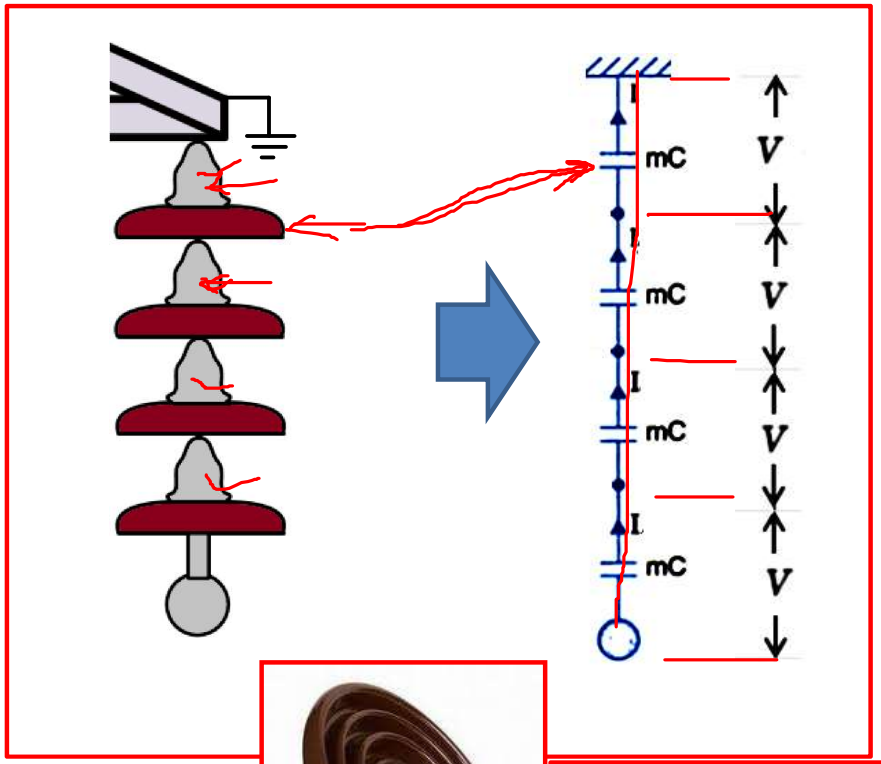
# EEN-206: Power Transmission and Distribution

