EEN-206: Power Transmission and Distribution

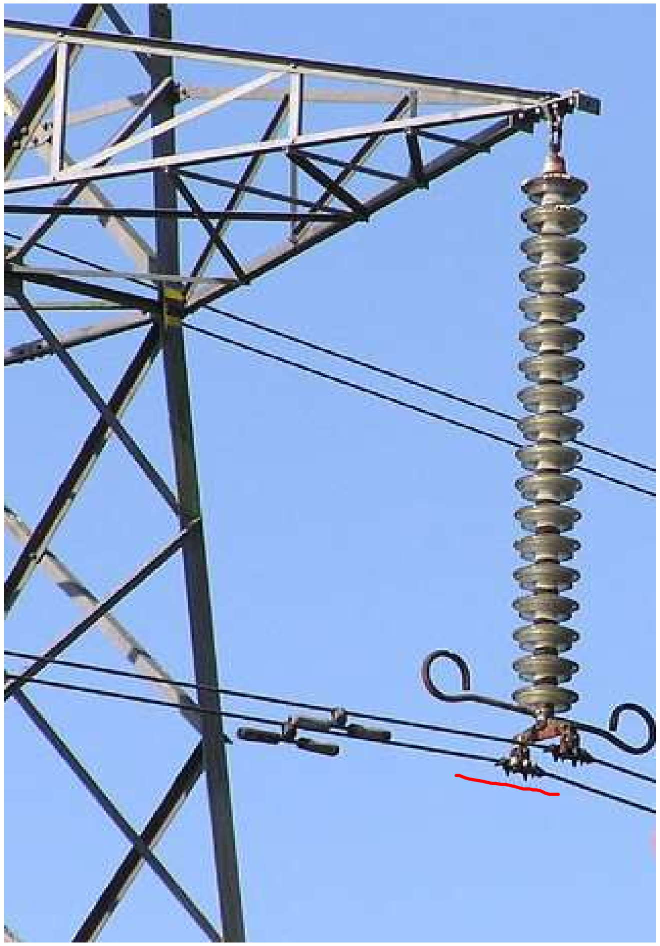
Lecture -09

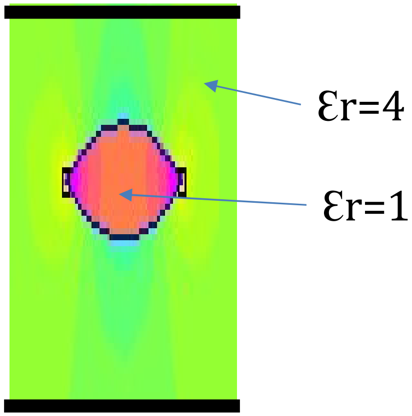
Chapter 2: Overhead Transmission Lines

- **Electrical Design**

Insulators for Overhead Line

- *Insulators* are used to insulate towers from the live conductors
- The insulators are attached to the tower and support the line conductors.
- **Important characteristics:**
  - Homogeneous materials without voids and impurities.
  - Minimum leakage current.
  - High dielectric or breakdown strength.
  - Mechanically strong to bear the conductor load
  - Longer life.



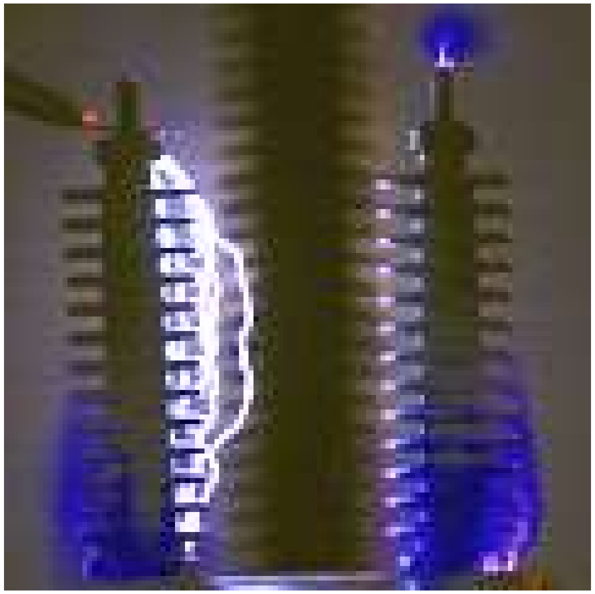


Insulator Ratings

- Three voltages ratings
  - Working voltage
  - Puncture voltage
  - Flashover voltage

$$\text{Safety Factor} = \frac{\text{Flashover Voltage}}{\text{Working Voltage}}$$

- Flashover voltage is less than puncture voltage.



