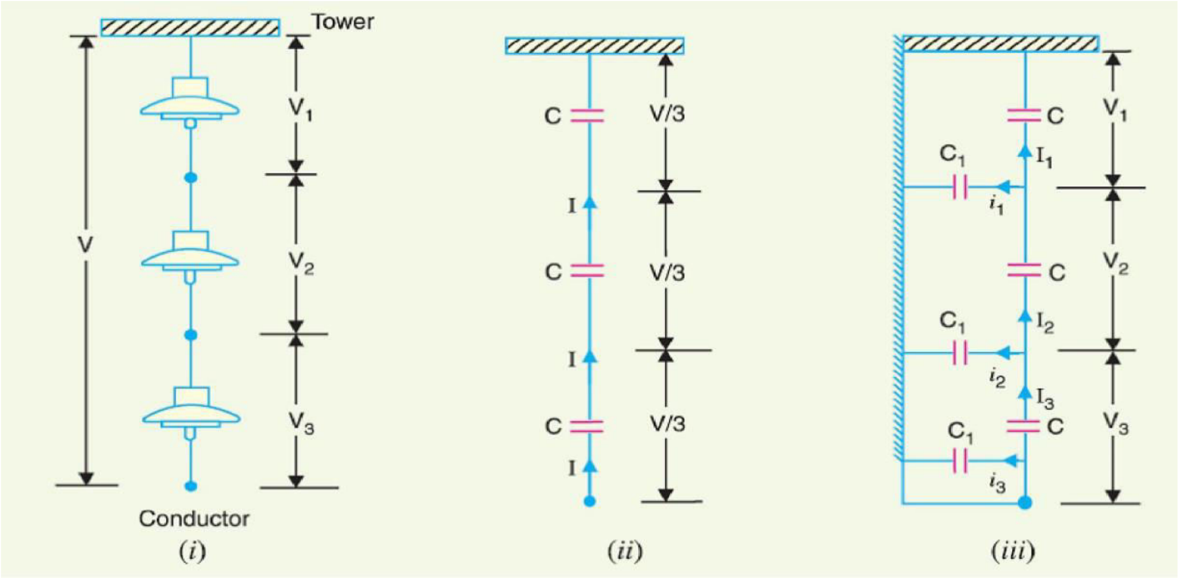


Fig 2.3- Suspension Insulator string

String Efficiency:

String Efficiency=

$$\frac{\text{Voltage across the string}}{\text{n*Voltage across disc near to conductor}}$$

Where n is the no. of discs in the string.

String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution.
Mathematical expression. Fig. 2.3(iii) shows the equivalent circuit for a 3-disc string. Let us suppose that self capacitance of each disc is C. Let us further assume that shunt capacitance C1 is some fraction K of self capacitance i.e., C1 = KC. Starting from the cross-arm or tower, the voltage across each unit is V1,V2 and V3 respectively as shown. Applying kirchoff's current law to node A
$I2 = I_1 + i_1$

$V_2 = V_1 \ C + V_1 \ C_1$

$V_2 \ C = V_1 \ C + V_1 \ KC$

$V_2 = V_1 \ (1 + K)$

$$\%string\ efficiency = \frac{V}{3 * V_3} 100$$

String Efficiency and methods to improve String Efficiency

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency i.e.,

Methods of Improving String Efficiency

By using longer cross-arms. The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance

By grading the insulators In this method, insulators of different dimensions are so chosen that each has a different capacitance. The insulators are capacitance graded i.e. they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (i.e., nearest to conductor) is reached. Since voltage is inversely proportional to capacitance, this method tends to equalise the potential distribution across the units in the string.

By using a guard ring The potential across each unit in a string can be equalized by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator.

Conductor Material

The most common conductor in use for transmission today is aluminum conductor steel reinforced (ACSR). Also seeing much use is all-aluminum-alloy conductor (AAAC). Aluminum is used because it has about half the weight of a comparable resistance copper cable (though larger diameter due to lower fundamental conductivity), as well as being cheaper. Copper was more popular in the past and is still in use, especially at lower voltages and for grounding. Bare copper conductors are light green.

BUNDLE CONDUCTORS

For higher amounts of current, **bundle conductors** are used for several reasons. Due to the skin effect, for larger conductors, the current capacity does not increase proportional to the cross-sectional area; instead, it is only with the linear dimension. Also, reactance decreases only slowly with size. But the cost and weight do increase with area. Due to this, several conductors in parallel become more economical.

