# *Corona*


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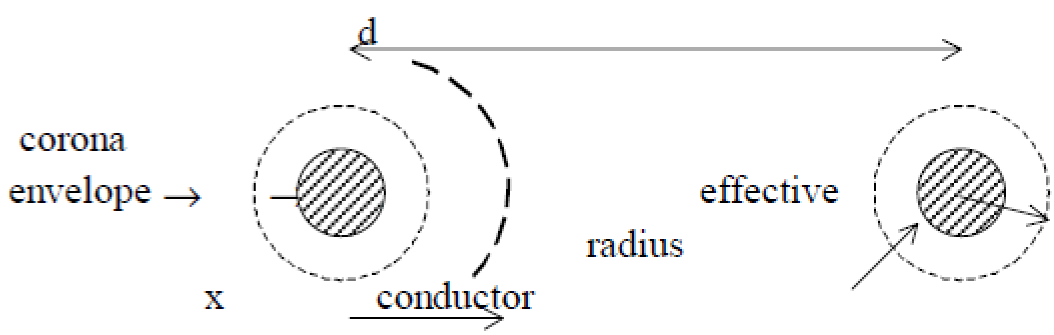
# Corona Discharge

- When a gradually increasing voltage is applied across two conductors, initially nothing will be observed.
- As the voltage is increased, the air surrounding the conductors get ionised, and at a certain voltage a hissing noise is heard caused by the formation of corona. This voltage is known as the disruptive critical voltage (dcv).
- A further increase in the voltage would cause a visible violet glow around the conductors. This voltage is the visual corc



# Corona Discharge

## Mechanism of corona discharge:

- **The stress surrounding the conductor is maximum at the conductor surface itself, and decreases rapidly as the distance from the conductor increases.**
- **Thus when the stress has been raised to critical value immediately surrounding the conductor, ionisation would commence only in this region and the air in this region would become conducting. The effect is to increase the effective conductor diameter while the voltage remains constant. This results in two effects.**

  1. Firstly, an increase in the effective sharpness of the conductor would reduce the stress outside this region, and
  2. secondly, this would cause a reduction of the effective spacing between the conductors leading to an increase in stress.

## Corona discharge

- **Depending on which effect is stronger, the stress at increasing distance can either increase or decrease. If the stress is made to increase, further ionisation would occur and flashover is inevitable.**
- **Under ordinary conditions, the breakdown strength of air can be taken as 30 kV/cm. Corona will of course be affected by the physical state of the atmosphere. In stormy weather, the number of ions present is generally much more than normal, and corona will then be formed at a much lower voltage than in fair weather. This reduced voltage is generally about 80% of the fair weather voltage.**

# Corona Discharge

## Mechanism of corona discharge:

- **The electric stress (=q, -q) at a distance x from a conductor of radius x, and separated from the return conductor by a distance d is given by**

$$\xi = \frac{l}{\varepsilon_0} \cdot \frac{q}{2\pi x l}$$

- where q is the charge on each conductor over length *l*
- Thus the potential V can be determined from.

$$V = \int \xi \, dx$$

$$V = \int_{r}^{d-r} \frac{q}{2\pi x \varepsilon_0} \cdot dx$$

For q per unit length, given C/m

# Corona Discharge

## Mechanism of corona discharge:

- **Since both charges (+q and -q) produce equal potential differences, the total potential difference between the two conductors is double this value. Thus the conductor to neutral voltage, which is half the difference would be equal to this value. Thus the conductor to neutra**

$$V = \frac{q}{2\pi\varepsilon_0} . \log_e\left(\frac{d-r}{r}\right)$$

- Therefor $\xi_x = \dfrac{V}{x \log_e \dfrac{d-r}{r}}$ ss at distance x is given by

[Note: $E_x$ and V can both be peak values or both rms values.

$$\xi_x = \frac{V}{x \log_e \frac{d}{r}} \quad \text{if } d \ll r$$

# Corona Discharge

## Mechanism of corona discharge:

- For three phase lines, with equilateral spacing, it can be shown that the stress is still given by the same expression when V is the voltage to neutral and d is the equilateral spacing.

$$\text{For air, } \xi_{max} = 30 \text{ kV/cm, so that } \xi_{rms} = 30/\sqrt{2} = 21.2 \text{ kV/cm.}$$

- Since there is no electric stress within the conductor, the maximum stress will occur when x is a minimum, that is at x = r.