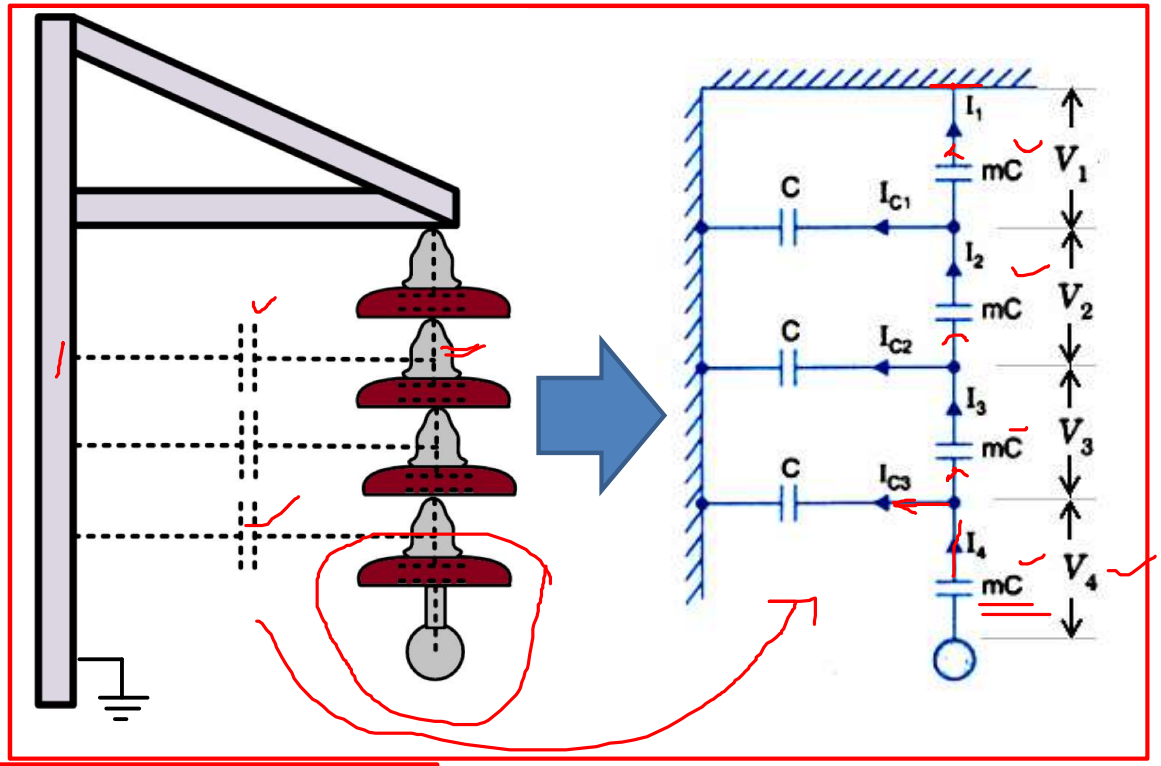
# Lecture -10

## Chapter 2: Overhead Transmission Lines

- **Electrical Design**

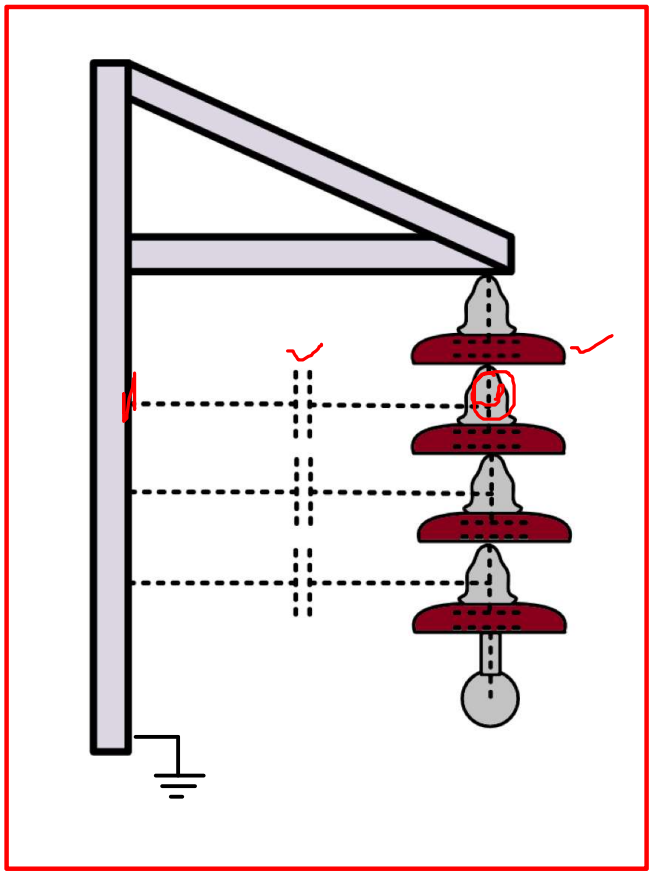
# Potential Distribution over String

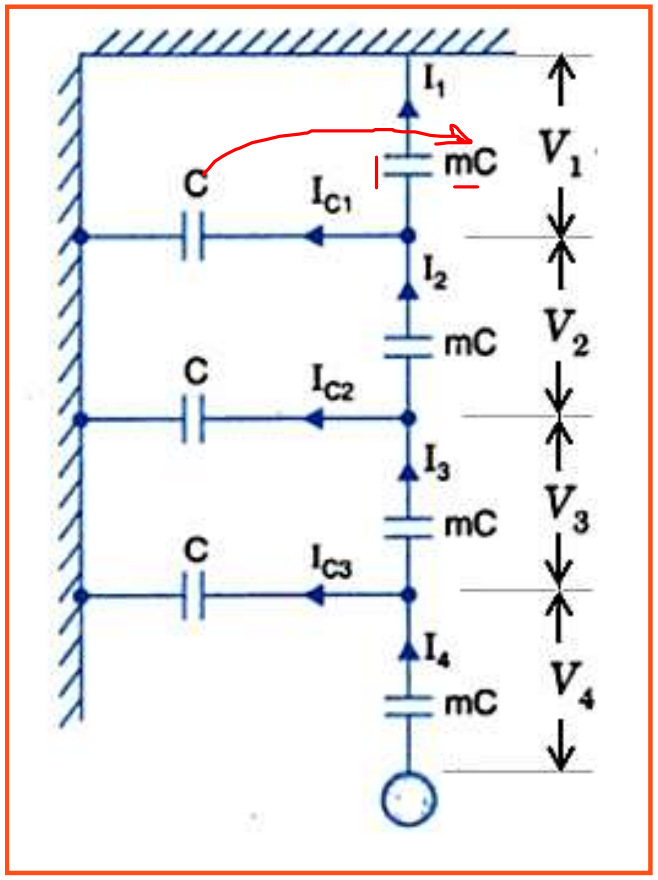



$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$ ->Approximately

# Potential Distribution Over a String





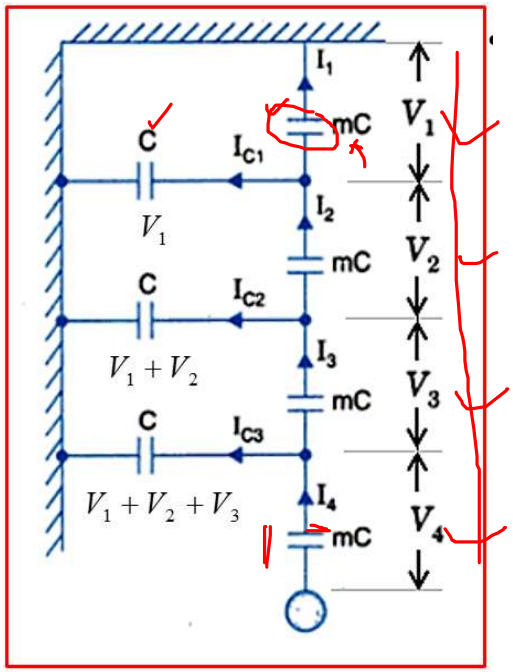

- **Capacitance of disc ($C_1$=$mC$):** Capacitance between metal works of the insulator units.