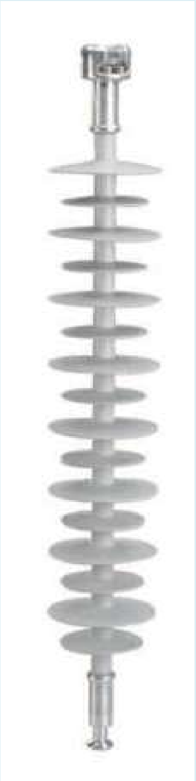
Insulators for Overhead Line

- **Porcelain:**
  - Porcelain (silica, felspar, and clay) is widely used as it is cheap.
  - It is thoroughly vitrified to remove voids and glazed before use to keep surface free of dust and moisture.
  - Breakdown strength is around 120-280 kV/cm

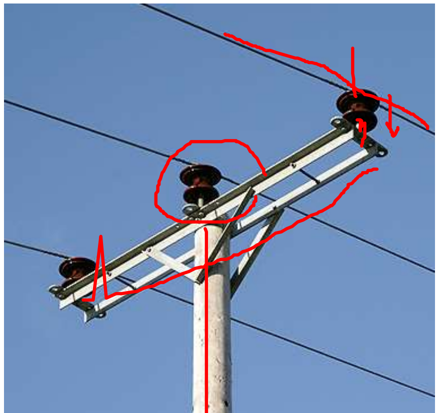
- **Toughened Glass:**
  - Toughened glass is another choice having higher dielectric strength (1200 kV/cm), mechanical strength and life, higher thermal shock resistant, lower coefficient of expansion
  - Flaws can be detected easily by visual inspection.
  - Main disadvantage is moisture rapidly condenses on the surface giving high surface leakage current.
  - Expensive

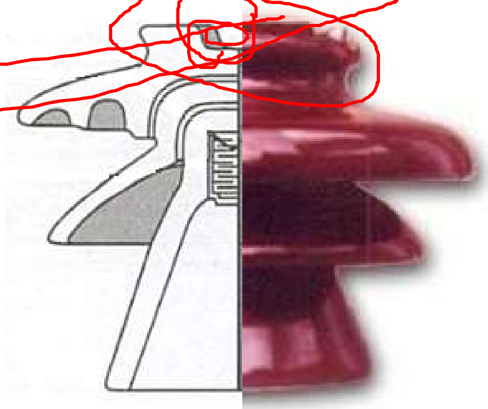
Insulators for Overhead Line

- **Polymeric Insulation:**
  - Silicone rubber and EPDM (Ethylene propylene diene monomer) are used for insulation purpose.
  - Low cost, light weight, smaller in size, higher life, improved dielectric performance under moderate pollution.
  - They are used in combination with fiber glass rod.
  - These are under field trials and may take time to be used extensively.
  - Tracking and erosion of the shed material, which can lead to bad pollution performance and can cause flashover.
  - Chalking and crazing of the insulator’s surface, which resulted in increased contaminant collection, arcing, and flashover.



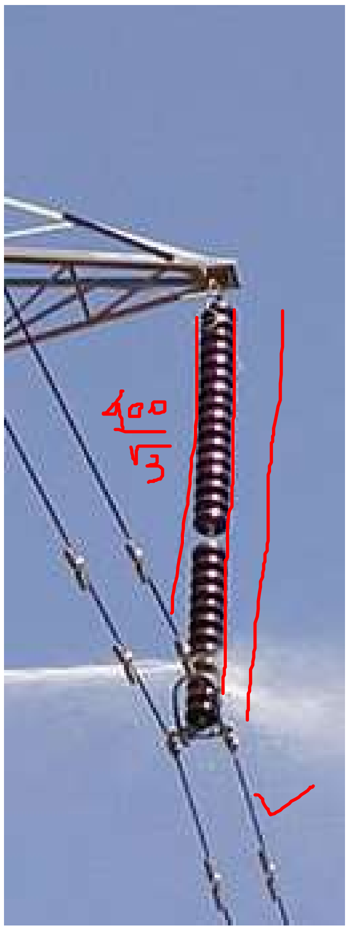
Pin Type Insulator

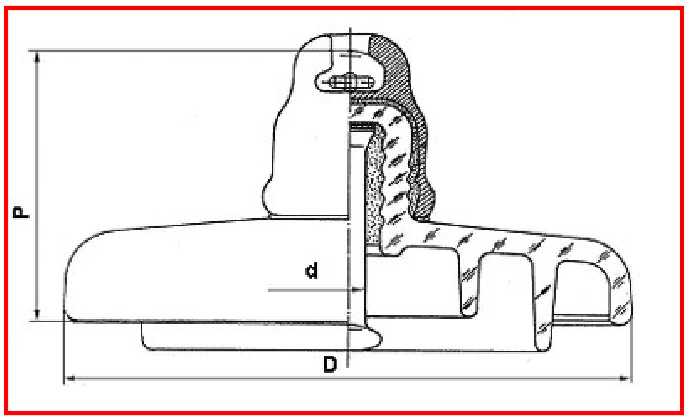




- Supported on steel bolt or pin which is firmly supported on cross-arm.
- Conductor is tied to insulator on groove by annealed binding wire.
- Usually used for 11 kV and 33 kV lines.
- They can be made in one piece up to 33 kV and two pieces for higher voltages.
- Pin type insulators are uneconomical for higher voltages.

