INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

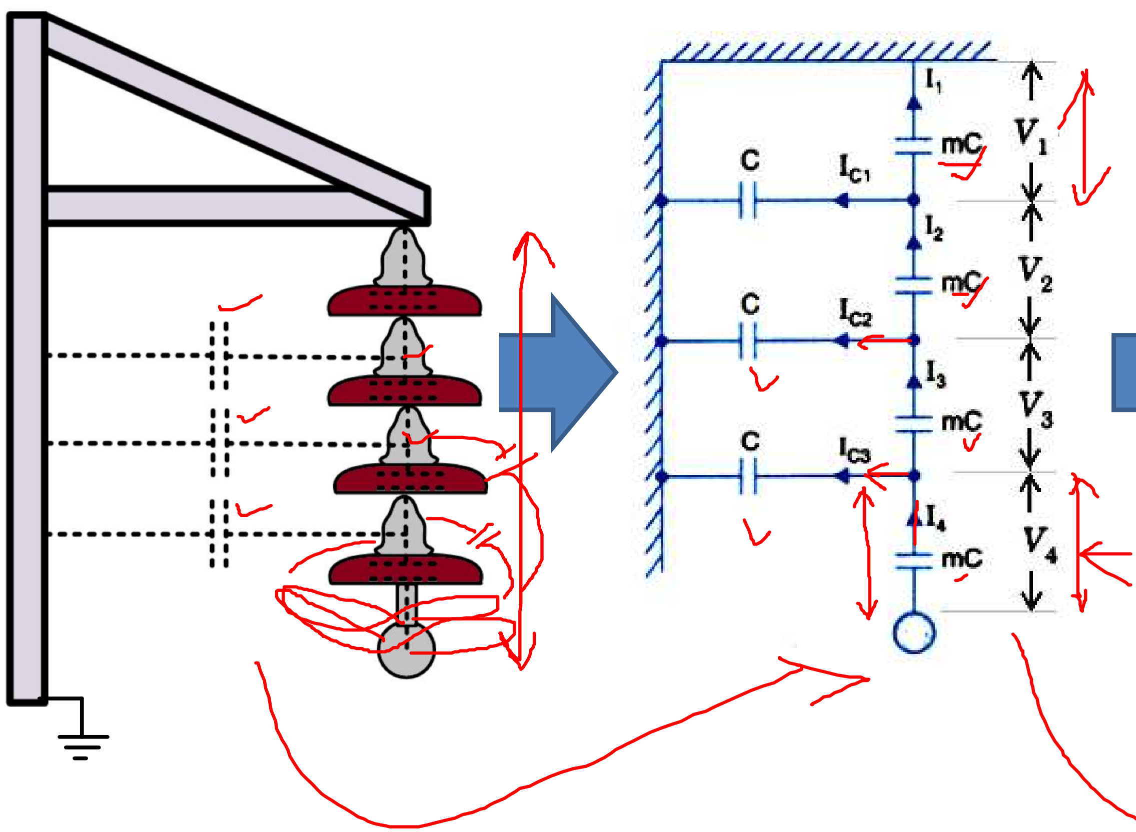
EEN-206: Power Transmission and Distribution

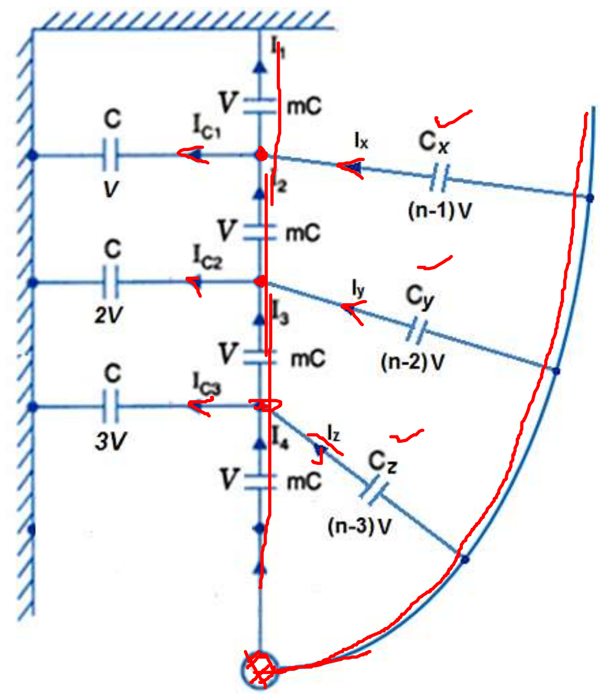
Lecture - 11

Chapter 2: Overhead Transmission Lines

- **Corona**

Static Shielding





Static Shielding (Theory Concept)

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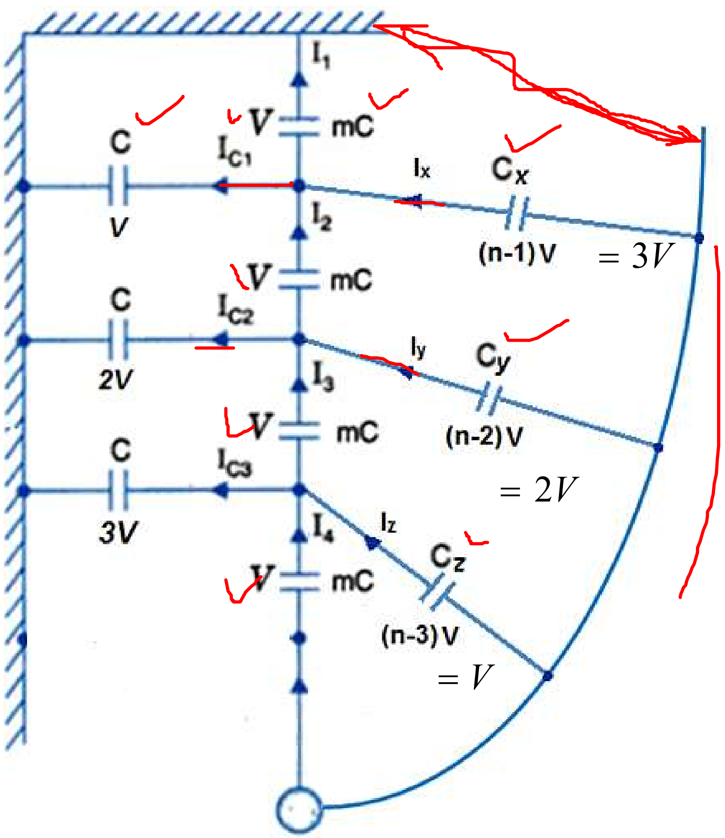


Static Shielding (Theory Concept)

