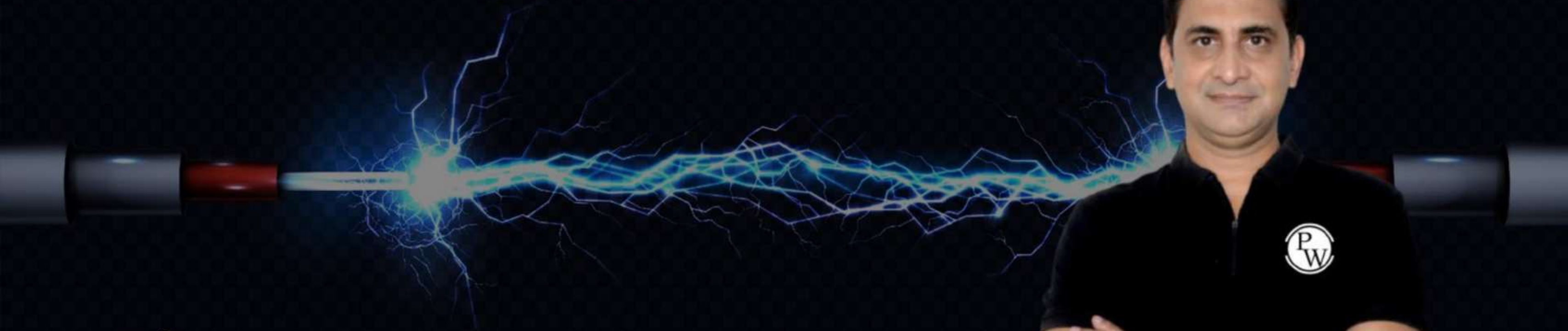


Electrical Engineering

Power System



Lecture No.-1
overhead line
Insulator

By- Ajay Gupta Sir



Recap Of previous class

- ✓ 1. Modification of SIL
 - ✓ 2. Question
-
-
-
-
-
-
-



Topics to be Covered



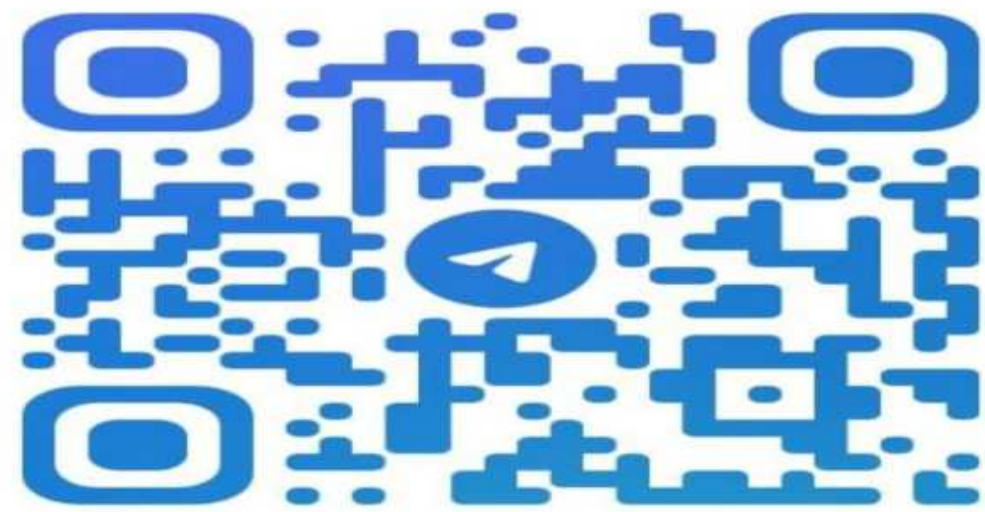
1. Types of Insulator



2. Voltage distribution in string



3. String Efficiency



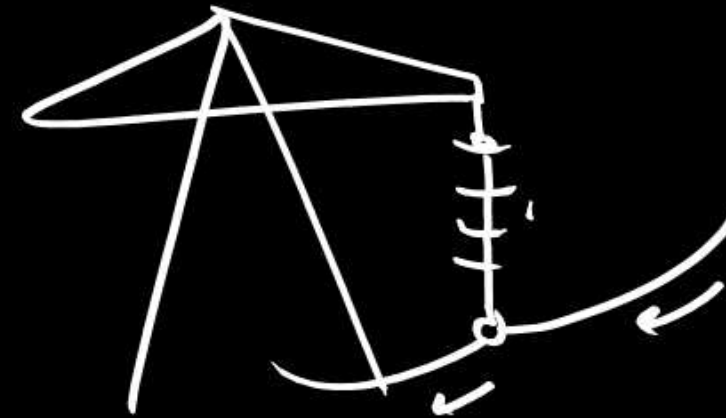
✓ @AJAYGUPTASIRPW

OVERHEAD LINE INSULATOR

- Insulator provide insulation of power conductor to ground (tower)
- It is attached with cross arm of tower
- It must provide necessary clearance against high voltage & worst atmosphere condition.

IMP

- Below 345 kV $\Rightarrow$ lighting over voltage
- Above 345 kV $\Rightarrow$ switching over voltage
- Insulator also provide mechanical support



Material→

1) Toughened glass:-

- Its outer surface are in compression & inter surface are in tension
- It is cheaper than porcelain
- Due to transparency, fault can be easily detected
- Moisture condenses easily on the surface, so its use is limited up to 33kV.
- its dielectric strength is higher than porcelain, it is 35 kV/inch

2. Glazed porcelain: -

- Glazing provide surface free from dirt & moisture.
- Stronger than glass & it is less affected by temperature

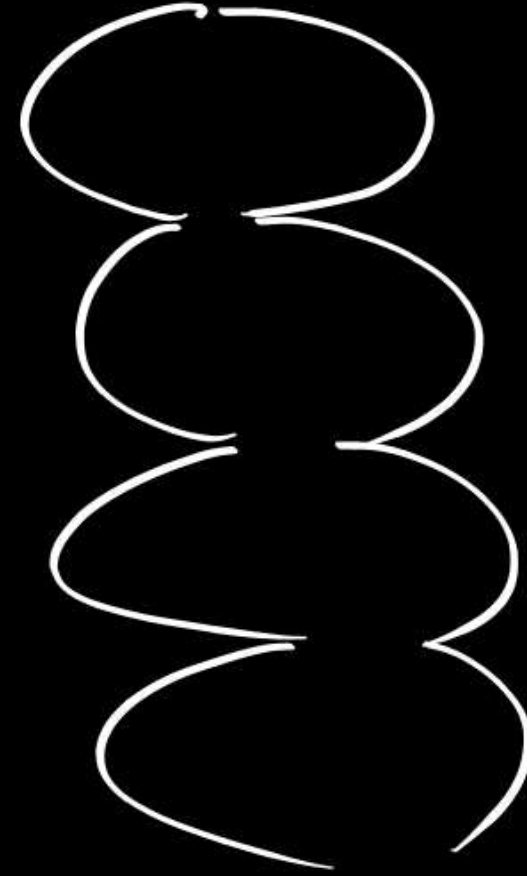
Dielectric strength 60 Kv/cm.

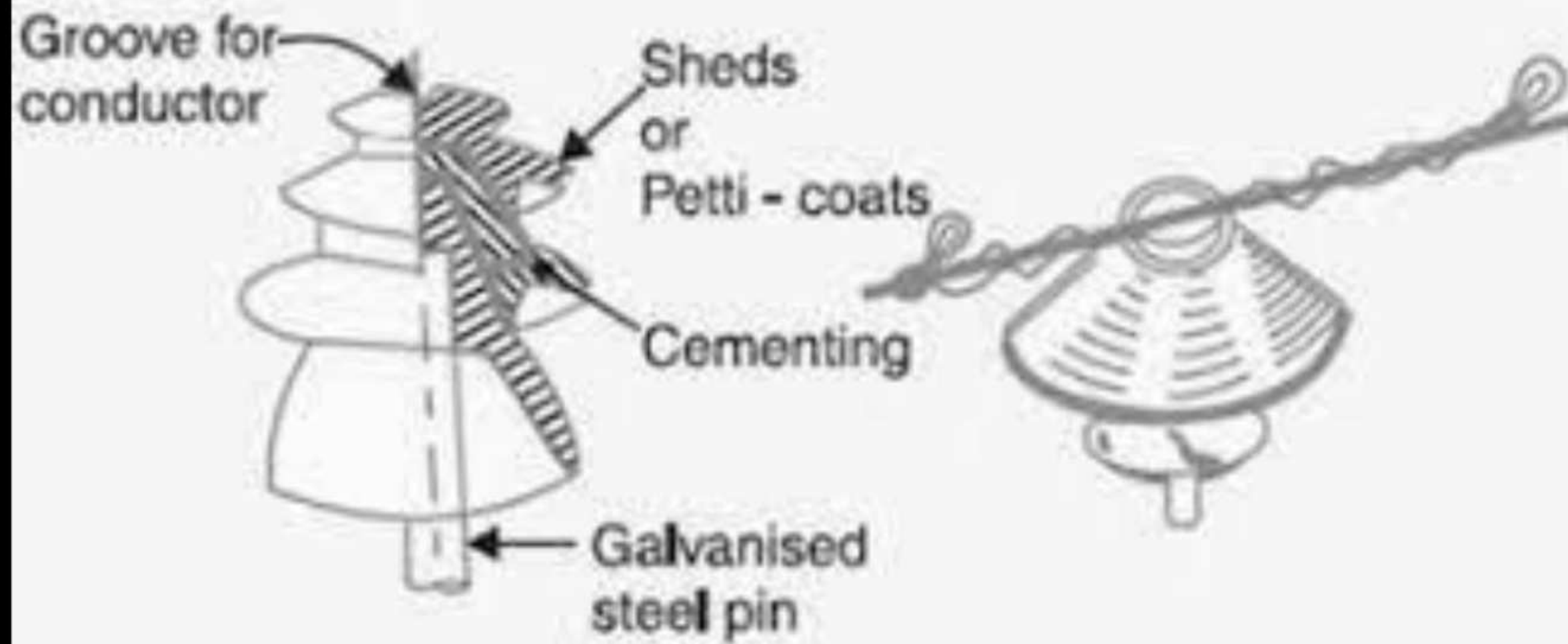
Type of Insulator: -

PIN Type insulator: -

- It is a single or multiple shed; it provide sufficient length of leakage path. So, flashover voltage is increased.
- PIN Insulator is used up to 33 KV.
- It is used up to 33 kV, beyond this voltage, size is become very bulky.
- The main disadvantage of pin insulator is that, at the time of puncture of insulator, complete set is to be changed

$$V = E \times d$$

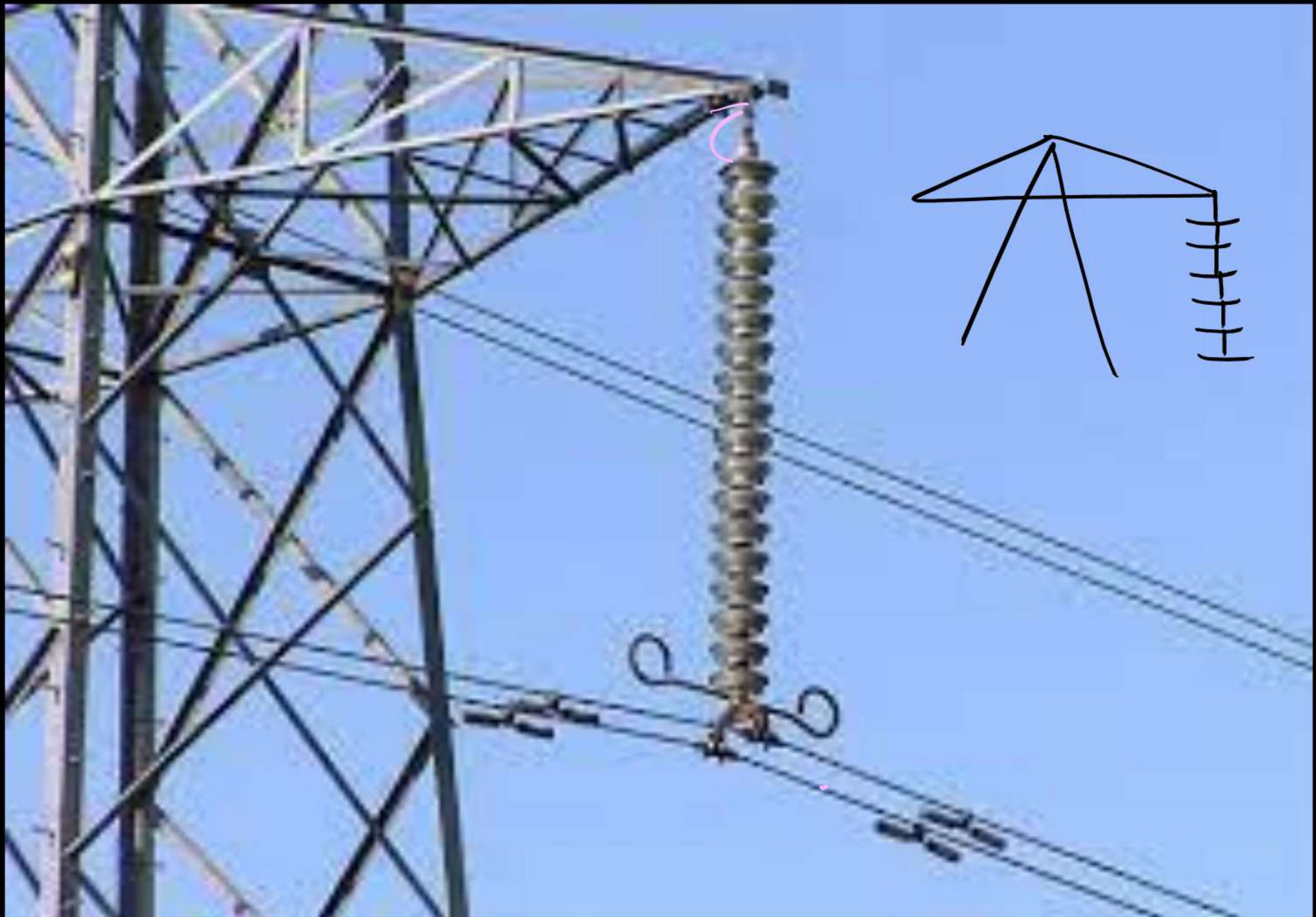




String insulator → Suspension/Disc Insulator



- It has porcelain disc units mounted one over another.
- Each disc has a single shed, grooved on the under surface to increase the distance between metal cap & metal pin.
- Each disc has metal cap at the top & metal pin underneath.
- Metal cap of one unit is connected metal pin of another unit to form the string.
- Suspension insulator are free to swing so clearness between power conductor & cross are should be more.
- Each unit of string insulator is design for 11 kV.
- With, wind pressure, both conductor & string swing together, so mechanical stress at point of attachment is less.
- String are at vertical plane (disc are at horizontal plane)