## Corona Discharge

Critical Disruptive Voltage: It is the minimum phase-neutral voltage at which corona occurs. Consider two conductors of radii r cm and spaced d cm apart. If V is the phase-neutral potential, then potential gradient at the conductor surface is given by:

$$E = g = \frac{V}{r \ln \frac{d}{r}} \text{ Volts/cm}$$

## Corona Discharge

In order that corona is formed, the value of g must be made equal to the breakdown strength of air. The breakdown strength of air at 76 cm pressure and temperature of 25ºC is 30 kV/cm (peak) or 21·2 kV/cm (r.m.s.) and is denoted by $g_0$. If $V_c$ is the phase-neutral potential required under these conditions, then,

$$E_d = g_0 = \frac{V_c}{r \ln \frac{d}{r}}$$

where $E_d$= breakdown strength of air at 760 Torr of mercury and 25ºC= 30 kV/cm (peak) or 21·2 kV/cm (r.m.s.)

Critical disruptive voltage $$V_c = g_0 r \ln \frac{d}{r}$$

## Electric Stress and Ionization Voltages

- The above expression for disruptive voltage is under standard conditions i.e. at 76 cm of Hg and 25ºC. However, if these conditions vary, the air density also changes, thus altering the value of $E_d$. The value of $E_d$ is directly proportional to air density.

$$\delta = \frac{p}{760} \cdot \frac{273+20}{273+t} = \frac{0.386\, p}{273+t}$$

- The disruptive critical voltage depends also on the surface smoothness of the conductor. When the surface of the conductor is irregular, it is more liable to corona. Thus an irregularity factor $m_0$ is introduced to account for this reduction. Typical values of this factor are

| | | |
|---|---|---|
| $m_0 = 1.0$ | | for smooth polished conductors, |
| $= 0.98$ to $0.93$ | | for roughened conductors, |
| $\approx 0.90$ | | for cables of more than 7 strands, and |
| $= 0.87$ to $0.83$ | | for 7 strand cables. |

# Electric Stress and Ionization Voltages

- The disruptive critical voltage can then be written as in the following equation.

- $V_{dis} = 21.2\ \delta\ m_0\ r \log_e (d/r)$ kV to neutral

## Electric Stress and Ionization Voltages

Visual Corona: Visual corona occurs at a higher voltage than the disruptive critical voltage. For the formation of visual corona, a certain amount of ionization, and the raising of an electron to an excited state are necessary. The production of light by discharge is not due to ionization, but due to excitation, and subsequent giving out of excess energy in the form of light and other electromagnetic waves. To obtain the critical voltage for visual corona formation, the disruptive critical voltage has to be multiplied by a factor dependent on the air density and the conductor radius.

The empirical formula for the formation of visual corona is:

$$V_{\text{Visual}} = 21.2\, m_v\, \delta\, r \left[ 1 + \frac{0.3}{\sqrt{\delta\, r}} \right] . \log_e \frac{d}{r}$$

# Electric Stress and Ionization Voltages

The values of the irregularity factor $m_v$ for visual corona is given by

$$
\begin{aligned}
m_v &= 1.0 && \text{for smooth conductors,} \\
&= 0.72 && \text{for local corona on stranded wires (patches)} \\
&= 0.82 && \text{for decided corona on stranded wires (all over the wire)}
\end{aligned}
$$

## Electric Stress and Ionization Voltages

Stable Corona formation: Consider two conductors, just on the limit of corona formation. Assume that there is a thin layer dr of ionised air around each conductor, so that the effective radius becomes (r + dr). The change in electric stress due to this layer can be determined using differentiation.