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

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

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

Voltages can be equal if

$$I_x = I_{C1}$$

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

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

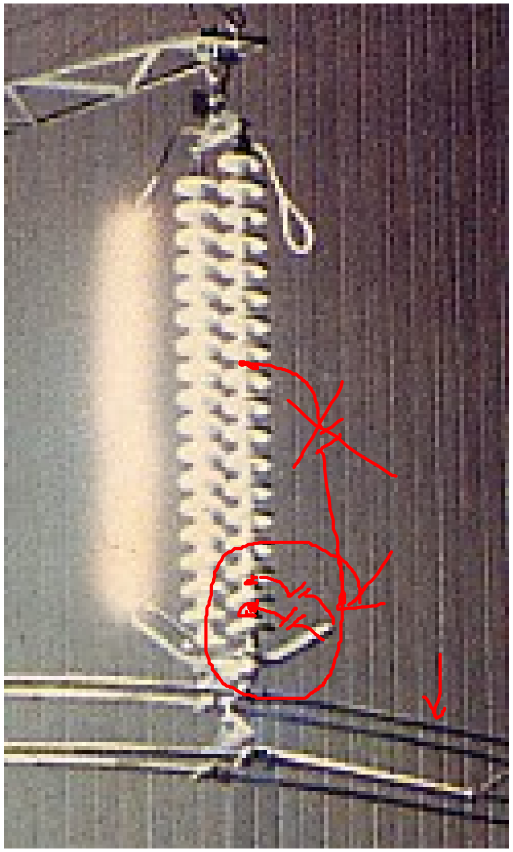
Also, $I_y = I_{C2}$

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

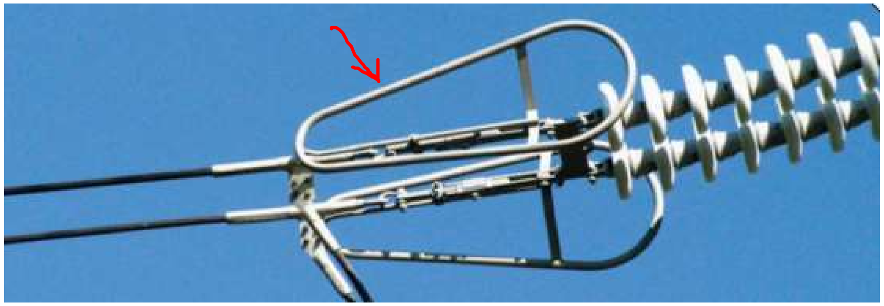
$$C_y = \frac{2C}{2} = \frac{2C}{n-2}$$

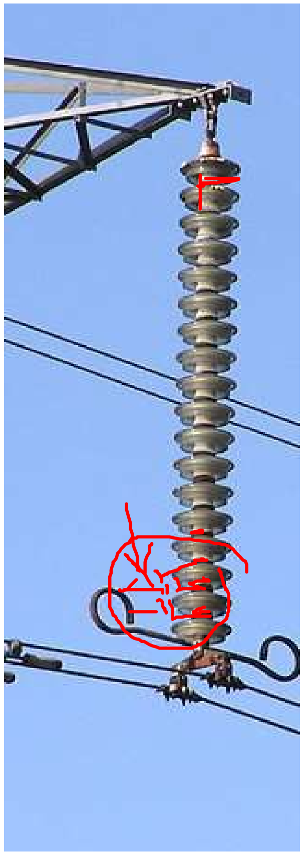
Similarly, $C_Z = \frac{3C}{(n-3)}$ and $C_p = \frac{pC}{(n-p)}$

Static Shielding (Practice)



- 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.



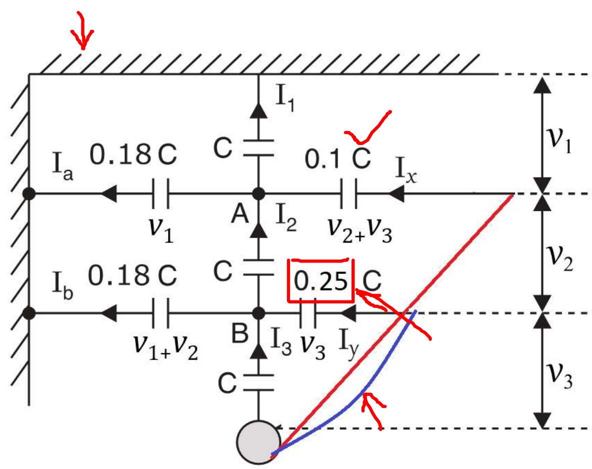


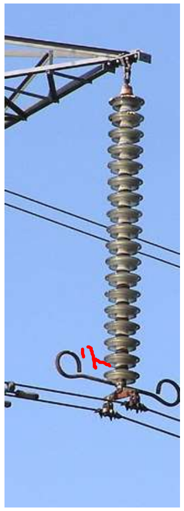
Ques-03

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.