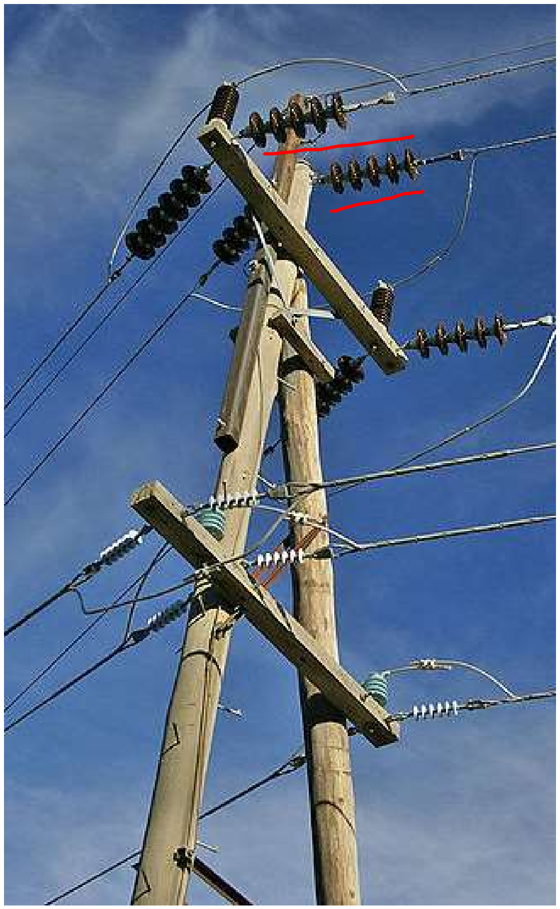
Suspension Type Insulators



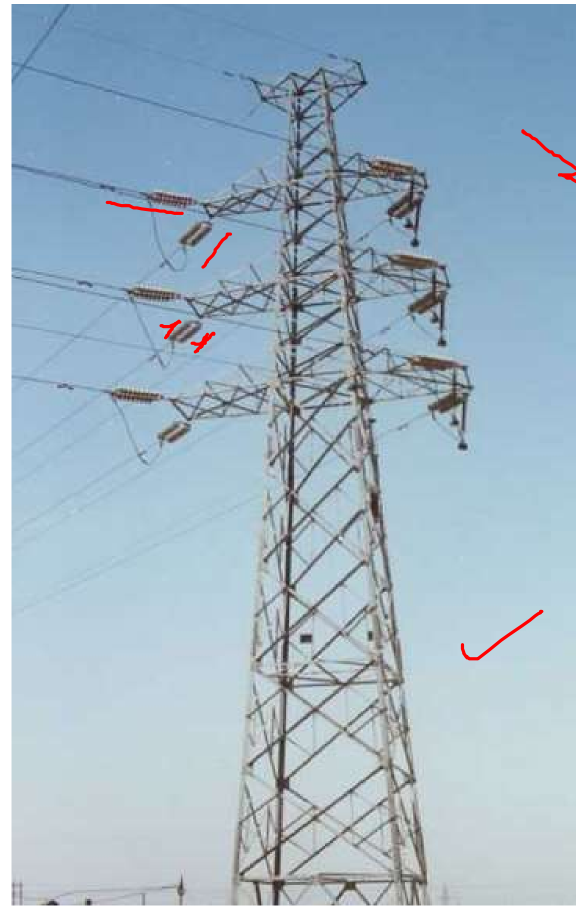


- Consists of one or more insulating units hung from cross arm and conductor is connected at lowest unit.
- String is free to swing (lower mechanical stresses); thus long cross arms are required.
- Economical voltages above 33 kV. Each typical unit is designed for 11 kV.
- Failed unit can be changed without changing whole string.
- Less lightning strike to conductors
- V shaped insulator strings can also be used to avoid the swings.
- 400 -> 21-23 units -> 3.84 m

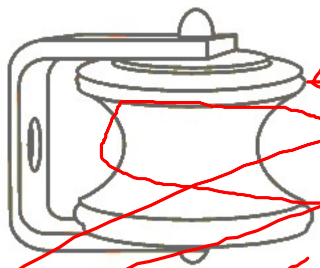
Strain Type Insulator



- The insulators are similar to suspension type insulator but used in horizontal position.
- Generally used at the towers with dead end, angle towers, and road and river crossings.
- They can take tension off the conductors. When tension is very high two or more strings are used in parallel.

