

Chapter: 05
Mechanical Features and Design of
Overhead Transmission Line:

Lecture : 19 & 20

TOPIC:

1. String Efficiency
2. Methods of improving string efficiency
3. Example

Chapter: 05

Mechanical Features and Design of Overhead Transmission Line:

1. Main components of overhead lines
2. Conductor materials
3. Line supports
4. Insulators, Types of insulators
5. String efficiency, Methods of improving string efficiency
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7. Sag in overhead lines, Calculation of sag
8. Examples.

1. Insulator

The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports *i.e.*, line conductors must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of *insulators*. The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. In general, the insulators should have the following desirable properties :

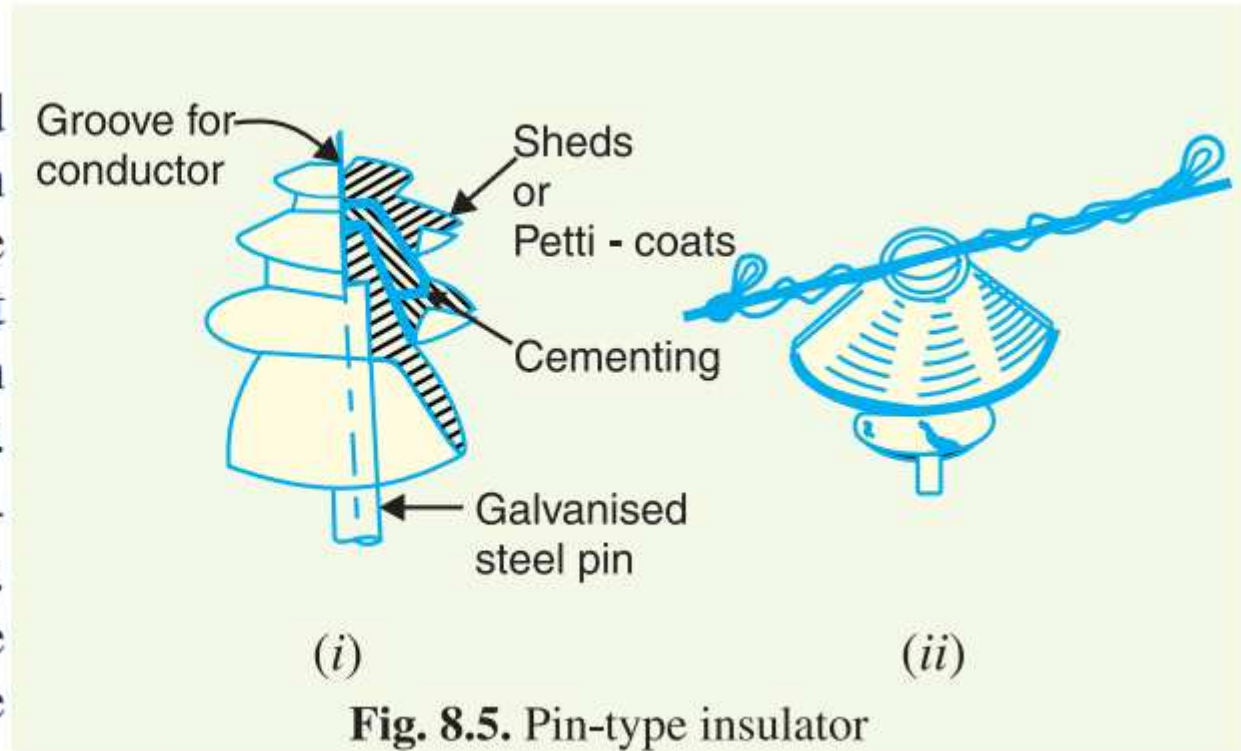
- (i) High mechanical strength in order to withstand conductor load, wind load etc.
- (ii) High electrical resistance of insulator material in order to avoid leakage currents to earth.
- (iii) High relative permittivity of insulator material in order that dielectric strength is high.
- (iv) The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.
- (v) High ratio of puncture strength to flashover.