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

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,

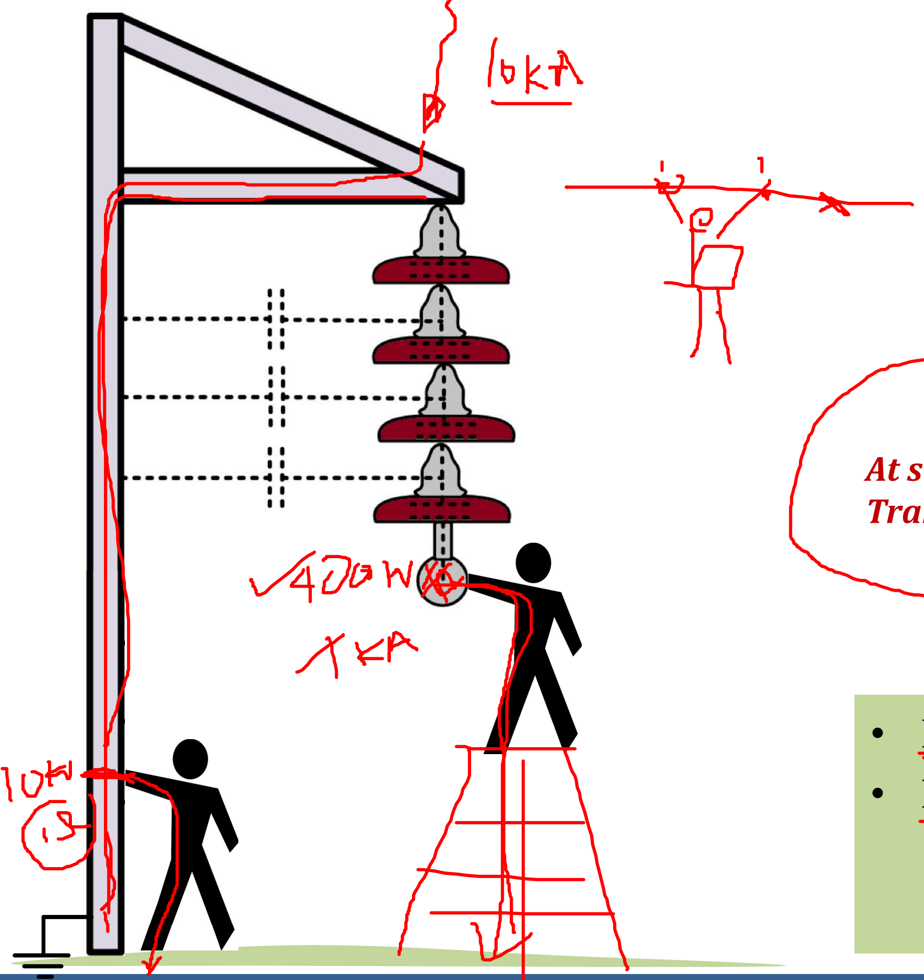
$$v_1 + v_2 + v_3 = V$$

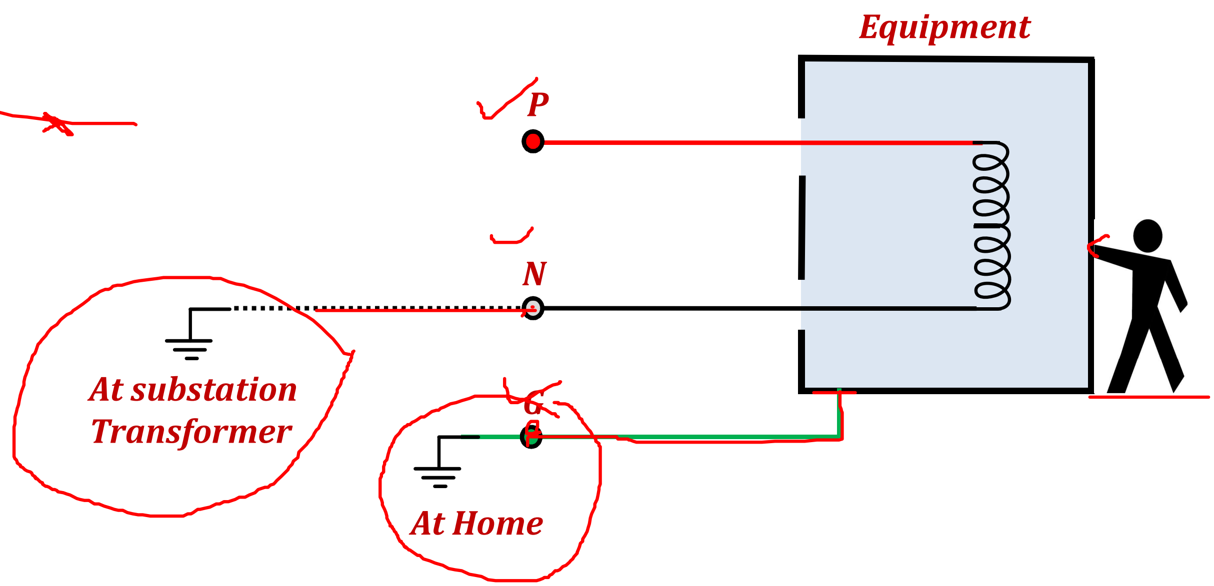
$$\eta = \frac{V}{n * v_3} * 100$$

Conductor

Guard ring

Few Other Questions





- Potential Difference is important.
- Earthing/grounding design
    - Touch Potential
    - Step Potential

Overhead transmission lines, how wind pressure acting on conductor increases its length, hence sag?

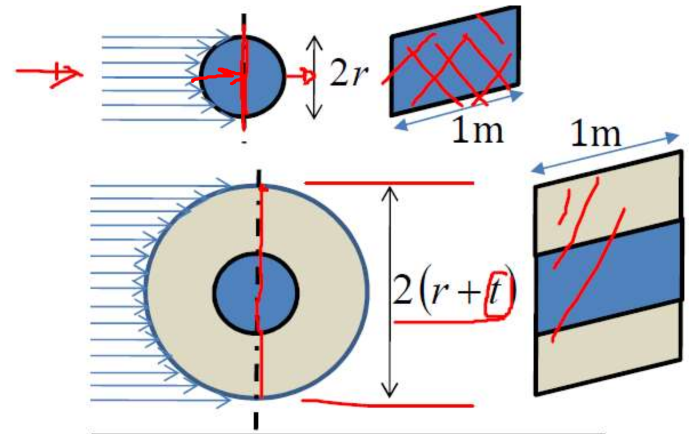
- The wind pressure acts on the conductor in horizontal direction. Assume that wind blows uniformly.
- If p is the wind pressure, wind loading (w_w)

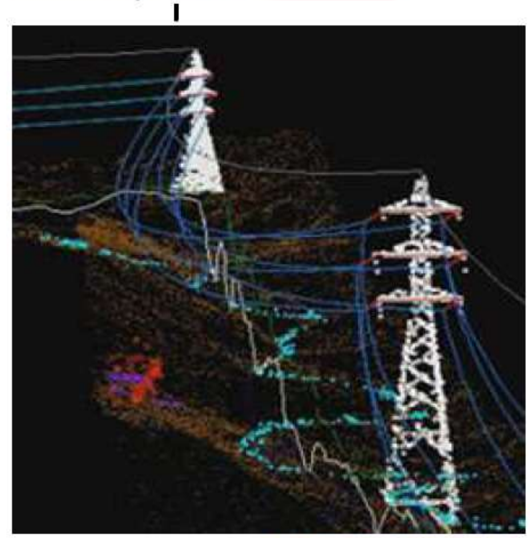
Conductor alone → $w_w = 2rp$ kg/m

Conductor + Ice → $w_w = 2(r+t)p$ kg/m

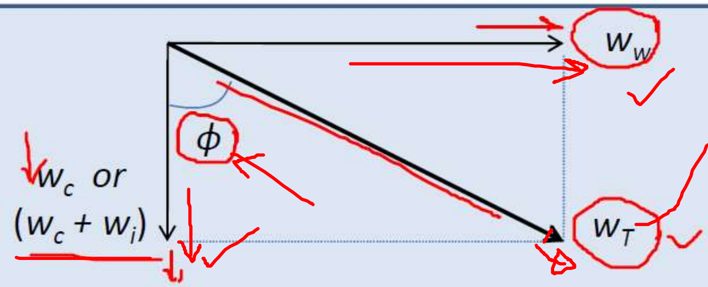
- The wind pressure depends on the velocity of the wind.

$$p = 0.006v^2 \text{ kg/m}^2$$





Overhead transmission lines, how wind pressure acting on conductor increases its length, hence sag?