Advantages

At extra high voltage, the electric field gradient at the surface of a single conductor is high enough to ionize air, which loses power and generates both audible noise and interference with communication systems

MECHANICAL DESIGN OF TRANSMISSION LINE

Sag in Overhead Transmission Line While erecting an overhead line, it is very important that conductors are under safe tension. If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension.

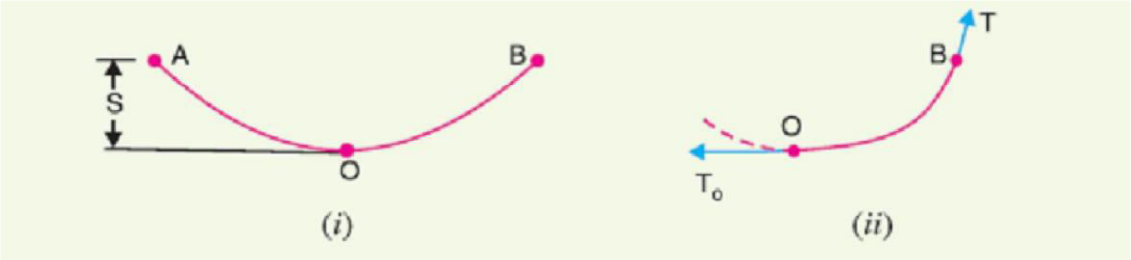


Fig 2.4- Sag in a transmission line

The following points may be noted:

When the conductor is suspended between two supports at the same level, it takes the shape of catenary. However, if the sag is very small compared with the span, then sag-span curve is like a parabola.

The tension at any point on the conductor acts tangentially. Thus tension T_0 at the lowest Point O acts horizontally as shown in Fig. (ii).

The horizontal component of tension is constant throughout the length of the wire.

The tension at supports is approximately equal to the horizontal tension acting at any point on the wire. Thus if T is the tension at the support B, then $T = T_0$.

Conductor sag and tension

This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level

Calculation of Sag: In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, effects of wind, ice loading and temperature variations. It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength i.e., minimum factor of safety in respect of conductor tension should be 2. We shall now calculate sag and tension of a conductor when (i) supports are at equal levels and (ii) supports are at unequal levels.

When supports are at equal levels. Consider a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig. 2.5

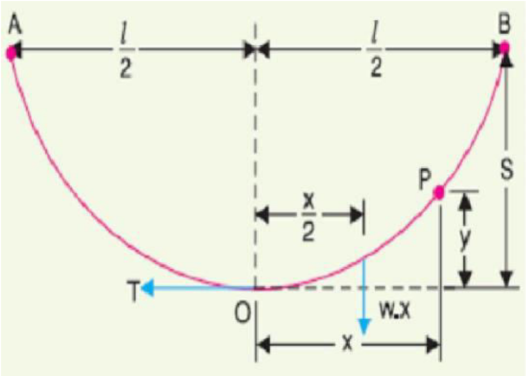


Fig 2.5- Sag Calculation

A conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.

5. It can be proved that lowest point will be at the mid-span. Let l = Length of span

w = Weight per unit length of conductor T = Tension in the conductor.

$$\text{Sag } S = \frac{wl^2}{8T}$$

Effect of wind and ice loading: The above formulae for sag are true only in still air and at normal temperature when the conductor is acted by its weight only. However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure.

