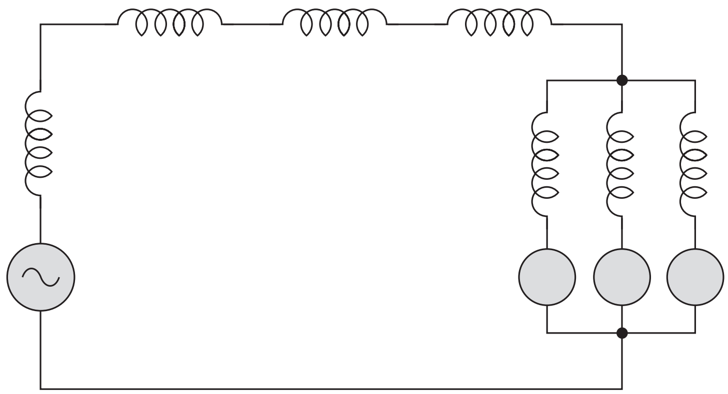
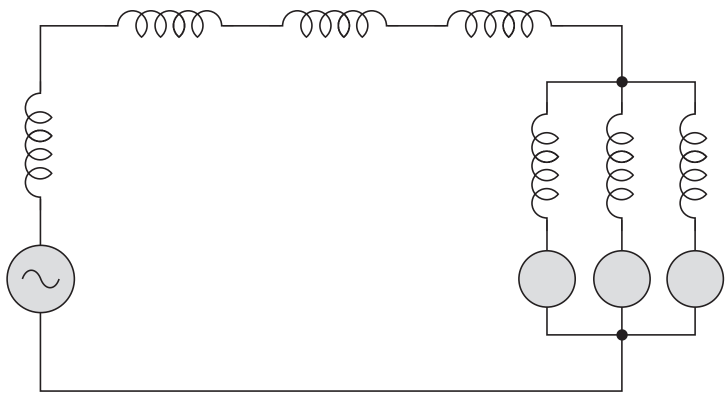


6

CORONA



6

Corona

INTRODUCTION

Corona phenomenon is the ionization of air surrounding the power conductor. Free electrons are normally present in free space because of radioactivity and cosmic rays. As the potential between the conductors is increased, the gradient around the surface of the conductor increases. Assume that the spacing between the conductors is large as compared with the diameter of the conductors. The free electrons will move with certain velocity depending upon the field strength. These electrons will collide with the molecules of air and in case the speed is large, they will dislodge electrons from these molecules, thereby the number of electrons will increase. The process of ionization is thus cumulative and ultimately forms an electron avalanche. This results in ionization of the air surrounding the conductor. In case the ratio of spacing between conductors to the radius of the conductor is less than 15, flash over will occur between the conductors before corona phenomenon occurs. Usually for overhead lines this ratio is far more than this number and hence flash-over can be regarded as impossible.

Corona phenomenon is, therefore, defined as a self-sustained electric discharge in which the field intensified ionization is localized only over a portion of the distance between the electrodes.

When a voltage higher than the critical voltage is applied between two parallel polished wires, the glow is quite even. After operation for a short time, reddish beads or tufts form along the wire, while around the surface of the wire there is a bluish white glow. If the conductors are examined through a stroboscope, so that one wire is always seen when at a given half of the wave, it is noticed that the reddish tufts or beads are formed when the conductor is negative and a smoother bluish white glow when the conductor is positive. The a.c. corona, viewed through a stroboscope, has the same appearance as direct current corona. As corona phenomenon is initiated, a hissing noise is heard and ozone gas is formed which can be detected by its characteristic odour.

6.1 CRITICAL DISRUPTIVE VOLTAGE

Consider a single-phase transmission line (Fig. 6.1). Let r be the radius of each conductor and d the distance of separation such that $d >> r$. Since it is a single-phase transmission line, let q be the charge per unit length on one of the conductors and hence $-q$ on the other. If the operating voltage is V, the potential of conductor A with respect to neutral plane N will be $V/2$ and that of B will be $-V/2$. Consider a point P at a distance x where we want to find the electric field intensity. Bring a unit positive charge at P.

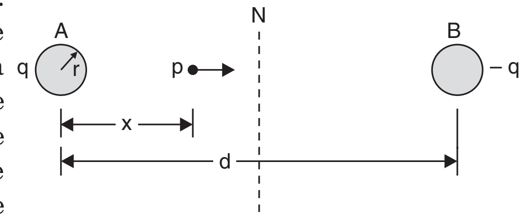


Fig. 6.1 1-ϕ transmission line.