- The resultant weight of the conductor is:

Conductor alone: $w_T = \sqrt{w_c^2 + w_w^2}$ kg/m

Conductor + Ice: $w_T = \sqrt{(w_c + w_i)^2 + w_w^2}$ kg/m

- The angle at which loading is acting is:

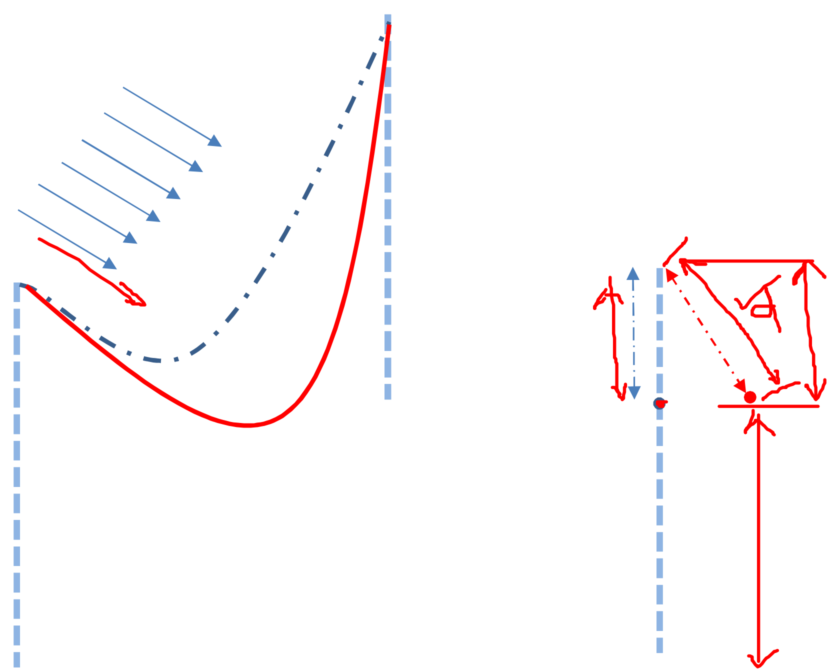
Conductor alone: $\phi = \tan^{-1}(w_w / w_c)$

Conductor + Ice: $\phi = \tan^{-1}(w_w / (w_c + w_i))$

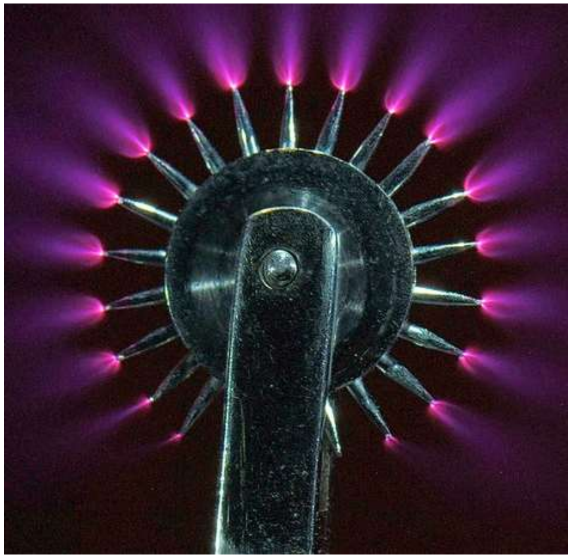
$$d = \frac{wl^2}{2H}$$

Vertical Sag

$$d_v = d\cos(\phi)$$

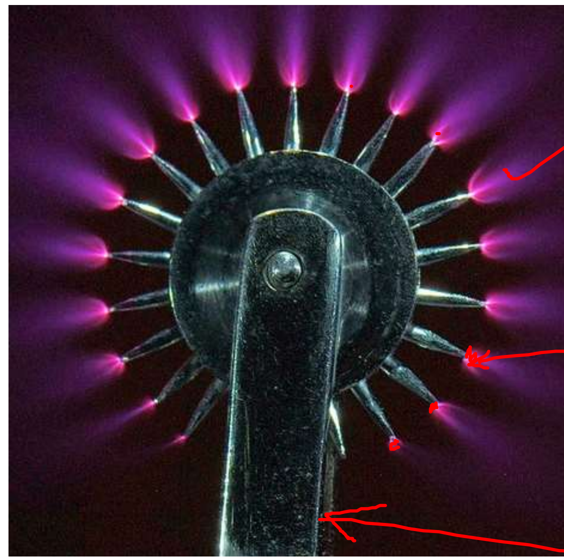


Displace and elongate



Corona

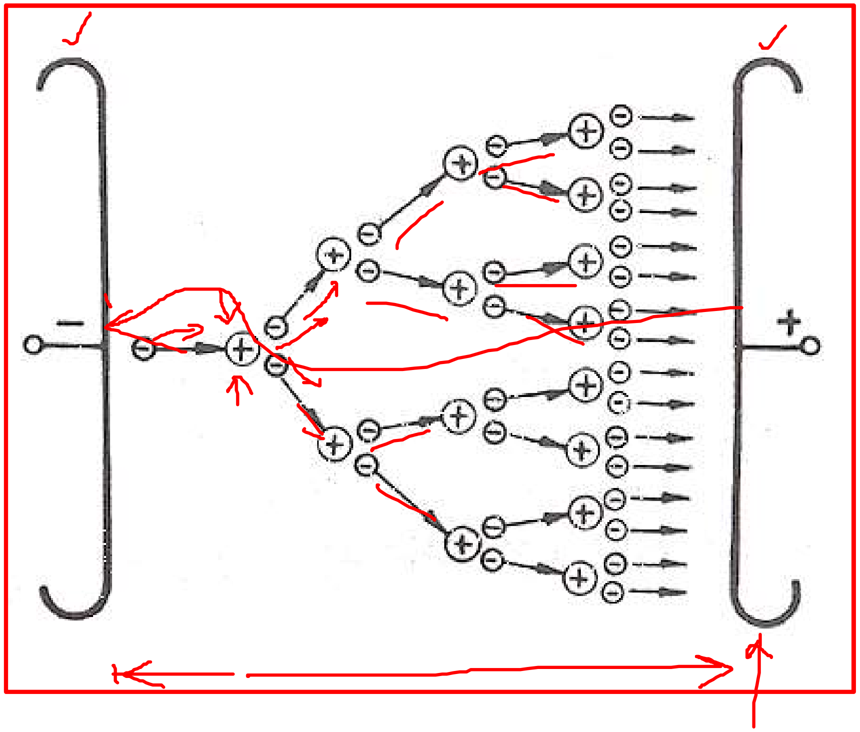
What is Corona?



"Corona is a luminous discharge due to ionization of the air surrounding an electrode, caused by a voltage gradient exceeding a certain critical value (breakdown strength of air (gas))."