Strain Insulator



- They are same as suspension insulator but string are placed in horizontal configuration.
- They are used to take the tension at line terminal at angle tower, road/river crossing.
- On extra long span like river/road crossing tower more string is used in parallel



Voltage (kV)	66	132	220	400	765
No. of Disc in suspension	4-5	9-10	15-16	22-23	35-37
Strain Insulator	6-9	11-12	17-18	24-25	38-40

$$\frac{132}{\sqrt{3} \times 11} = \underline{7}$$

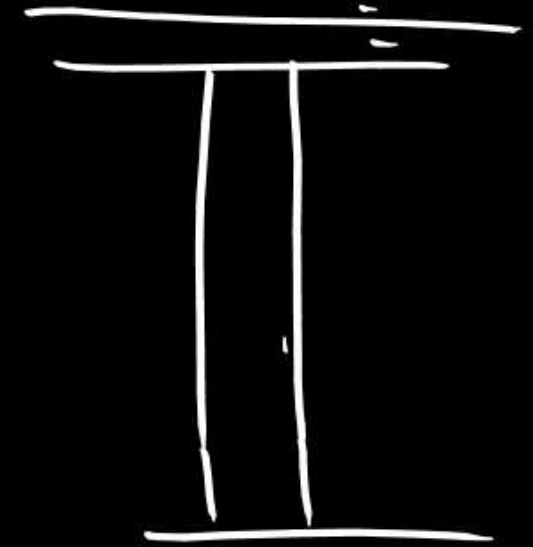
Shakle Insulator →

- It is used for distribution line
- It can be used at sharp edge, dead end.



Post Insulator →

They are used to support bus-bar & disconnecting switches in sub-station

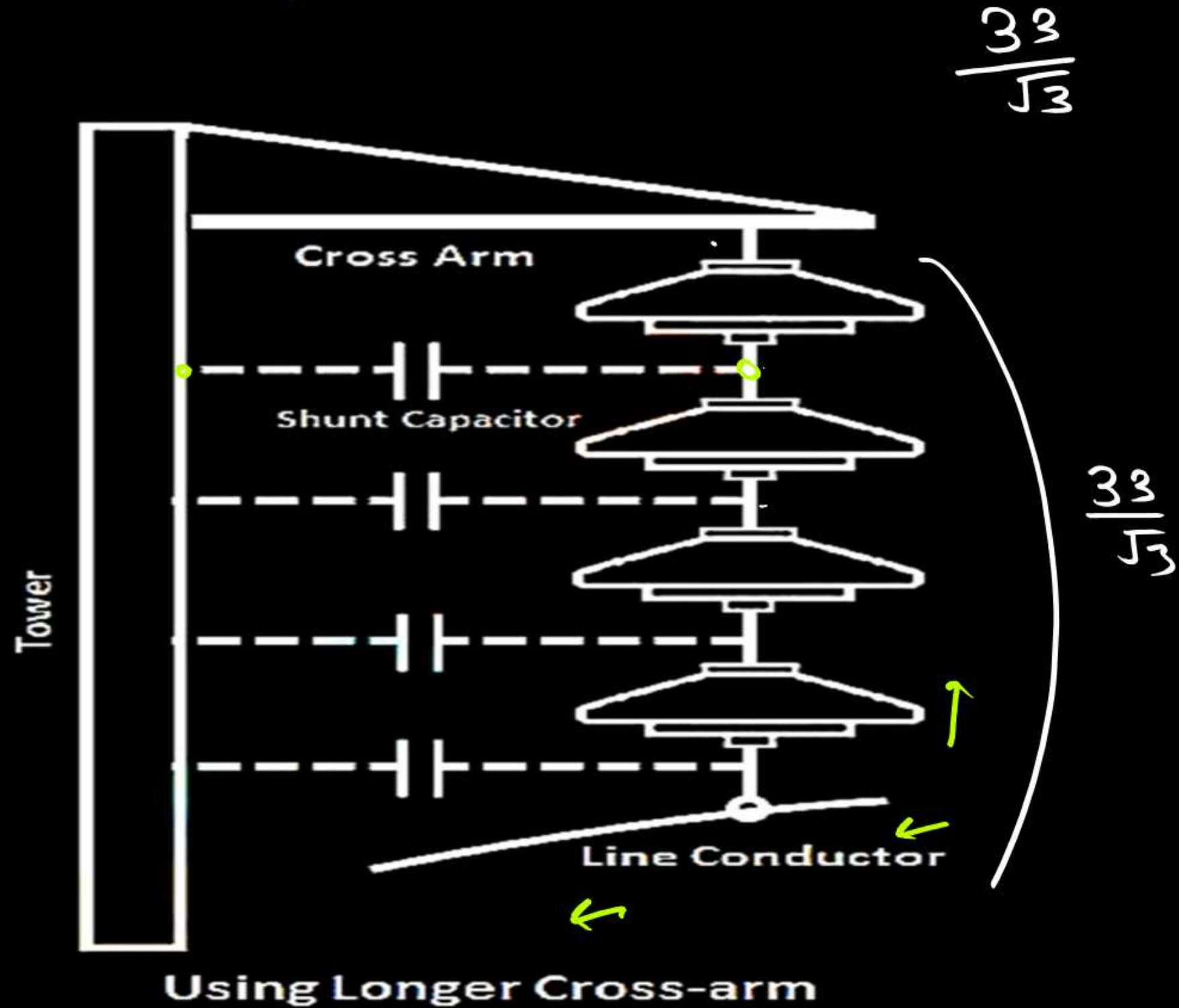
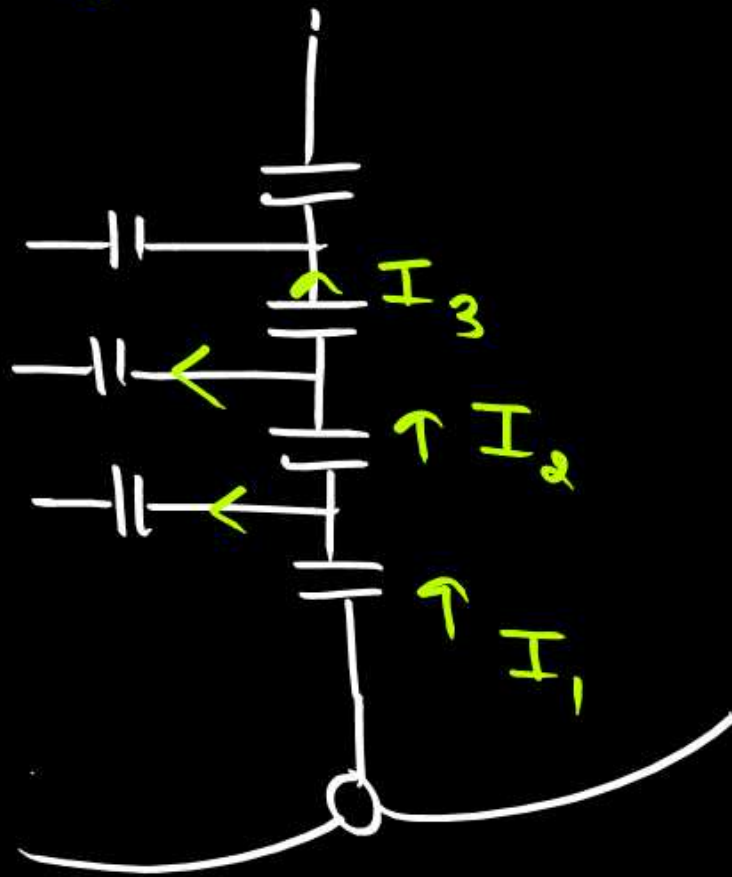


Voltage distribution over a string

$$V = IX_c = -I \frac{1}{j\omega C}$$

$$I_1 > I_2 > I_3$$

$$V_1 > V_2 > V_3$$



Voltage distribution over a string

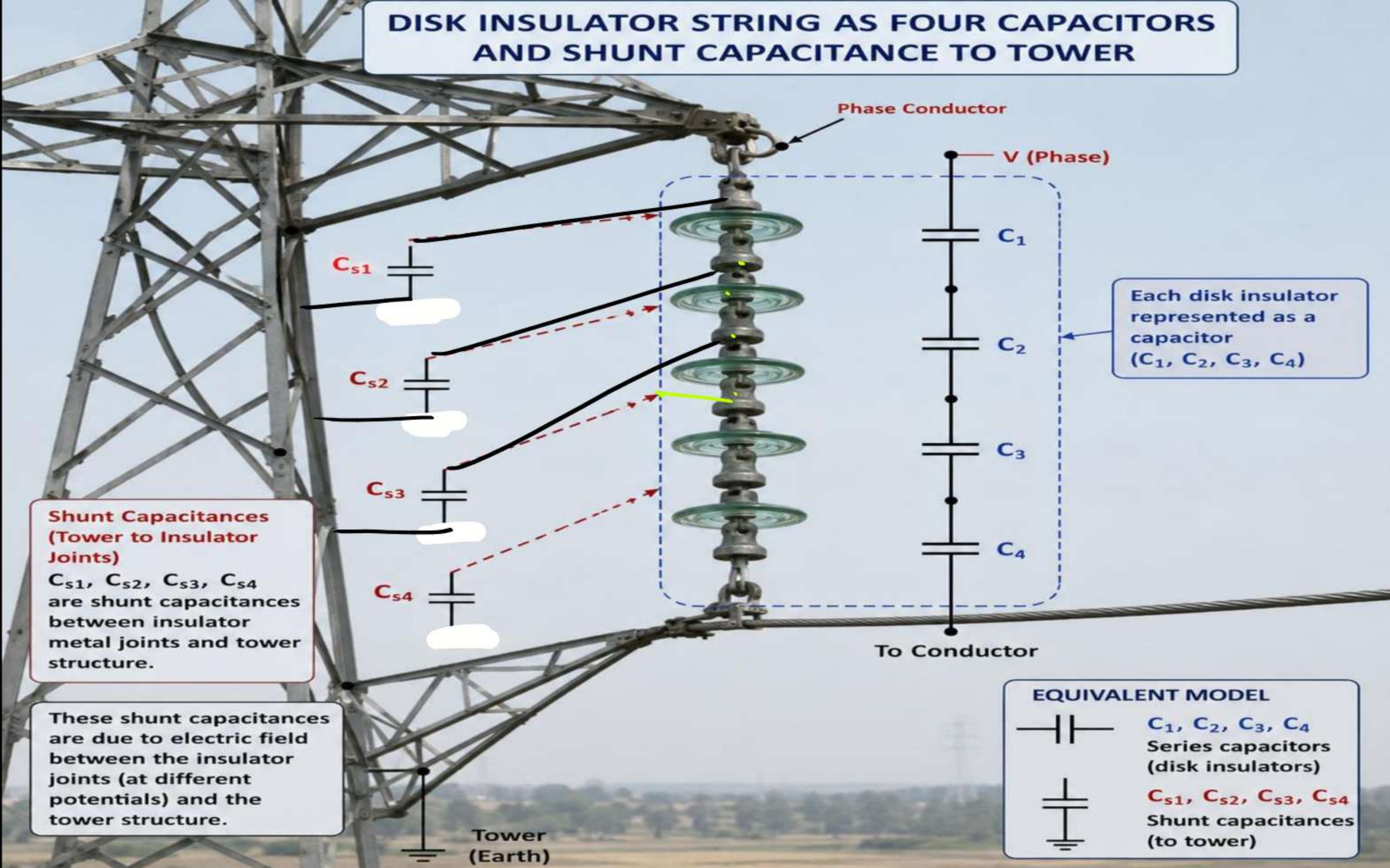
- Each disc is considered as a capacitor (as dielectric material porcelain exists between metal pin and metal joint). It is called self capacitance or mutual capacitance & complete string works as a capacitor voltage divider.
- If there were mutual capacitance alone, then charging current^(leakage current) would have been the same through all the discs and consequently voltage across each unit would have been the same.
- However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance or stray capacitance.

Voltage distribution over a string

(Leakage current)

- 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.
- So voltage across the disc will be more, which is nearer to conductor & it decrease as we move toward the cross arm.
- 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.

DISK INSULATOR STRING AS FOUR CAPACITORS AND SHUNT CAPACITANCE TO TOWER



Shunt Capacitances (Tower to Insulator Joints)
 $C_{s1}, C_{s2}, C_{s3}, C_{s4}$ are shunt capacitances between insulator metal joints and tower structure.

These shunt capacitances are due to electric field between the insulator joints (at different potentials) and the tower structure.

Each disk insulator represented as a capacitor (C_1, C_2, C_3, C_4)

EQUIVALENT MODEL

	C_1, C_2, C_3, C_4 Series capacitors (disk insulators)
	$C_{s1}, C_{s2}, C_{s3}, C_{s4}$ Shunt capacitances (to tower)

IN PRACTICE:
 $C_1 = C_2 = C_3 = C_4$ (approximately)
 $C_{s1}, C_{s2}, C_{s3}, C_{s4}$ depend on geometry, height, and tower configuration.