The field due to A will be repulsive and that due to B will be attractive; thereby the electric field intensity at P due to both the line charges will be additive and it will be

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

The potential difference between the conductors

$$V = -\int_{d-r}^{r} E_x dx = \int_{r}^{d-r} \frac{q}{2\pi\varepsilon_0}\left[\frac{1}{x} + \frac{1}{d-x}\right] dx$$

$$= \frac{q}{2\pi\varepsilon_0}\Big[\ln x - \ln (d-x)\Big]_r^{d-r}$$

$$= \frac{q}{2\pi\varepsilon_0} . 2 \ln \frac{d-r}{r} = \frac{q}{\pi\varepsilon_0} \ln \frac{d-r}{r} \quad (6.1)$$

Since r is very small as compared to d, $d - r \simeq d$.

$$\therefore \quad V = \frac{q}{\pi\varepsilon_0} \ln \frac{d}{r} \quad (6.2)$$

Now gradient at any point x from the centre of the conductor A is given by

$$E_x = \frac{q}{2\pi\varepsilon_0}\left[\frac{1}{x} + \frac{1}{d-x}\right]$$

$$= \frac{q}{2\pi\varepsilon_0} \cdot \frac{d}{x(d-x)}$$

Substituting for q from the above equation,

$$q = \frac{\pi\varepsilon_0 V}{\ln \dfrac{d}{r}}$$

$$E_x = \frac{\pi\varepsilon_0 V}{\ln \dfrac{d}{r}} \cdot \frac{1}{2\pi\varepsilon_0} \cdot \frac{d}{x(d-x)}$$

$$= \frac{V}{2 \ln \frac{d}{r}} \cdot \frac{d}{x(d-x)}$$

$$= \frac{V' d}{x(d-x) \ln \frac{d}{r}} \tag{6.3}$$

Here V' is the line to neutral voltage of the system. In case of 3-phase system

$$V' = \frac{V_L}{\sqrt{3}}$$

where V_L is the line to line voltage.

From the expression for the gradient it is clear that for a given transmission system the gradient increases as x decreases *i.e.*, the gradient is maximum when $x = r$, the surface of the conductor, and this value is given by

$$g_{\max} = E_r = E_{\max} = \frac{V' d}{r(d-r) \ln \frac{d}{r}}$$

$$\simeq \frac{V'}{r \ln \frac{d}{r}}$$

or

$$V' = r g_{\max} \ln \frac{d}{r} \tag{6.4}$$

Critical disruptive voltage is defined as the voltage at which complete disruption of dielectric occurs. This voltage corresponds to the gradient at the surface equal to the breakdown strength of air. This dielectric strength is normally denoted by g_0 and is equal to 30 kV/cm peak at NTP *i.e.*, 25°C and 76 cm of Hg.

At any other temperature and pressure

$$g_0' = g_0 \cdot \delta \tag{6.5}$$

where δ is the air density correction factor and is given by

$$\delta = \frac{3.92b}{273 + t} \tag{6.6}$$

where b is the barometric pressure in cm of Hg and t the temperature in °C.

Therefore, the critical disruptive voltage is given by

$$V' = r g_0 \, \delta \ln \frac{d}{r} \text{ kV} \tag{6.7}$$

In deriving the above expression, an assumption is made that the conductor is solid and the surface is smooth. For higher voltages ACSR conductors are used. The cross-section of such a conductor is a series of arcs of circles each of much smaller diameter than the conductor as a whole. The potential gradient for such a conductor will, in consequence, be greater than for the equivalent smooth conductor, so that the breakdown voltage for a stranded conductor will be somewhat less than for a smooth conductor. The irregularities on the surface of such a conductor are increased further because of the deposition of dust and dirt on its surface and the breakdown voltage is further reduced. An average value for the ratio of breakdown voltage for such a conductor and a smooth conductor lies between 0.85 to unity and is denoted by m_0. Suitable values of m_0 are given below:

Polished wires	1.0
Roughened or weathered wires	0.98 to 0.93
Seven strand cable	0.87 to 0.83
Large cables with more than seven strands	0.90 approx.

