3.2 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

We shall now calculate sag and tension of a conductor when

(i) supports are at equal levels and

(ii) supports are at unequal levels.

(i) 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.8.2. It can be proved that lowest point will be at a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.3.2.1 It can be proved that lowest point will be at the mid-span.

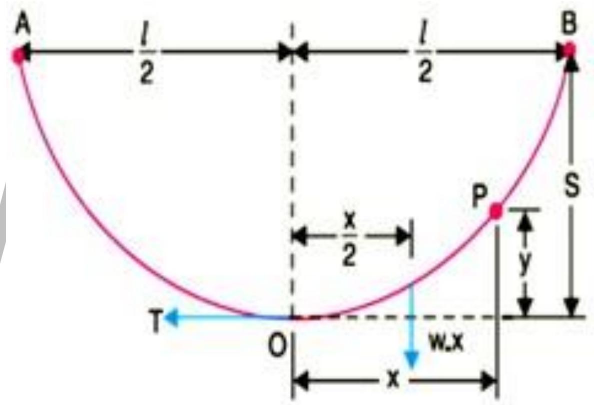

Figure 3.2.1 Supports are at Equal Levels

[Source: "Principles of Power System" by V.K.Mehta Page: 187]

conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.3.2.1. 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.

Consider a point P on the conductor. Taking the lowest point O as the origin, let the co-ordinates of point P be x and y. Assuming that the curvature is so small that curved length is equal to its horizontal projection (i.e., OP = x), the two forces acting on the portion OP of the conductor are :

(a) The weight wx of conductor acting at a distance x/2 from O.

Moment of force due to weight = wx× x/2

(b) The tension T acting at O .

Moment of force due to tension = Ty

Equating the moments of above two forces about point O, we get,

$$Ty = wx \times \frac{x}{2}$$

$$y = \frac{wx^2}{2T}$$

The maximum dip (sag) is represented by the value of *y* at either of the supports *A* and *B*. At support *A*, *x* = *l*/2 and *y* = *S*, Sag

$$S = \frac{w(l/2)^2}{2T}$$

$$= \frac{wl^2}{8T}$$

(ii) When supports are at unequal levels. In hilly areas, we generally come across conductors

suspended between supports at unequal levels. Fig. 3.2.2 shows a conductor suspended between two supports *A* and *B* which are at different levels. The lowest point on the conductor is *O*.

Let

l = Span length

h = Difference in levels between two supports

*x*1 = Distance of support at lower level (*i.e.*, *A*) from *O*

*x*2 = Distance of support at higher level (*i.e. B*) from *O*

T = Tension in the conductor

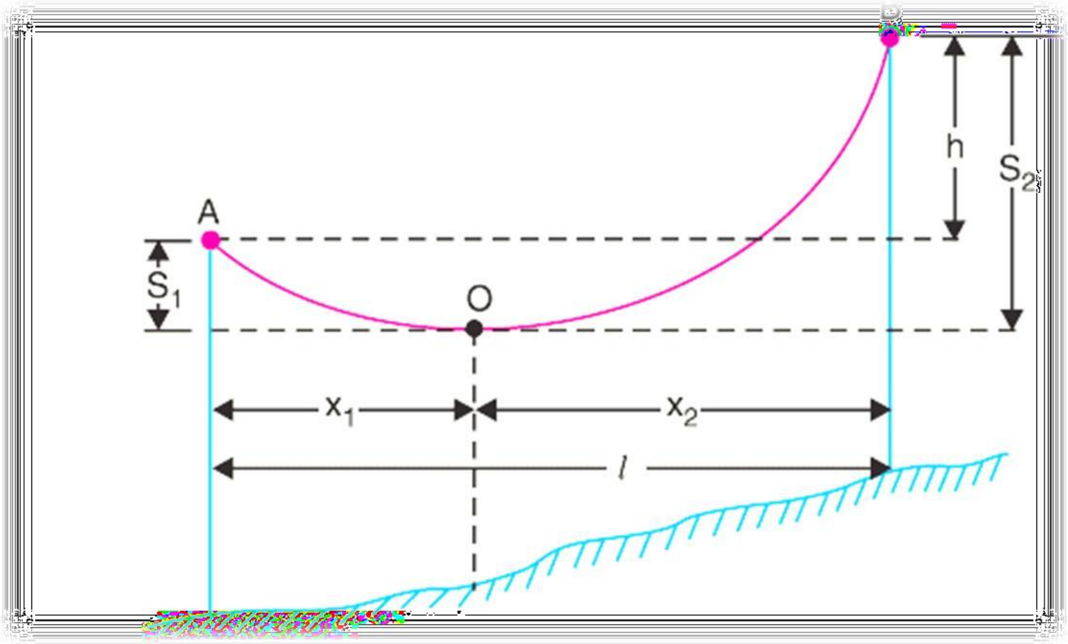

Figure 3.2.2 Supports are at UnEqual Levels

[Source: "Principles of Power System" by V.K.Mehta Page: 188]

$$S_1 = \frac{wx_1^2}{2T}$$

$$S_2 = \frac{Wx_2^2}{2T}$$

$$x_1 + x_2 = l$$

$$S_2 - S_1 = \frac{w(x_2^2 - x_1^2)}{2T}$$

$$S_2 - S_1 = \frac{w(x_1 + x_2)(x_2 - x_1)}{2T}$$

$$S_2 - S_1 = \frac{wl(x_2 - x_1)}{2T}$$

$$S_2 - S_1 = h$$

$$h = \frac{wl(x_2 - x_1)}{2T}$$

$$x_2 - x_1 = \frac{2Th}{wl}$$

$$x_1 = \frac{l}{2} - \frac{T\,h}{w\,l}$$

$$x_2 = \frac{l}{2} + \frac{T\,h}{w\,l}$$

3.2.1 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. The weight of ice acts vertically downwards *i.e.*, in the same direction as the weight of conductor. The force due to the wind is assumed to act horizontally *i.e.*, at right angle to the projected surface of the conductor.Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in Fig.3.2.3.