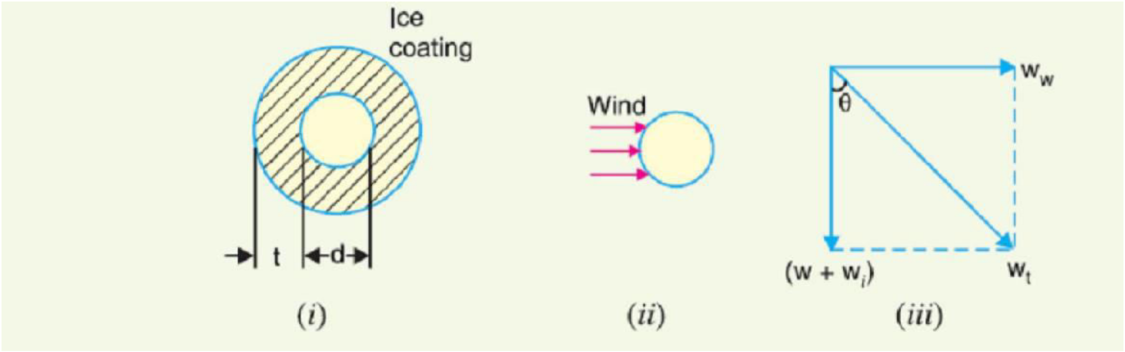


Fig 2.6- Effect of Ice and Wind

Total weight of conductor per unit length is

$$w_t = (w + w_i)^2 + w_w^{\ 2}$$

Where w = weight of conductor per unit length

= conductor material density × volume per unit length

w_i = weight of ice per unit length

density of ice * volume of ice per unit length

$$= \text{density of ice x } \frac{\pi}{4}\left[(d + 2t)^2 - d^2\right] \times 1$$

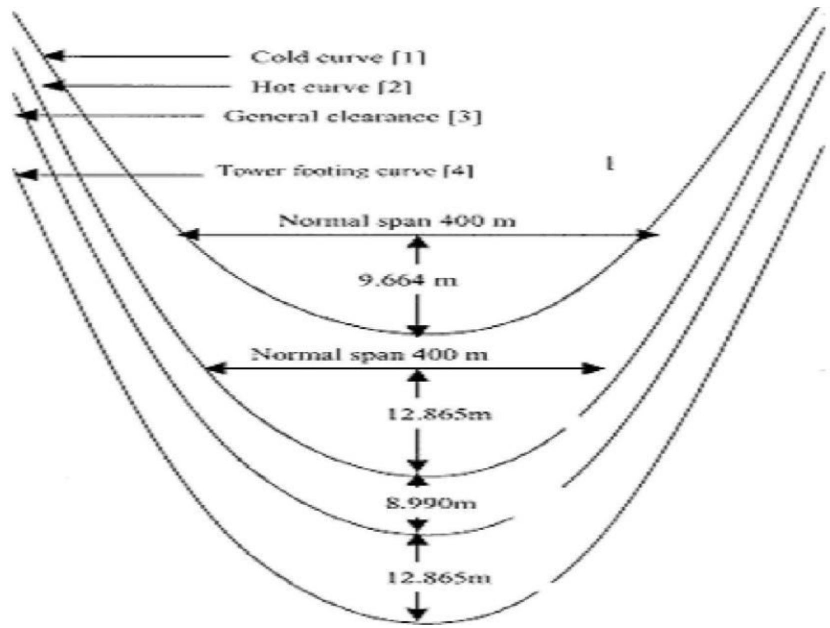
w_w = wind force per unit length

wind pressure per unit area × projected area per unit length

wind pressure x [(d + 2t)* 1]

Sag Template

: A Sag Template is a very important tool with the help of which the position of towers on the Profile is decided so that they conform to the limitations of vertical and wind loads on any particular tower, and minimum clearances, as per I.E. Rules, required to be maintained between the line conductor to ground, telephone lines, buildings, streets, navigable canals, power lines, or any other object coming under or near the line.



A Sag Template is specific for the particular line voltage, the conductor used and the applicable design conditions. Therefore, the correct applicable Sag Template should be used. A Sag Template consists of a set of parabolic curves drawn on a transparent celluloid or a crylic clear sheet duly cut in over the maximum conductor sag curve to allow the conductor curve to be drawn and the lowest points of the conductor sag to be marked on the profile when the profile is placed underneath it.

UNIT-V
UNDERGROUND CABLES

INSULATED CABLES: Electric power can be transmitted or distributed either by overhead system or by underground cables. The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chance of faults, smaller voltage drop and better general appearance. However, their major drawback is that they have greater installation cost and introduce insulation problems at high voltages compared with the equivalent overhead system.

Underground Cables:-An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover. Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements. In general, a cable must fulfill the following necessary requirements:

The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. Stranding is done so that conductor may become flexible and carry more current.

The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.

Construction of Cables:Figure shows the general construction of a 3-conductor cable. The various parts are

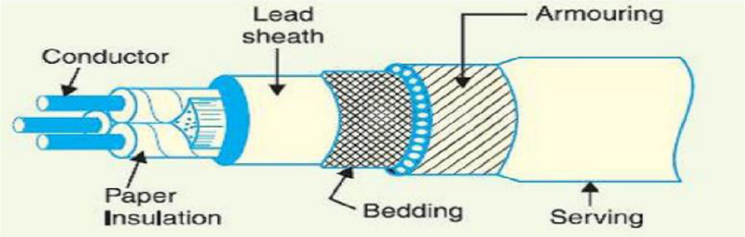


Fig 2.9- Cable

Cores or Conductors. A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. For instance, the 3 conductor cable shown in Figure is used for 3-phase service. The conductors are made of tinned copper or aluminum and are usually stranded in order to provide flexibility to the cable.