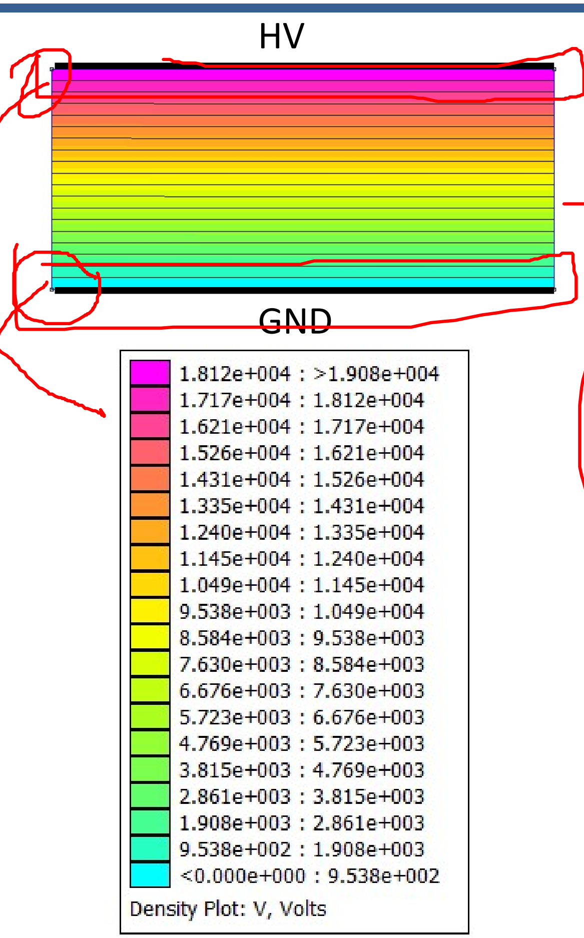
Source: http://en.wikipedia.org/wiki/Corona_discharge

Ionization and Breakdown Process

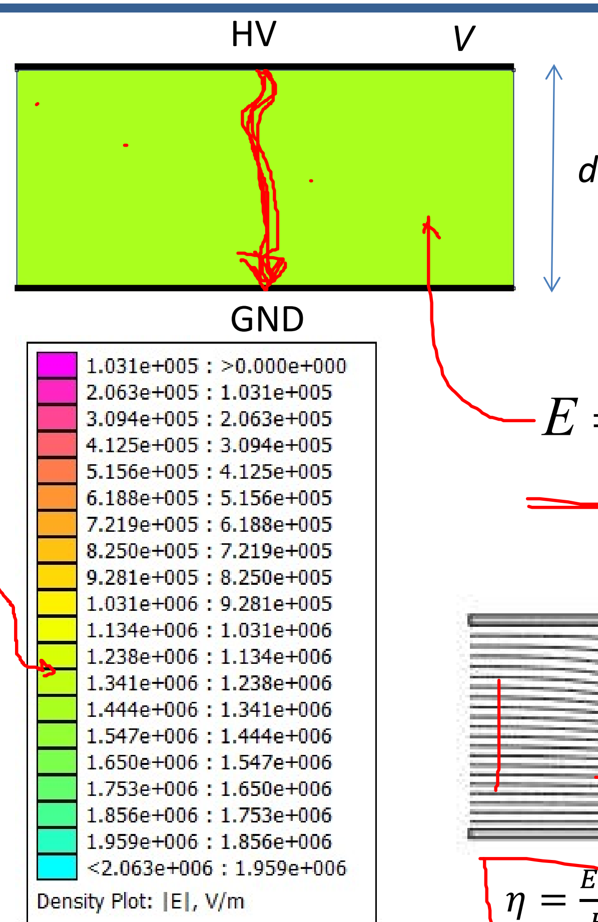


- The electrons gets accelerated in electric field. The velocity of electron depends on the intensity of the electric field.
- If the electric field strength exceeds certain critical value, electrons gain sufficient velocity and energy to knock one of the outer orbit electron from the one of the two atoms of air molecule.
- This is called as ionization and the ion formed with the missing electrons are called as positive ion.
- Both electrons then again gets accelerated in electric field causing more ionizations and ultimately forms an electron avalanche.