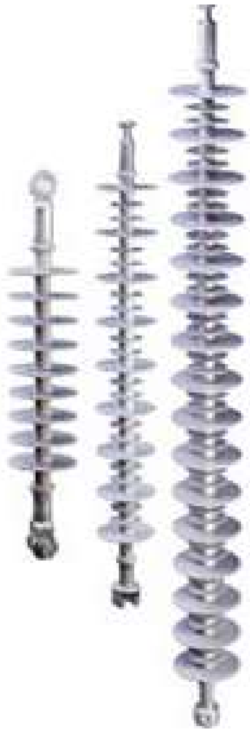


Shackle, Post, and Polymeric Insulators



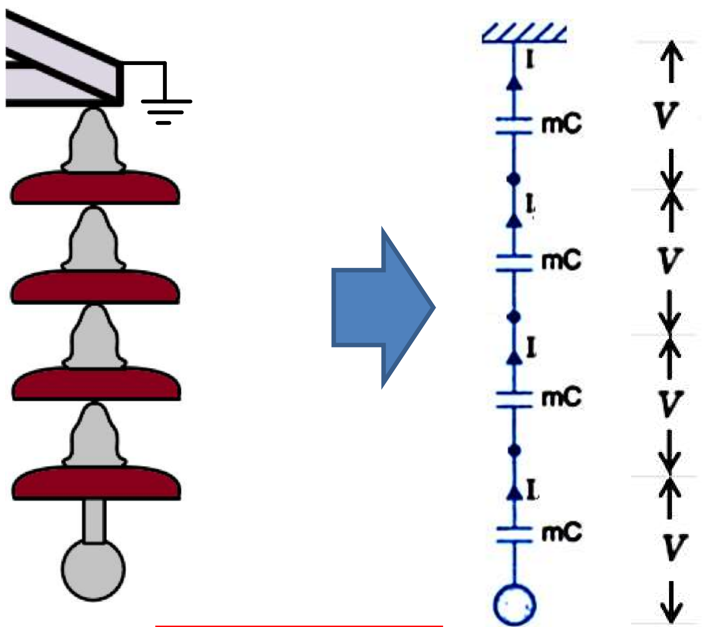
Shackle insulators or spool insulators

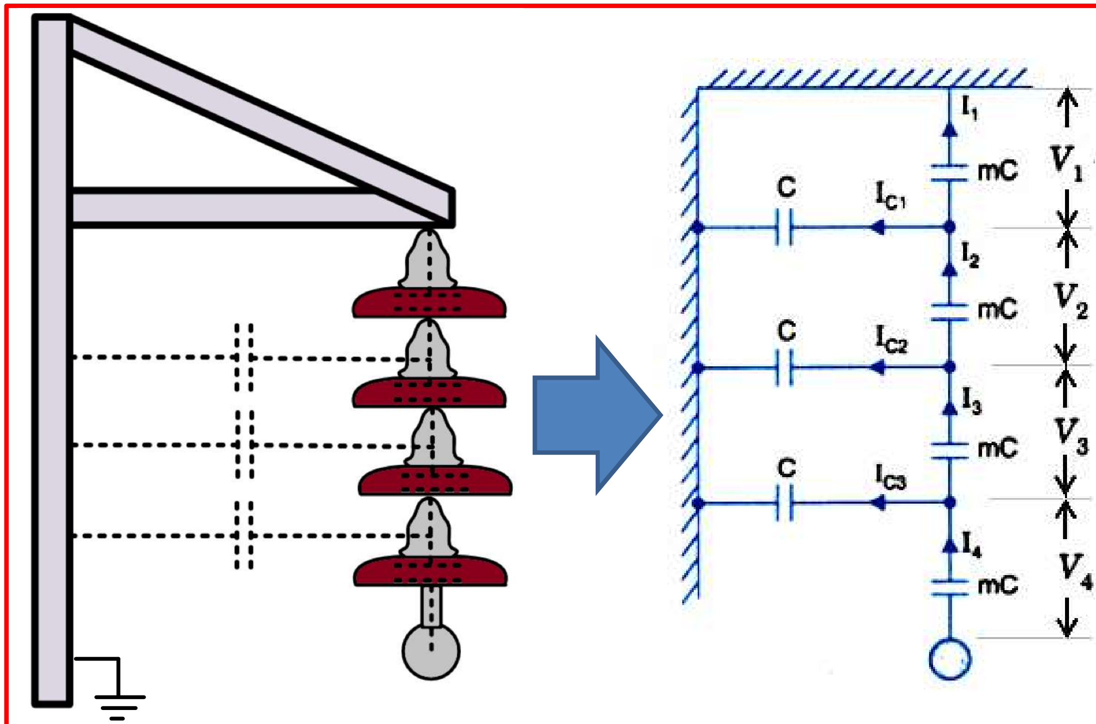
Post type insulators

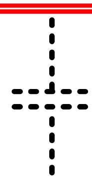


Polymeric insulators

Potential Distribution over String

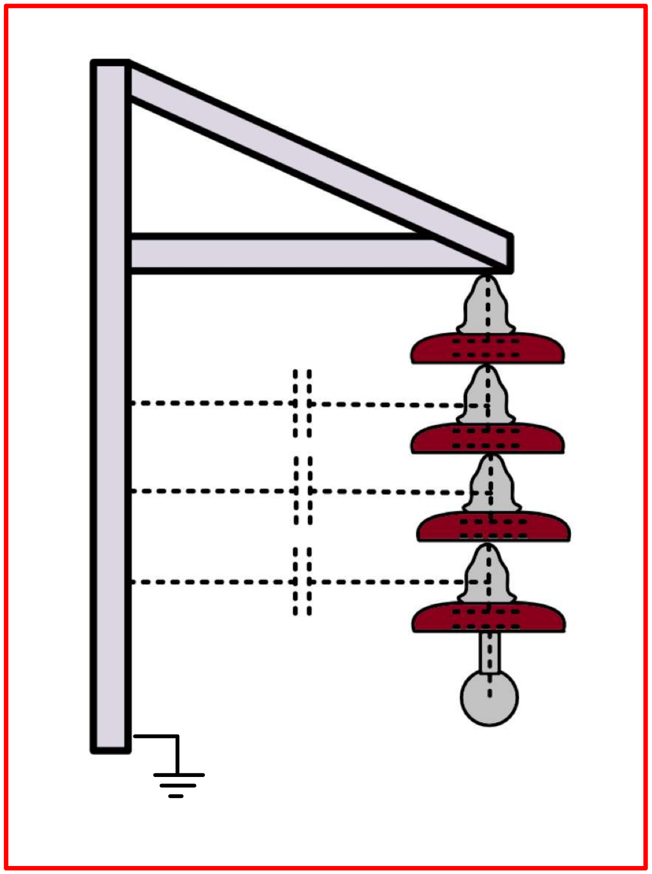