Insulation. Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable. The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound.

Insulating Materials for Cables:-The satisfactory operation of a cable depends to a great extent upon the characteristics of insulation used. Therefore, the proper choice of insulating material for cables is of considerable importance. In general, the insulating materials used in cables should have the following properties:

High insulation resistance to avoid leakage current.

High dielectric strength to avoid electrical breakdown of the cable.

High mechanical strength to withstand the mechanical handling of cables.

(iv)Non-hygroscopic i.e., it should not absorb moisture from air or soil. The moisture tends to decrease the insulation resistance and hastens the breakdown of the cable. In case the insulating material is hygroscopic, it must be enclosed in a waterproof covering like lead sheath.
The principal insulating materials used in cables are rubber, vulcanized rubber, impregnated paper and polyvinyl chloride

1. **Rubber**: Rubber may be obtained from milky sap of tropical trees or it may be produced from oil products. It has relative permittivity varying between 2 and 3, dielectric strength is about 30 kV/mm and resistivity of insulation is 1017 cm.

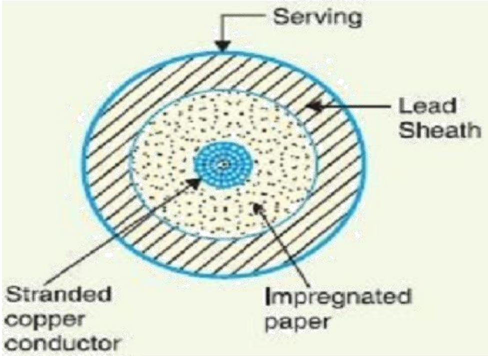
Vulcanised India Rubber (V.I.R.). It is prepared by mixing pure rubber with mineral matter such as zinc oxide, red lead etc., and 3 to 5% of sulphur

Impregnated paper. It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinic or naphthenic material. This type of insulation has almost superseded the rubber insulation

Polyvinyl chloride (PVC). This insulating material is a synthetic compound. It is obtained

from the polymerization of acetylene and is in the form of white powder.

Classification of Cables: -Cables for underground service may be classified in two ways according to (i) the type of insulating material used in their manufacture (ii) the voltage for which they are manufactured. However, the latter method of classification is generally preferred, according to which cables can be divided into the following groups



Low-tension (L.T.) cables — upto 1000 V

High-tension (H.T.) cables — upto 11,000 V

Super-tension (S.T.) cables — from 22 kV to 33 kV (iv)Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
Extra super voltage cables — beyond 132 kV
A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc. For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand.

Cable for 3-phase

In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used. For voltages upto 66 kV, 3-core cable (i.e., multi-core construction) is preferred due to economic reasons. However, for voltages beyond 66 kV, 3-core-cables become too large and unwieldy and, therefore, single-core cables are used. The following types of cables are generally used for 3-phase service:
Belted cables — upto 11 kV
Screened cables — from 22 kV to 66 kV
Pressure cables — beyond 66 kV

Dielectric Stress in Cable

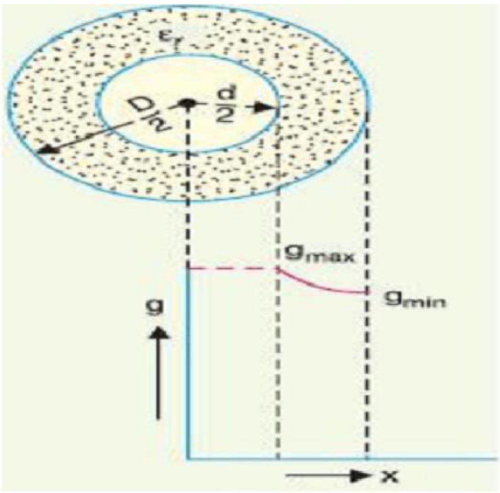


Fig 2.11- Dielectric Stress in Cable

Under operating conditions, the insulation of a cable is subjected to electrostatic forces. This is known as dielectric stress. The dielectric stress at any point in a cable is in fact the potential gradient (or electric intensity) at that point. Consider a single core cable with core diameter d and internal sheath diameter D. The electric intensity at a point x metres from the centre of the cable is