2. Types of Insulator

8.5 Types of Insulators

The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulators. There are several types of insulators but the most commonly used are pin type, suspension type, strain insulator and shackle insulator.

1. Pin type insulators. The part section of a pin type insulator is shown in Fig. 8.5 (i). 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 [See Fig. 8.5 (ii)].

Pin type insulators are used for transmission and distribution of electric power at voltages upto 33 kV. Beyond operating voltage of 33 kV, the pin type insulators become too bulky and hence uneconomical.

$$\text{Safety factor of insulator} = \frac{\text{Puncture strength}}{\text{Flash - over voltage}}$$

It is desirable that the value of safety factor is high so that flash-over takes place before the insulator gets punctured. For pin type insulators, the value of safety factor is about 10.



Pin type insulator



Suspension insulator

2 Suspension type insulators. The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 kV. For high voltages (>33 kV), it is a usual practice to use suspension type insulators shown in Fig. 8.7. They

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.

Advantages

- (i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.
- (ii) Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.
- (iii) If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.
- (iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.
- (v) In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.
- (vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

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 Fig. 8.8. The discs of strain insulators are used in the vertical plane. When the tension in lines is exceedingly high, as at long river spans, two or more strings are used in parallel.

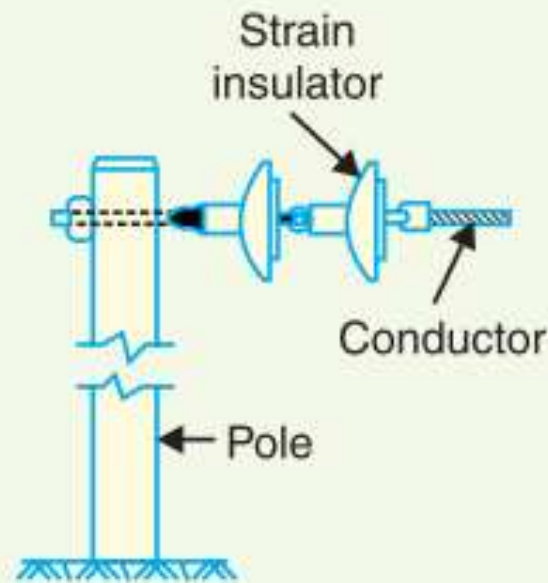


Fig. 8.8. Strain insulator.