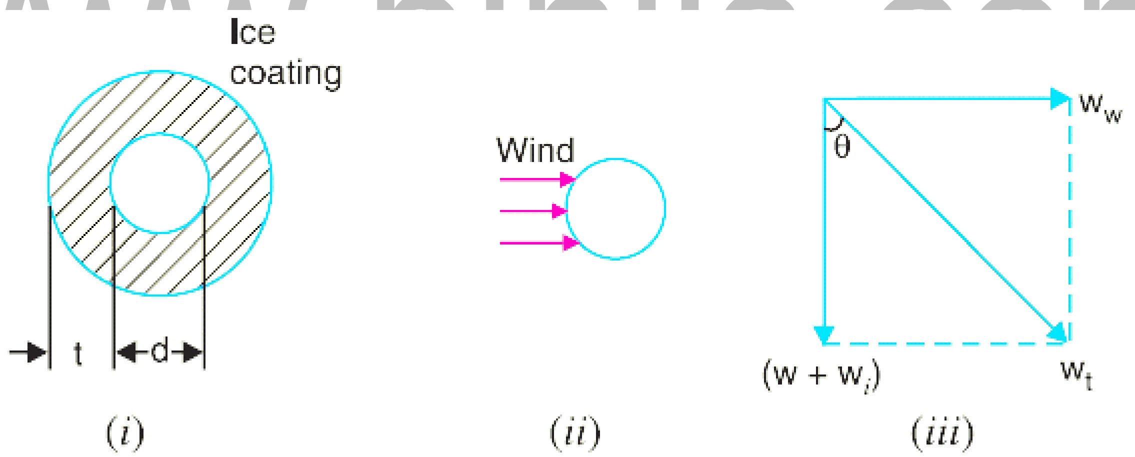

Figure 3.2.3 Effect of Wind and Ice Loading

[Source: "Principles of Power System" by V.K.Mehta Page: 189]

Total weight of conductor per unit length is,

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

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

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

$$= \text{density of ice} \times \pi\, t\,(d+t)^*$$

w_w = *wind force per unit length*

= *wind pressure per unit area × projected area per unit length*

= wind Pressure × [(d + 2t) × 1]

When the conductor has wind and ice loading also, the following points may be noted :

(i) The conductor sets itself in a plane at an angle θ to the vertical where

$$\tan\theta = \frac{w_w}{w+w_i}$$

(ii) The sag in the conductor is given by,

$$S = \frac{w_t l^2}{2T}$$

Hence S represents the slant sag in a direction making an angle θ to the vertical. If no specific mention is made in the problem, then slant slag is calculated by using the above formula.

(iii) The vertical sag = S cos θ

Problem 1

A 132 kV transmission line has the following data : Wt. of conductor = 680 kg/km ; Length of span = 260 m ; Ultimate strength = 3100 kg ; Safety factor = 2

Calculate the height above ground at which the conductor should be supported. Ground clearance required is 10 metres.

Solution:

Wt. of conductor/metre run, w = 680/1000 = 0·68 kg

Working tension, $$T = \frac{\text{Ultimate strength}}{\text{Safety factor}} = \frac{3100}{2} = 1550 \text{ kg}$$

Span length, l = 260 m

$$\therefore \quad \text{Sag} = \frac{w\,l^2}{8T} = \frac{0\cdot 68 \times (260)^2}{8 \times 1550} = 3\cdot 7 \text{ m}$$

Problem 2

A transmission line has a span of 150 m between level supports. The conductor has a cross-sectional area of 2 cm2. The tension in the conductor is 2000 kg. If the specific gravity of the conductor material is 9·9 gm/cm3 and wind pressure is 1·5 kg/m length, calculate the sag. What is the vertical sag?

Solution:

Span length, $l = 150$ m; Working tension, $T = 2000$ kg

Wind force/m length of conductor, $w_w = 1\cdot5$ kg

Wt. of conductor/m length, w = Sp. Gravity × Volume of 1 m conductor

$= 9\cdot9 \times 2 \times 100 = 1980 \text{ gm} = 1\cdot98 \text{ kg}$

Total weight of 1 m length of conductor is

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1\cdot98)^2 + (1\cdot5)^2} = 2\cdot48 \text{ kg}$$

$$\text{Sag, } S = \frac{w_t l^2}{8T} = \frac{2\cdot48 \times (150)^2}{8 \times 2000}$$

$$= 3.48 \text{ m}$$

This is the value of slant sag in a direction making an angle θ with the vertical. Referring to Fig. 8.27, the value of θ is given by ;

$$\tan\theta = w_w/w = 1\cdot5/1\cdot98 = 0\cdot76$$

$$\theta = \tan^{-1} 0\cdot76 = 37\cdot23°$$

$$\text{Vertical sag} = S\cos\theta$$

$$= 3\cdot48 \times \cos 37\cdot23°$$

$$= 2.77 \text{ m}$$

Problem 3

A transmission line has a span of 275 m between level supports. The conductor has an effective diameter of 1·96 cm and weighs 0·865 kg/m. Its ultimate strength is 8060 kg. If the conductor has ice coating of radial thickness 1·27 cm and is subjected to a wind pressure of 3·9 gm/cm2 of projected area, calculate sag for a safety factor of 2. Weight of 1 c.c. of ice is 0·91 gm.

Solution:

Span length, l = 275 m ; Wt. of conductor/m length, w = 0·865 kg

Conductor diameter, d = 1·96 cm ; Ice coating thickness, t = 1·27 cm

Working tension, T = 8060/2 = 4030 kg

Volume of ice per metre (*i.e.*, 100 cm) length of conductor

$$= \pi\, t\,(d + t) \times 100 \text{ cm}^3$$

$$= \pi \times 1{\cdot}27 \times (1{\cdot}96 + 1{\cdot}27) \times 100 = 1288 \text{ cm}^3$$

Weight of ice per metre length of conductor is

$$w_i = 0{\cdot}91 \times 1288 = 1172 \text{ gm} = 1{\cdot}172 \text{ kg}$$

Wind force/m length of conductor is

$$w_w = [\text{Pressure}] \times [(d + 2t) \times 100]$$

$$= [3{\cdot}9] \times (1{\cdot}96 + 2 \times 1{\cdot}27) \times 100 \text{ gm}$$

$$= 1755 \text{ gm}$$

$$= 1{\cdot}755 \text{ kg}$$

Total weight of conductor per metre length of conductor is

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

$$w_t = \sqrt{(0.865 + 1.172)^2 + (1.755)^2}$$

$$= 2{\cdot}688 \text{ kg}$$

Sag ,

$$S = \frac{\quad}{\quad}$$

$$= \frac{2.688 \times (275)^2}{8 \times 4030}$$

$$= \; 6.8 \text{ m}$$

Problem 4

The towers of height 30 m and 90 m respectively support a transmission line conductor at water crossing. The horizontal distance betwen the towers is 500 m. If the tension in the conductor is 1600 kg, find the minimum clearance of the conductor and water and clearance mid-way between the supports. Weight of conductor is 1·5 kg/m. Bases of the towers can be considered to be at water level.

Solution:

Fig. 3.2.4 shows the conductor suspended between two supports *A* and *B* at different levels with *O* as the lowest point on the conductor.