String efficiency:

It is a measure of degree of utilization of a material in string.

$$\eta = \frac{\text{Voltage across string}}{\text{No of disc} \times \text{voltage of lower most unit}}$$

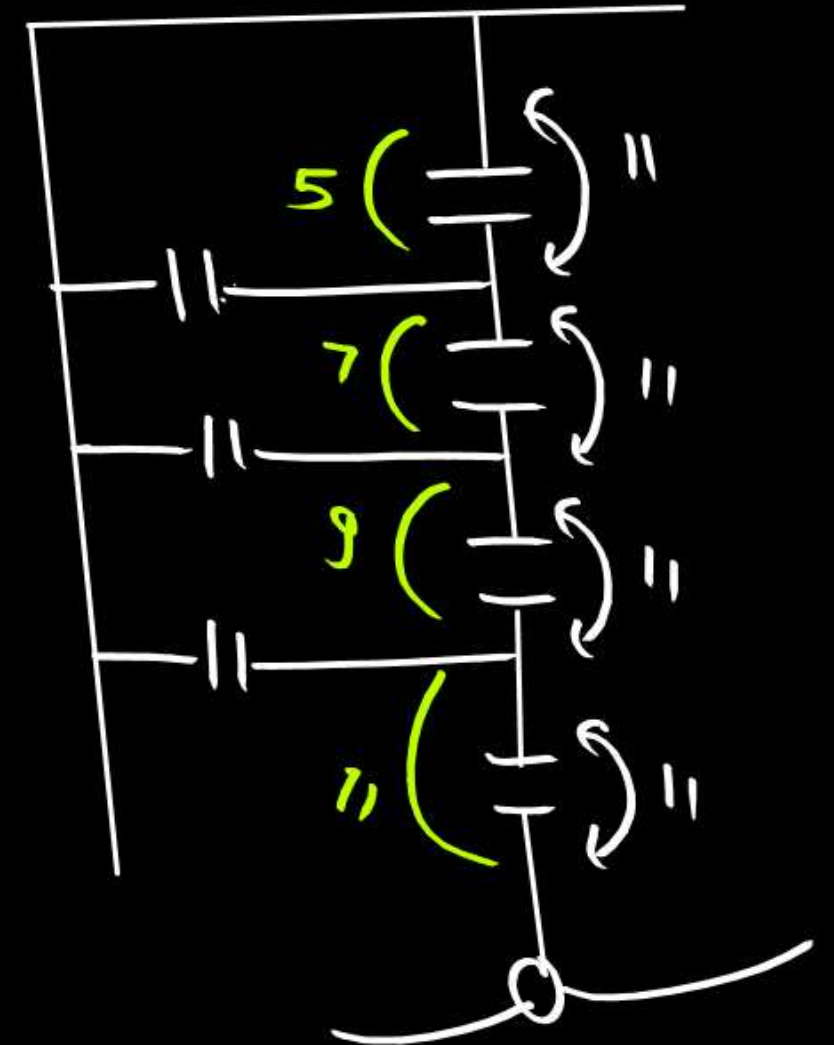
44 kV

32 kV

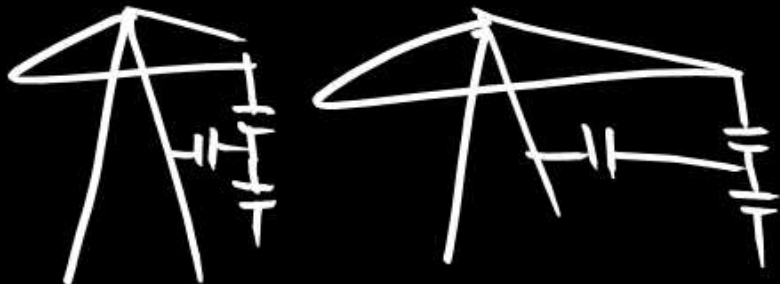
$$\frac{32}{44}$$

$$\frac{32}{4 \times 11}$$

$$\frac{44}{4 \times 11} = 100\%$$



- 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 the same.
- The string efficiency reduces with increase in no of disc.
- String efficiency decreases, if distance between tower & conductor decreases.



Calculation of String efficiency:

$$I = \frac{V}{X_c} = \frac{V}{1/j\omega c} = j\omega cV$$



KCL at Node 1

$$I_2 = I_1 + j_1$$

$$\cancel{j\omega} V_2 = \cancel{j\omega} c V_1 + \cancel{j\omega} (k) V_1$$

$$V_2 = V_1(1+k) \quad \text{---(1)}$$

$$k = \frac{\text{Stray Capacitance}}{\text{Self capacitance}}$$

$$K = \frac{C_1}{c}$$

$$C_1 = kc$$

KCL at Node 2

$$\frac{V_2}{1/j\omega C} = j\omega C V_2$$

$$I_3 = I_2 + I_1$$

$$j\omega C V_3 = j\omega C V_2 + j\omega (kC) (V_1 + V_2)$$

$$V_3 = kV_1 + (1+k)V_2$$

$$V_3 = kV_1 + (1+k)(1+k)V_1$$

$$V_3 = V_1 [k + 1 + 2k + k^2]$$

$$V_3 = V_1 [1 + 3k + k^2]$$

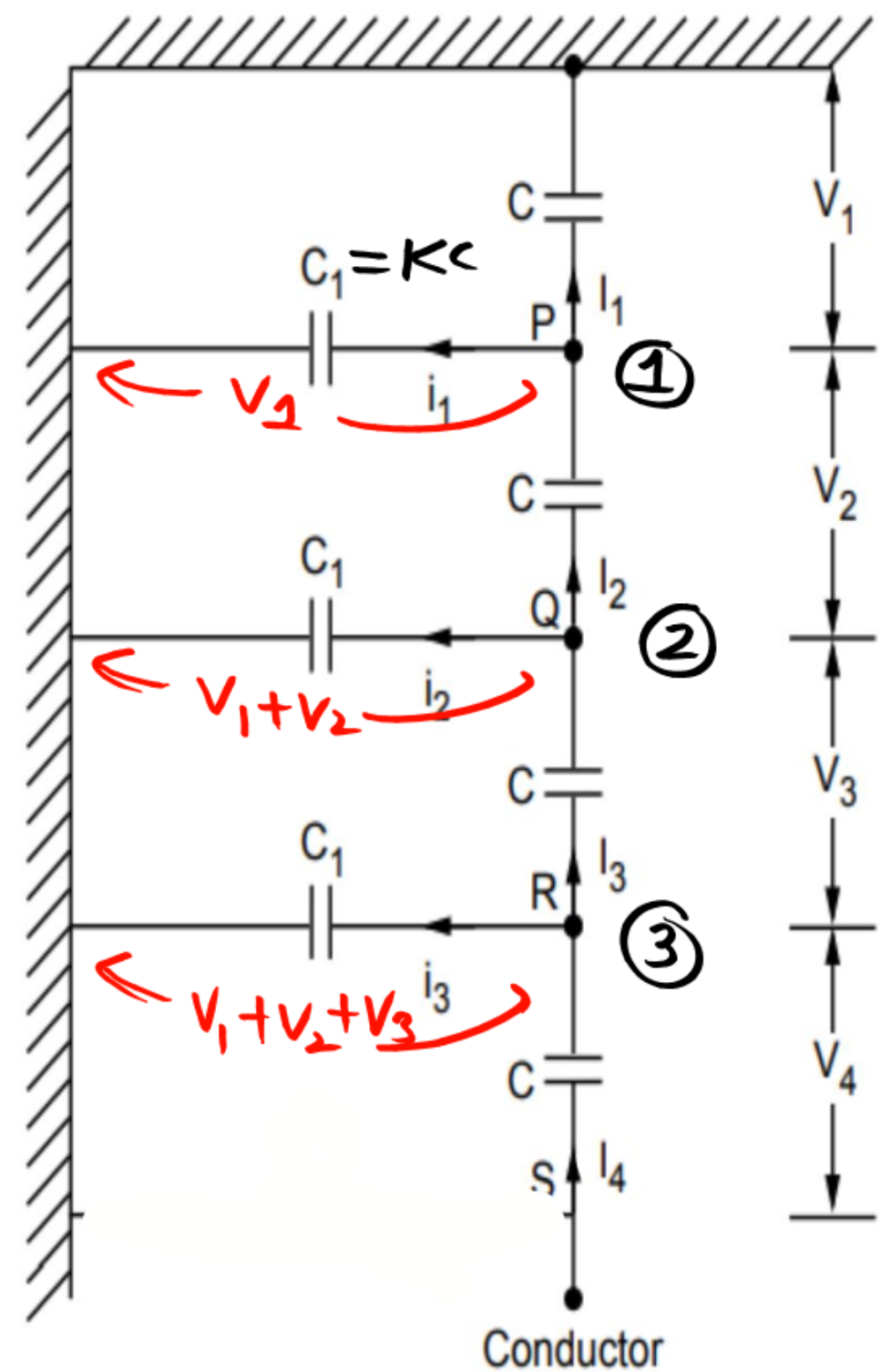


Fig. 5.1

KCL at Node 3

$$I_4 = I_3 + j_3$$

$$\cancel{j\omega\epsilon}V_4 = \cancel{j\omega\epsilon}V_3 + \cancel{j\omega(k\epsilon)}(V_1 + V_2 + V_3)$$

$$V_4 = kV_1 + kV_2 + (1+k)V_3$$

$$V_4 = kV_1 + k(1+k)V_1 + (1+k)(1+3k+k^2)V_1$$

$$V_4 = V_1 [k + k + k^2 + 1 + 3k + k^2 + k + 3k^2 + k^3]$$

$$V_4 = V_1 [1 + 6k + 5k^2 + k^3]$$

Remember

$$V_1 = V_1$$

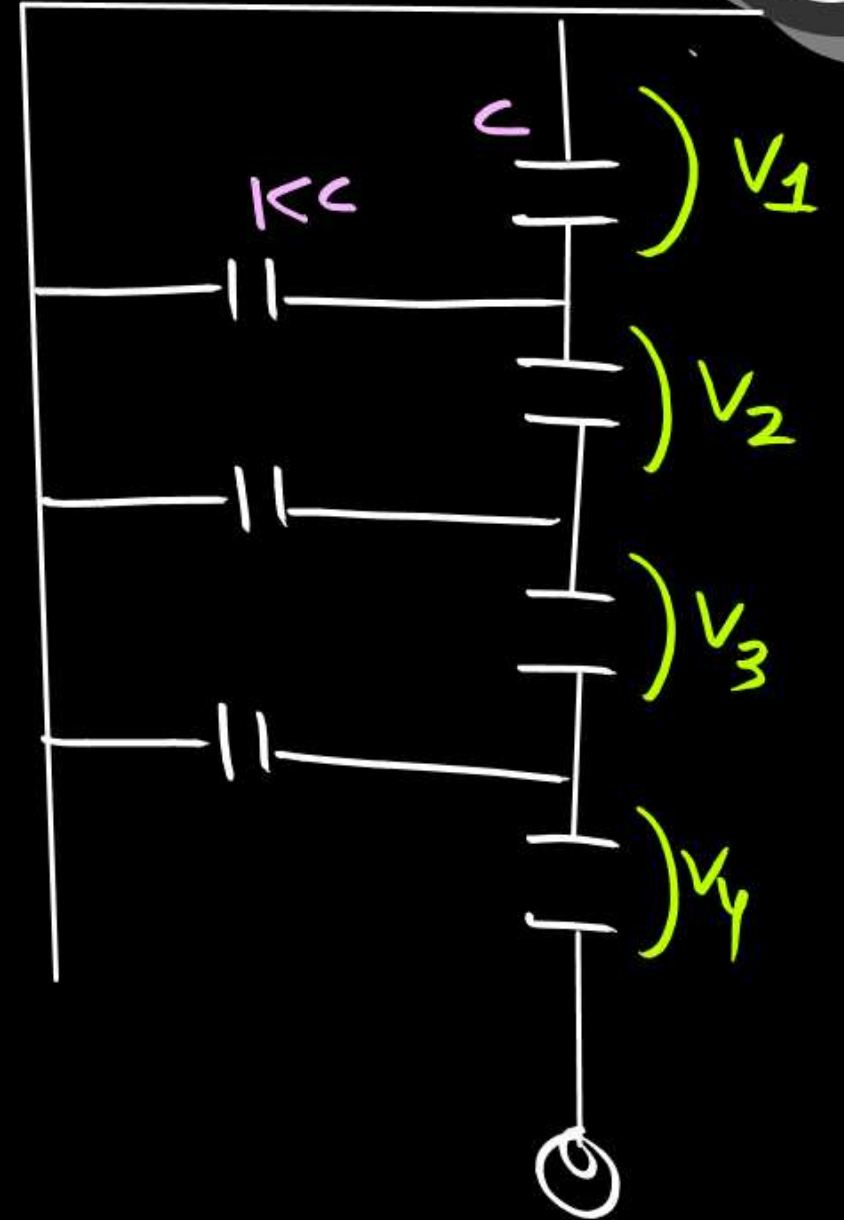
$$(k < 1)$$

$$V_2 = (1+k) V_1$$

$$V_3 = (1+3k+k^2) V_1$$

$$V_4 = (1+6k+5k^2+k^3) V_1$$

$$\eta = \frac{V_1 + V_2 + V_3 + V_4}{4 \times V_1}$$



Remember (For 3 Disk)