Uniform Field

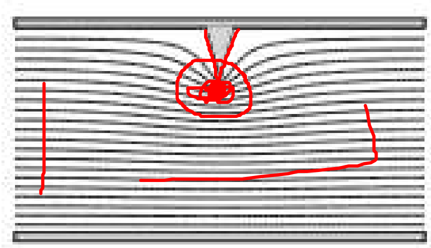


Voltage



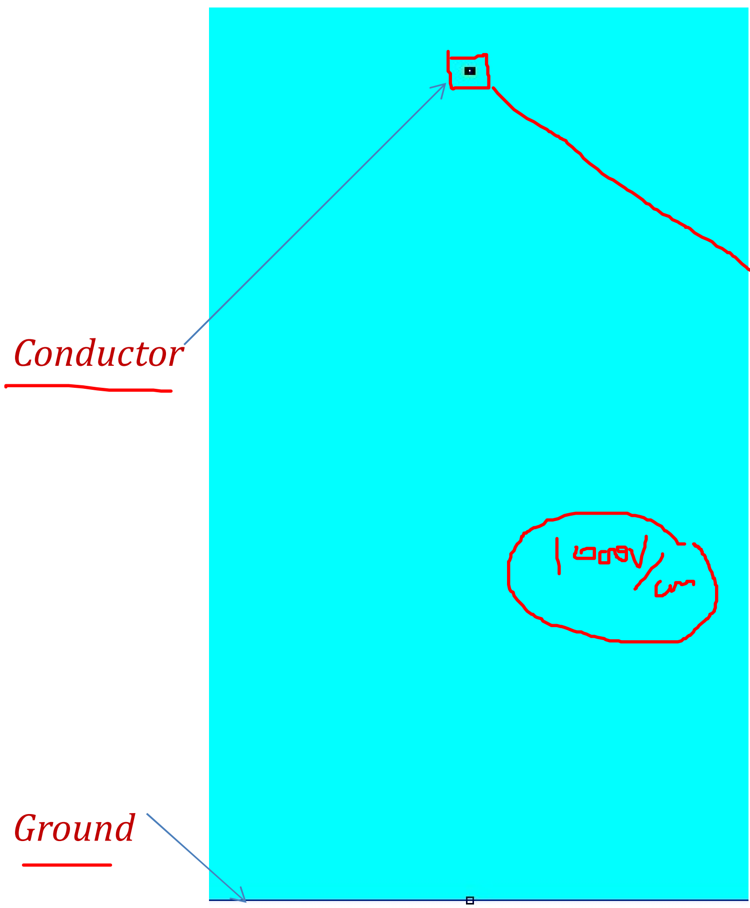
Electric Field

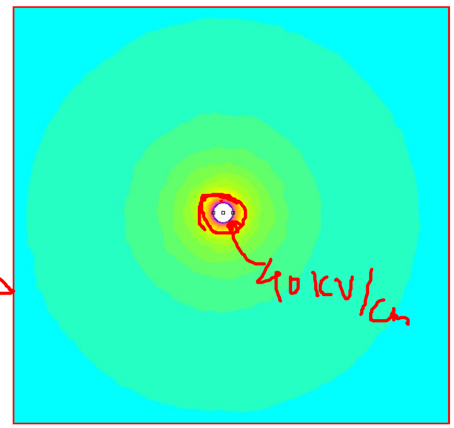
$$E = \frac{V}{d}$$



$\boxed{\eta = \frac{E_{max}}{E_{av}}}$ in hundreds or thousands

Non-Uniform Field





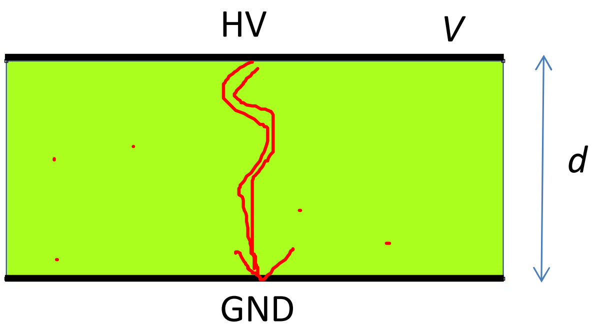
$$\eta = \frac{E_{max}}{E_{av}}$$

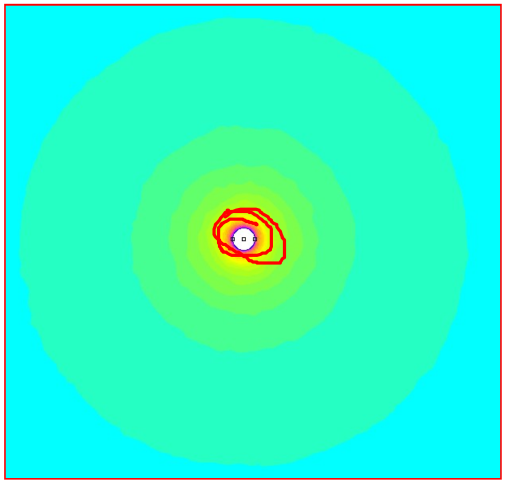
It is in thousands

- There are always free-electrons in the air due to **ultraviolet radiations from sun, cosmic rays from outer space, radioactivity of earth**, etc.
- Therefore in non-uniform field, some region of dielectric experiences higher field strength than the critical value, while other region field stress is well below critical value.

Corona

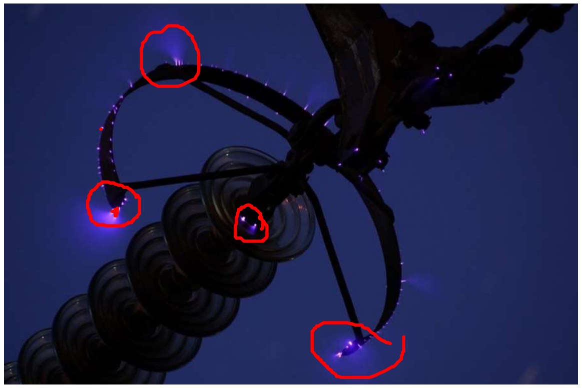
- The breakdown of a gas takes place when a self sustained discharge or **ionization process** is set in.
- This takes place when the electric field stress exceeds **a certain critical value**.
- For air breakdown strength (at 25^0C and 760 mm Hg) is 30 kV/cm for DC and 30 kV/cm (peak) for AC. $\frac{30}{\sqrt{2}}$ (rms)
- In the case of uniform field, this condition is satisfied at all the points and there will be complete breakdown by forming an arc between the electrodes.
- However, if the electric field is highly non-uniform the breakdown condition may not be all over the gap.

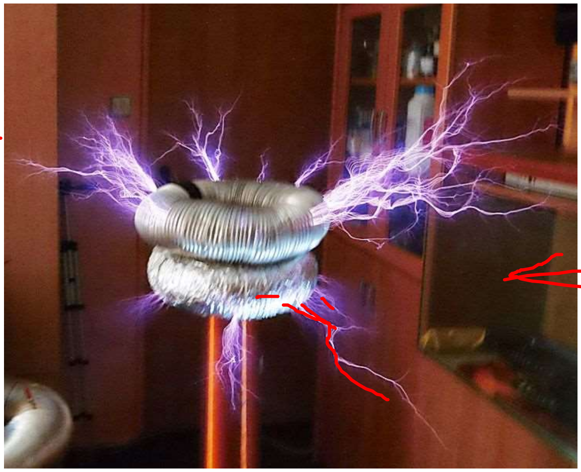




Corona Formation

- Thus, self sustained discharge condition will be valid **only in the strong field region** giving rise to corona.
- This associated with **a glow and a hissing (or frying sound)** and when it takes place in air and **ozone, oxides of nitrogen and nitric acid** (in the presence of moisture) are formed.
- The corona manifests itself by **visual corona, audible noise, radio interference.**
- The avalanches, being electrons in motion, actually constitute electric current and produces electro-magnetic field in the vicinity. Since they are sudden and short in duration induce high frequency voltage pulses in nearby radio antenna.
- The **positive conductor** has more **uniform bluish (or violet) white glow** near to conductor
- **Negative polarity** isolated **reddish tufts or beads** are formed.

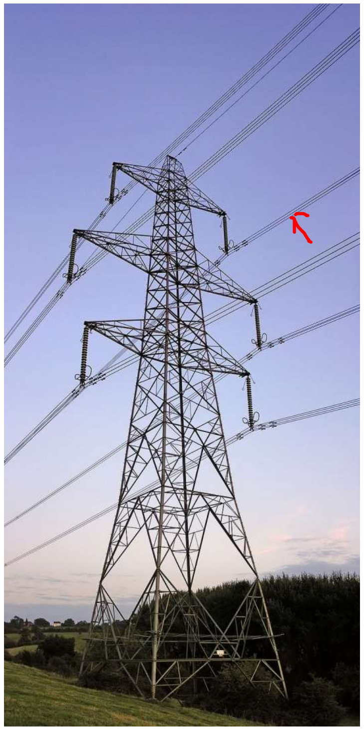




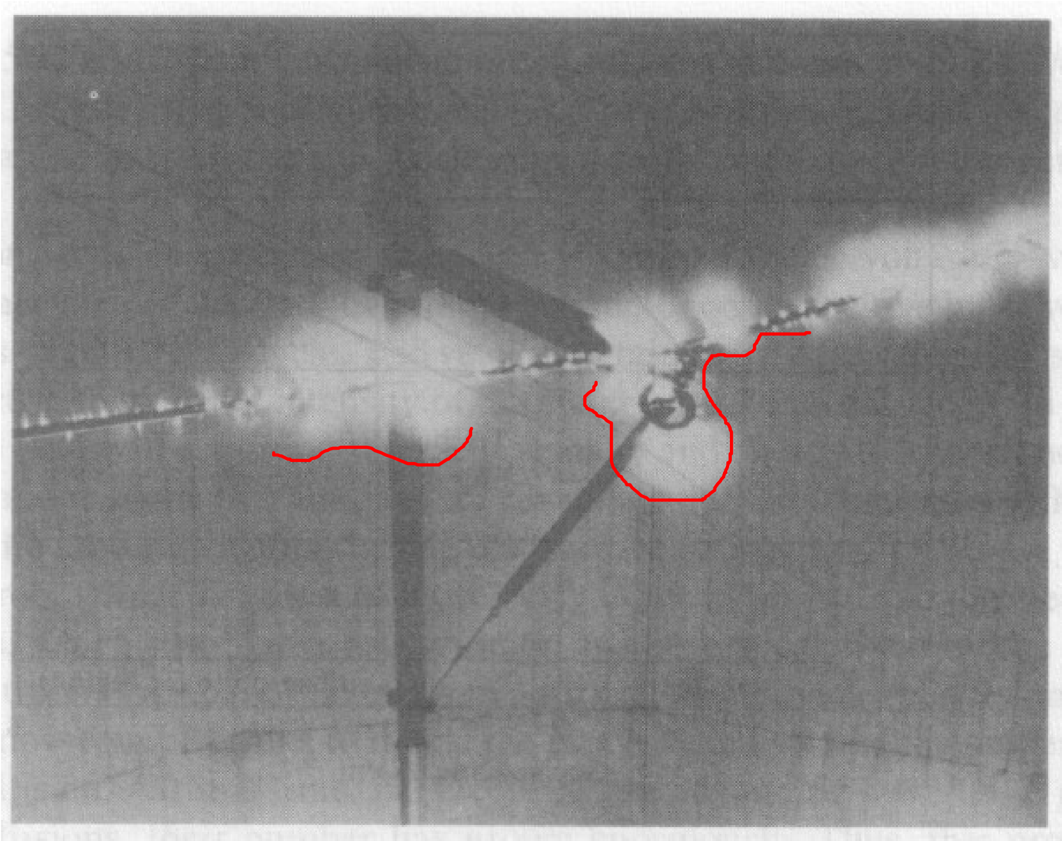
Source: http://en.wikipedia.org/wiki/Corona_discharge