- **Capacitance to ground ($C$):** capacitance between metal work of insulator to tower.

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



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

# String Efficiency




- Let m = 5

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

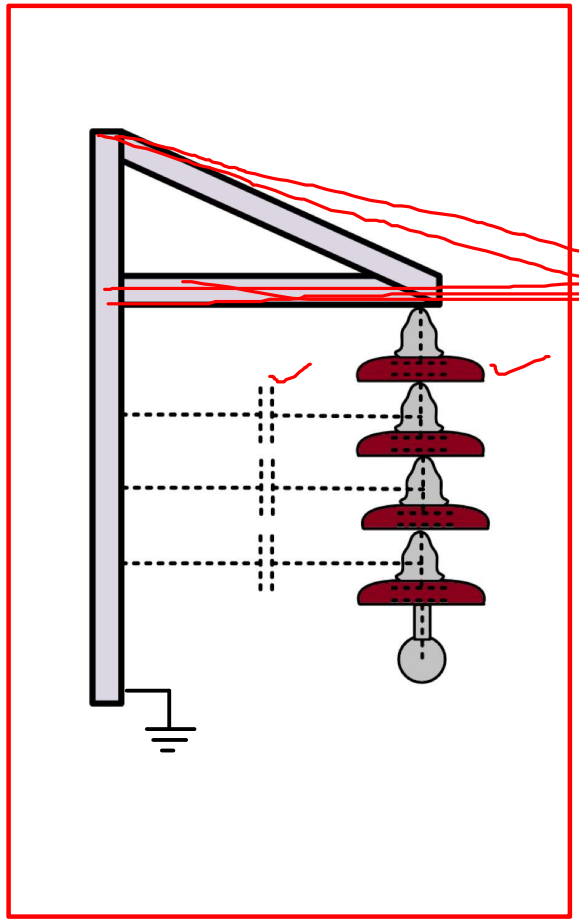
$$V_3 = \left[1 + \frac{3}{m} + \frac{1}{m^2}\right] V_1 \Rightarrow V_3 = 1.64 V_1$$