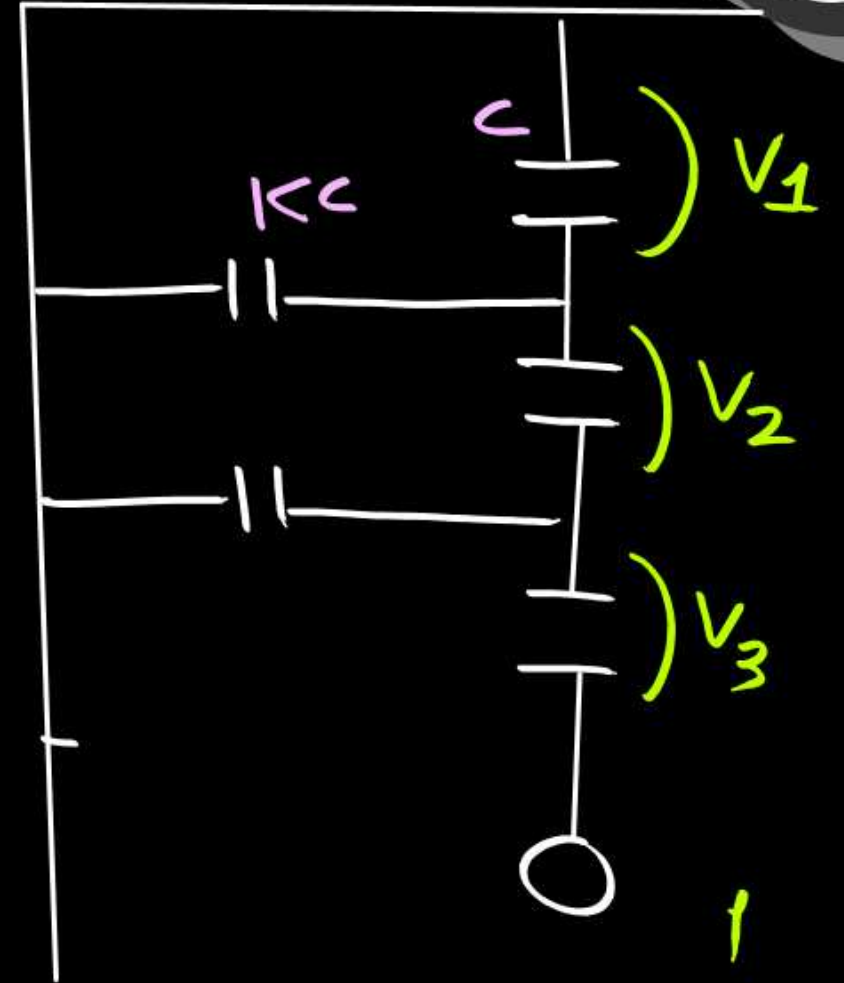
$$V_1 = V_1$$

$$V_2 = (1+k)V_1$$

$$V_3 = (1+3k+k^2)V_1$$

$$\eta = \frac{V_1 + V_2 + V_3}{3 \times V_3}$$

$$(k < 1)$$



Important Point



- 1> The voltage across the disc is Max^m . if Disk is nearest to line. Take it as a rated voltage of disk
- 2> String voltage = $V_1 + V_2 + V_3 - -$ (Per phase voltage)
- 3) T.L Voltage = $\sqrt{3} \times \text{phase voltage}$.

Q. An insulator string for 132 kV line has 4 disc. The shunt capacitance between each joint & metal work is 10% of capacitance of each disc. Find the voltage distribution and string efficiency.

$$V_1 + V_2 + V_3 + V_4 = \frac{132}{\sqrt{3}} = 76.21 \text{ kV} \quad - \textcircled{1}$$

$$k = 0.1$$

$$\rightarrow V_1 = V_1$$

$$\rightarrow V_2 = (1+k)V_1 = (1+0.1)V_1 = 1.1V_1$$

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

$$V_3 = (1 + 0.3 + 0.01) V_1$$

$$\rightarrow V_3 = 1.31 V_1$$

$$V_4 = (1 + 6K + 5K^2 + K^3) V_1$$

$$V_4 = (1 + 0.6 + 0.05 + 0.001) V_1$$

$$V_4 = 1.651 V_1$$

V_2

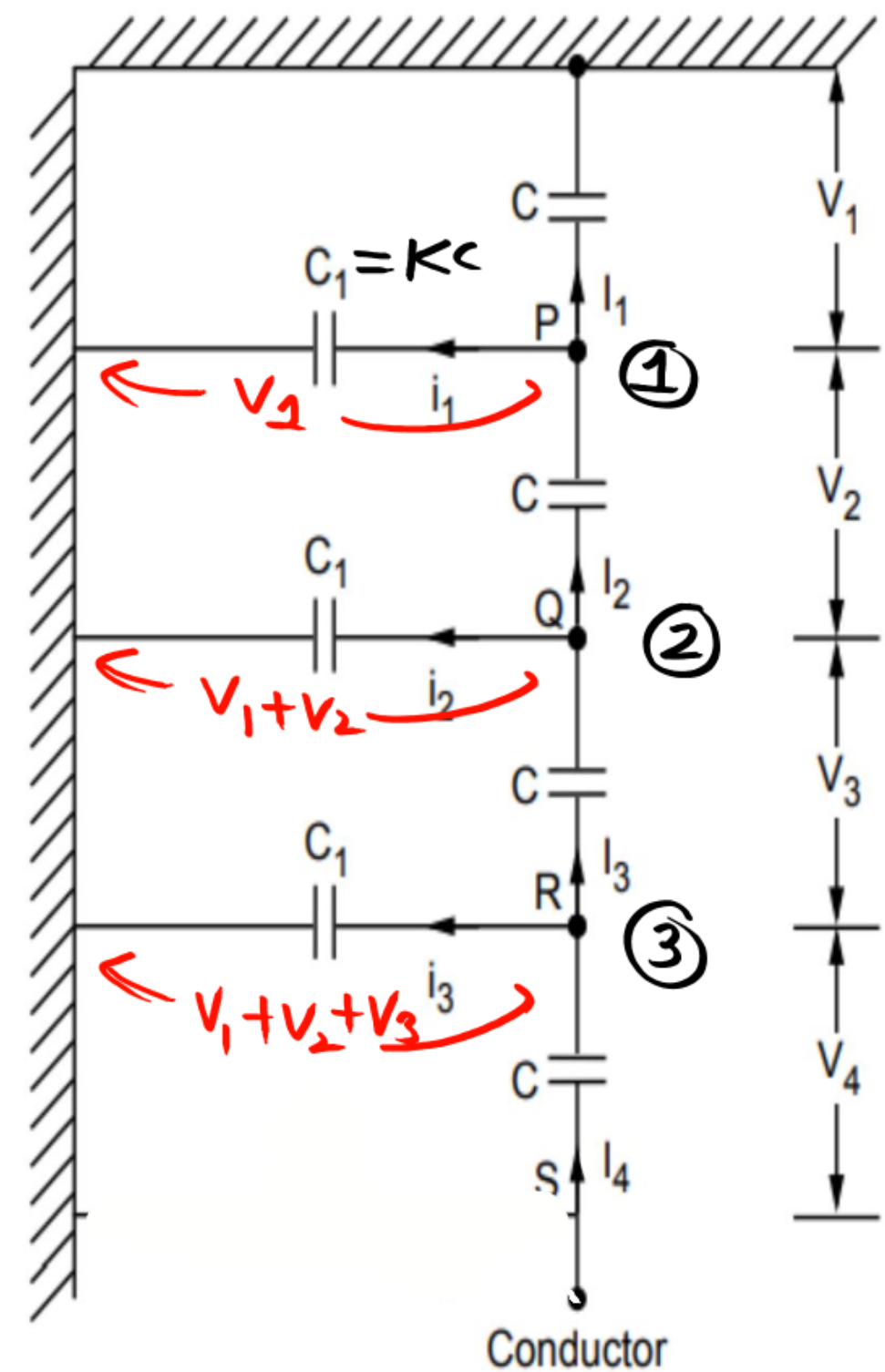


Fig. 5.1

Put value of V_2, V_3 & V_4 in eqⁿ (1)

$$V_1 + V_2 + V_3 + V_4 = 76.21$$

$$V_1 + 1.1V_1 + 1.31V_1 + 1.651V_1 = 76.21$$

$$5.061V_1 = 76.21$$

$$\rightarrow V_1 = 15.058 \text{ kV}$$

$$\rightarrow V_2 = 1.1(15.058) = 16.564 \text{ kV}$$

$$\rightarrow V_3 = 1.31(15.058) = 19.726 \text{ kV}$$

$$\rightarrow V_4 = 1.651(15.058) = 24.86 \text{ kV}$$

$$\eta = \frac{V_1 + V_2 + V_3 + V_4}{4V_4}$$

$$\eta = \frac{76.21}{4 \times 24.86} = 0.7664$$

$$= \underline{76.64\%}$$

#Q. Two insulator discs of identical capacitance value C make up a string for a 22kV, 50 Hz, single phase overhead line insulation system. If the pin to earth capacitance is also C, then the string efficiency is [ESE-2003]

A 50%

B 75%

C 90%

D 86%

$$K = \frac{C}{C} = 1$$

$$V_1 = V_1$$

$$V_2 = (1+K)V_1 = (1+1)V_1 = 2V_1$$

$$\eta = \frac{V_1 + V_2}{2(V_2)} = \frac{V_1 + 2V_1}{2(2V_1)} = \frac{3}{4} = 0.75$$

#Q. In a three-unit insulator string, voltage across the lowest unit is 17.5kV and string efficiency is 84.28%. The total voltage across the string will be equal to [ESE-2001]

A 8.825 kV

B 44.25 kV

C 88.25 kV

D 442.5 kV

$$\eta = \frac{(V_1 + V_2 + V_3)}{3 V_3}$$

$$0.8428 = \frac{V_1 + V_2 + V_3 + V_4}{3(17.5)}$$

$$V_1 + V_2 + V_3 + V_4 = 44.25$$



2 Minutes Summary

- Types of Insulator
- Voltage distribution
- String efficiency.

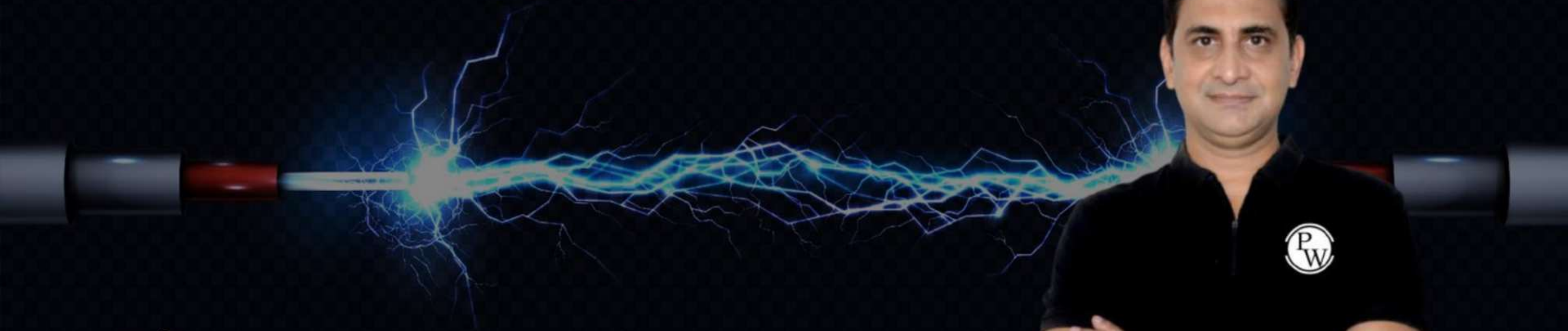
Thank you

GW
Soldiers !



Electrical Engineering

Power System



Lecture No.-2
Over head line
Insulator

By- Ajay Gupta Sir



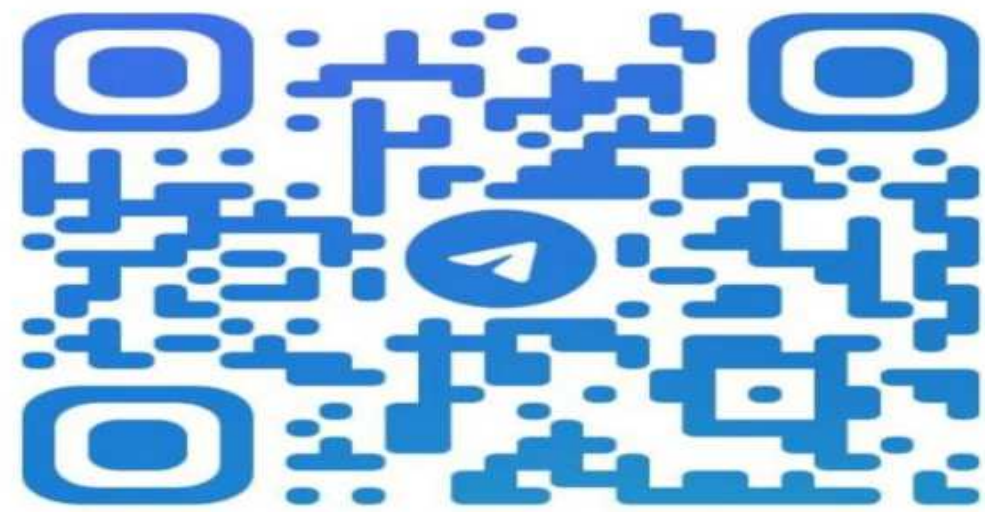
Recap Of previous class

- ✓ 1. Types of insulator
- ✓ 2. Voltage distribution
- ✓ 3. String Efficiency



Topics to be Covered

- ✓ 1. Method to improve string efficiency
- ✓ 2. Capacitance grading
- ✓ 3. Static shielding



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Q.



An insulator string having 3 disc, each having the same working voltage of 15 KV. The ratio of stray capacitance to self capacitance is $1/8$, Find out voltage of transmission line?