The final expression for the critical disruptive voltage after taking into account the atmospheric conditions and the surface of the conductor is given by

$$V' = rg_0\delta m_0 \ln \frac{d}{r} \text{ kV} \tag{6.8}$$

When the voltage applied corresponds to the critical disruptive voltage, corona phenomenon starts but it is not visible because the charged ions in the air must receive some finite energy to cause further ionization by collisions. For a radial field, it must reach a gradient g_v at the surface of the conductor to cause a gradient g_0, a finite distance away from the surface of the conductor. The distance between g_v and g_0 is called the energy distance. According to Peek this distance is equal to $(r + 0.301\sqrt{r}\,)$ for two parallel conductors and $(r + 0.308\sqrt{r}\,)$ for co-axial conductors. From this it is clear that g_v is not constant as g_0 is, and is a function of the size of the conductor.

$$g_v = g_0\delta\left(1+\frac{0.3}{\sqrt{r\delta}}\right) \text{ kV/cm for two wires in parallel.} \tag{6.9}$$

Also if V_v is the critical visual disruptive voltage, then

$$V_v = g_v r \ln \frac{d}{r}$$

or

$$g_v = \frac{V_v}{r \ln \frac{d}{r}} = g_0\delta\left(1+\frac{0.3}{\sqrt{r\delta}}\right)$$

or

$$V_v = rg_0\delta\left[1+\frac{0.3}{\sqrt{r\delta}}\right]\ln\frac{d}{r} \text{ kV} \tag{6.10}$$

In case the irregularity factor is taken into account,

$$V_v = g_0 m_v\, \delta r\left[1+\frac{0.3}{\sqrt{r\delta}}\right]\ln\frac{d}{r}$$

$$= 21.1 m_v\, \delta r\left[1+\frac{0.3}{\sqrt{r\delta}}\right]\ln\frac{d}{r} \text{ kV r.m.s.} \tag{6.11}$$

where r is the radius in cms. The irregularity factor m_v has the following values:

m_v = 1.0 for polished wires

= 0.98 to 0.93 for rough conductor exposed to atmospheric severities

= 0.72 for local corona on stranded conductors.

Since the surface of the conductor is irregular, the corona does not start simultaneously on the whole surface but it takes place at different points of the conductor which are pointed and this is known as local corona. For this m_v = 0.72 and for decided corona or general corona m_v = 0.82.

Example 6.1: Find the critical disruptive voltage and the critical voltages for local and general corona on a 3-phase overhead transmission line, consisting of three stranded copper conductors spaced 2.5 m apart at the corners of an equilateral triangle. Air temperature and pressure are 21°C and 73.6 cm Hg respectively. The conductor dia, irregularity factor and surface factors are 10.4 mm, 0.85, 0.7 and 0.8 respectively.

Solution: The critical disruptive voltage is given by

$$V_d = 21.1\, m\, \delta r \ln \frac{d}{r}$$

where $\delta = \frac{3.92b}{273+t} = \frac{3.92 \times 73.6}{273+21} = \frac{3.92 \times 73.6}{294} = 0.9813$

$$V_d = 21.1 \times 0.85 \times 0.9813 \times 0.52 \ln \frac{250}{0.52} = 56.5 \text{ kV}$$

or the critical disruptive line to line voltage = $56.5 \times \sqrt{3}$ = 97.89 kV **Ans.**

The visual critical voltage is given by

$$V_v = 21.1\, m\, \delta r \left(1 + \frac{0.3}{\sqrt{r\delta}}\right) \ln \frac{d}{r}$$

Here m = 0.7 for local corona

= 0.8 for decided corona or general corona

Now $\sqrt{r\delta} = \sqrt{0.52 \times 0.9813} = 0.71433$

$\therefore$ V_v for local corona $= 21.1 \times 0.7 \times 0.9813 \times 0.52(1 + 0.42) \ln \frac{d}{r}$

$= 10.7 \times 6.175$

$= 66.07$ kV

The line to line voltage will be $66.0725.\sqrt{3}$ = 114.44 kV.

The visual critical voltage for general corona will be

$$114.44 \times \frac{0.8}{0.7} = 130.78 \text{ kV} \quad \textbf{Ans.}$$

Example 6.2: A conductor with 2.5 cm dia is passed centrally through a porcelain bushing ε_r = 4 having internal and external diameters of 3 cm and 9 cm respectively. The voltage between the conductor and an earthed clamp surrounding the porcelain is 20 kV r.m.s. Determine whether corona will be present in the air space round the conductor.