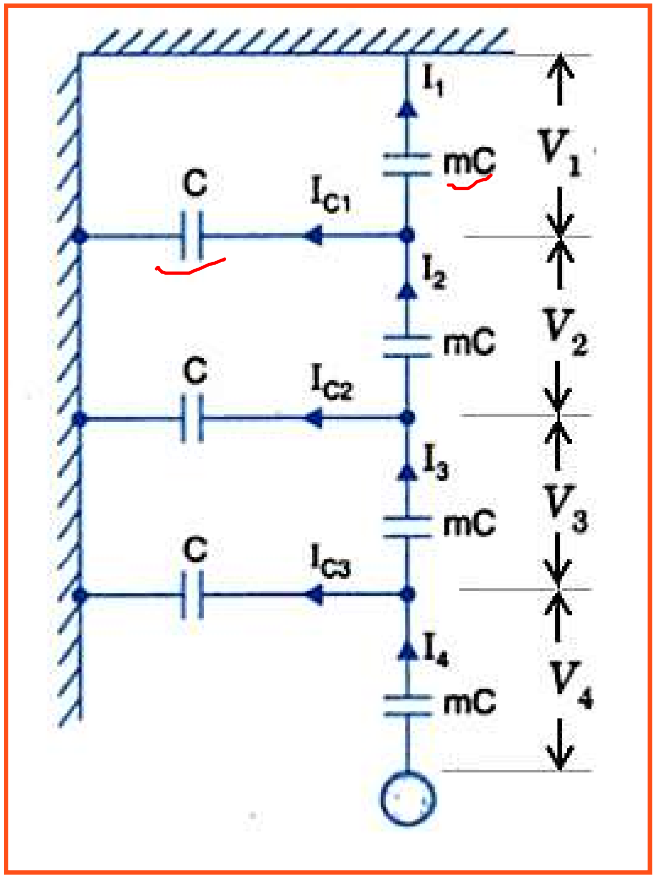




$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$ ->Approximately

Potential Distribution Over a String



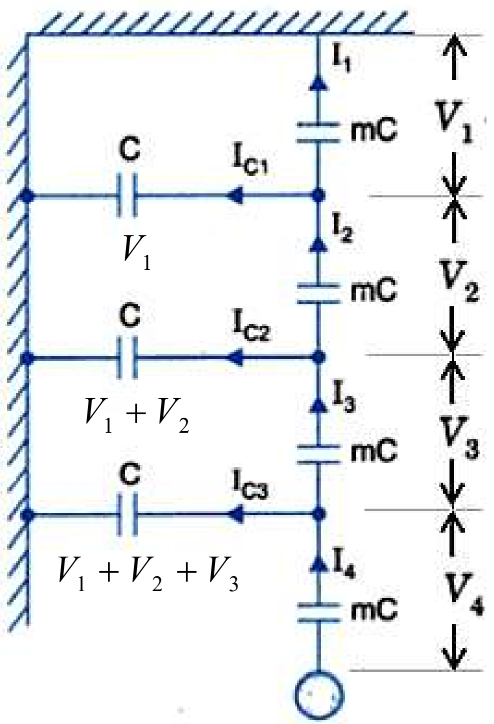


- **Capacitance of disc:** Capacitance between metal work of the insulator units; sometimes called as mutual capacitance.
- **Capacitance to ground:** capacitance between metal work of insulator to tower.