Why Corona is Important for transmission lines?

- Corona from conductors may cause **audible noise and radio interference.**
- Audible noise from conductors may **violate noise standards**.
- Radio noise from conductors may **interfere with radio, television, and communications systems**.
- **Corona loss may be significant (during rainy season)** when compared with resistive loss of conductors.
- Corona can cause possible **damage to polymeric insulators**.
- Therefore, **corona free lines** needs to be designed which requires an understanding of factors that affect corona.

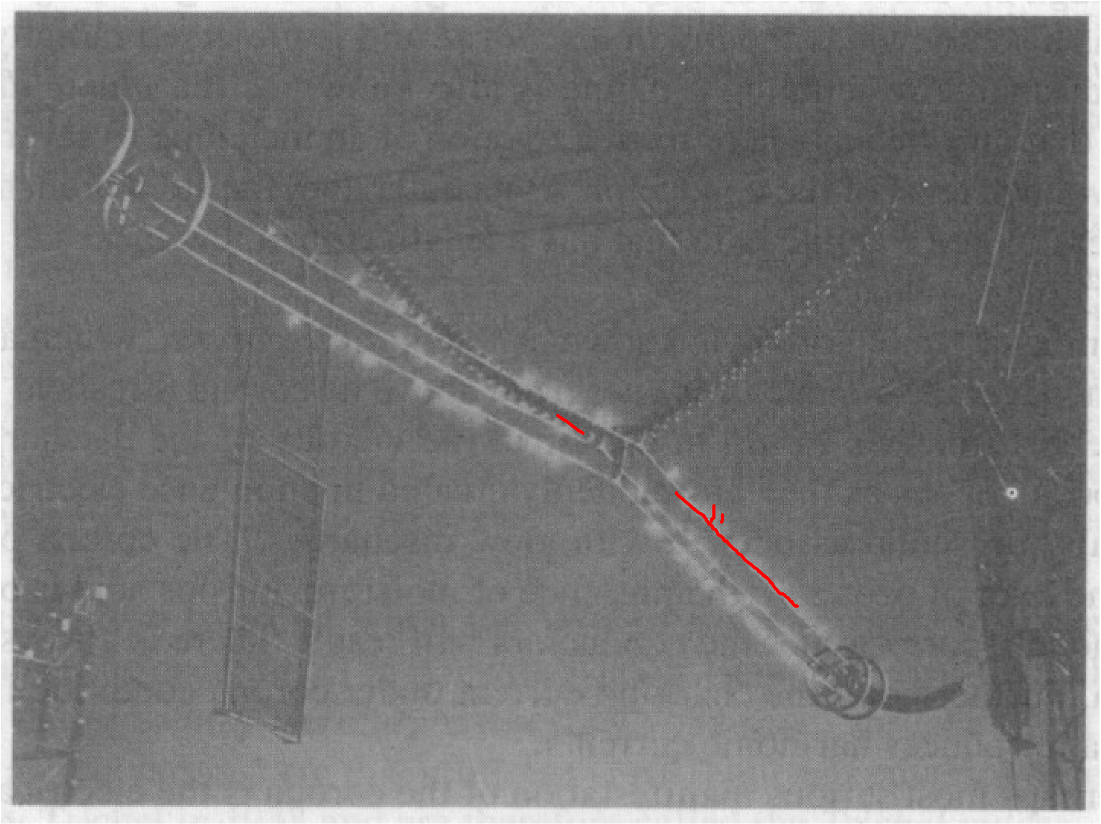


Corona (Laboratory Testing)



Ref: Gonen T., “Electric Power Transmission System Engineering: Analysis and Design”, John Wiley and Sons.

Corona (Laboratory Testing)



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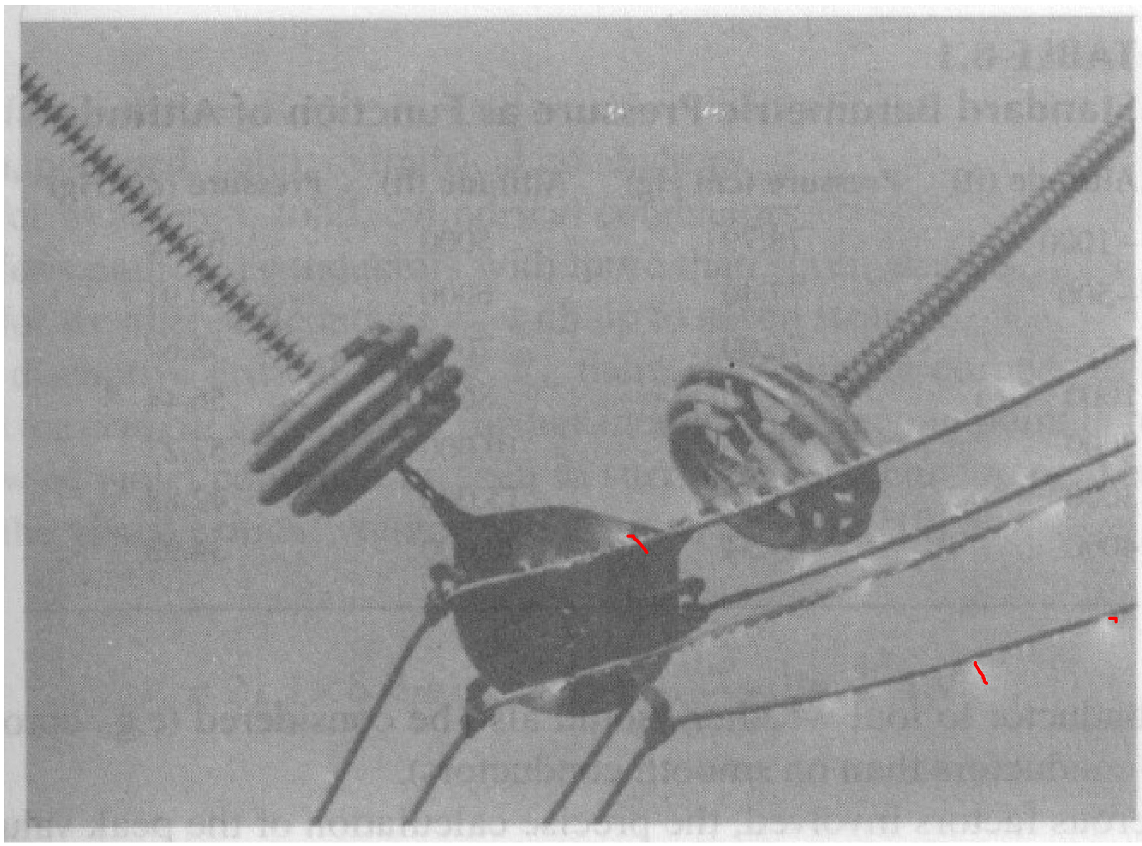
Corona (Testing)