Here, l = 500 m ; w = 1·5 kg ; T = 1600 kg.

Difference in levels between supports, h = 90 − 30 = 60 m. Let the lowest point O of the conductor be at a distance $x1$ from the support at lower level (*i.e.*, support A) and at a distance $x2$ from the support at higher level (*i.e.*, support B).

Obviously, $x1 + x2 = 500$ m

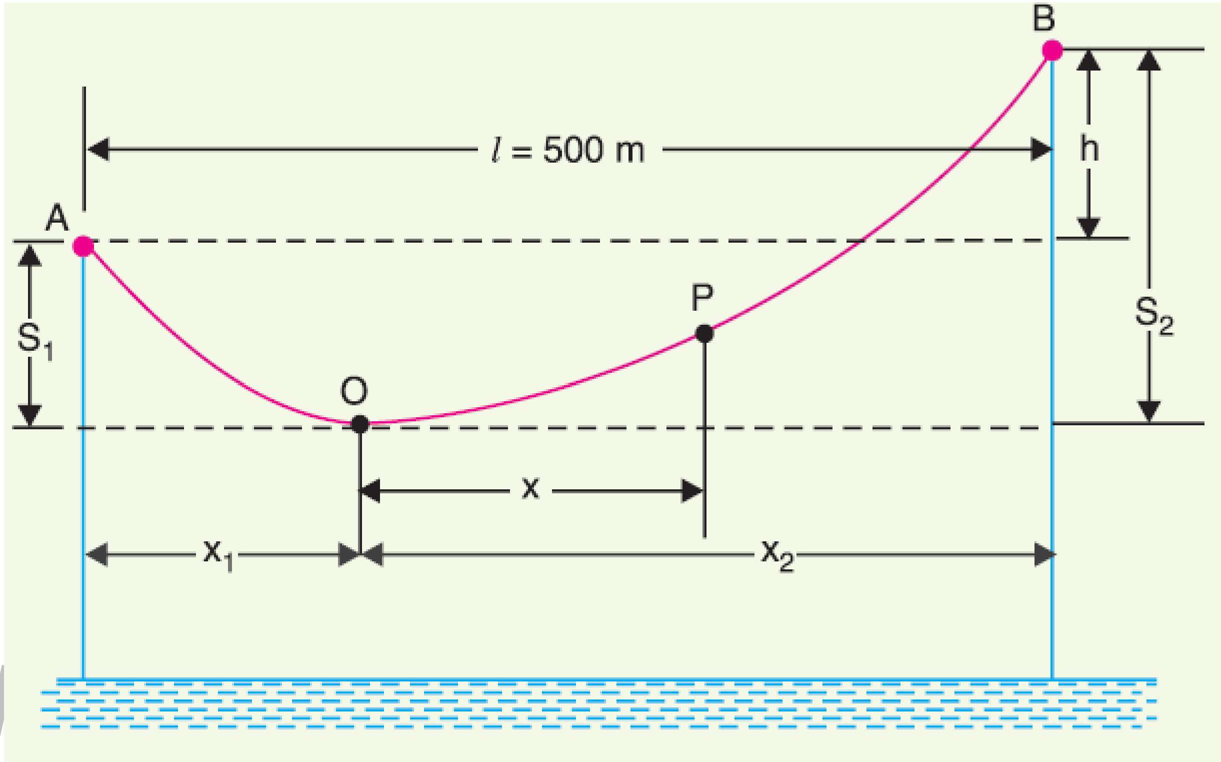

Figure 3.2.4 Conductor b/w two Supports

[Source: "Principles of Power System" by V.K.Mehta Page: 193]

$$\text{Sag } S_1 = \frac{w\,x_1^2}{2T} \quad \text{and} \quad \text{Sag } S_2 = \frac{w\,x_2^2}{2T}$$

$$h = S_2 - S_1 = \frac{w\,x_2^2}{2T} - \frac{w\,x_1^2}{2T}$$

$$60 = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$x_2 - x_1 = \frac{60 \times 2 \times 1600}{1 \cdot 5 \times 500} = 256 \text{ m}$$

we get, x_1 = 122 m ; x_2 = 378 m

$$S = \frac{w_t l^2}{2T}$$

$$= \frac{1.5 \times (122)^2}{2 \times 1600}$$

$= 7m$

Clearance of the lowest point *O* from water level

$= 30 - 7 =$ **23 m**

Let the mid-point *P* be at a distance *x* from the lowest point *O*.

Clearly,

$x = 250 - x1$

$= 250 - 122$

$= 128$ m

Sag at mid-point *P*,

$$S_{mid} = \frac{wx^2}{2T}$$

$$= \frac{1.5 \times (128)^2}{2 \times 1600}$$

$= 7.68$ m

Clearance of mid-point *P* from water level

$= 23 + 7{\cdot}68$

$= 30{\cdot}68$ m

3.7 METHODS OF IMPROVING STRING EFFICIENCY

It has been seen above that potential distribution in a string of suspension insulators is not uniform. The maximum voltage appears across the insulator nearest to the line conductor and decreases progressively as the cross arm is approached. If the insulation of the highest stressed insulator breaks down or flash over takes place, the breakdown of other units will take place in succession. This necessitates equalizing the potential across the various units of the string *i.e.* to improve the string efficiency. The various methods for this purpose are:

(i) 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. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used. However, limitations of cost and strength of tower do not allow the use of very long cross-arms. In practice, K = 0·1 is the limit that can be achieved by this method.

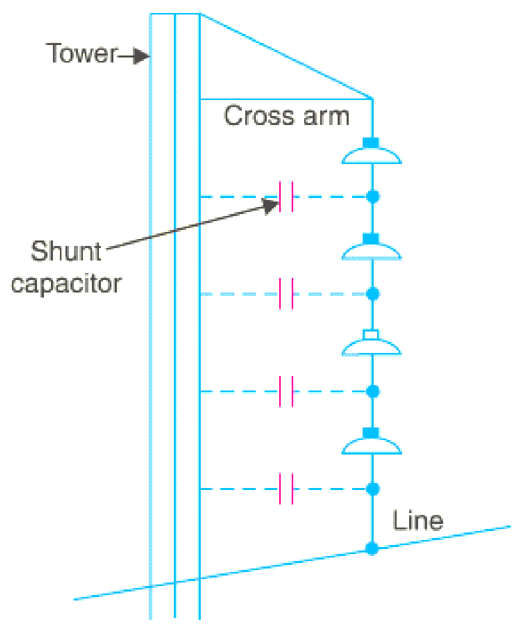

Figure 3.7.1 Longer Cross- Arms

[Source: "Principles of Power System" by V.K.Mehta Page: 170]

(ii) 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 equalize the potential distribution across the units in the string. This method has the disadvantage that a large number of different-sized insulators are required. However, good results can be obtained by using standard insulators for most of the string and larger units for that near to the line conductor.