$$m = \frac{\text{Capacitance per insulator}}{\text{Capacitance to ground}} = \frac{mC}{C}$$

http://www.epemag.net/electricity-generation-pylons.html

Potential Distribution over a String



- If V is voltage across the conductor and ground. We have:

$$V = V_1 + V_2 + V_3 + V_4$$

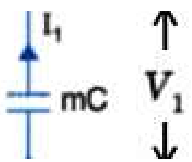
Also $$I_2 = I_1 + I_{C1}$$

$$j\omega mCV_2 = j\omega mCV_1 + j\omega CV_1$$

$$mV_2 = mV_1 + V_1$$

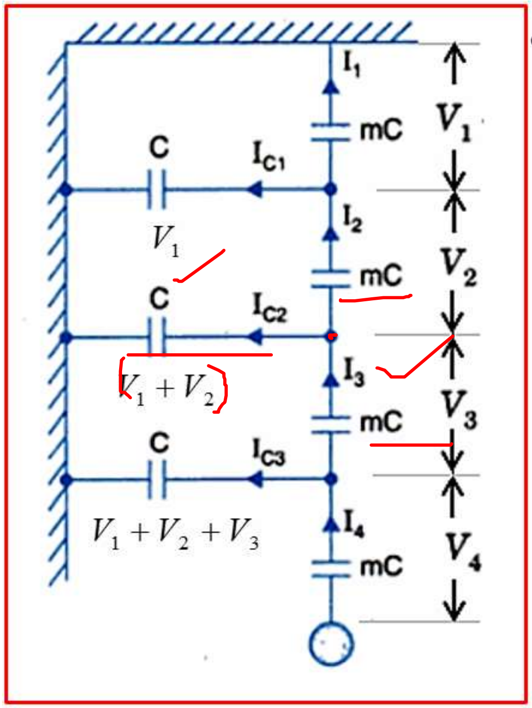
$$V_2 = \left(\frac{m+1}{m}\right)V_1$$

$$V_2 = \left[1 + \frac{1}{m}\right]V_1$$



$$X_C = \frac{1}{j\omega(mC)} \Rightarrow I_1 = \frac{V_1}{X_C} = j\omega mCV_1$$

Potential Distribution over the String



$$V_2 = \left(\frac{m+1}{m}\right)V_1$$

Similarly, $I_3 = I_2 + I_{C_2}$

$$j\cancel{\omega} m\cancel{C} V_3 = j\cancel{\omega} m\cancel{C} V_2 + j\cancel{\omega}\cancel{C}\left(V_1 + V_2\right)$$

$$mV_3 = (m+1)V_2 + V_1$$

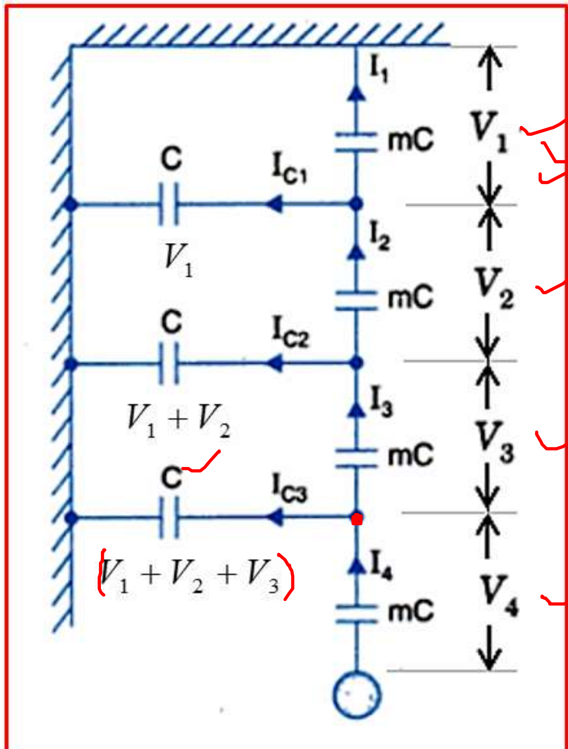
$$mV_3 = (m+1)\left(\frac{m+1}{m}\right)V_1 + V_1$$

$$V_3 = \frac{(m+1)^2}{m^2}V_1 + V_1$$

$$= \frac{\left(m^2 + 3m + 1\right)}{m^2}V_1$$

$$V_3 = \left[1 + \frac{3}{m} + \frac{1}{m^2}\right]V_1$$

Potential Distribution over the String



$$V_2 = \left(\frac{m+1}{m}\right)V_1 \quad \text{and} \quad V_3 = \frac{\left(m^2+3m+1\right)}{m^2}V_1$$

- **Similarly,** $I_4 = I_3 + I_{C_3}$

$$j\omega mCV_4 = j\omega mCV_3 + j\omega C\left(V_1 + V_2 + V_3\right)$$

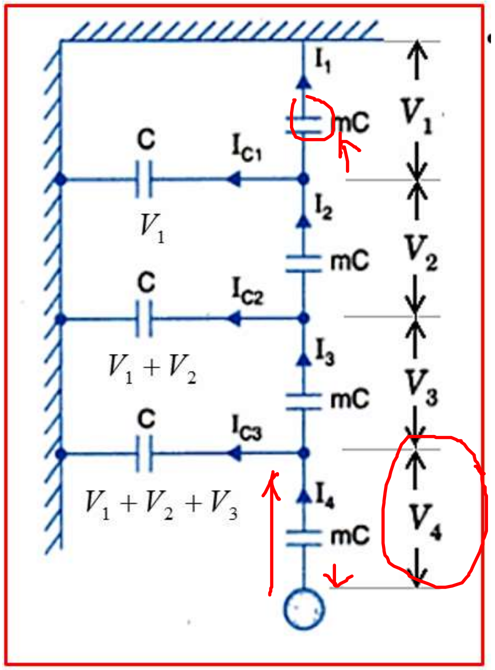
$$mV_4 = mV_3 + \left(V_1 + V_2 + V_3\right)$$