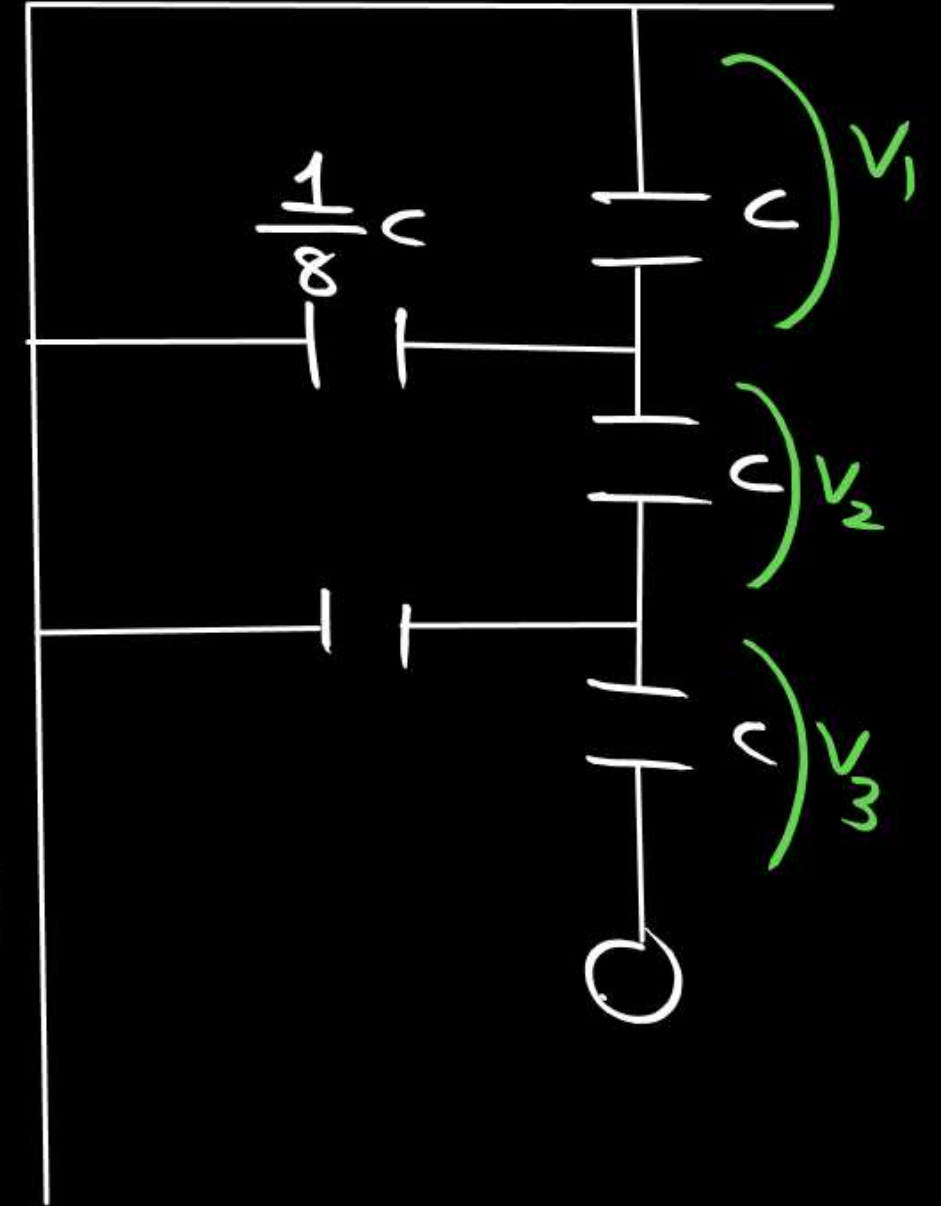
- A 37.92 kV
- ☒ B 65.68 kV
- C 52.9 kV
- D 48.3 kV

$$K = \frac{1}{8}$$

$$V_1 = V_1$$

$$V_2 = (1 + K) V_1 = \left(1 + \frac{1}{8}\right) V_1 = \frac{9}{8} V_1$$

$$V_3 = (1 + 3K + K^2) V_1 = \left(1 + \frac{3}{8} + \frac{1}{64}\right) V_1 = \frac{89}{64} V_1$$



$$\rightarrow V_3 = 15 \text{ kV}$$

$$\frac{89}{64} V_1 = 15$$

$$\rightarrow V_1 = 10.786$$

$$\rightarrow V_2 = \frac{9}{8} V_1 = \frac{9}{8} \times 10.786 = 12.134.$$

$$\text{String voltage} = V_1 + V_2 + V_3$$

$$= 10.786 + 12.134 + 15 = 37.92$$

$$Line = \sqrt{3} \times 37.92 = 65.67 \text{ kv}$$

Q.



An insulator string having 3 disc, each having the same working voltage of 15 KV. The ratio of stray capacitance to self capacitance is $1/8$, Find out string efficiency?

A 75.6%

B 87.3%

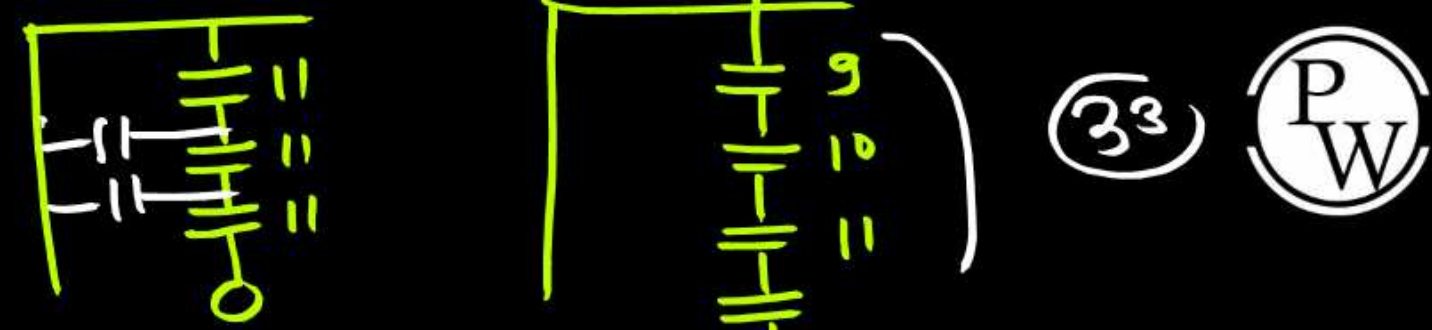
C 79.3%

D 84.27%

$$\eta = \frac{V_1 + V_2 + V_3}{3 V_3}$$

$$\eta = \frac{37.92}{3 \times 15} = 0.8426$$
$$= 84.26\%$$

Improvement of 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 crossarm is approached.
- If the insulation of the highest stressed insulator (i.e. nearest to conductor) breaks down or flash over) takes place, the breakdown of other units will take place in succession.
- This necessitates to equalise the potential across the various units of the string i.e. to improve the string efficiency.
- The various methods for this purpose are:



1. 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, $K = \underline{0.1}$ is the limit that can be achieved by this method.

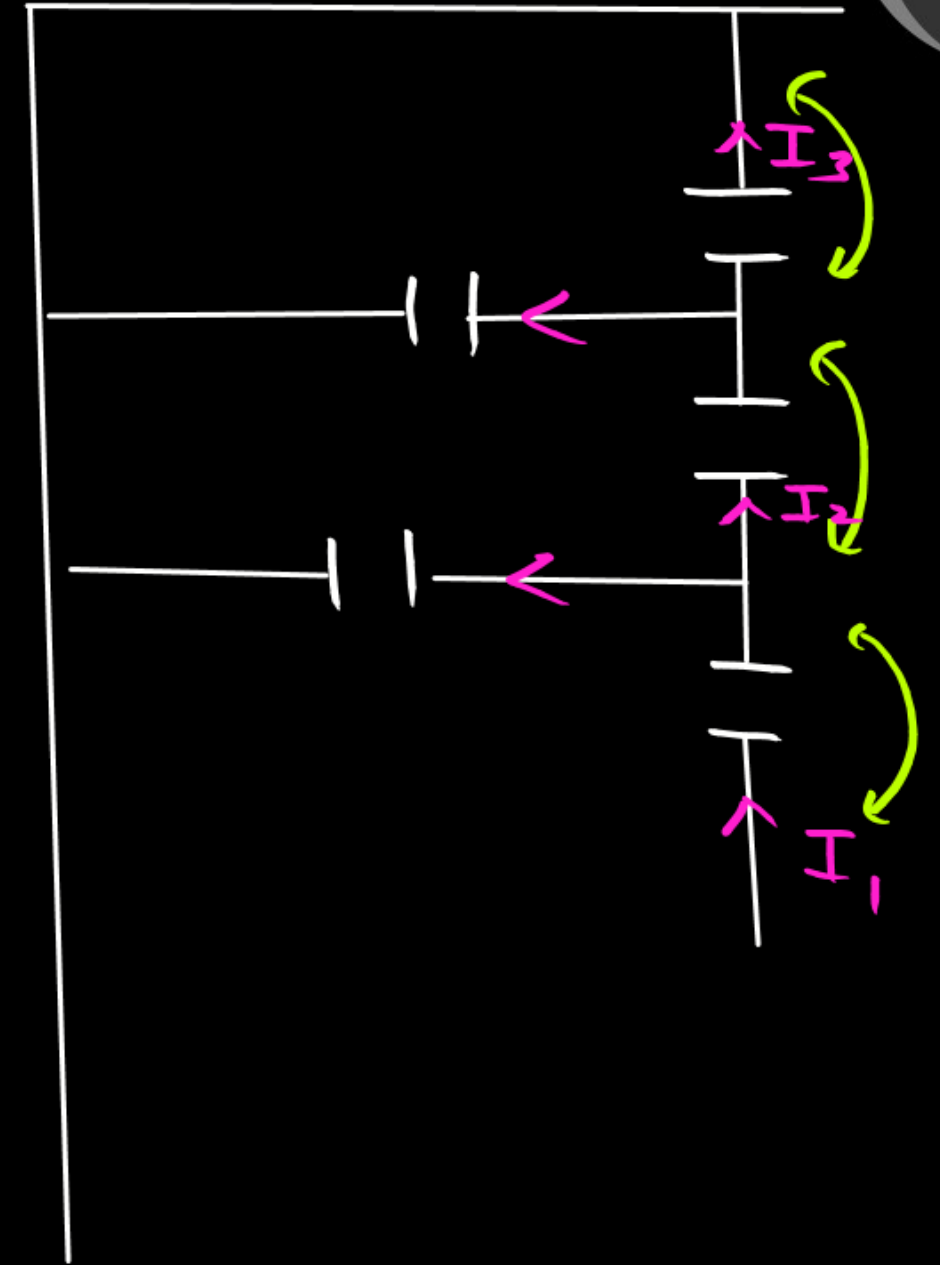
2. By capacitance grading.

- 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 equalise 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.

$$C_1 > C_2 > C_3$$

$$I_1 > I_2 > I_3$$

$$V = IX_c = \frac{I}{j\omega C}$$



- Suppose after capacitance grading the voltage across each unit is become uniform v .
- The capacitance of disc nearer to tower is C_1 .
- The capacitance of n th number of disc from tower is C_n .
- The capacitance of $\downarrow$ th number of disc from tower is C_{n+1}
 $(n+1)$

$$I_{n+1} = I_n + I_x$$

Stray Capacitance

$$j\omega C_{n+1} V = j\omega C_n V + j\omega (kC) (nV)$$

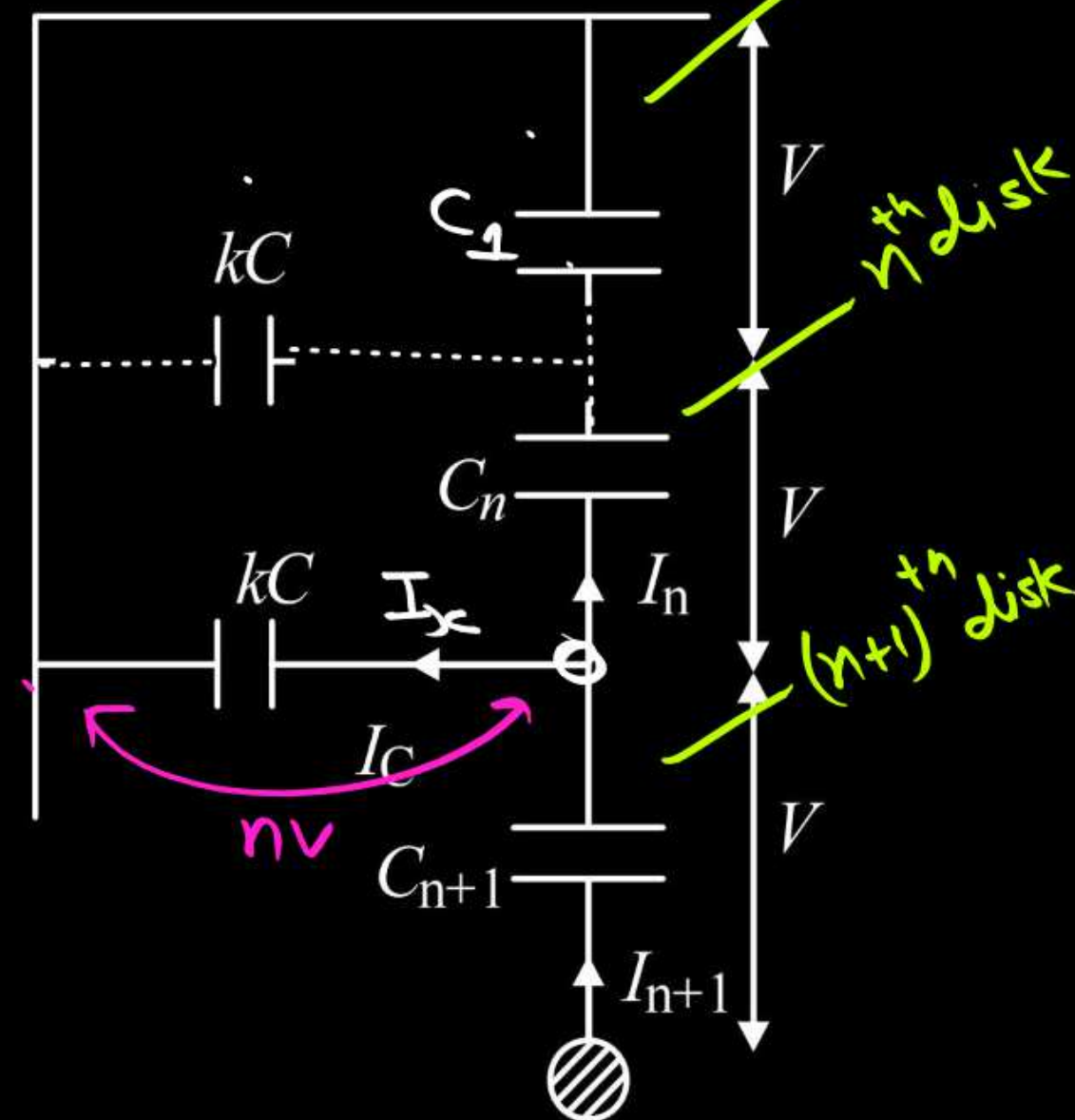
$$C_{n+1} = C_n + (kC)n$$

$$n=1 \quad C_2 = C_1 + kC$$

$$n=2 \quad C_3 = C_2 + 2(kC)$$

$$n=3 \quad C_4 = C_3 + 3(kC)$$

⋮



Q.