(iii) By Using A Guard Ring

The potential across each unit in a string can be equalised by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as shown in the Fig The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is contoured in such a way that shunt capacitance currents i1, i2 etc. are equal to metal fitting line capacitance currents i′1, i′2 etc. The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.

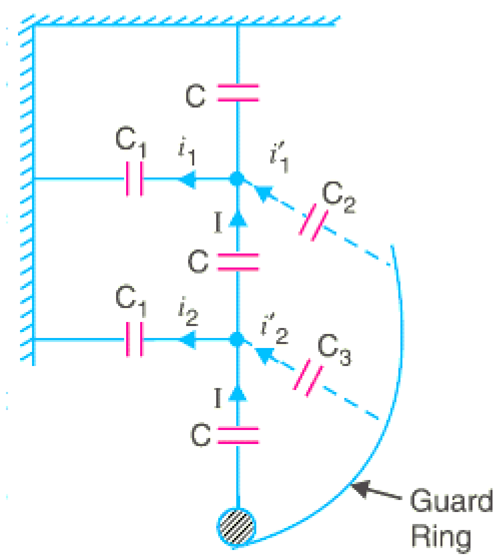

Figure 3.7.2 A Guard Ring

[Source: "Principles of Power System" by V.K.Mehta Page: 171]

Problem 1

In a 33 kV overhead line, there are three units in the string of insulators. If the capacitance between each insulator pin and earth is 11% of self-capacitance of each insulator, find (i) the distribution of voltage over 3 insulators and (ii) string efficiency.

Solution

The equivalent circuit of string insulators is,

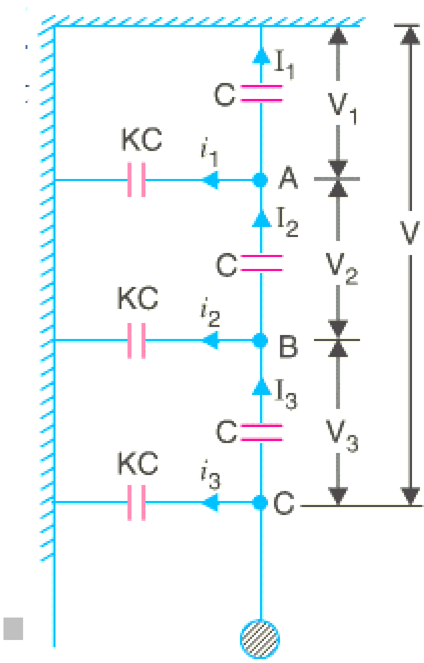

Figure 3.7.3 Equivalent circuit of string insulators

[Source: "Principles of Power System" by V.K.Mehta Page: 171]

$$K = \frac{\text{Shunt Capacitance}}{\text{Self - capacitance}} = 0.11$$

$$\text{Voltage across string, } V = 33/\sqrt{3} = 19{\cdot}05 \text{ kV}$$

At Junction A

$$I_2 = I_1 + i_1$$

$$V_2 \omega C = V_1 \omega C + V_1 K \omega C$$

$$V_2 = V_1 (1 + K) = V_1 (1 + 0{\cdot}11)$$

$$V_2 = 1{\cdot}11\, V_1$$

At Junction B

$$I_3 = I_2 + i_2$$
$$V_3 \omega C = V_2 \omega C + (V_1 + V_2) K \omega C$$
$$V_3 = V_2 + (V_1 + V_2) K$$
$$= 1{\cdot}11 V_1 + (V_1 + 1{\cdot}11\, V_1)\, 0{\cdot}11$$
$$V_3 = 1{\cdot}342\, V_1$$

(i) Voltage across the whole string is

$$V = V_1 + V_2 + V_3 = V_1 + 1{\cdot}11\, V_1 + 1{\cdot}342\, V_1 = 3{\cdot}452\, V_1$$
$$19{\cdot}05 = 3{\cdot}452\, V_1$$

$\therefore$ Voltage across top unit, $V_1 = 19{\cdot}05/3{\cdot}452$

= 5·52 kV

Voltage across middle unit, $V_2 = 1{\cdot}11\, V_1 = 1{\cdot}11 \times 5{\cdot}52$

= 6.13 kV

Voltage across bottom unit, $V_3 = 1{\cdot}342\, V_1 = 1{\cdot}342 \times 5{\cdot}52$

= 7.4 Kv

(ii) String efficiency

$$= \frac{\text{Voltage across string}}{\text{No. of insulators} \times V_3} \times 100 = \frac{19\cdot 05}{3 \times 7\cdot 4} \times 100$$

= 85.8 %

3.5 POTENTIAL DISTRIBUTION OVER SUSPENSION INSULATOR STRING

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig. shows 3-disc string of suspension insulators. The porcelain portion of each disc is in between two metal links. Therefore, each disc forms a capacitor C as shown in Fig. This is known as mutual capacitance or self-capacitance. If there were mutual capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same i.e., V/3 as shown However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging current is not the same through all the discs of the string Therefore, voltage across each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum voltage. Thus referring to Fig V3 will be much more than V2 or V1.