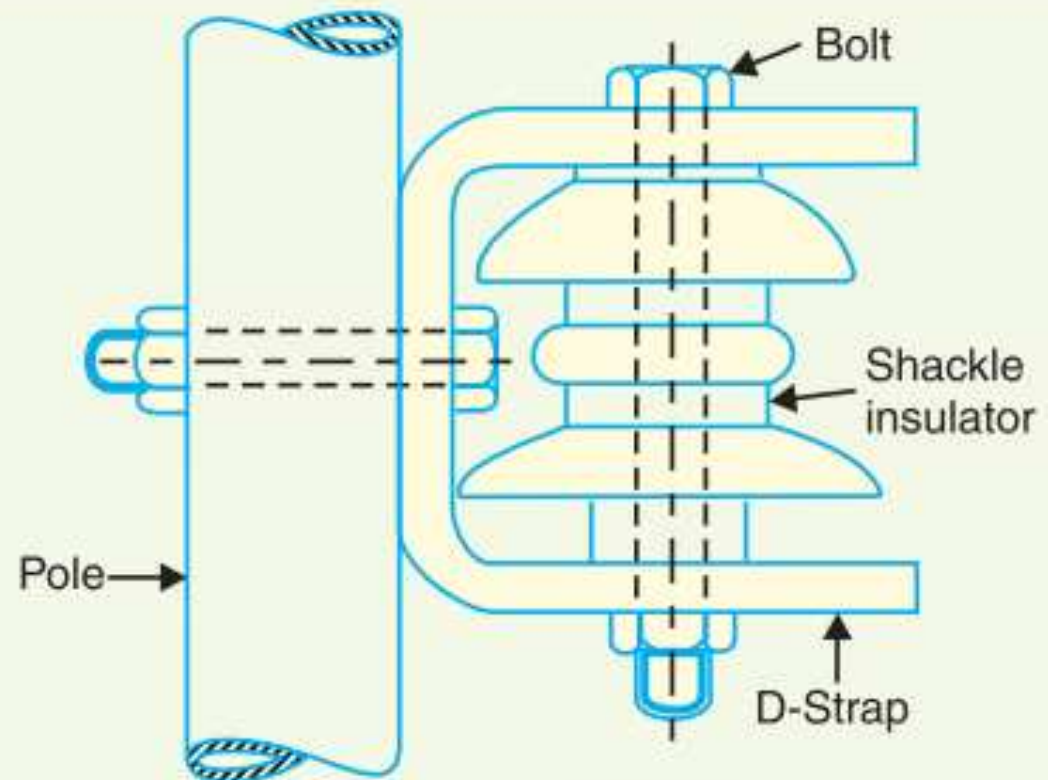


Fig. 8.9

4. Shackle insulators. In early days, the shackle insulators were used as strain insulators. But now a days, they are frequently used for low voltage distribution lines. 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. Fig. 8.9 shows a shackle insulator fixed to the pole. The conductor in the groove is fixed with a soft binding wire.

String Efficiency

8.7 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.,*

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

where

n = number 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. 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.

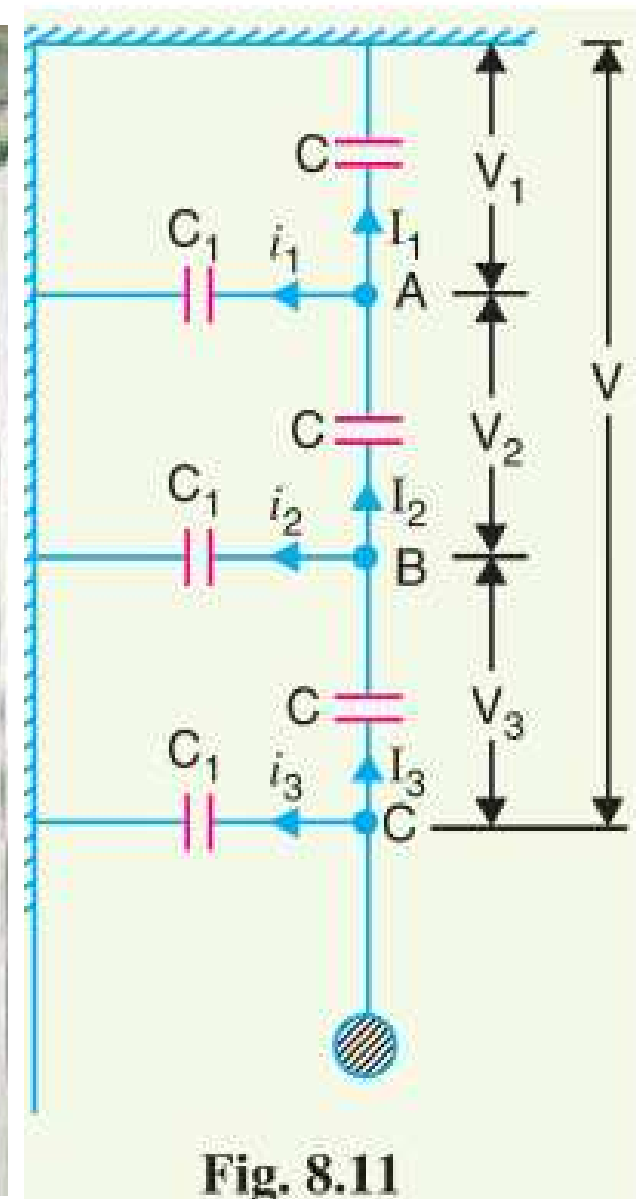


Fig. 8.11

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

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

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

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

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

Mathematical expression. Fig. 8.11 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 C_1 is some fraction K of self-capacitance *i.e.*, $C_1 = KC$. Starting from the cross-arm or tower, the voltage across each unit is V_1, V_2 and V_3 respectively as shown.

