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Chapter- Corona

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Corona

Syllabus:-Reasons for corona, critical disruptive voltage and visual critical voltage Effects of pressure, temperature and irregularity of conductor surface, Losses in corona and its reduction.

After reading this chapter, the students should be able to:

- Phenomena and reason for occurrence of corona
- Calculate critical disruptive voltage,
- Local corona voltage and losses due to corona.

Introduction:-

- *The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as* **corona.**
- When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low.
- However, when the applied voltage exceeds a certain value, called *critical disruptive voltage,* the conductors are surrounded by a faint violet glow called corona.
- The phenomenon of corona is accompanied by a hissing sound, production of ozone, power loss and radio interference.
- The higher the voltage is raised, the larger and higher the luminous envelope becomes, and greater are the sound, the power loss and the radio noise.
- If the applied voltage is increased to breakdown value, a flash-over will occur between the conductors due to the breakdown of air insulation.
- If the conductors are polished and smooth, the corona glow will be uniform throughout the length of the conductors, otherwise the rough points will appear brighter.
- With DC voltage, there is difference in the appearance of the two wires. The positive wire has uniform glow about it, while the negative conductor has spotty glow.

Theory of corona formation:-

- Some ionisation is always present in air due to cosmic rays, ultraviolet radiations and radioactivity.
- Therefore, under normal conditions, the air around the conductors contains some ionised particles (*i.e.,* free electrons and +ve ions) and neutral molecules.
- When potential difference is applied between the conductors, potential gradient is set up in the air which will have maximum value at the conductor surfaces.
- Under the influence of potential gradient, the existing free electrons acquire greater velocities. The greater the applied voltage, the greater the potential gradient and more is the velocity of free electrons.
- When the potential gradient at the conductor surface reaches about 30 kV per cm (max. value), the velocity acquired by the free electrons is sufficient to strike a neutral molecule with enough force to dislodge one or more electrons from it.
- This produces another ion and one or more free electrons, which in turn are accelerated until they collide with other neutral molecules, thus producing other ions.
- Thus, the process of ionisation is cumulative. The result of this ionisation is that either corona is formed or spark takes place between the conductors.

Factors Affect Corona:-

- The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends :
- (*i*) ***Atmosphere.*** As corona is formed due to ionsiation of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.
- (*ii*) ***Conductor size.*** The corona effect depends upon the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thus a stranded conductor has irregular surface and hence gives rise to more corona that of a solid conductor.
- (*iii*) ***Spacing between conductors.*** If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.
- (*iv*) ***Line voltage.*** The line voltage greatly affects corona. If it is low, there is no change in the condition of air surrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that electrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is formed.

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:

$$g = \frac{V}{r \log_e \frac{d}{r}}$$

- 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 (hg column) pressure and temperature of 25ºC is 30 kV/cm (*max*) 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,

$$g = \frac{V}{r \log_e \frac{d}{r}}$$

- where g_0=breakdown strength of air at 76 cm of mercury and 25ºC = 30 kV/cm (*max*) or 21·2 kV/cm (*r.m.s.*)
- Hence, critical disruptive voltage, is $V_C = g_0 r \log_e \frac{d}{r}$
- The above expression for disruptive voltage is under standard conditions *i.e.,* at 76 cm of Hg column and 25ºC. However, if these conditions vary, the air density also changes, thus altering the value of g_0. The value of g_0 is directly proportional to air density.
- Thus the breakdown strength of air at a barometric pressure of b cm of mercury and temperature of tºC becomes δ_{g0}. where $\delta\ =\ air\ density\ factor = \frac{3.92b}{273+t}$

Critical disruptive voltage:-

- Under standard conditions, the value of $\delta = 1$.
- Critical disruptive voltage, $V_C = g_0 \delta r \log_e \frac{d}{r}$
- Correction must also be made for the surface condition of the conductor. This is accounted for by multiplying the above expression by irregularity factor m_0.
- Hence, Critical disruptive voltage, $V_C = m_0 g_0 \delta r \log_e \frac{d}{r}\, kV/phase$

where, m_0 = 1 for polished conductors

= 0·98 to 0·92 for dirty conductors

= 0·87 to 0·8 for stranded conductors

Visual critical voltage:-

- *It is the minimum phase-neutral voltage at which corona glow appears all along the line conductors.*
- It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage Vc but at a higher voltage V_V, called *visual critical voltage.*
- The phase-neutral effective value of visual critical voltage is given by the following empirical formula:

$$V_V = mvg_0\delta r\left(1 + \frac{0.3}{\sqrt{\delta r}}\right)\log_e \frac{d}{r}\, kV/phase$$

where, m_0 = 1 for polished conductors

= 0·72 (for local corona) to 0·82 (for decided corona) for rough conductors

=0.92 to 0.98 for rough conductor

Power loss due to corona:-

- Formation of corona is always accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action.
- When disruptive voltage is exceeded, the power loss due to corona is given by:

1) Peek's Formula:-

$$P = 242.2\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}(V - VC)^2 \times 10^{-5}\ kW/km/phase;\text{ for fair weather condition}$$

$$P = 242.2\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}(V - 0.8VC)^2 \times 10^{-5}\ kW/km/phase;\text{ for foul weather condition}$$

where f = supply frequency in Hz

V = phase-neutral voltage (*r.m.s.*)

V_C= disruptive voltage (*r.m.s.*) per phase

This formula is valid when i) V/VC ratio is more than 1.8; ii) Severe corona is observed; iii) $r > 0.25$ cm; iv) $25 < f < 120$ Hz.