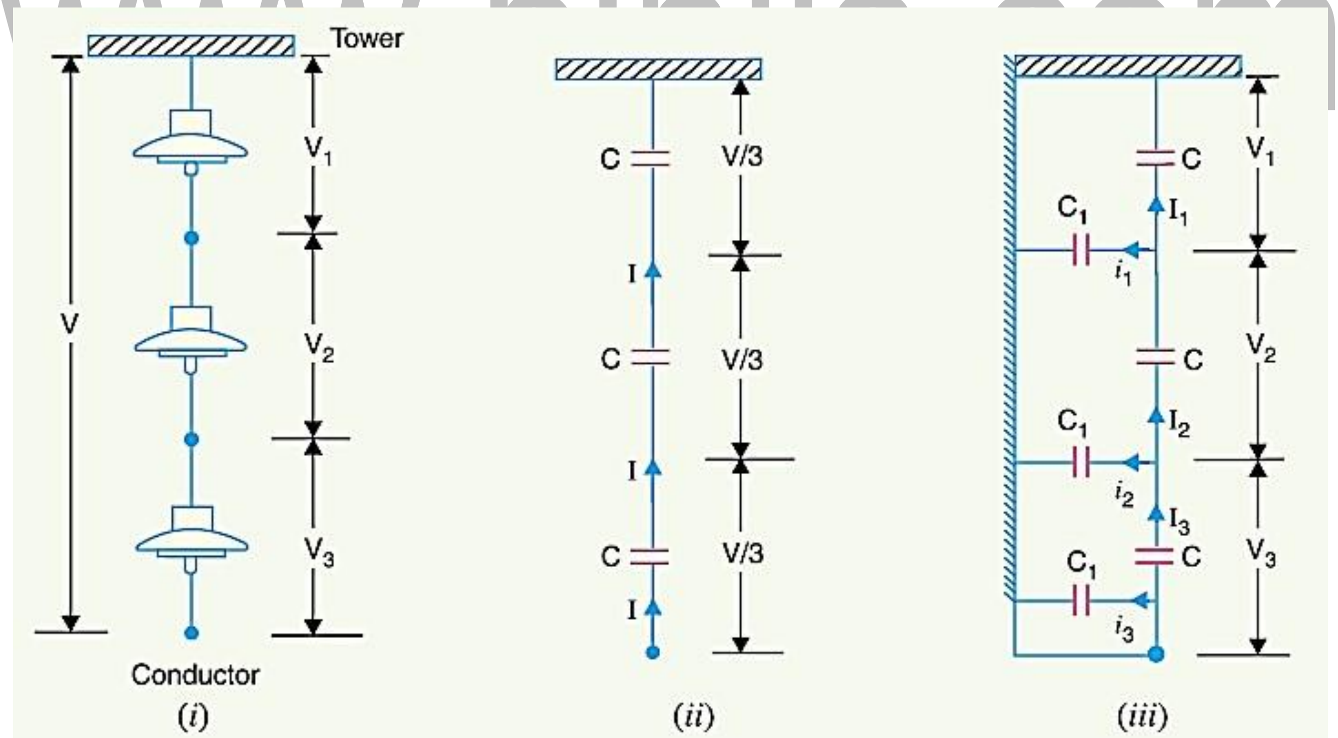

Figure 3.1 Potential Distribution

[Source: "Principles of Power System" by V.K.Mehta Page: 168]

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.
- If the voltage impressed across the string were d.c., then voltage across each unit would be the same. It is because insulator capacitances are ineffective for d.c.

3.1 SAG IN OVERHEAD LINES

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. In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag. The difference in level between points of supports and the lowest point on the conductor is called sag. Following Fig. shows a conductor suspended between two equal level supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point on the conductor is O and the sag is S. The following points may be noted

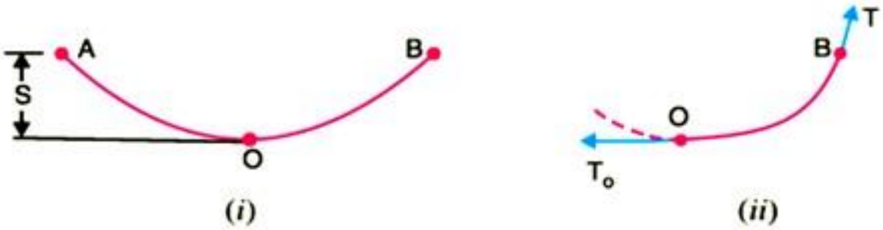

Figure 3.1 Sag in Overhead lines

[Source: "Principles of Power System" by V.K.Mehta Page: 187]

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

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

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

(iv) 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 = TO

3.6 STRING EFFICIENCY

As stated above, the voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of 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.,

$$\text{string efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}}$$

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. Thus 100% string efficiency is an ideal case for which the voltage across each disc will be exactly the same. Although it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.

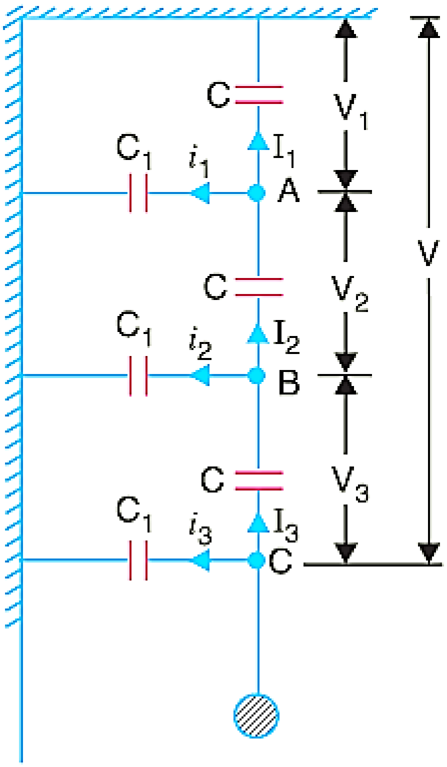

Figure 3.6.1 Equivalent Circuit - 3-Disc String

[Source: "Principles of Power System" by V.K.Mehta Page: 169]

Mathematical Expression. Fig. 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 Kirchhoff's current law to node *A*, we get,

$I_2 = I_1 + i_1$

or $V_2\omega C^* = V_1\omega C + V_1\omega C_1$

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

$\therefore\ V_2 = V_1(1 + K)$ ...(*i*)

Applying Kirchhoff's current law to node *B*, we get,

$I_3 = I_2 + i_2$

or $V_3\omega C = V_2\omega C + (V_1 + V_2)\omega C_1$

or $V_3\omega C = V_2\omega C + (V_1 + V_2)\omega KC$

or $V_3 = V_2 + (V_1 + V_2)K$ ...(*i*)

$= KV_1 + V_2(1 + K)$

$= KV_1 + V_1(1 + K)^2$ [$\therefore\ V2 = V1(1 + K)$]

$= V_1[K + (1 + K)^2]$

$\therefore\ V_3 = V_1[1 + 3K + K^2]$ ...(*ii*)

Voltage between conductor and earth (*i.e.*, tower) is

$V = V_1 + V_2 + V_3$

$= V_1 + V_1(1 + K) + V1(1 + 3K + K_2)$

$= V_1(3 + 4K + K^2)$

$\therefore\ V = V_1(1 + K)(3 + K)$ ...(*iii*)

From expressions (*i*), (*ii*) and (*iii*), we get,

$$\frac{V_1}{1} = \frac{V_2}{1 + K} = \frac{V_3}{1 + 3K + K^2} = \frac{V}{(1 + K)(3 + K)}$$

$\therefore$ Voltage across top unit, $V_1 = \dfrac{V}{(1 + K)(3 + K)}$

Voltage across second unit from top, $V_2 = V_1(1 + K)$

Voltage across third unit from top, $V_3 = V_1(1 + 3K + K^2)$

$$\% \text{ string efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100$$

$$= \frac{V}{n \times 3V_3} \times 100$$

The following points may be noted from the above mathematical analysis :

(i)If $K = 0{\cdot}2$ (Say), then from exp. (*iv*), we get, $V_2 = 1{\cdot}2\ V_1$ and $V_3 = 1{\cdot}64\ V_1$. This clearly shows that disc nearest to the conductor has maximum voltage across it; the voltage across other discs decreasing progressively as the cross-arm in approached.