$$E_x = \frac{Q}{2\pi\varepsilon_0\varepsilon_r x} \quad \text{volts/m}$$

By definition, electric intensity is equal to potential gradient. Therefore, potential gradient g at point x meters from the Centre of cable is

$$g = E_x$$

$$g = \frac{E}{2\pi\varepsilon_0\varepsilon_r x} \quad \text{volts/m}$$

Potential difference V between conductor and sheath is

$$V = \frac{Q}{2\pi\varepsilon_0\varepsilon_r}\ln\frac{D}{d} \quad \text{volts}$$

$$Q = \frac{2\pi\varepsilon_0\varepsilon_r V}{\ln\frac{D}{d}}$$

Substituting the value of Q, we get

$$g = \frac{V}{x\ln\frac{D}{d}} \quad \text{volts/m}$$

Maximum potential gradient is

$$g_{max} = \frac{2V}{d \ln \frac{D}{d}} \text{ volts/m}$$

Minimum potential gradient is

$$g_{min} = \frac{2V}{D \ln \frac{D}{d}} \text{ volts/m}$$

$$\frac{g_{max}}{g_{min}} = \frac{D}{d}$$

Most Economical Size of Conductor:

It has already been shown that maximum stress in a cable occurs at the surface of the conductor. For safe working of the cable, dielectric strength of the insulation should be more than the maximums tress.

$$g_{max} = \frac{2V}{d \ln \frac{D}{d}} \text{ volts/m}$$

Most economical conductor diameter is

cc $$d = \frac{D}{2.718}$$

and the value of g_{max} under this condition is

$$g_{max} = \frac{2V}{d} \text{ volts/m}$$

Grading of Cables

The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables. It has already been shown that electrostatic stress in a single core cable has a maximum value (g_{max}) at the conductor surface and goes on decreasing as we move towards the sheath. The maximum voltage that can be safely applied to a cable depends upon g_{max} i.e., electrostatic stress at the conductor surface.

(i) Capacitance grading (ii) Intersheath grading

Capacitance Grading:

The process of achieving uniformity in the dielectric stress by using layers of different dielectrics is known as capacitance grading.

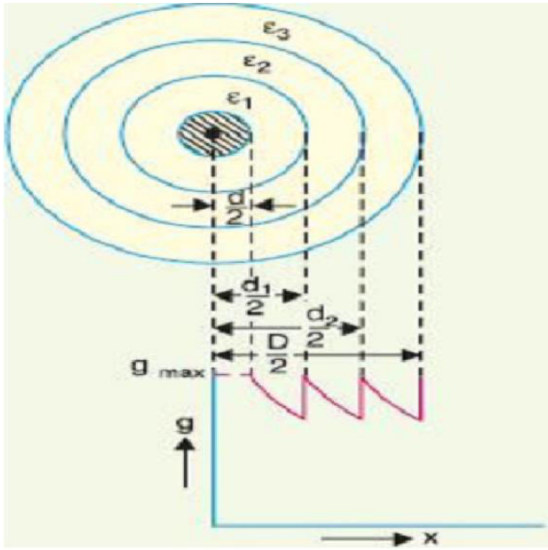


Fig 2.12- Capacitance grading

In capacitance grading, the homogeneous dielectric is replaced by a composite dielectric. The composite dielectric consists of various layers of different dielectrics in such a manner that relative permittivity >r of any layer is inversely proportional to its distance from the center

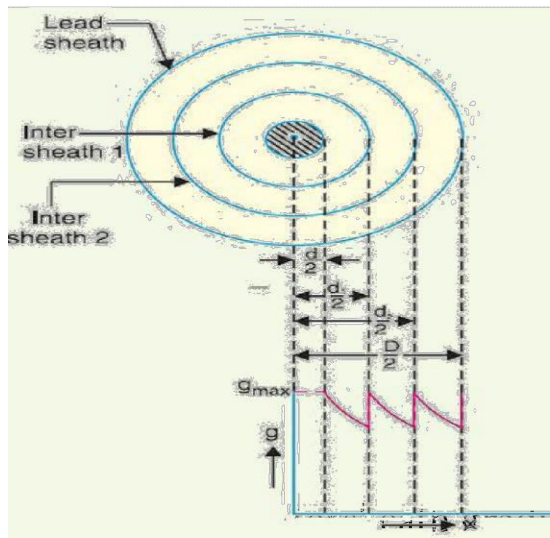
There are three dielectrics of outer diameter d_1, d_2 and D and of relative permittivity >1, >2 and >3 respectively. If the permittivity are such that >1 > 2 > 3 and the three dielectrics are worked at the same maximum stress, then