A string of 6 suspension insulator to be graded to obtain the uniform distribution of voltage. If pin to earth capacitance is C and self capacitance of bottom unit is $25C$. Find out the self capacitance to top insulator discs?

$$KC = C$$

$$C_{n+1} = C_n + n(KC)$$

$$C_{n+1} = C_n + nC$$

$$n=1$$

$$C_2 = C_1 + C \quad \text{--- (1)}$$

$$n=2$$

$$C_3 = C_2 + 2C = (C_1 + C) + 2C = C_1 + 3C$$

$$n=3$$

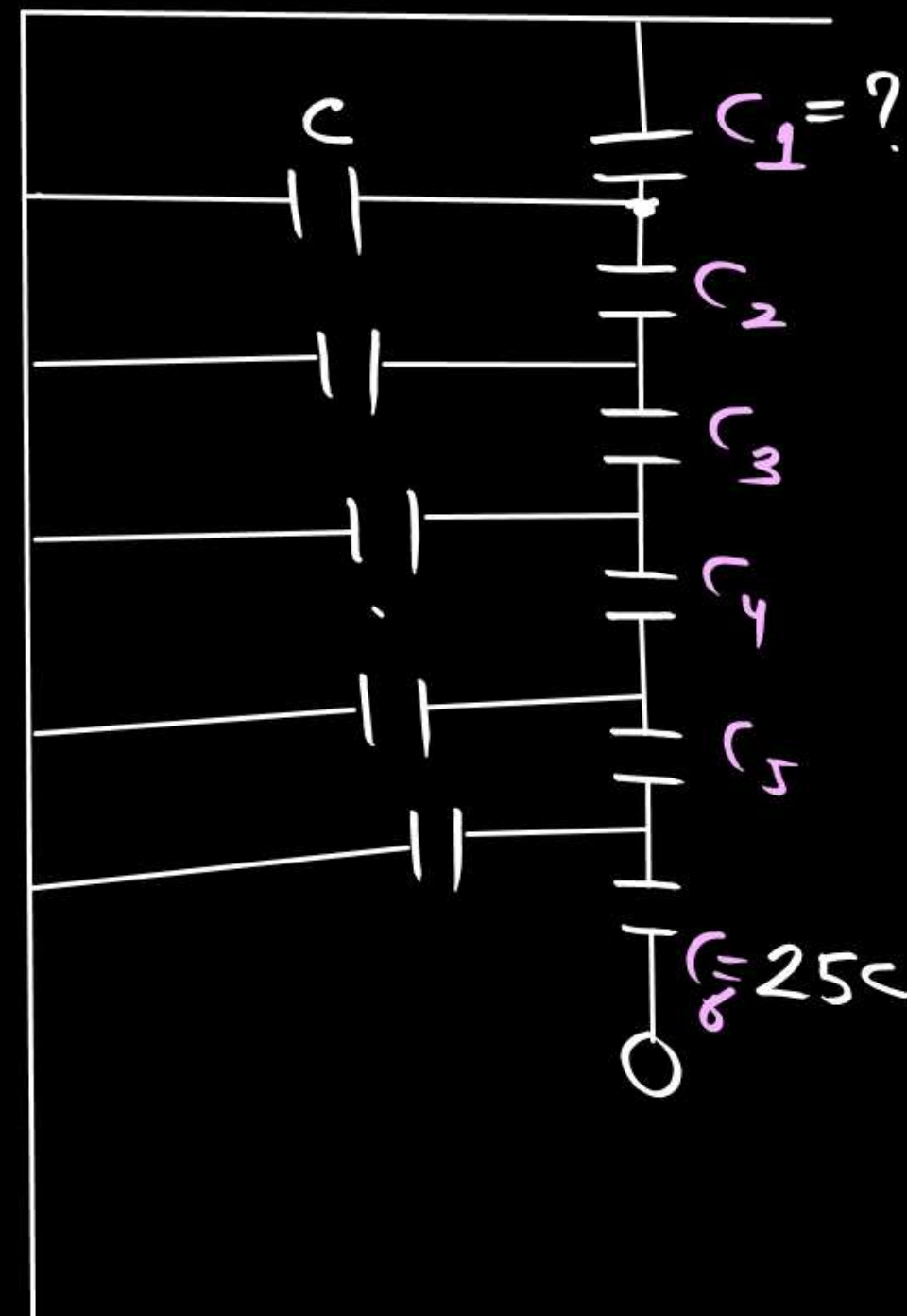
$$C_4 = C_3 + 3C = (C_1 + 3C) + 3C = C_1 + 6C$$

$$n=4$$

$$C_5 = C_4 + 4C = (C_1 + 6C) + 4C = C_1 + 10C$$

$$n=5$$

$$C_6 = C_5 + 5C = (C_1 + 10C) + 5C = C_1 + 15C$$



A

2C

B

5C

C

10C

D

15C

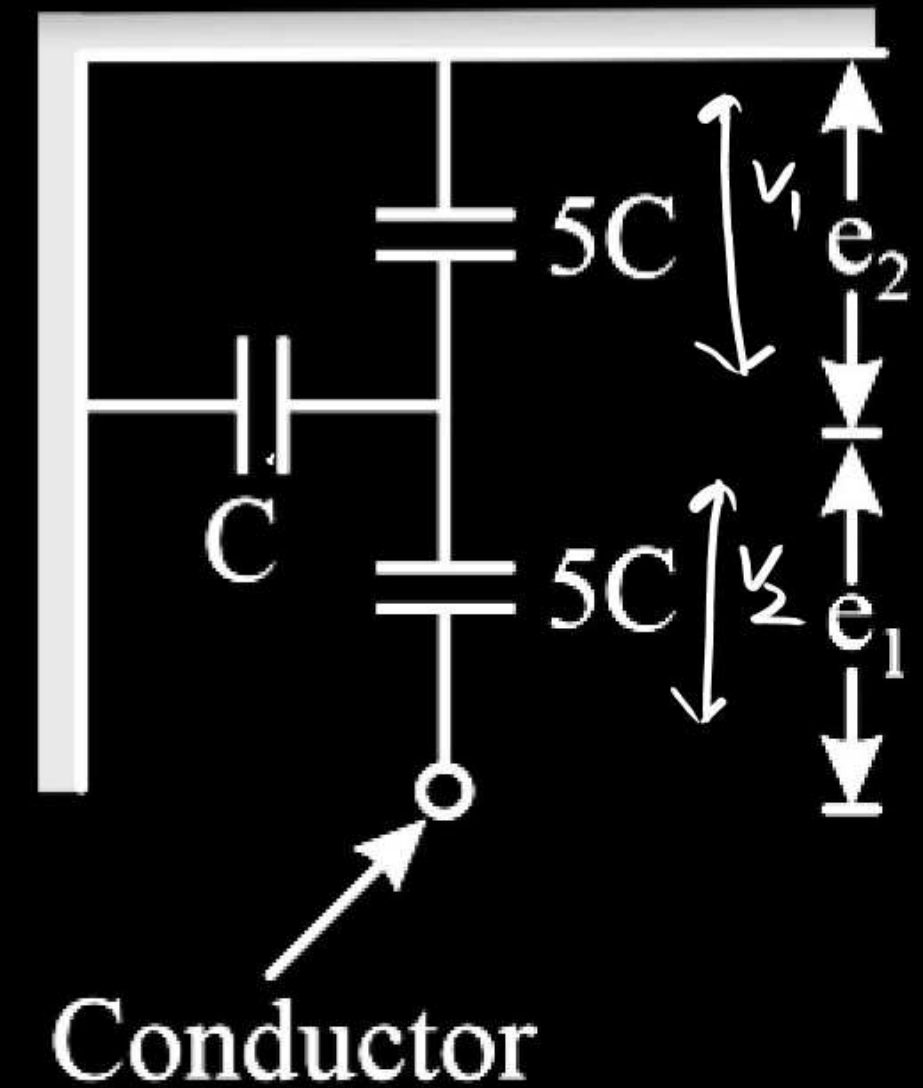
$$C_6 = 25c$$

$$C_1 + 15c = 25c$$

$$\underline{C_1 = 10c}$$

Q. Consider a three-phase, 50Hz, 11 kV distribution system. Each of the conductors is suspended by an insulator string having two identical porcelain air insulators. The self capacitance of the insulator is 5 times the shunt capacitance between the link and the ground, as shown in the figures. The voltage across the two insulators are

$$K = \frac{C}{5C} = \frac{1}{5}$$



- (A) $e_1 = 3.74$ kV, $e_2 = 2.61$ kV
- (B) $e_1 = 3.46$ kV, $e_2 = 2.89$ kV
- (C) $e_1 = 6.0$ kV, $e_2 = 4.23$ kV
- (D) $e_1 = 5.5$ kV, $e_2 = 5.5$ kV

$$\rightarrow V_1 = V_1$$

$$V_2 = (1+k) V_1$$

$$V_2 = (1 + \frac{1}{5}) V_1$$

$$\rightarrow V_2 = \frac{6}{5} V_1 \checkmark$$

$$V_1 + V_2 = \frac{11}{\sqrt{3}}$$

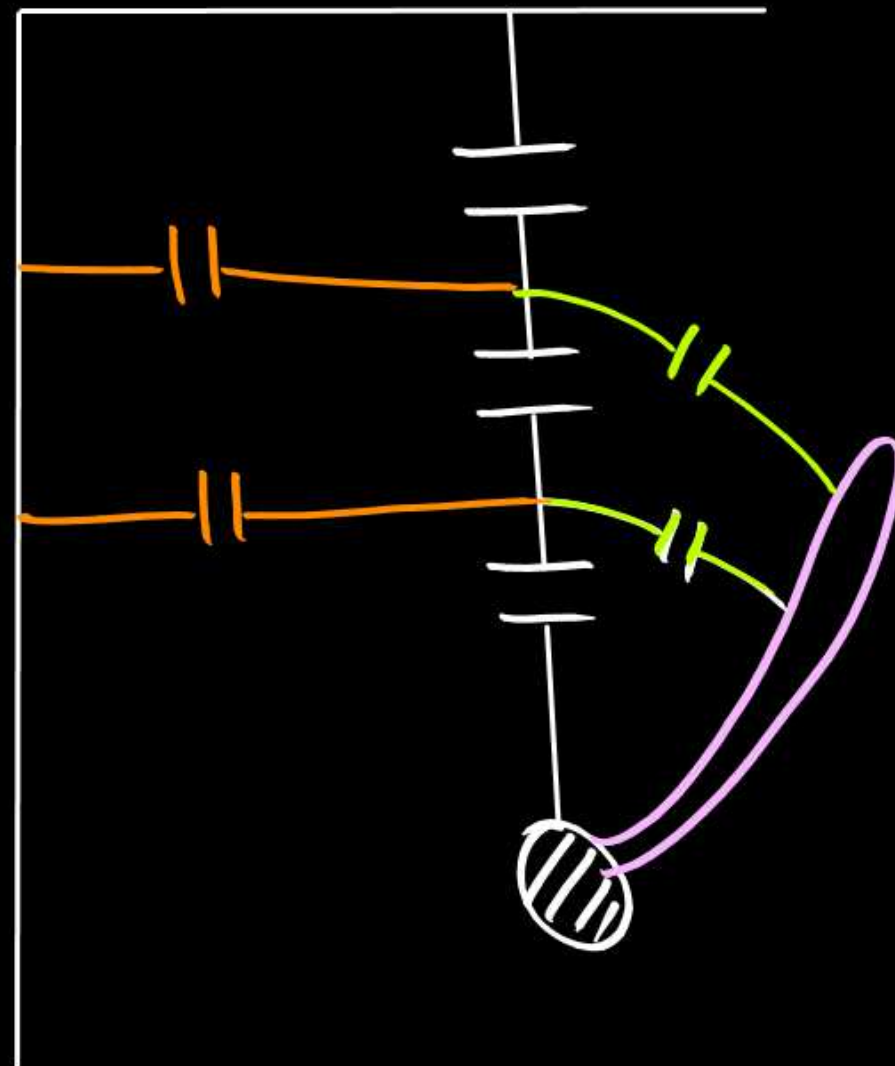
$$V_1 + \frac{6}{5} V_1 = \frac{11}{\sqrt{3}}$$