(ii) The greater the value of K (= $C1/C$), the more non-uniform is the potential across the Discs and lesser is the string efficiency.

(iii) The inequality in voltage distribution increases with the increase of number of discs in the string. Therefore, shorter string has more efficiency than the larger one.

3.8 TESTING OF INSULATOR

To ensure the desired performance of an electrical insulator, that is for avoiding unwanted insulator failure, each insulator has to undergo numbers of insulator test. Before going through testing of insulator we will try to understand different causes of insulator failure. Because insulator testing ensures the quality of electrical insulator and chances for failure of insulation depend upon the quality of insulator.

(i) Cracking Of Insulator

The porcelain insulator mainly consists of three different materials. The main porcelain body, steel fitting arrangement and cement to fix the steel part with porcelain. Due to changing climate conditions, these different materials in the insulator expand and contract in different rate. These unequal expansion and contraction of porcelain, steel and cement are the chief cause of cracking of insulator.

(ii) Defective Insulation Material

If the insulation material used for insulator is defective anywhere, the insulator may have a high chance of being puncher from that place.

(iii) Porosity In The Insulation Materials

If the porcelain insulator is manufactured at low temperatures, it will make it porous, and due to this reason it will absorb moisture from air thus its insulation will decrease and leakage current will start to flow through the insulator which will lead to insulator failure.

(iv) Improper Glazing on Insulator Surface

If the surface of porcelain insulator is not properly glazed, moisture can stick over it. This moisture along with deposited dust on the insulator surface, produces a conducting path. As a result the flash over distance of the insulator is reduced. As the flash over distance is reduced, the chance of failure of insulator due to flash over becomes more.

(v) Flash Over Across Insulator

If flash over occurs, the insulator may be over heated which may ultimately results into shuttering of it.

(vi) Mechanical Stresses on Insulator

If an insulator has any weak portion due to manufacturing defect, it may break from that weak portion when mechanical stress is applied on it by its conductor. These are the main causes of insulator failure. Now we will discuss the different insulator test procedures to ensure minimum chance of failure of insulation.

3.8.1 Types of Testing Of Insulators

Following are the different types of tests that are carried out on overhead line insulators.

1. Flashover tests
2. Performance tests
3. Routine tests

Flashover Tests Of Insulators

Three types of flashover tests are conducted before the insulator is said to have passed the flashover test.

1. Power frequency dry flashover test
2. Power frequency wet flashover test
3. Impulse frequency flashover test

Power Frequency Dry Flashover Test

The insulator to be tested is mounted in the same manner in which it is to be used. Then, a variable voltage source of power frequency is connected between the electrodes of the insulator. The voltage is gradually increased up to the specified voltage. This specified voltage is less than the minimum flashover voltage. The voltage at which surrounding air of the insulator breaks down and become conductive is known as flashover voltage. The insulator must be capable of withstanding the specified voltage for one minute without flashover.

Power Frequency Wet Flashover Test (Rain Test)

In this test also, the insulator to be tested is mounted in the same manner in which it is to be used. Similar to the above test, a variable voltage source of power frequency is connected between the electrodes. Additionally, in this test, the insulator is sprayed with water at an angle of 45° in such a manner that its precipitation should not be more than 5.08 mm/min. The voltage is then gradually increased up to the specified voltage. The voltage is maintained at the specified value for 30 seconds or one minute and the insulator is observed for puncture or breakdown. If the voltage is maintained for one minute, this test is also called as one-minute rain test.

Impulse Frequency Flashover Test

This test is to ensure that the insulator is capable of sustaining high voltage surges caused by lightning. The insulator under test is mounted in the same manner as in above tests. An impulse voltage generator which generates a very high voltage at a frequency of several hundred kilohertz is connected to the insulator. This voltage is applied to the insulator and spark-over voltage is noted. The ratio of impulse spark-over voltage to spark-over voltage at power frequency is called as the impulse ratio. This ratio should be approximately 1.4 for pin type insulators and 1.3 for suspension type insulators.

3.8.2 Performance Tests Of Insulators

1. Temperature cycle test
2. Puncture voltage test
3. Mechanical strength test
4. Electro-mechanical test
5. Porosity test

Temperature Cycle Test

In this test, the insulator under test is first heated in water at 70° for one hour. Then the insulator is immediately cooled at 7° for another hour. This cycle is repeated three times. Then the insulator is dried and its glazing is thoroughly observed for any damages or deterioration.

Puncture Voltage Test

The purpose of this test is to determine the puncture voltage. The insulator to be tested is suspended in insulating oil. A voltage is applied and increased gradually until the puncture takes place. The voltage at which insulator starts to puncture is called as puncture voltage. This voltage is usually 30% higher than that of the dry flash-over voltage for a suspension type insulators.

Mechanical Strength Test

In this test, the insulator under test is applied by 250% of the maximum working load for one minute. This test is conducted to determine the ultimate mechanical strength of the insulator.

Electro-Mechanical Test

This test is conducted only for suspension type insulators. In this test, a tensile stress of 250% of maximum working tensile stress is applied to the insulator. After this, the insulator is tested for 75% of dry spark-over voltage.

Porosity Test

In this test, a freshly manufactured insulator sample is broken into pieces. These pieces are then immersed into a 0.5% to 1% alcohol solution fuchsine dye under pressure of 150 kg/cm^2 for several hours (say 24 hours). After that, the pieces are removed from the solution and examined for the penetration of the dye into it. This test indicates the degree of porosity.

3.8.3 Routine Tests Of Insulators

1. High voltage test
2. Proof load test
3. Corrosion test

High Voltage Test

This test is usually carried out for pin insulators. In this test, the insulator is inverted and placed into the water up to the neck. The spindle hole is also filled with water and a high voltage is applied for 5 minutes. The insulator should remain undamaged after this test.

Proof Load Test

In this test, each insulator is applied with 20% in excess of working mechanical load (say tensile load) for one minute. The insulator should remain undamaged after this test.