Applying Kirchhoff's current law to node A, we get,

$$I_2 = I_1 + i_1$$

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

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

$\therefore V_2 = V_1 (1 + K)$

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

$$I_3 = I_2 + i_2$$

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

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

or $V_3 = V_2 + (V_1 + V_2)K$

...(i)

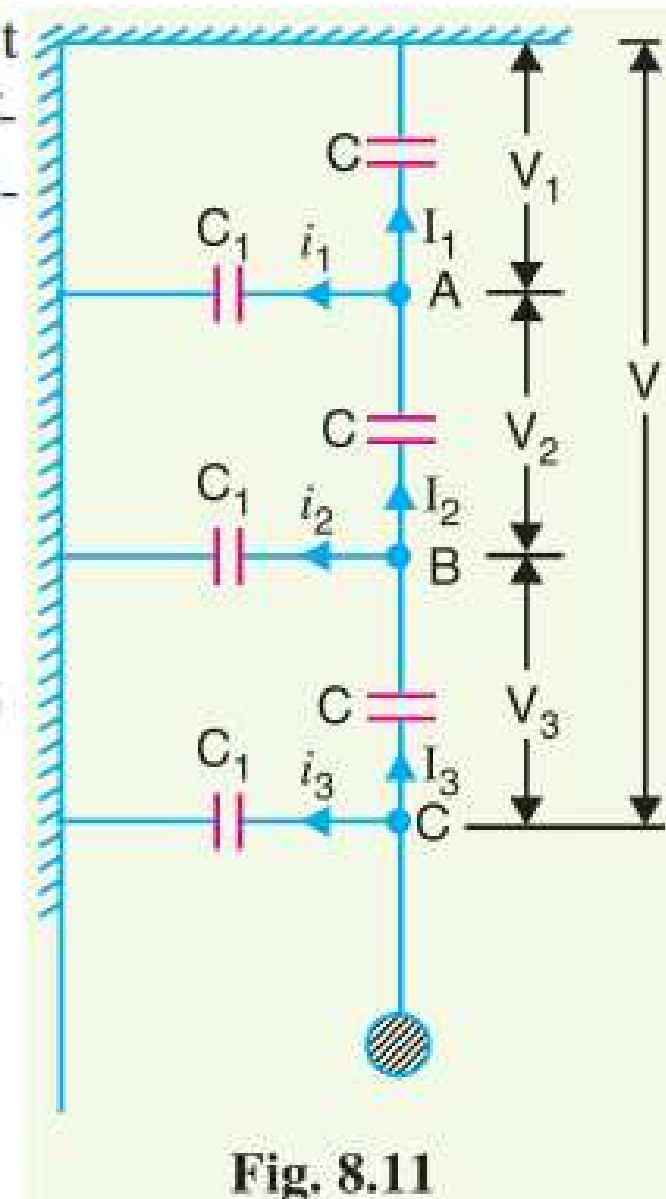


Fig. 8.11

$$= KV_1 + V_2 (1 + K)$$

$$= KV_1 + V_1 (1 + K)^2$$

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

$$[\because V_2 = V_1 (1 + K)]$$

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

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

$$V = V_1 + V_2 + V_3$$

$$= V_1 + V_1(1 + K) + V_1 (1 + 3K + K^2)$$

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

$$\therefore V = V_1(1 + K) (3 + K) \quad \dots(iii)$$

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

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

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

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

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

$$\begin{aligned} \text{\%age String efficiency} &= \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100 \\ &= \frac{V}{3 \times V_3} \times 100 \end{aligned}$$