Solution: Let $g_{1\,max}$ be the maximum gradient on the surface of the conductor and $g_{2\,max}$ the maximum gradient on the inner side of the porcelain

$$g_{1\,max} = \frac{q}{2\pi\varepsilon_0 r}$$

$$g_{2\,max} = \frac{q}{2\pi\varepsilon_0\varepsilon_r r_1}$$

$$\therefore \quad g_{1\,max}\, r = g_{2\,max}\, \varepsilon_r r_1$$

$$g_{1\,max} \times 1.25 = g_{2\,max} \times 4 \times 1.5$$

$$\therefore \quad g_{1\,max} = 4.8 g_{2\,max}$$

or

$$g_{2\,max} = \frac{g_{1max}}{4.8} = 0.208 g_{1\,max}$$

Now

$$20 = g_{1\,max}\, r \ln \frac{1.5}{1.25} + g_{2\,max} \times 1.5 \ln \frac{4.5}{1.5}$$

$$= 1.25 g_{1\,max} \ln \frac{1.5}{1.25} + 0.208 g_{1\,max} \times 1.5 \ln \frac{4.5}{1.5}$$

$$= 0.228 g_{1\,max} + 0.3427 g_{1\,max}$$

$$= 0.570 g_{1\,max}$$

$$\therefore \quad g_{1\,max} = \frac{20}{0.570} = 35 \text{ kV/cm.}$$

Since the gradient exceeds 21.1 kV/cm, corona will be present.

Example 6.3: Determine the critical disruptive voltage and corona loss for a 3-phase line operating at 110 kV which has conductor of 1.25 cm dia arranged in a 3.05 metre delta. Assume air density factor of 1.07 and the dielectric strength of air to be 21 kV/cm.

Solution: The disruptive critical voltage

$$V = 21\, m\, \delta r \ln \frac{d}{r}$$

$$= 21 \times 1.07 \times 0.625 \ln \frac{305}{0.625}$$

$$= 21 \times 1.07 \times 0.625 \times 6.19 = 87 \text{ kV} \quad \textbf{Ans.}$$

The line to line voltage is $87\sqrt{3} = 150.6$ kV.

Since the operating voltage is 110 kV, the corona loss will be absent.

Corona loss zero. **Ans.**

Example 6.4: A single phase overhead line has two conductors of dia 1 cm with a spacing of 1 metre between centres. If the dielectric strength of air is 21 kV/cm, determine the line voltage for which corona will commence on the line.

Solution: The disruptive critical voltage (phase)

$$V_d = 21\delta r \ln \frac{d}{r} = 21.1 \times 0.5 \ln \frac{100}{0.5}$$

$$= 21 \times 0.5 \times 5.2983 = 55.6 \text{ kV.} \quad \textbf{Ans.}$$

6.2 CORONA LOSS

The ions produced by the electric field result in space charges which move round the conductor. The energy required for the charges to remain in motion is derived from the supply system.

The space surrounding the conductor is lossy. In order to maintain the flow of energy over the conductor in the field wherein this additional energy would have been otherwise absent, it is necessary to supply this additional loss from the supply system. This additional power is referred to as corona loss.

An experimental set up (Fig. 6.2) can be arranged to measure corona loss in case of d.c. in a concentric cylinder case.

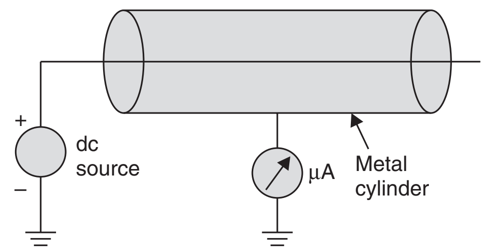


Fig. 6.2 Corona loss measurement with d.c. source.

Since the phenomenon is resistive, the loss will be *VI* watt. Peek made a number of experiments to study the effect of various parameters on the corona loss and he deduced an empirical relation.

$$P = 241 \times 10^{-5} \frac{(f + 25)}{\delta} \sqrt{\frac{r}{d}} (V_p - V_0)^2 \text{ kW/km/phase} \quad (6.12)$$

where f is the frequency of supply, δ the air density correction factor, V_p the operating voltage in kV and V_0 the critical disruptive voltage. The equation derived is for a fair weather condition. The approximate loss under foul weather condition is obtained by taking V_0 as 0.8 times the fair weather value. As a matter of fact, with perfectly smooth and cylindrical conductors no corona loss occurs until visual critical voltage is reached when the loss suddenly takes a definite value as calculated by the above formula. It then follows the quadratic law for higher voltages. The empirical relation as derived by Peek has certain limitations and gives correct results only if the supply frequency lies between 25 to 120 Hz, the conductor radius is greater than 0.25 cm and the ratio $\frac{V_p}{V_0} > 1.8$. Also a small error in m_0, the irregularity factor, will lead to wrong results when using this formula.