2) Peterson's formula:- $P = F \times \frac{1.11066\times10^{-4} fV^2}{\left(\log\frac{d}{r}\right)^2}$; where F = factor which varies with V/VC ratio

V/VC:-	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**
F:-	0.012	0.018	0.05	0.08	0.30	1

Advantages and Disadvantages of Corona:-

- Corona has many advantages and disadvantages. In the correct design of a high voltage overhead line, a balance should be struck between the advantages and disadvantages.

➢ **Advantages:-**

(i) Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the conductor is increased. The increased diameter reduces the electrostatic stresses between the conductors.

(ii) Corona reduces the effects of transients produced by surges.

(iii) Voltage surges on transmission lines are unaffected by corona until their potential exceeds the corona threshold. Above this point the effect is quite dramatic, as is shown in experimental evidence in figure 1. Here, the shapes of surges as they originated and at intervals as they travelled down a 132-kV transmission line. Note, corona has removed the initial peak by the time the wave has travelled only 1.5 miles. Thereafter attenuation continuous but a reduced to rate. The kind of distortion that builds the centre and tail of the wave at the expense of the front is quite evident.

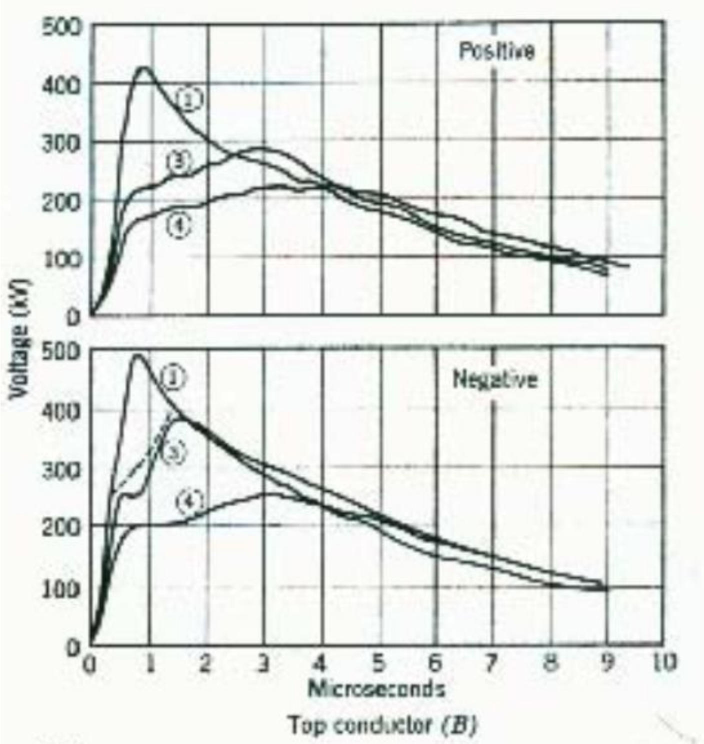


Figure 1

Advantages and Disadvantages of Corona:-

- **Disadvantages:-**

(i) Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

(ii) Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.

(iii) The current drawn by the line due to corona is non-sinusoidal and hence non-sinusoidal voltage drop occurs in the line. This may cause inductive interference with neighbouring communication lines.

Methods of Reducing Corona Effect:-

It has been seen that intense corona effects are observed at a working voltage of 33 kV or above. Therefore, careful design should be made to avoid corona on the sub-stations or bus-bars rated for 33 kV and higher voltages otherwise highly ionised air may cause flash-over in the insulators or between the phases, causing considerable damage to the equipment.

The corona effects can be reduced by the following methods:

(i) ***By increasing conductor size****:-* By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that *ACSR* conductors which have a larger cross-sectional area are used in transmission lines.

(ii) ***By increasing conductor spacing:-*** By increasing the spacing between conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated. However, spacing cannot be increased too much otherwise the cost of supporting structure (*e.g.,* bigger cross arms and supports) may increase to a considerable extent.

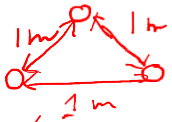
(iii) ***By using Corona Ring:-***

CORONA RING

Problem:- *A 3-phase line has conductors 2 cm in diameter spaced equilaterally 1 m apart. If the dielectric strength of air is 30 kV (max) per cm, find the critical disruptive voltage for the line. Take air density factor* $\delta = 0{\cdot}952$ *and i~~rregulari~~ty factor* $m_0 = 0{\cdot}9$.