Total p.d. between core and earthed sheath is

$$= V_1 + V_2 + V_3$$

$$V = \frac{g_{max}}{2}\left[d \ln\frac{d_1}{d} + d_1 \ln\frac{d_2}{d_1} + d_2 \ln\frac{D}{d_2}\right]$$

Intersheath Grading: : In this method of cable grading, a homogeneous dielectric is used, but it is divided into various layers by placing metallic inters heaths between the core and lead sheath.



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Consider a cable of core diameter d and outer lead sheath of diameter D. Suppose that two intersheaths of diameters d_1 and d_2 are inserted into the homogeneous dielectric and maintained at some fixed potentials.

Since the dielectric is homogeneous, the maximum stress in each layer is the same i.e.,

$$g_{1\max} = g_{2\max} = g_{3\max} = g_{\max}$$

$$\frac{V_1}{\frac{d}{2}\ln\frac{d_1}{d}} = \frac{V_2}{\frac{d_1}{2}\ln\frac{d_2}{d_1}} = \frac{V_2}{\frac{d_2}{2}\ln\frac{D}{d}}$$

As the cable behaves like three capacitors in series, therefore, all the potentials are in phase i.e. Voltage between conductor and earthed lead sheath is

$$V = V_1 + V_2 + V_3$$

Inter sheath grading has three principal disadvantages. Firstly, there are complications in fixing the sheath potentials.

Measurement of capacitance of 3-core cables

In three-core cables, capacitance does not have a single value, but can be lumped as shown in below figure.

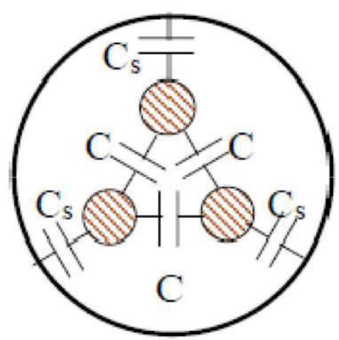

Fig 2.14- Cable Capacitance

These can be separated from measurements as described in the following section.
Strap the 3 cores together and measure the capacitance between this bundle and the sheath as shown in figure.

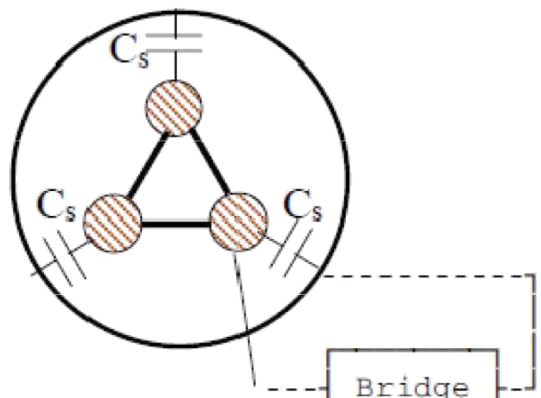

Fig 2.16-Capacitance Measurement

Connect 2 of the cores to the sheath and measure between the remaining core and the sheath.
Measured value $C_{m2} = 2\,C + C_s$

i.e. $C = (C_{m2} - C_s)/2 = (3\,C_{m2} - C_{m1})/6$
Which gives the capacitance between the conductors.

The effective capacitance to neutral Co of any of the cores may be obtained by considering the star equivalent. This gives

$$C_0 = C_s + 3C = \frac{1}{3}C_m 1 + 3\frac{3C_m^2 - C_m^1}{6}$$

$$C_0 = \frac{3}{2}C_m^2 - \frac{1}{6}C_m^1$$

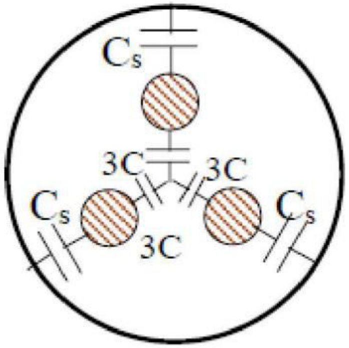

Fig 2.17-Calculation of C_0

In the breakdown of actual 3-core belted cables, it is generally observed that charring occurs at those places where the stress is tangential to the layers of paper