Factors Affecting Corona Loss

The following are the factors that affect corona loss on overhead transmission lines:

(*i*) Electrical factors,

(*ii*) Atmospheric factors, and

(*iii*) Factors connected with the conductors.

The factors are discussed one by one in the sequence.

Electrical Factors: Frequency and waveform of supply: Referring to the expression (6.12) for corona loss it is seen that corona loss is a function of frequency. Thus higher the frequency of supply the higher are corona losses. This shows that d.c. corona loss is less as compared with a.c. corona. Actually because of corona phenomenon in case of a.c. third harmonics are always present and hence the frequency is not only 50 Hz but it contains 3rd harmonic component also. Hence the corona loss is still large as compared with 50 Hz alone.

Field Around the Conductor: The field around the conductor in addition to being a function of the voltage, depends upon the configuration of the conductors, *i.e.,* whether they are placed in vertical configuration, delta formation etc. Say if the formation is horizontal the field near the middle conductor is large as compared to the outer conductors *i.e.,* the critical disruptive voltage is lower for the middle conductors and hence the corona loss on the middle conductor is more as compared with the two outer conductors. The height of the conductors from the ground has its effect on corona loss. The smaller the height, the greater the corona loss.

When lines are irregularly spaced, the surface gradients of the conductors and hence the corona losses if any are unequal.

Atmospheric Factors: Pressure and temperature effect: From the expression for loss (6.12) it is clear that it is a function of air density correction factor δ which appears directly in the denominator of the expression and indirectly in the value of critical disruptive voltage.

$$V_0 = 21.1 m_0\, \delta r \ln \frac{d}{r} \text{ kV}$$

The lower the value of δ the higher the loss; because loss is $\alpha(V - V_0)^2$, the lower the value of δ, the lower the value of V_0 and hence higher the value of $(V - V_0)^2$, where V is the operating voltage in kV. This shows that the effect of δ on corona loss is very serious. For lower values the pressure should be low and temperature higher. It is for this reason that the corona loss is more on hilly areas than on plain areas.

Dust, Rain, Snow and Hail Effect: The particles of dust clog to the conductor; thereby the critical voltage for local corona reduces which increases corona loss. Similarly, the bad atmospheric conditions such as rains, snow and hailstorm reduce the critical disruptive voltage and hence increase the corona loss.

Factors Connected with the Conductor: Diameter of the Conductor: From the expression (6.12) for corona loss it can be seen that the conductor size appears at two places and if other things are assumed constant,

$$\text{loss} \propto \sqrt{\frac{r}{d}}$$

and

$$\text{loss} \propto (V - V_0)^2$$

It appears from the first relation that loss is proportional to the square root of the size of the conductor, *i.e.,* larger the dia of the conductor larger will be the loss. But from the second expression as V_0 is approximately directly proportional to the size of the conductor, hence larger the size of the conductor larger will be the critical disruptive voltage and hence smaller will be the factor $(V - V_0)^2$. It is found in practice that the effect of the second proportionality is much more than the first on the corona losses, and hence larger the size of the conductor lower is the corona loss.

Number of Conductors/Phases: For operating voltage 380 kV and above it is found that one conductor per phase gives large corona loss and hence large radio interference (*RI*) level which interferes with the communication lines which normally run parallel to the power lines. This problem of large corona loss is solved by using two or more than two conductors per phase which is known as bundling of conductors. By bundling the conductors the self GMD of the conductors is increased thereby; the critical disruptive voltage is increased and hence corona loss is reduced.

Profile of the Conductor: By this is meant the shape of the conductor whether cylindrical, flat, oval etc. Because of field uniformity in case of cylindrical conductor the corona loss is less in this as compared to any other shape.

Surface Conditions of the Conductors: The conductors are exposed to atmospheric conditions. The surface would have dirt etc. deposited on it which will lower the disruptive voltage and increase corona loss.

Heating of the Conductor by Load Current: The heating of the conductor by the load current has an indirect reducing effect on the corona loss. Without such heating the conductor would tend to have a slightly lower temperature than the surrounding air. In the absence of heating, dew in the form of tiny water drops would form on the conductor in foggy weather or at times of high humidity, which induces additional corona. The heating effect of the load current is, however, large enough to prevent such condensation.

During rains, the heating of the conductor has no influence on the corona loss but, after the rain it accelerates the drying of the conductor surface. The time during which the water drops remain on the surface is reduced and the loss is also reduced.

For long transmission lines which pass through routes of varying altitudes, the average value of corona loss is obtained by finding out the corona loss per km at a number of points and then an average is taken out.