Corrosion Test

In this test, the insulator with its metal fitting is suspended into a copper sulfate solution for one minute. Then the insulator is removed from the solution and wiped and cleaned. This procedure is repeated for four times. Then the insulator is examined for any metal deposits on it. There should be zero metal deposits on the insulator.

3.3 TOWERS

The towers shall be of following types:-

a) Double circuit (DA, DB, DC & DD type) of HVPN's KRR Design for both 0.4sq" ACSR Zebra and 0.2sq" ACSR Panther.

b) Single Circuit (A, B,C & D) of 0.4sq" ACSR Zebra to be designed by the Bidder. The towers are of self supporting lattice steel type, designed to carry the line conductors with necessary insulators, earthwire and all fittings under all loading conditions.

The tower shall be fully galvanized structure.

New Design 132kV S/C towers and 132kV D/C KRR Design towers to be fabricated shall have a combination of two grades of steel, as detailed in structural drawings/bill of material. One is MS steel and other is HT steel conforming to IS:2062.

3.3.1 TYPE OF TOWERS

The towers are classified as given below for 132 KV lines.

A) FOR KRR Design D/C Towers:-

Type of Tower	Deviation limit	Typical use
DA	0 deg.-2 deg.	To be used as tangent tower.
DB	2 deg.-15 deg.	a) Tension towers with tension insulators string. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
	0 deg.	d) To be used as Section Tower
DC	15 deg.-30 deg.	a) Tension towers with tension insulators string. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
DD	30 deg.-60 deg.	a) Tension towers with tension insulators string. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Dead end with 0 deg. to 15 deg. deviation both on line and substation side (slack span).

	55 deg	d) When DD type tower used with **+12m to +25m** Extension by restricting the span to **250m.**
		e) For river crossing anchoring with longer wind span with 0 deg. deviation on crossing span side and 0 to 30 deg. deviation on other side.

Table 3.3.1 Types of D/C Towers

[https://www.electrical4u.com/electrical-transmission-tower-types-and-design/]

B) For New 132kV S/C towers of 0.4sq" (to be designed by the Bidder):-

Type of Tower	Deviation limit	Typical use
A	0 deg.-2 deg.	To be used as tangent tower upto 2 deg. deviation
B	0 deg.-15 deg.	a) To be used for line Angle deviation from 0 to 15 Deg. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
	0 deg.	d) Section tower.
C	15 deg.-30 deg.	a) To be used for line Angle deviation from 15 to 30 Deg. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Also to be designed for anti-cascading condition.
D	30 deg.-60 deg.	a) To be used for line Angle deviation from 30 deg. to 60 Deg. b) Tension towers for uplift forces resulting from an uplift span upto 200 m. c) Complete Dead end with 0 deg. to 15 deg. deviation both on line and gantry side (slack span).
	0 deg.	d) For river crossing anchoring anchoring with longer wind span with 0 deg. deviation on crossing span side and 0 to 30 deg. deviation on other side.

Table 3.3.1 Types of S/C Towers

[https://www.electrical4u.com/electrical-transmission-tower-types-and-design/]

3.3.2 LINE SUPPORTS

The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties :

(i) High mechanical strength to withstand the weight of conductors and wind loads etc.

(ii) Light in weight without the loss of mechanical strength.

(iii) Cheap in cost and economical to maintain.

(iv) Longer life.

(v) Easy accessibility of conductors for maintenance.

The line supports used for transmission and distribution of electric power are of various types including wooden poles, steel poles, R.C.C. poles and lattice steel towers. The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions.

1. Wooden poles.

These are made of seasoned wood (sal or chir) and are suitable for lines of moderate X-sectional area and of relatively shorter spans, say upto 50 metres. Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition. The wooden poles generally tend to rot below the ground level, causing foundation failure. In order to prevent this, the portion of the pole below the ground level is impregnated with preservative compounds like creosote oil. Double pole structures of the 'A' or 'H' type are often used (See Fig. 8.2) to obtain a higher transverse strength than could be economically provided by means of single poles.

The main objections to wooden supports are :

(i) tendency to rot below the ground level

(ii) comparatively smaller life (20-25 years)

(iii) cannot be used for voltages higher than 20 kV

(iv) less mechanical strength and (v) require periodical inspection.

2. Steel poles.

The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities. This type of supports need to be galvanised or painted in order to prolong its life. The steel poles are of three types *viz.*,

(i) rail poles

(ii) tubular poles and

(iii) rolled steel joints.

3. RCC poles.

The reinforced concrete poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports. The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight. Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.

4. Steel towers.

In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say upto 11 kV. However, for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand most severe climatic conditions and permit the use of longer spans. The risk of interrupted serivce due to broken or punctured insulation is considerably reduced owing to longer spans. Tower footings are usually grounded by driving rods into the earth. This minimises the lightning troubles as each tower acts as a lightning conductor.

3.4 TYPES OF INSULATOR

There are mainly three types of insulator likewise

1. Pin Insulator
2. Suspension Insulator
3. Stray Insulator

In addition to that there are other two types of electrical insulator available mainly for low voltage application, i.e. stay insulator and shackle insulator.

1. Pin Type Insulators

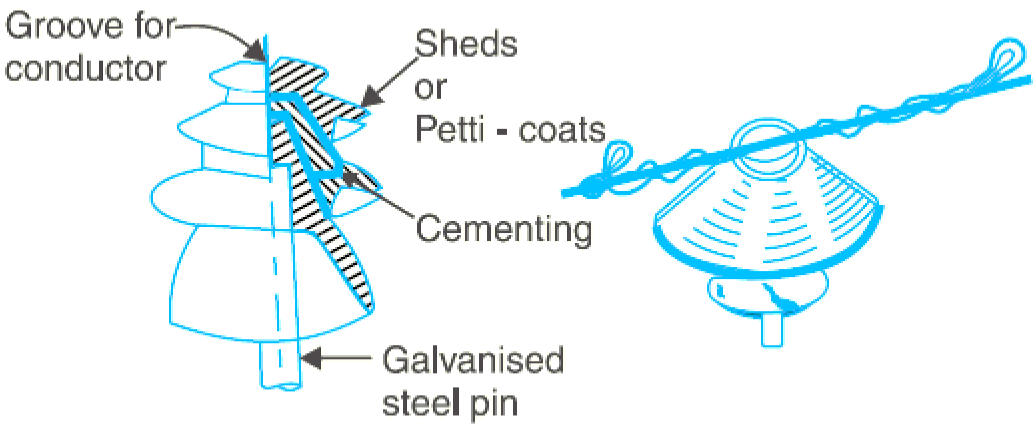

Figure 3.4.1 Pin Type Insulators

[Source: "Principles of Power System" by V.K.Mehta Page: 165]

As the name suggests, the pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor. Pin type insulators are used for transmission and distribution of electric power at voltages up to 33 kV. Beyond operating voltage of 33 kV, the pin type insulators become too bulky and hence uneconomical.