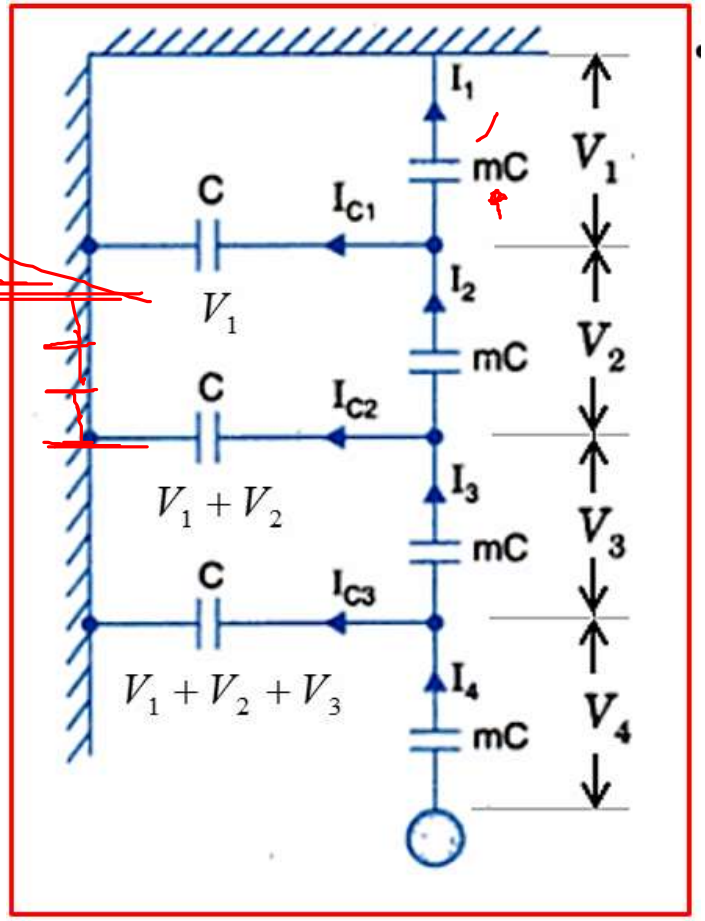
$$V_4 = \left[1 + \frac{6}{m} + \frac{5}{m^2} + \frac{1}{m^3}\right] V_1 \Rightarrow V_4 = 2.41 V_1$$

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

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

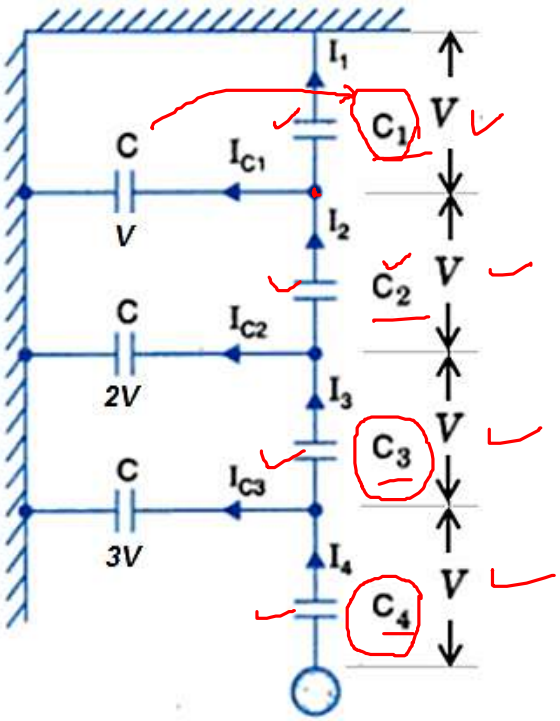
# Selection of m






- 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, $C_2 = C_1 + C$

$$C_3 = C_1 + 3C = C_1 + (1+2)C$$

$$C_4 = C_1 + 6C = C_1 + (1+2+3)C$$

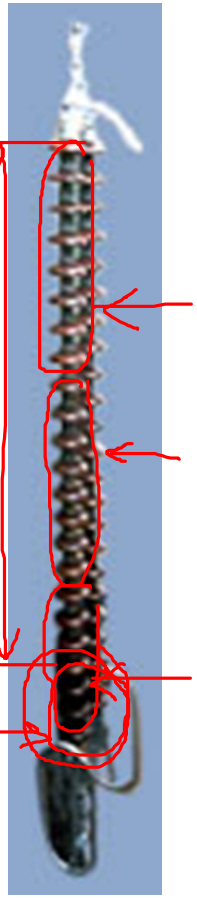
Generalized case:

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

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

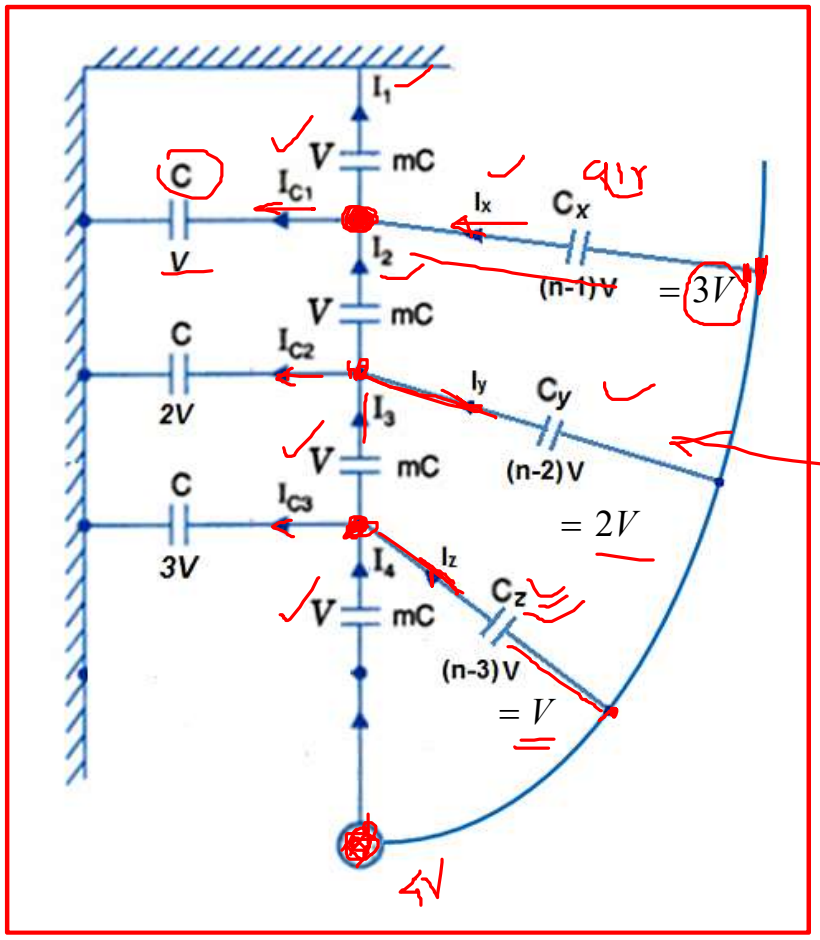
$$C_2 = 6C,\ C_3 = 8C,\ C_4 = 11C,\ \text{and so on}$$