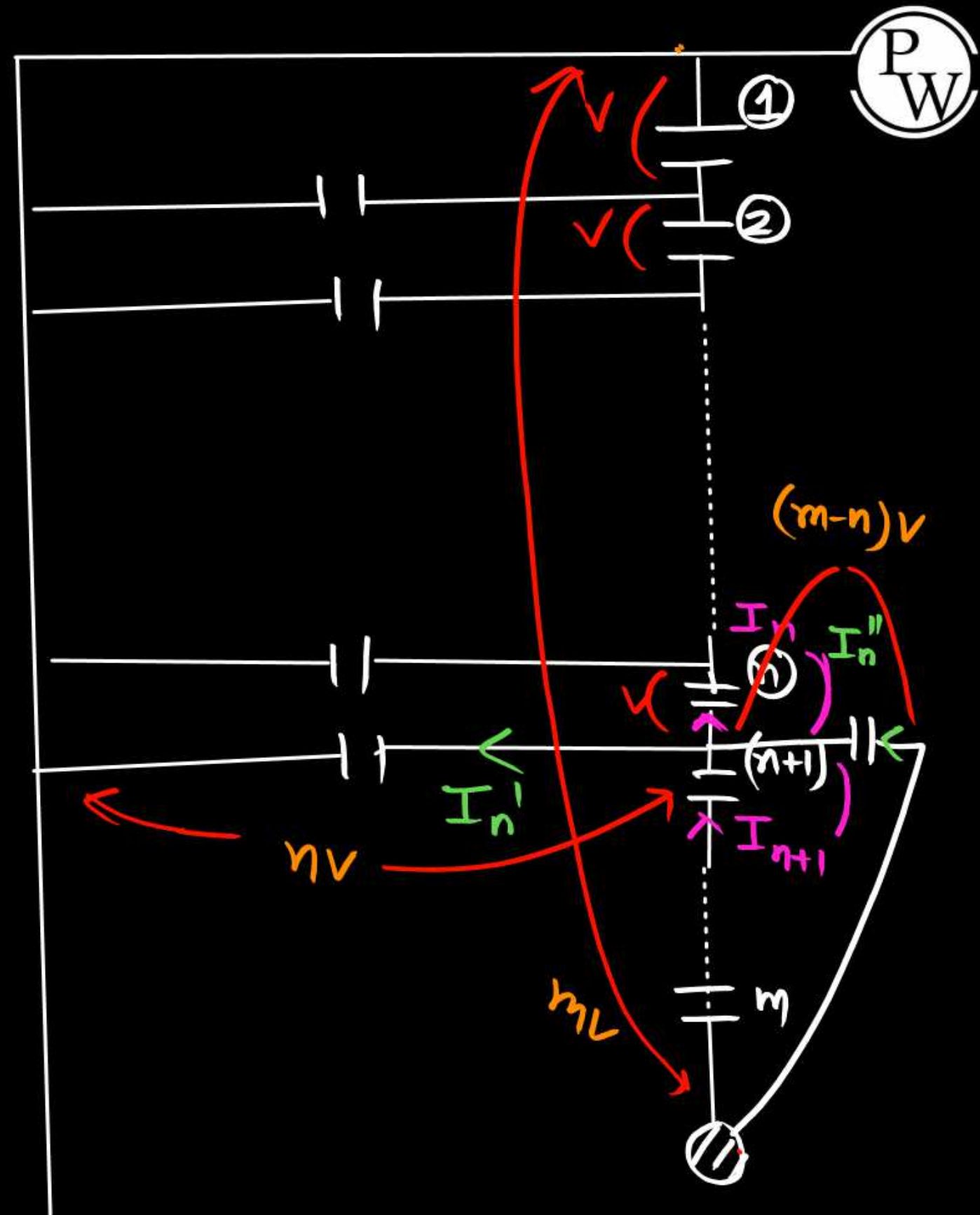
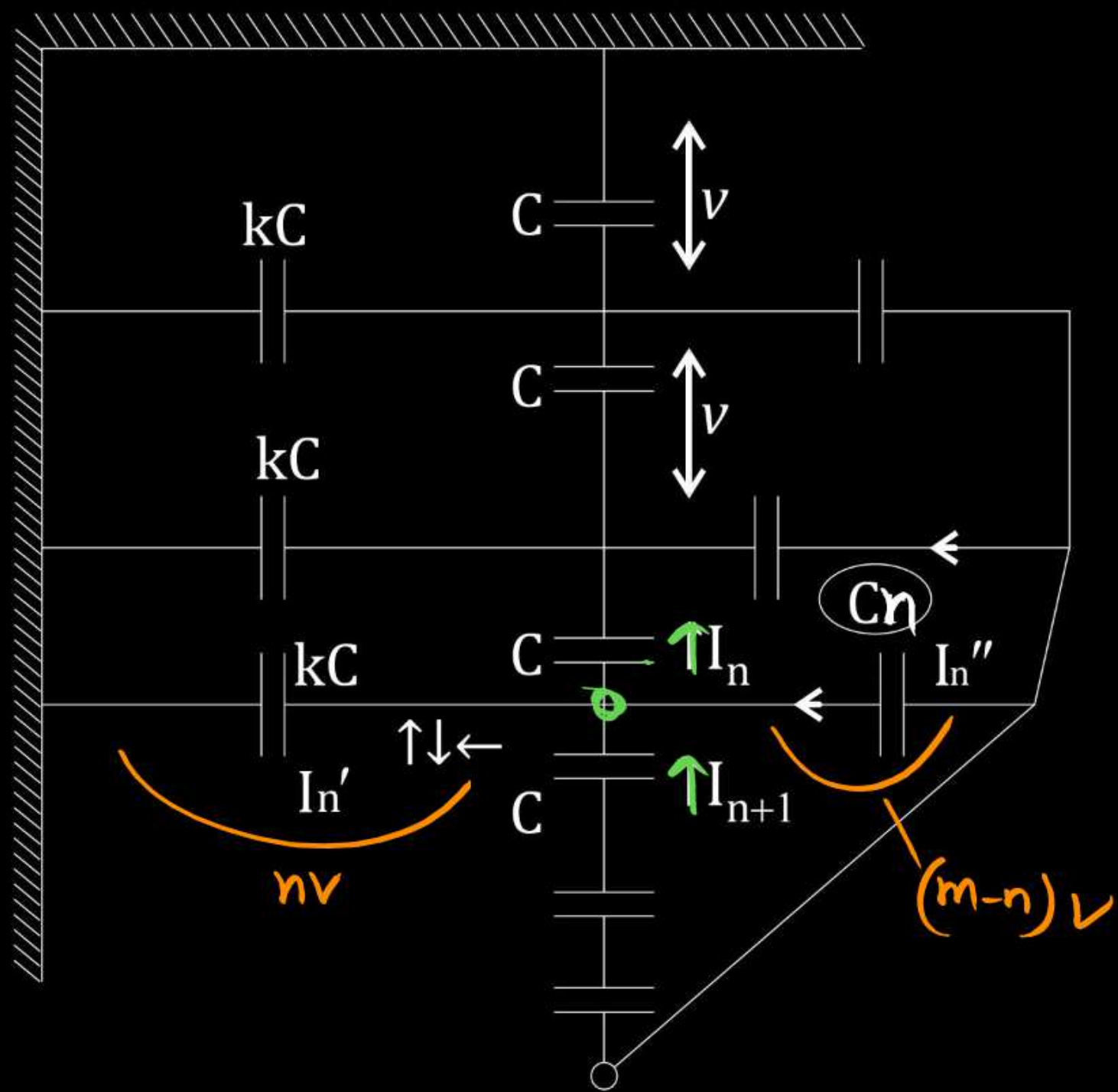
$$\frac{11}{5} V_1 = \frac{11}{\sqrt{3}}$$

$$V_1 = \frac{5}{\sqrt{3}} = 2.886 \text{ — } E_2$$

$$V_2 = \frac{6}{5} V_1 = \frac{6}{5} \times 2.886 = 3.464 \text{ } E_1$$

3. Static Shielding : It uses a large metal ring surround the bottom unit and connected to conductor (Line). It is called Guard ring (grading ring). It increases the effective capacitance to bottom unit. It introduces the capacitance between line & different metal joint.





➤ The voltage distribution is become unequal because current flowing through each disc is not same.

➤ Now with grading ring

$$\underline{I_{n+1}} + I_n'' = I_n' + \underline{I_n}$$

So, if $I_n'' = I_n'$ then, $I_{n+1} = I_n$

Suppose, if voltage across all the units become equal = V

$$I_n'' = I_n'$$

Suppose total number of line = m

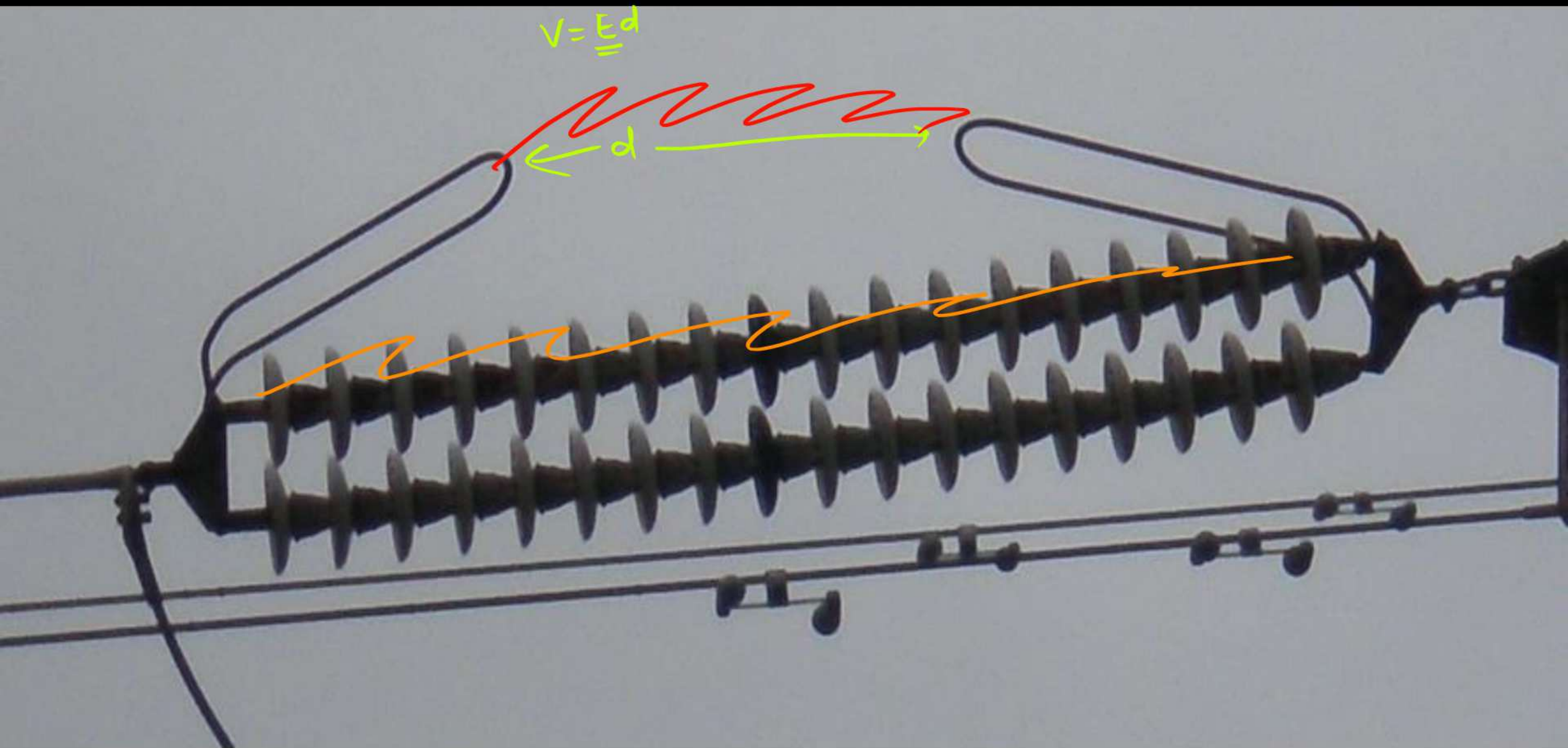
So total voltage across all the unit = mV

$$I_n' = I_n''$$

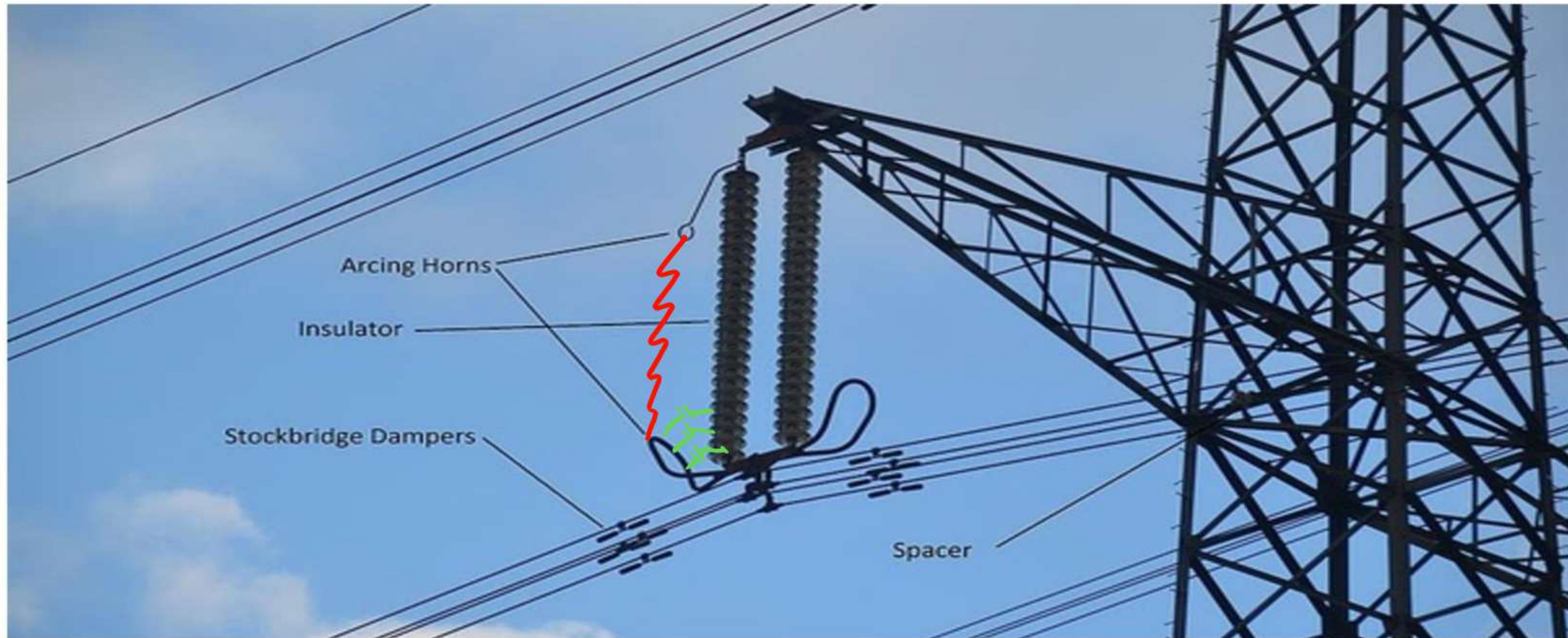
$$\cancel{j\omega}(Kc) n \checkmark = \cancel{j\omega} C_n (m-n) \checkmark$$