Thus d/dr $\left( \dfrac{E}{r \log_e \dfrac{d}{r}} \right)$

d/r > e (=2.718) for stable corona.

Under this condition, the effective increase in diameter lowers the electric stress and no further stress increase is formed, and corona is stable. If on the other hand, d/r < e, then the effective increase in the diameter raises the electric stress, and this causes a further ionization and a further increase in radius, and finally leads to flash-over.

# Electric Stress and Ionization Voltages

In practice, the effective limiting value of d/r is about 15 and not **e** (=2.718). For normal transmission lines, the ratio d/r is very much greater than 15 and hence stable corona always occurs before flashover.

**Power loss due to corona:** **There is a power loss due to the formation of corona that affects the transmission efficiency of the lines. This power loss is affected by the atmospheric and line conditions too. Power loss due to corona under fair weather condition is given by**

$$P = \frac{244}{\delta}(f+25)\sqrt{\frac{r}{D}}\left(V_{\text{ph}} - V_{\text{d0}}\right)^2 \times 10^{-5} \text{ kW/km/phas}$$

where, $V_{\text{ph}}$ = voltage to neutral in kV

$V_{\text{d0}}$ = disruptive critical voltage to neutral in kV

$f$ = supply frequency in Hz

For storm weather conditions, the disruptive critical voltage is to be taken as 80% of disruptive critical voltage under fair weather conditions.

# Disadvantages

1. Transmission efficiency is affected due to corona loss. Even under fair weather conditions some lossis encountered.
2. With the appearance of the corona glow, the charging current increases and introduces harmonics.
3. Inductive interference to neighboring communication lines due to the non-sinusoidal voltage drop that occurs in the line.
4. Due to the formation of the corona, ozone gas is generated which chemically react with the conductor and causes corrosion.

**A three-phase, 220 kV, 50 Hz transmission line has equilateral triangular spacing of side 2 m. The conductor diameter is 3.0 cm. The air density factor and the irregularity factor is 0.95 and 0.83, respectively. Find the disruptive critical voltage and corona loss per kilometre. Assume any data required.**

Solution:

Line voltage = 220 kV(L–L)

Frequency, $f = 50$ Hz

Spacing between conductors, $D = 2$ m (equilateral spacing)

Radius of conductor, $r = d/2 = 3.0/2 = 1.5$ cm

Irregularity factor, $m_0 = 0.83$

Air density factor, $\delta = 0.95$

Assume dielectric strength of air, $g_0 = 21.2$ kV/cm

Disruptive critical voltage $V_d = m_0 g_0 \delta r \ln\left(\frac{D}{r}\right)$ kV

$$= 21.2 \times 0.83 \times 0.95 \times 1.5 \ln\left(\frac{200}{1.5}\right)$$

$$= 122.685 \text{ kV}$$

Corona loss, $P_c = 244\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}(V - V_{d0})^2 \times 10^{-5}$ kW/km/phase

$$= 244\left(\frac{50+25}{0.95}\right)\sqrt{\frac{1.5}{200}}(127 - 122.685)^2 \times 10^{-5}$$

$$= 0.3106 \text{ kW/km/phase}$$

Total corona loss $= 3 \times 0.3106$

$$= 0.9318 \text{ kW/km}$$

# Methods for reducing corona

The corona effect can be reduced by using:

Conductors with large diameters: The voltage at which the corona occurs can be increased by increasing the size of the conductor and hence, the corona loss can be reduced.

Hollow conductors: These are used to increase the effective diameter of the conductor without using any additional material. Since, corona loss is inversely proportional to the diameter of the conductor, corona loss decreases with an increase in the diameter.

Bundled conductors: These are made up of two or more sub-conductors and is used as a single-phase conductor.

Increase of spacing d between conductors.