# 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.

# Static Shielding




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

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

$$I_4 + I_z = I_3 + I_{C3}$$

Voltages can be equal if

$$I_x = I_{C1}$$

$$\omega C_x (3V) = \omega C V$$

$$C_x = \frac{C}{3} = \frac{C}{n-1}$$

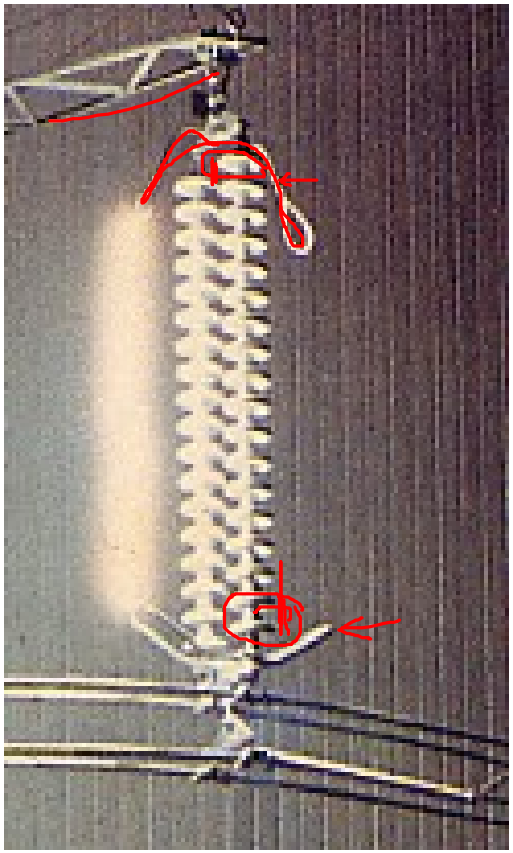
Also, $I_y = I_{C2}$

$$\omega C_y (2V) = \omega C (2V)$$

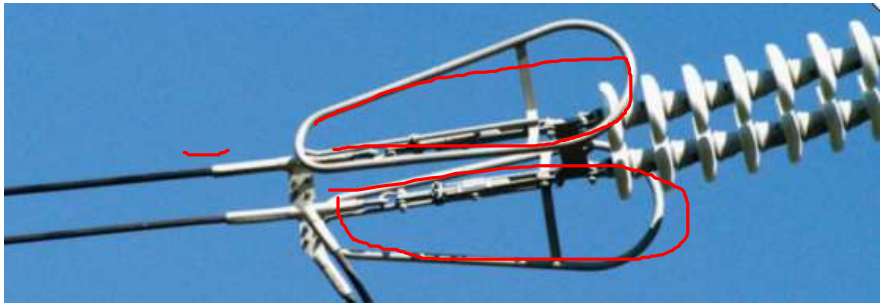
$$C_y = \frac{2C}{2} = \frac{2C}{n-2}$$

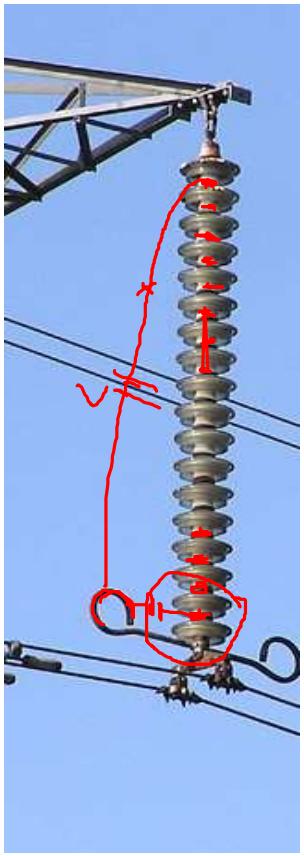
Similarly, $C_Z = \frac{3C}{(n-3)}$ and $C_p = \frac{pC}{(n-p)}$

# Static Shielding

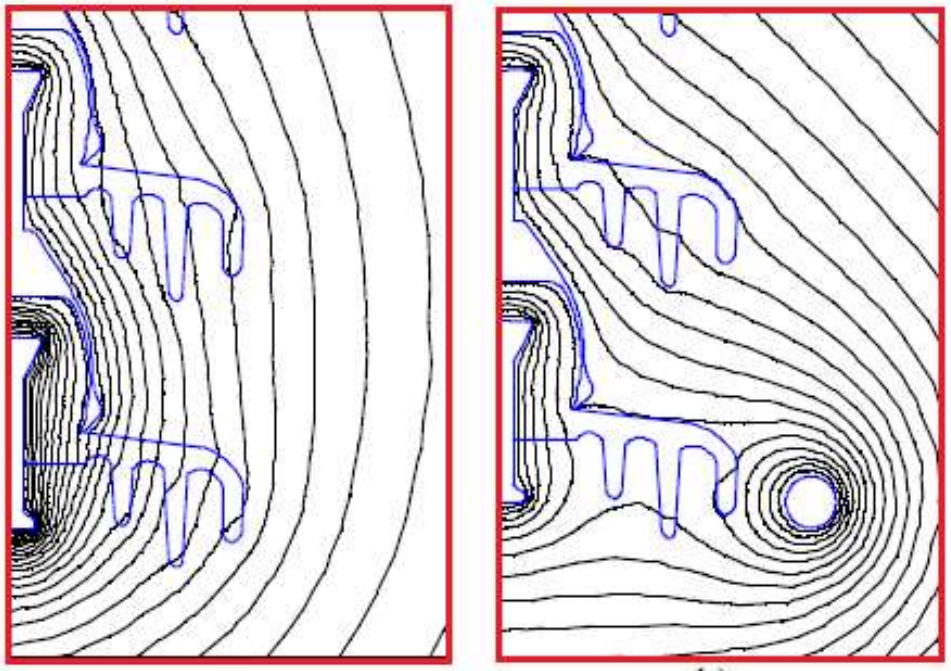


- In practice, it is very difficult to achieve the condition of equal voltages.
- However the partial advantage can be gained by this method using grading ring (*guard ring*) and used normally.
- Further, when the horn gap is also used, it also protect the insulator from the flashover.





# Static Shielding: Corona Ring




**a)** contour plots without corona ring
**b)** contour plots with corona ring

# Tutorial - 03

# Ques-01

A voltage of 33kV, 50Hz is impressed across a string of three identical disc units. The self capacitance of each disc is 10 times the capacitance of pin to earth. (a) Calculate the voltage across each disc and the string efficiency ignoring leakage current. (b) Calculate maximum voltage the string can withstand if the maximum voltage per disc is 20kV.