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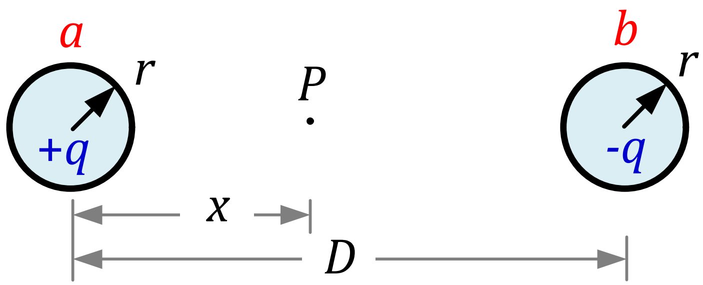
Critical Disruptive Voltage

- The minimum potential difference required between the conductor to start ionization is called *critical disruptive voltage* or *corona inception voltage*



Also $D >> r$ for typical power transmission line

$$E_x = \frac{q}{2\pi\varepsilon_0 x} + \frac{q}{2\pi\varepsilon_0 (D-x)} = \frac{q}{2\pi\varepsilon_0}\left(\frac{1}{x} + \frac{1}{(D-x)}\right)$$

$$E_x = \frac{q}{2\pi\varepsilon_0}\left(\frac{D}{x(D-x)}\right)$$

Potential Difference between the conductor

$$V = -\int_{D-r}^{r} E_x = -\int_{D-r}^{r} \frac{q}{2\pi\varepsilon_0}\left(\frac{1}{x} + \frac{1}{(D-x)}\right) = \frac{q}{2\pi\varepsilon_0}\left[\ln x - \ln(D-x)\right]\Big|_{r}^{D-r} = \frac{q}{2\pi\varepsilon_0}\left[\ln(D-r) - \ln(r) - \ln(r) + \ln(D-r)\right]$$

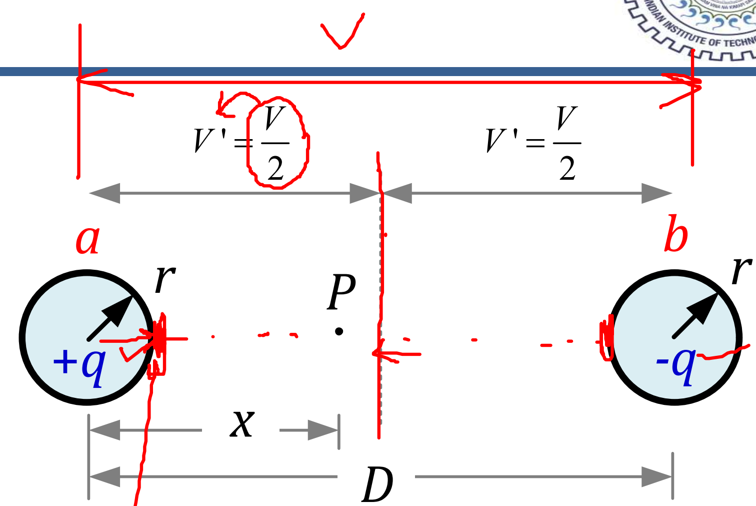
$$V = \frac{q}{2\pi\varepsilon_0}\ln\frac{(D-r)^2}{r^2} = \frac{q}{\pi\varepsilon_0}\ln\frac{(D-r)}{r} \approx \frac{q}{\pi\varepsilon_0}\ln\frac{D}{r}$$

$$q = \frac{\pi\varepsilon_0 V}{\left(\ln\frac{D}{r}\right)}$$

Critical Disruptive Voltage

$$E_x = \frac{q}{2\pi\varepsilon_0}\left(\frac{D}{x(D-x)}\right)$$ and $$q = \frac{\pi\varepsilon_0 V}{\left(\ln\frac{D}{r}\right)}$$ 2

$$E_x = \frac{\cancel{\pi\varepsilon_0} V}{\left(\ln\frac{D}{r}\right)}\frac{1}{2\cancel{\pi\varepsilon_0}}\left(\frac{D}{x(D-x)}\right) = \frac{(V/2)}{\left(\ln\frac{D}{r}\right)}\left(\frac{D}{x(D-x)}\right)$$



In the given system, voltage with respect to ground $V'=V/2$

$$E_x = \frac{V'}{\left(\ln\frac{D}{r}\right)}\left(\frac{D}{x(D-x)}\right)$$

Gradient will be maximum at conductor surface i.e. $x=r$

$$E_{\max} = \frac{V'}{\left(\ln\frac{D}{r}\right)}\left(\frac{D}{r(D-r)}\right) \approx \frac{V'}{\left(\ln\frac{D}{r}\right)}\left(\frac{1}{r}\right)$$

Therefore, $$\boxed{V' = r\,E_{\max}\left(\ln\frac{D}{r}\right)}$$

Critical Disruptive Voltage

$$V' = E_{max}\, r\left(\ln\frac{D}{r}\right)$$

When E_{max} reaches g_0 (breakdown strength of air) air breaks down.

$$V' = g_0\, r\, \ln(D/r)$$

- For 25^0C and 760 mm Hg, and smooth cylindrical conductor

$$g_0 = 30 \text{ kV/cm (Peak/DC)} \quad \text{OR} \quad g_0 = \frac{30}{\sqrt{2}} = 21.2 \text{ kV/cm (rms)}$$

- Above g_0 is for fair (standard) weather conditions, at any other condition,

$$V' = g_0\, \delta\left(r \ln(D/r)\right)$$

where, δ is the relative air density or air density correction factor.

$$\delta = \frac{p}{273+t}\cdot\frac{273+25}{760} = 0.392\frac{p}{273+t}$$

Thank You