## 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.

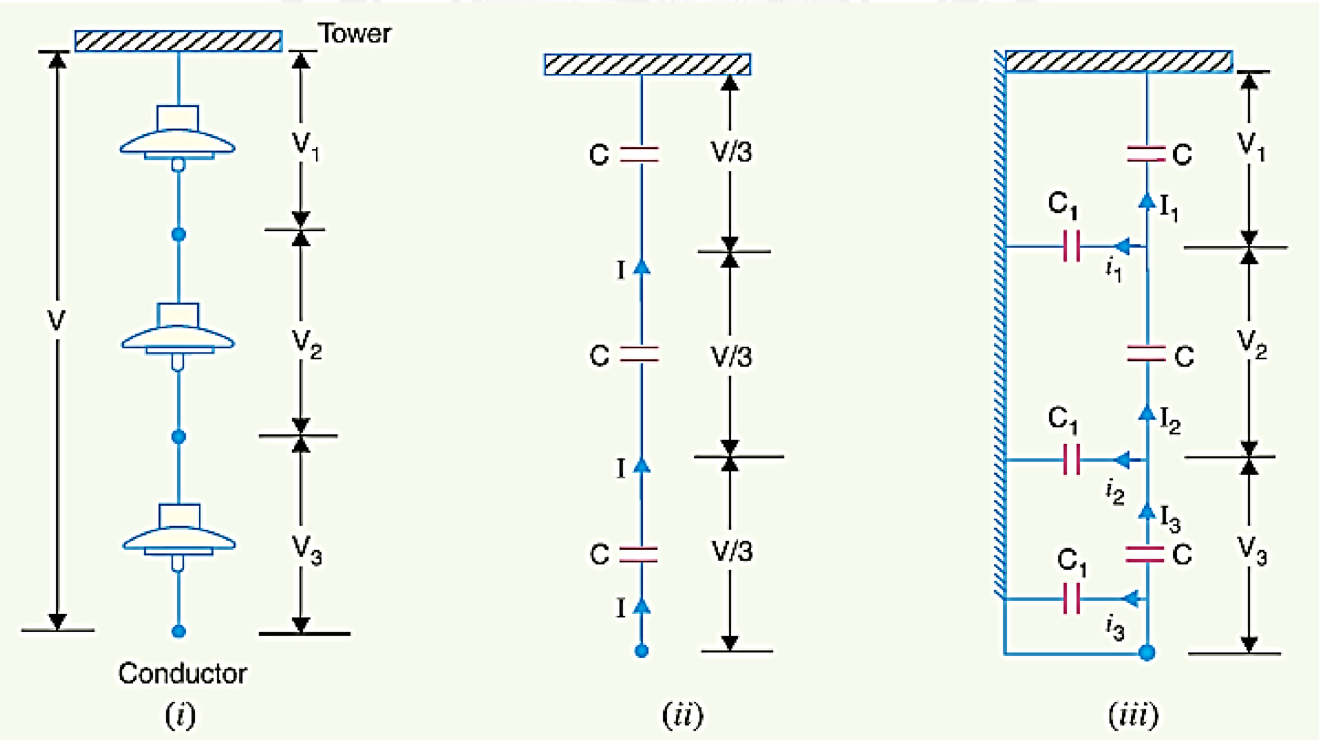


**Figure 3.1 Potential Distribution**

*[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.

## 3.6 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.,

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

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.

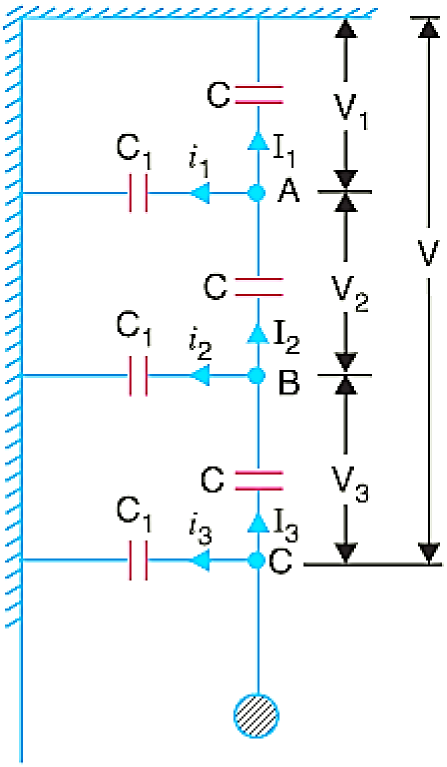


**Figure 3.6.1 Equivalent Circuit - 3-Disc String**

*[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 $V_2\omega\, C = V_1\omega\, C + V_1\omega\, K\, C$