## Explanation and Hints

(a) No. of discs, n = 3

$C = 10C'$

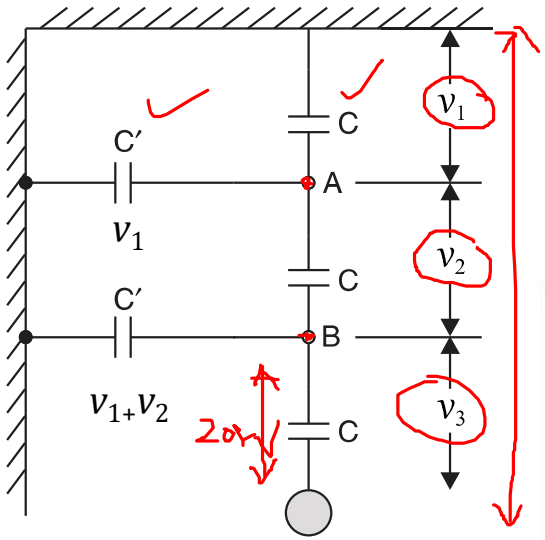
$$v_2 = \left[1 + \frac{1}{m}\right] v_1$$

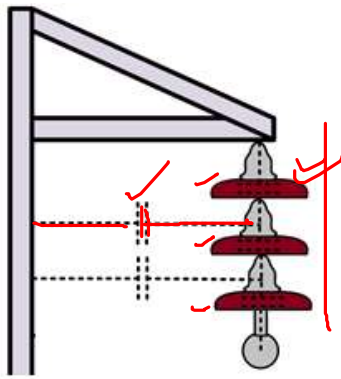
$$v_3 = \left[1 + \frac{3}{m} + \frac{1}{m^2}\right] v_1$$

$$\text{String Effciency} = \frac{\text{Voltage Across String}}{\text{n} \times \text{Voltage across unit adjacent to line}} \times 100$$

$V = v_1 + v_2 + v_3$

(b) $v_3$=20 kV -> $v_1$ -> $v_2$ -> $V = v_1 + v_2 + v_3$



# Ques-02

A string of 6 suspension insulators is to be graded for obtaining uniform voltage distribution across the string. If pin to earth capacitances are equal to C and the capacitance of the top insulator disc is 10C. Find the capacitance of each unit in terms of C.