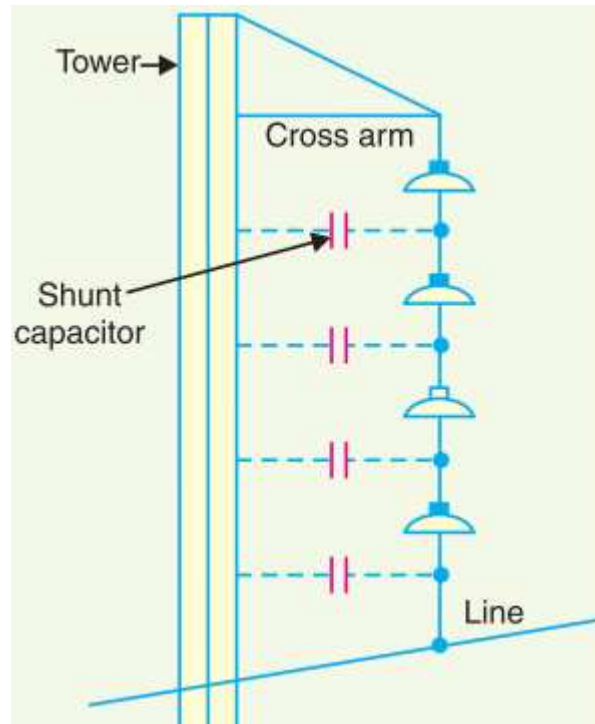
The following points may be noted from the above mathematical analysis :

- (i) If $K = 0.2$ (Say), then from exp. (iv), we get, $V_2 = 1.2 V_1$ and $V_3 = 1.64 V_1$. 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 is approached.
- (ii) The greater the value of $K (= C_1/C)$, 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.

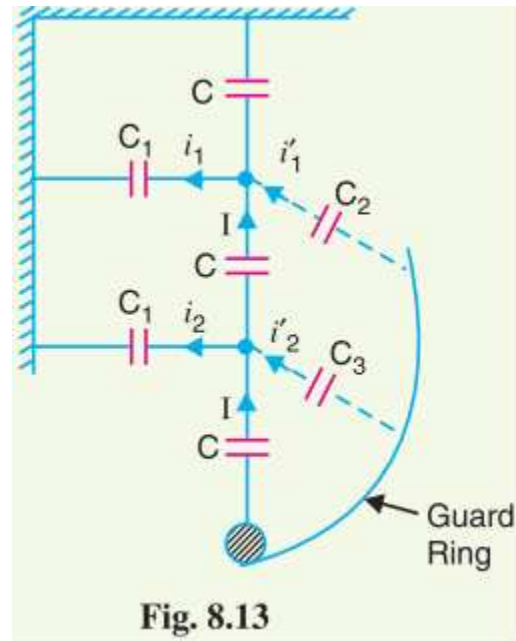
Methods of improving string efficiency

1. *By using longer cross-arms.*
2. *By grading the insulators.*
3. *By using a guard ring.*

By using longer cross-arms.



By using a guard ring



Example 8.1. 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.

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

$$K = C_1 / C = 0.11 \text{ as per given detail}$$

$$V = \text{Phase Voltage Across String} = 33\text{KV} / \text{Sqrt}^*(3) = 19.05$$

$$V_1 = [19.05 / (1 + .011) * (3 + 0.11)] = 5.52 \text{ KV}$$

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

$$V_2 = 5.52 * (1 + 0.11) = 6.13 \text{KV}$$

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

$$V_3 = 5.52 (1 + 3 * 0.11 + (0.11)^2) = 7.4 \text{KV}$$

$$\begin{aligned}\% \text{age String efficiency} &= \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100 \\ &= \frac{V}{3 \times V_3} \times 100\end{aligned}$$

Example 8.2. A 3-phase transmission line is being supported by three disc insulators. The potentials across top unit (i.e., near to the tower) and middle unit are 8 kV and 11 kV respectively. Calculate (i) the ratio of capacitance between pin and earth to the self-capacitance of each unit (ii) the line voltage and (iii) string efficiency.

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

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

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

$$\begin{aligned} \text{\%age String efficiency} &= \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100 \\ &= \frac{V}{3 \times V_3} \times 100 \end{aligned}$$

Thank You