Causes of Insulator Failures:

Insulators are required to withstand both mechanical and electrical stresses. The latter type is primarily due to line voltage and may cause the breakdown of the insulator. The electrical breakdown of the insulator can occur either by flash-over or puncture.

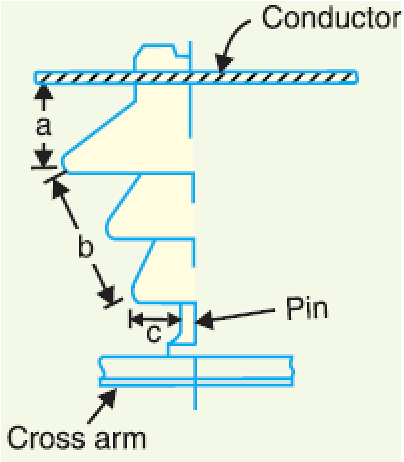

Figure 3.4.2 Insulator Failures

[Source: "Principles of Power System" by V.K.Mehta Page: 166]

In flashover, an arc occurs between the line conductor and insulator pin (i.e., earth) and the discharge jumps across the air gaps, following shortest distance. Figure shows thearcing distance (i.e. a + b + c) for the insulator. In case of flash-over, the insulator will continue to act in its proper capacity unless extreme heat produced by the arc destroys the insulator. In case of puncture, the discharge occurs from conductor to pin through the body of the insulator. When such breakdown is involved, the insulator is permanently destroyed due to excessive heat. In practice, sufficient thickness of porcelain is provided in the insulator to avoid puncture by the line voltage. The ratio of puncture strength to flashover voltage is known as safety factor.

2. Suspension Type

For high voltages (>33 kV), it is a usual practice to use suspension type insulators shown in Figure. Consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower. Each unit or disc is designed for low voltage, say 11 kV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66 kV, then six discs in series will be provided on the string.

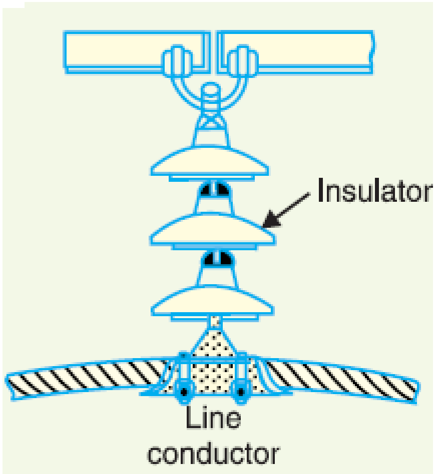

Figure 3.4.2 Suspension Type

[Source: "Principles of Power System" by V.K.Mehta Page: 166]

Advantages of suspension type:

- 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 anyone disc is damaged, the whole string does not become useless because the damaged disc can be replaced.
- 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.
- 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.
- 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.

3. Strain Insulators

When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used. For low voltage lines (< 11 kV), shackle insulators are used as strain insulators. However, for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators as shown in Figure.

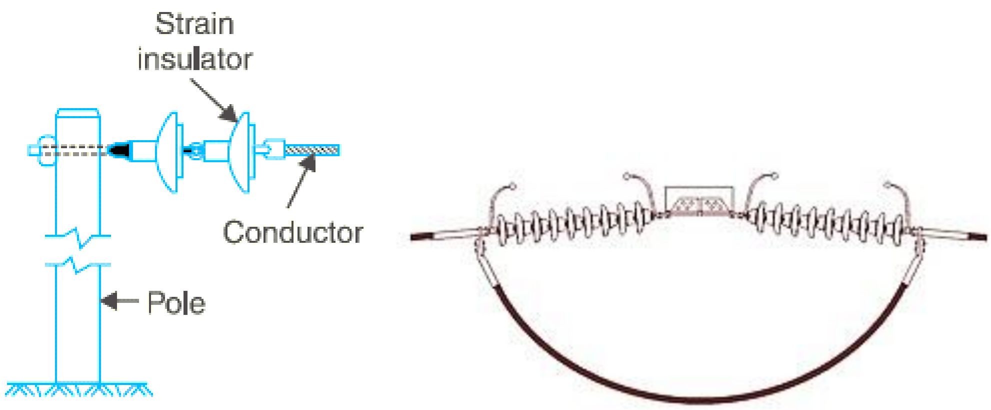

Figure 3.4.3 Strain Insulators

[Source: "Principles of Power System" by V.K.Mehta Page: 167]

The discs of strain insulators are used in the vertical plane. When the tension in lines is exceedingly high, at long river spans, two or more strings are used in parallel.

4. Shackle Insulators

In early days, the shackle insulators were used as strain insulators. But now a day, they are frequently used for low voltage distribution lines.

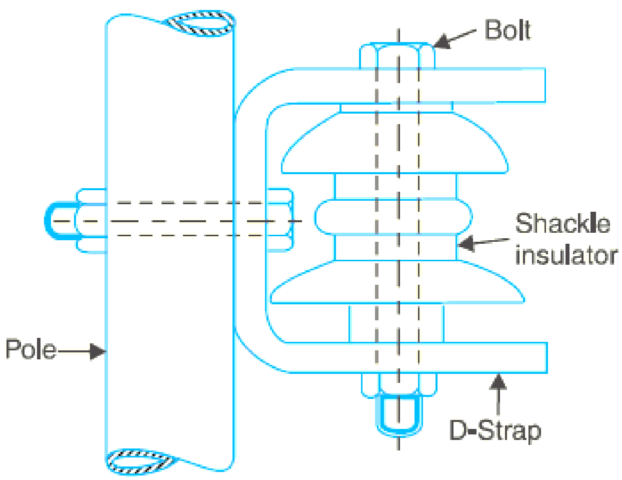

Figure 3.4.4 Shackle Insulators

[Source: "Principles of Power System" by V.K.Mehta Page: 167]

Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm.

5. Stay Insulator

For low voltage lines, the stays are to be insulated from ground at a height. The insulator used in the stay wire is called as the stay insulator and is usually of porcelain and is so designed that in case of breakage of the insulator the guy-wire will not fall to the ground.

There are several methods of increasing the string efficiency or improving voltage distribution across different units of a string.

Figure 3.4.5 Shackle Insulators

[https://www.electrical4u.com/types-of-electrical-insulator-overhead-insulator/]