**Explanation and Hints**

No. of discs n = 6

$m = \frac{10C}{C} = 10$

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

$C_1 = 10C$

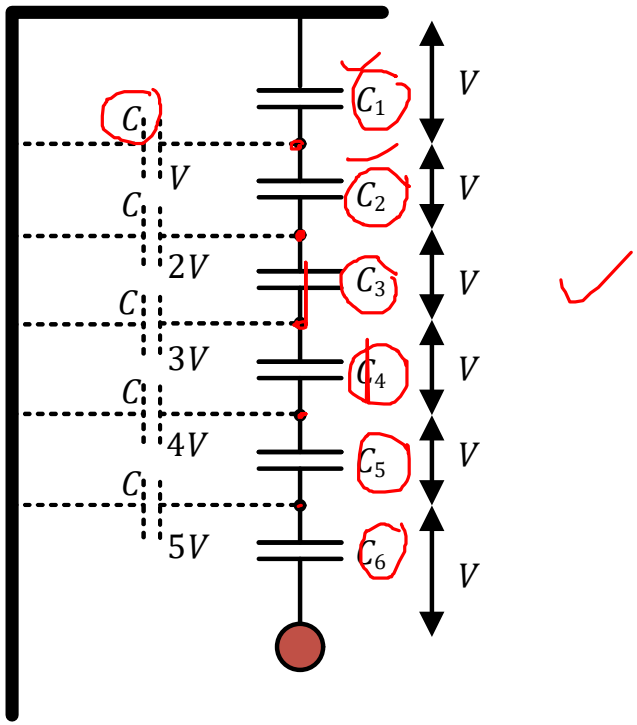
$C_2 = C_1 + 1C$

$C_3 = C_1 + 3C$

$C_4 = C_1 + 6C$

$C_5 = C_1 + 10C$

& $C_6 = C_1 + 15C$

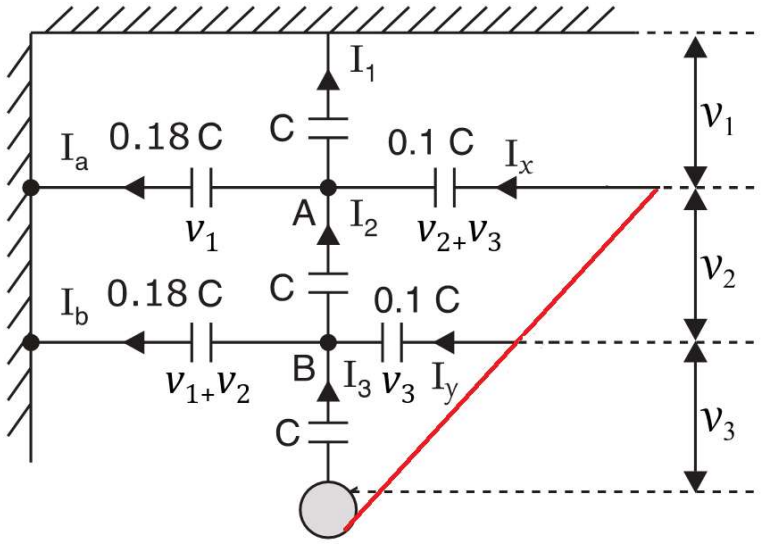


# Ques-03

Each of the three insulators forming a string has a self capacitance of *C* Farad. The shunting capacitance between earth and metal work of each insulator is 0.18 C while it is 0.1 C between metal work and line.

a) Calculate the voltage across each insulator as a percentage of line conductor voltage to earth and string efficiency.

b) If the guard ring is provided, increasing the capacitance between line and metal work of lowest unit to 0.25C. Calculate redistribution of voltage and new string efficiency.




## Explanation and Hints

a) Applying KCL at node A:

$$I_2 + I_x = I_a + I_1$$

$$j\omega C\, v_2 + j\omega(0.1C)\,(v_2 + v_3) = j\omega(0.18C)\, v_1 + j\omega C\, v_1$$

Now, KCL at node B

$$I_3 + I_y = I_b + I_2$$

$$j\omega C\, v_3 + j\omega(0.1C)\, v_3 = j\omega\,(0.18C)\,(v_1 + v_2) + j\omega C\, v_2$$

And,

$$v_1 + v_2 + v_3 = V$$

$$\eta = \frac{V}{n * v_3} * 100$$

# Ques-03

Each of the three insulators forming a string has a self capacitance of *C* Farad. The shunting capacitance between earth and metal work of each insulator is 0.18C while it is 0.1C between metal work and line.

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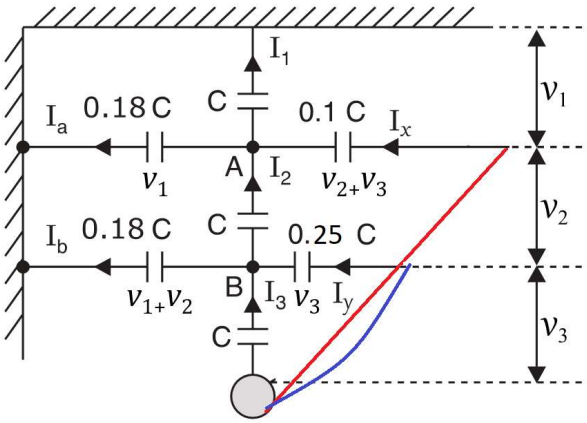


## Explanation and Hints

b) Applying KCL at node A:

$$I_2 + I_x = I_a + I_1$$

$$j\omega C\, v_2 + j\omega\,(0.1C)\,(v_2 + v_3) = j\omega(0.18C)\, v_1 + j\omega C\, v_1$$

Now, KCL at node B

$$I_3 + I_y = I_b + I_2$$

$$j\omega C\, v_3 + j\omega(0.25C)\, v_3 = j\omega\,(0.18C)\,(v_1 + v_2) + j\omega C\, v_2$$

And,

$$v_1 + v_2 + v_3 = V$$

$$\eta = \frac{V}{n * v_3} * 100$$

Conductor

Guard ring

# Distribution of Marks

**CWS**

- **50 Marks**
  - Best three out of four class tests after each 10 lectures (30 Marks).
  - Tutorial and class attendance, and assignment submissions (15 Marks)
  - Class interactions (5 Marks)

**ETE**

- **50 Marks**


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# Thank You