$$C_n = \frac{(Kc) n}{m-n}$$

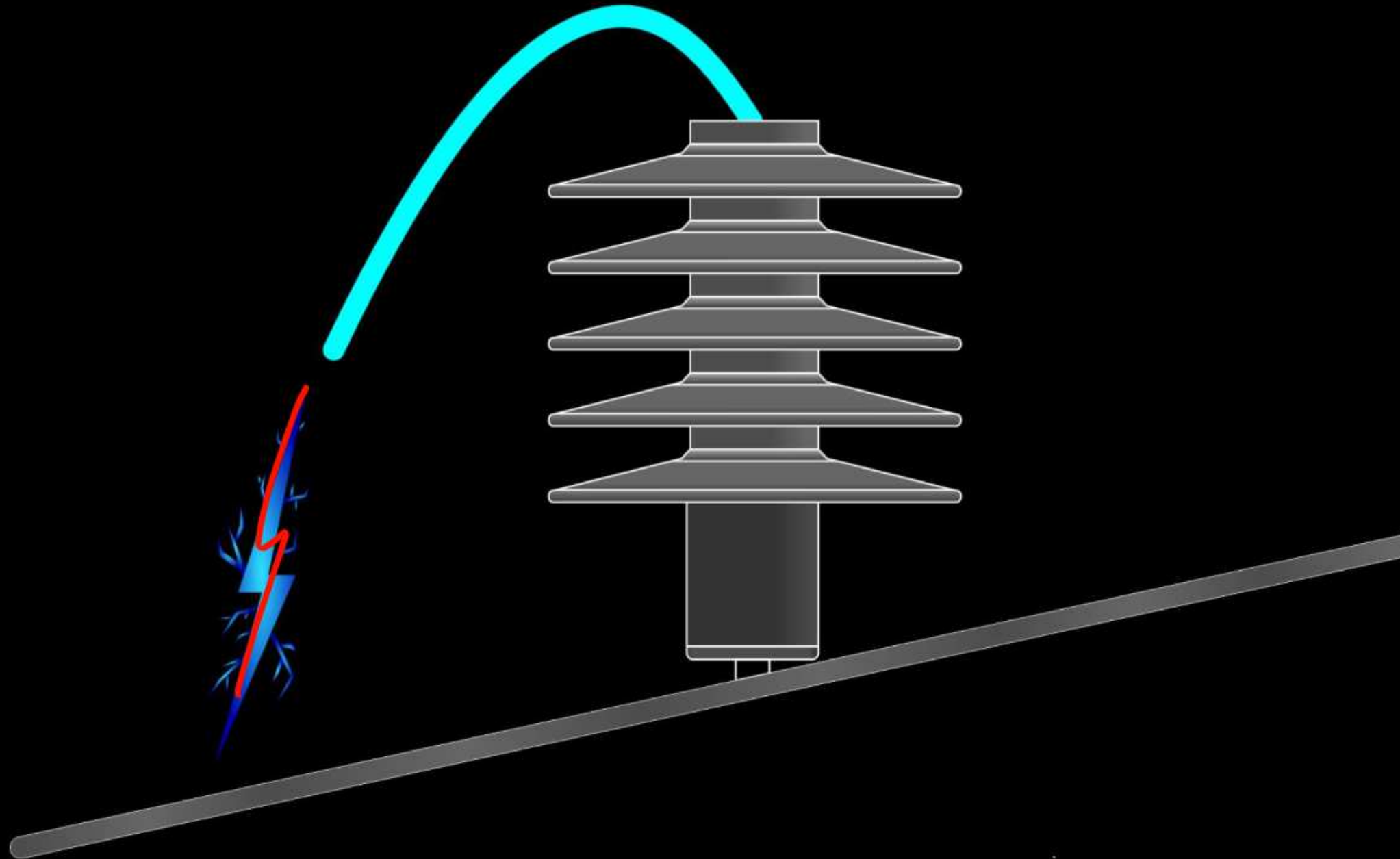
C_n = Capacitance between
metal joint and grading ring
for n^{th} disk.



Why Arc Horn are used in High Voltage Transmission Line?



- Every insulator string is provided with arching horn at tower & line end so in case of flashover arc will be take path between the horn, so insulator string will not be damaged.



Whenever high voltage created due to surges (lightning & switching overvoltage)



The distance between two horn is less than the distance between power line & cross arm



so $\underline{E} \uparrow = \frac{V}{d \downarrow}$ so electric field between two horn will high in magnitude

If $E >$ dielectric strength of air



Air is become ionized



So, Flashover (Arc) occur between two horns.

Q.



A 3-insulator unit is fitted with guard ring. The capacitance the line link pin and metal work & guard ring can be assumed to be 15% & 5% of capacitance of each unit. Determine voltage distribution & string efficiency.

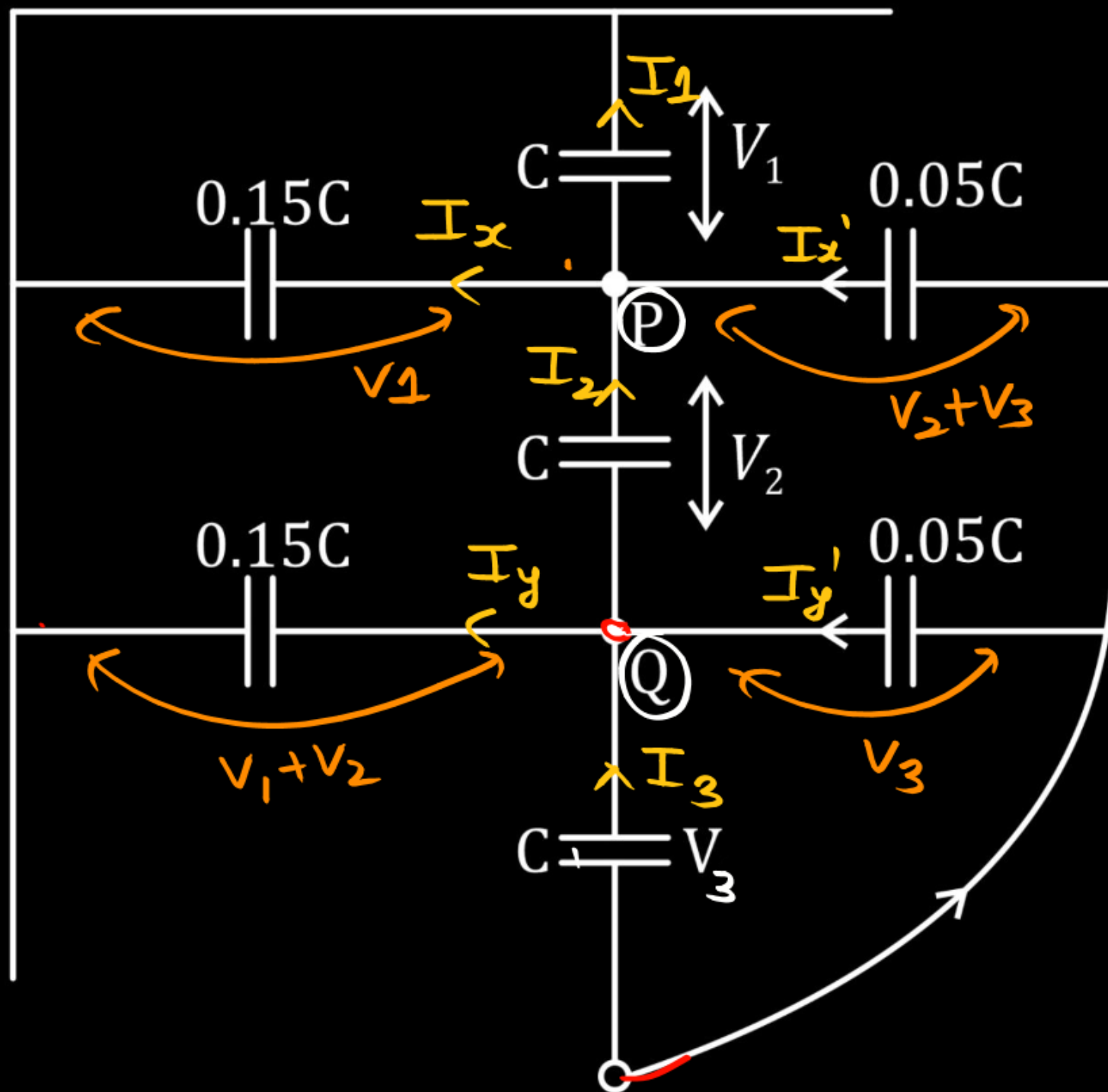
KCL at Node P

$$I_2 + I_x' = I_1 + I_x$$

$$\cancel{j\omega C} V_2 + \cancel{j\omega}(0.05\cancel{C})(V_2 + V_3) = \cancel{j\omega C} V_1 + \cancel{j\omega}(0.15\cancel{C}) V_1$$

$$V_2 + 0.05 V_2 + 0.05 V_3 = 1.15 V_1$$

$$V_3 = \frac{1.15 V_1 - 1.05 V_2}{0.05} \quad \text{--- (1)}$$



KCL at Point Q

$$I_3 + I_y' = I_2 + I_y$$

$$\cancel{j\omega C} V_3 + \cancel{j\omega(0.05C)} V_3 = \cancel{j\omega C} V_2 + \cancel{j\omega(0.15C)} (V_1 + V_2)$$

$$1.05 V_3 = 0.15 V_1 + 1.15 V_2$$

$$V_3 = \frac{0.15 V_1 + 1.15 V_2}{1.05} \quad \text{--- (2)}$$

From eq ① and ②

$$\frac{1.15V_1 - 1.05V_2}{0.05} = \frac{0.15V_1 + 1.15V_2}{1.05}$$

$$1.16V_2 = 1.2V_1$$

$$\rightarrow V_2 = 1.034 V_1$$

$$\rightarrow V_3 = \frac{1.15V_1 - 1.05(1.034V_1)}{0.05} = 1.2753 V_1$$

$$\eta = \frac{V_1 + V_2 + V_3}{3V_3} = \frac{V_1 + 1.034V_1 + 1.2753V_1}{3(1.2753V_1)} = 0.8649$$
$$= 86.49\%$$

Q.



3 Phase line is supported by suspension string having 3 units. The voltage across nearest to line is 20 kV and that across adjacent units is 15 kV. The ratio of capacitance of joint to capacitance of disc is

A 1.847

B 0.32

C 0.18

D 0.29

$$V_3 = 20 \text{ kV}$$

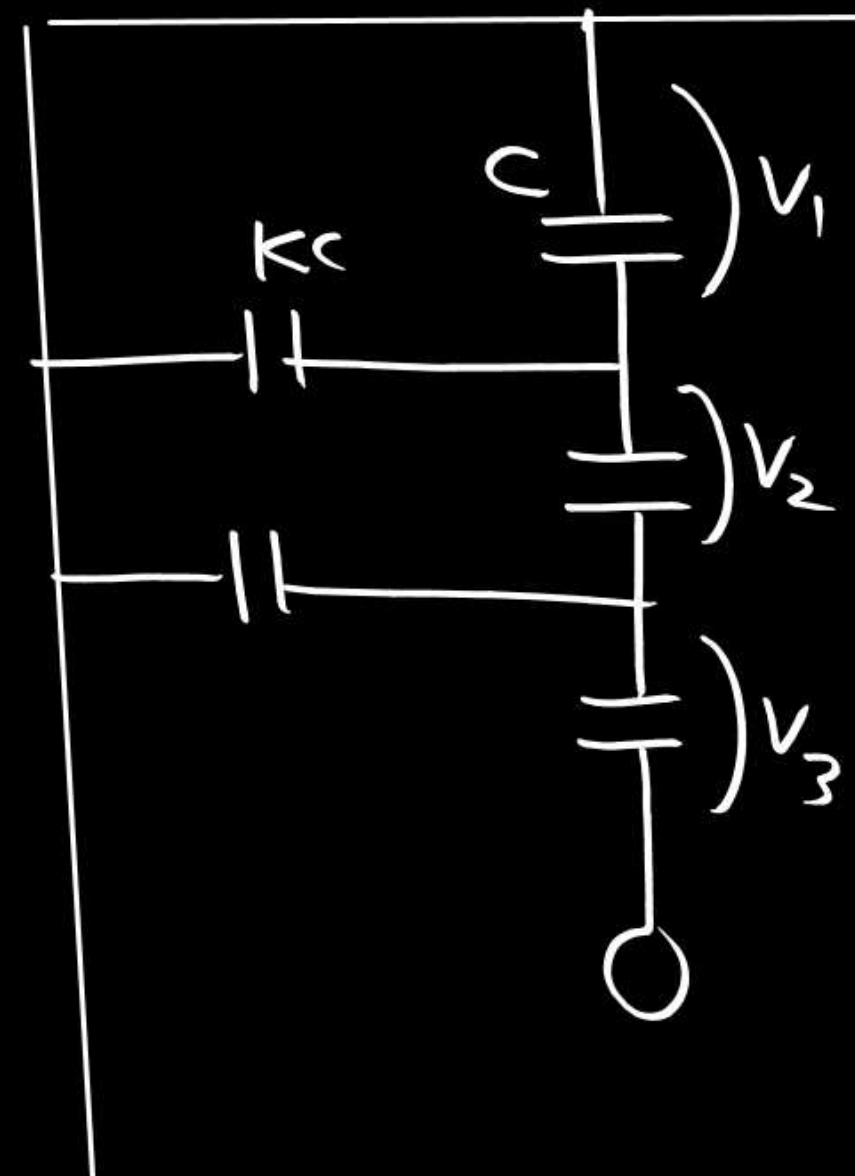
$$K = ?$$

$$V_2 = 15$$

$$V_2 = (1+K)V_1 = 15 \quad - (1)$$

$$V_3 = (1+3K+K^2)V_1 = 20 \quad - (2)$$

$$\frac{e_{q^n(2)}}{e_{q^n(1)}} = \frac{(1+3K+K^2)V_1}{(1+K)V_1} = \frac{20}{15} = \frac{4}{3}$$



$$3 + 9k + 3k^2 = 4 + 4k$$

$$3k^2 + 5k - 1 = 0$$

$$k = \frac{-5 \pm \sqrt{25 + 12}}{6} = 0.18$$



2 Minutes Summary

→ Method to Improvement of String n

→ Question.

Thank you

GW
Soldiers !