$r = 1\,\text{cm}$

$d = 100\,\text{cm}$



$g_0 = \dfrac{30}{\sqrt{2}} = 21{\cdot}2\,\text{kV (rms/cm)}$

$\delta = 0.952$

$m_0 = 0{\cdot}9$

$V_c = m_0 g_0 \delta \underset{\text{cm}}{r} \ln\left(\dfrac{d}{r}\right)$ ← GMD

$V_c = 0{\cdot}9 \times 21{\cdot}2 \times 0{\cdot}952 \times 1 \times \ln\left(\dfrac{100}{1}\right)$

$= 83\,649$ kV → phase voltage.

$(V_c)_{\text{Line}} = \sqrt{3}\, V_c$

$= 144{\cdot}8844\,\text{kV}$

Problem:- *A 132 kV line with 1·956 cm dia. conductors is built so that corona takes place if the line voltage exceeds 210 kV (r.m.s.). If the value of potential gradient at which ionisation occurs can be taken as 30 kV per cm, find the spacing between the conductors.*

$g_o = 21.2$ kV(rms)/cm

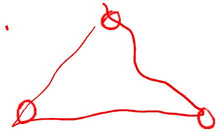
$m_o = 1$

$\delta = 1$

$r = \frac{1.956}{2}\text{ cm} = 0.978\text{ cm}$

$d = ?$

$V_c = \frac{210}{\sqrt{3}}\text{ kV} = 121.2435\text{ kV}$



GMD =

$$121.2435 = 1 \times 21.2 \times 1 \times 0.978 \times \ln\left(\frac{d}{0.978}\right)$$

$$\ln\left(\frac{d}{0.978}\right) = \frac{121.2435}{(21.2 \times 0.978)}$$

$$= 5.8477$$

$$\frac{d}{0.978} = e^{(5.8477)}$$

$$d = 0.978 \times e^{(5.8477)}$$

$$= 338.815\text{ cm}$$

Problem:*-Certain 3-phase equilateral transmission line has a total corona loss of 53 kW at 106 kV and a loss of 98 kW at 110·9 kV. What is the disruptive critical voltage? What is the corona loss at 113 kV?*

$$P_{Loss} = 3 \times \left[242.2 \frac{(f+25)}{\delta} \sqrt{\frac{r}{d}} (V - V_c)^2 \times 10^{-5} \right] \text{ kW/km}$$

$P_{Loss} = 53\text{ kW} / \Rightarrow 106\text{ kV}.$

$P_{Loss} = 98\text{ kW} / \Rightarrow 110.9\text{ kV}.$

$P_{Loss} = \ ? \ / \Rightarrow 113\text{ kV}.$

$V_c = \ ??.$

$$\frac{106}{\sqrt{3}} = 61.2\text{ kV}$$

$$\frac{110.9}{\sqrt{3}} = 64.028\text{ kV}$$

$$\frac{113}{\sqrt{3}} = 65.24\text{ kV}.$$

$$P_{Loss} \propto (V - V_c)^2$$

$$53 \Leftarrow P_{Loss} \propto (61.2 - V_c)^2 \quad \text{— (1)}$$

$$98 \ \cancel{106} \Leftarrow P_{Loss} \propto (64.028 - V_c)^2 \quad \text{— (2)}$$

$$\frac{53}{98 \ \cancel{106}} = \frac{(61.2 - V_c)^2}{(64.028 - V_c)^2}$$

$$\frac{61.2 - V_c}{64.028 - V_c} = \sqrt{\frac{53}{98}}$$

$$V_c = 53.35\text{ kV}$$

$$113\text{ kV} \Leftarrow P_{Loss} \propto (65.24 - 53.35)^2 \quad \text{— (3)}$$

$$\frac{53}{P_{Loss}} = \frac{(61.2 - 53.35)^2}{(65.24 - 53.35)^2}$$

$$P_{Loss} = 121.5906\text{ kW}.$$

Problem:-Estimate the corona loss for a three-phase, 110 kV, 50 Hz, 150 km long transmission line consisting of three conductors each of 10 mm diameter and spaced 2·5 m apart in an equilateral triangle formation. The temperature of air is 30ºC and the atmospheric pressure is 750 mm of mercury. Take irregularity factor as 0·85. Ionisation of air may be assumed to take place at a maximum voltage gradient of 30 kV/ cm.

$r = 0.5\,cm$

$d = 250\,cm$

$t = 30^\circ C$

$b = 75\,cm$ of Hg Column

$m_o = 0.85$

$g_o = 21.2\,kV(rms)/cm.$

$$\delta = \frac{3.92 b}{273+t}$$

$$\delta = \frac{3.92 \times 75}{303}$$

$$= 0.9703$$

$$V_c = 0.85 \times 21.2 \times 0.9703 \times 0.5 \ln\left(\frac{250}{0.5}\right)$$

$$= 54.3306\,kV.$$

P_{Loss}/km/phase

$$= 242.2 \times \left(\frac{50+25}{0.9703}\right)\sqrt{\frac{0.5}{250}}\left(\frac{110}{\sqrt{3}} - 54.3306\right)^2 \times 10^{-5}\ kW$$

$$= 0.7052\,kW.$$

$$P_{Loss}/phase = (0.7052 \times 150)\,kW$$

$$= 105.7852\,kW.$$

$$\text{Total } P_{Loss} = 3 \times 105.7852\ kW$$

$$= \underline{317.34\ kW}$$