$\therefore\ V_2 = V_1\,(1 + K)$ ...(*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 $V_3\ \omega\ C = V_2\omega\ C + (V_1 + V_2)\ \omega\ K\ C$

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, $V_3 = V_1\,(1 + 3K + K^2)$

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

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

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.

### 3.7 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.

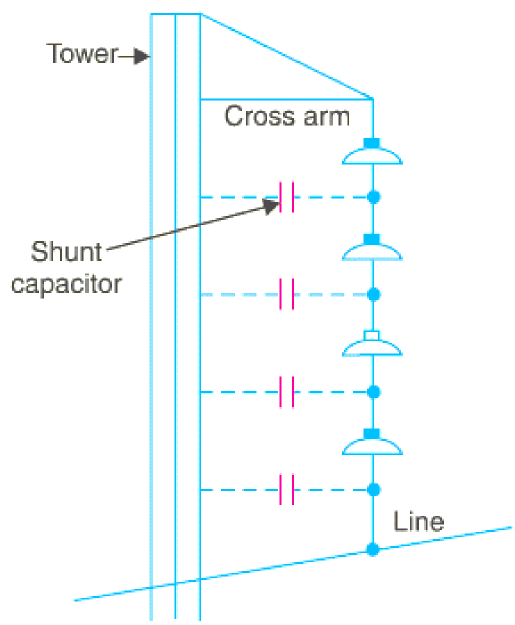


**Figure 3.7.1 Longer Cross- Arms**

*[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.

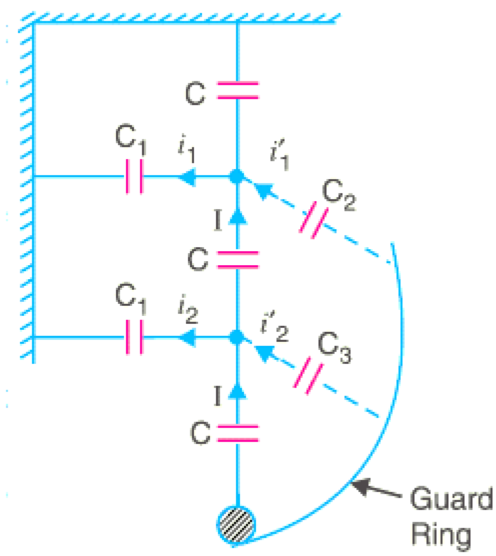


**Figure 3.7.2 A Guard Ring**

*[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,

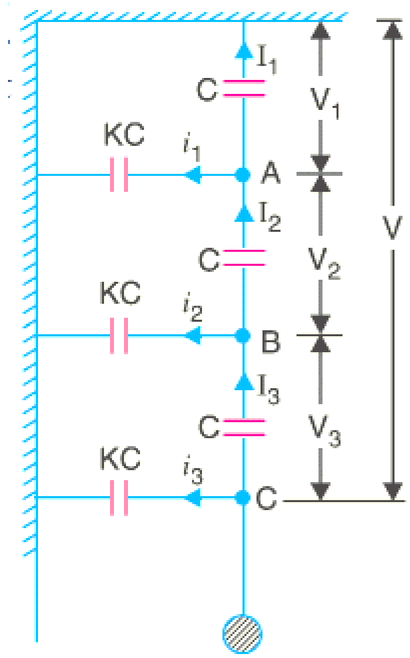


**Figure 3.7.3 Equivalent circuit of string insulators**

*[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

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

($i$) Voltage across the whole string is

$$
\begin{aligned}
V &= V_1 + V_2 + V_3 = V_1 + 1{\cdot}11\ V_1 + 1{\cdot}342\ V_1 = 3{\cdot}452\ V_1 \\
19{\cdot}05 &= 3{\cdot}452\ V_1
\end{aligned}
$$

$\therefore$ 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 %