$$mV_4 = m\frac{\left(m^2+3m+1\right)}{m^2}V_1 + \left(V_1 + \left(\frac{m+1}{m}\right)V_1 + \frac{\left(m^2+3m+1\right)}{m^2}V_1\right)$$

$$V_4 = \left(\frac{\left(m^2+3m+1\right)}{m^2} + \frac{\left(3m^2+4m+1\right)}{m^3}\right)V_1$$

$$V_4 = \left[1 + \frac{6}{m} + \frac{5}{m^2} + \frac{1}{m^3}\right]V_1$$

String Efficiency



- Let m = 5

$$V_2 = \left[1 + \frac{1}{m}\right] V_1 \Rightarrow V_2 = 1.2 V_1$$

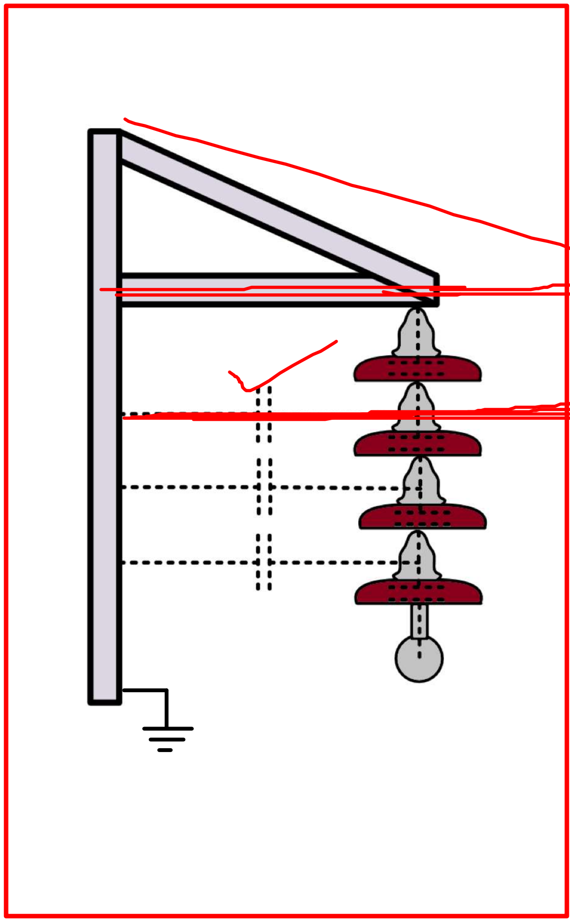
$$V_3 = \left[1 + \frac{3}{m} + \frac{1}{m^2}\right] V_1 \Rightarrow V_3 = 1.64 V_1$$

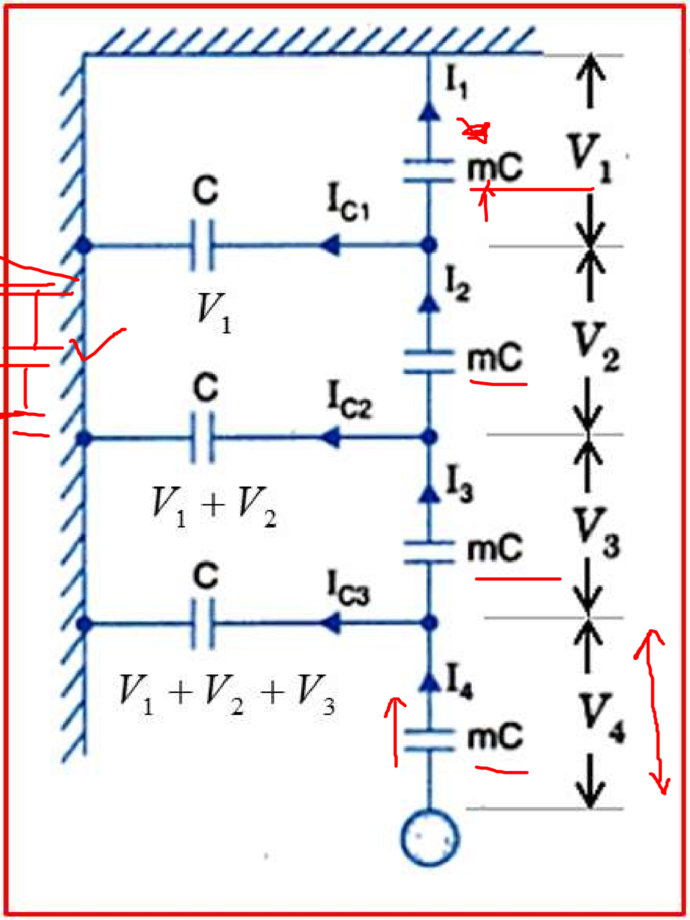
$$V_4 = \left[1 + \frac{6}{m} + \frac{5}{m^2} + \frac{1}{m^3}\right] V_1 \Rightarrow V_4 = 2.41 V_1$$

$$\text{String Effciency} = \frac{\text{Voltage Across String}}{\text{n} \times \text{Voltage across unit adjacent to line}} \times 100 = \frac{V_1 + V_2 + V_3 + V_4}{4 \times V_4}$$

$$= \frac{(1 + 1.2 + 1.64 + 2.41) V_1}{4 \times 2.41 V_1} \times 100 = 63.8\%$$

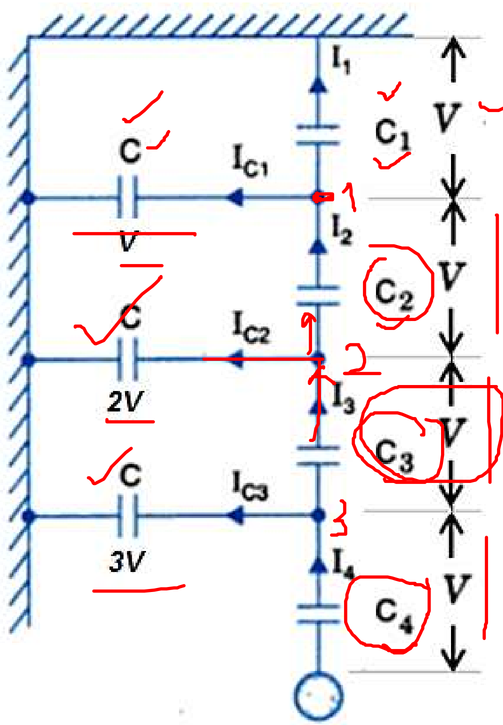
Selection of m





- If the value of *m* is increased, which can be achieved by increasing the cross-arm length.
- Increased cross-arm length decreases the capacitance between earth and metallic connections.
- However increasing cross-arm length is not economical after certain distance.
- Theoretically, one can achieve equal voltage distribution when *m* is infinity.
- It is found that value of *m* greater than 10 is not economical.

Grading of Units



- Voltage across capacitor is inversely proportional to the capacitance for given current.
- By correct grading of capacitances complete equality voltage can be achieved.
- We have,

$$I_2 = I_{C1} + I_1$$

$$\cancel{\omega} C_2 \cancel{V} = \cancel{\omega} C \cancel{V} + \cancel{\omega} C_1 \cancel{V}$$

$$C_2 = (C + C_1)$$

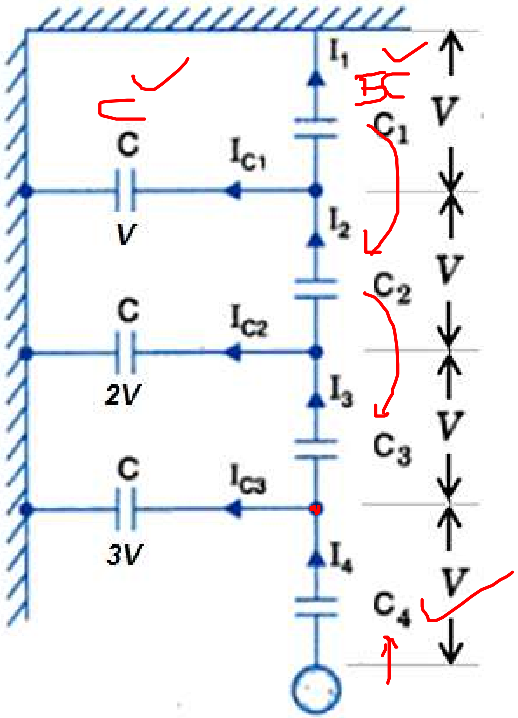
- Similarly,

$$I_3 = I_{C2} + I_2$$

$$\cancel{\omega} C_3 \cancel{V} = \cancel{\omega} C(2\cancel{V}) + \cancel{\omega} C_2 \cancel{V}$$

$$C_3 = 2C + C_2$$

Grading of Units



$$But\ \ C_2 = (C + C_1)$$

$$C_3 = 2C + (C + C_1)$$

$$C_3 = 3C + C_1$$

$$C_3 = C_1 + (1+2)C$$

$C_4 = C_1 + 6C$

Similarly, $C_4 = C_1 + (1 + 2 + 3)C$

Generalized case:

$$C_n = C_1 + (1 + 2 + 3 + \cdots + (n-1))C$$

For example, if $C_1 = 5C$, then

$C_2 = 6C$, $C_3 = 8C$, $C_4 = 11C$, and so on

Grading of Units

- Thus if capacitance of one unit is fixed other capacitances can be easily determined.
- This requires units of different capacities, which is uneconomical and impractical.
- It needs large stock of different sizes of units, which overweighs the advantage of string insulator.
- Therefore this method is usually not employed except for very high voltage lines.
- In that case, string is graded in groups, may be two/three.
- Good results can be obtained by using insulators of one size for most of the units and larger units for the one OR two adjacent to line.

Thank You