Methods of Reducing Corona Loss

These losses can be reduced by using

(*i*) large dia conductors,

(*ii*) hollow conductors, and

(*iii*) bundled conductors.

It has already been discussed how large dia and bundled conductors reduce the corona losses. The idea of using the hollow conductors is again the same *i.e.*, to have a large diameter without materially adding to its weight. In one of the designs one or more layers of copper wires are stranded over a twisted *I*-beam core. Another design consists of tongued and grooved copper segments spiralled together to form a self-supporting hollow tube. This conductor has a smooth surface. Expanded steel cored aluminium conductors which incorporate plastic or fibrous spacing material have also been proposed. Lines using the above types of conductors are more expensive than those using the conventional type and the economic limit to the conductor diameter appears to be somewhat between 3.75 and 5 cms. These special conductors are more effective in reducing corona. Losses during fair weather conditions and there may not be the same degree of improvement during bad weather conditions.

Example 6.5: Determine the corona characteristics of a 3-phase line 160 km long, conductor diameter 1.036 cm, 2.44 m delta spacing, air temperature 26.67°, altitude 2440 m, corresponding to an approximate barometric pressure of 73.15 cm, operating voltage 110 kV at 50 Hz.

Solution: Radius of conductor = $\frac{1.036}{2}$ = 0.518 cm

The ratio $\frac{d}{r} = \frac{2.44}{0.518} \times 100 = 471$

and $\sqrt{\frac{r}{d}} = \sqrt{\frac{1}{471}} = 0.046075$

$$\delta = \frac{3.92b}{273+t} = \frac{3.92 \times 73.15}{273+26.67} = 0.957$$

Assuming a surface irregularity factor 0.85, the critical disruptive voltage

$$V_d = 21.1 \times 0.85\delta r \ln \frac{d}{r}$$

$$= 21.1 \times 0.85 \times 0.957 \times 0.518 \ln 471$$

$$= 54.72 \text{ kV line to neutral}$$

The visual critical voltage $V_v = 21.1 m_v \delta r \left(1 + \frac{0.3}{\sqrt{r\delta}}\right) \ln \frac{d}{r}$

Assuming a value of $m_v = 0.72$,

$$V_v = 21.1 \times 0.72 \times 0.957 \times 0.518 \left(1 + \frac{0.3}{\sqrt{0.518 \times 0.957}}\right) \ln 471 = 66 \text{ kV}$$

The power loss = $241 \times 10^{-5} \frac{f+25}{\delta} \sqrt{\frac{r}{d}} (V - V_d)^2$ kW/phase/km

$$= 241 \times 10^{-5} \times \frac{75}{0.957} \times 0.046075(63.5 - 54.72)^2$$

$$= 0.671 \text{ kW/phase/km}$$

or $= 107.36$ kW/phase

or $= 322$ kW for three phases.

The corona loss under foul weather condition will be when the disruptive voltage is taken as 0.8 × fair weather value, *i.e.,*

$$V_d = 0.8 \times 54.72 = 43.77 \text{ kV}$$

∴ Loss per phase/km will be

$$241 \times 10^{-5} \frac{75}{0.957} 0.046075(63.5 - 43.77)^2 = 3.3875 \text{ kW/km/phase}$$

or 542 kW/phase

or Total loss = 1626 kW for all the three phases. **Ans.**

6.3 LINE DESIGN BASED ON CORONA

It is desirable to avoid corona loss on power lines under fair weather conditions. Bad weather conditions such as rain sleet greatly increase the corona loss and also lower the critical voltage of the line. On account of the latter effect, it is not practical to design high voltage lines which will be corona-free at all times. If the lines are designed without corona even during bad weather conditions, the size of the towers and the conductors will be uneconomical. Since the bad weather conditions in a particular region prevail only for a very short duration of the year, the average corona loss throughout the year will be very small. A typical transmission line may have a fair weather loss of 1 kW per 3-phase mile and foul weather loss of 20 kW per three phase mile.

6.3.1 Disadvantages of Corona

(*i*) There is a definite loss of power even though it is not much during fair weather condition. (*ii*) When corona is present the effective capacitance of the conductors is increased because the effective dia of the conductor is increased. This effect increases the flow of charging current. Because of corona triple frequency currents flow through the ground in case of a grounded system and they give rise to a voltage of triple frequency in an ungrounded system. These triple frequency currents and voltages interfere with the communication circuits due to electromagnetic and electrostatic induction effects.

6.3.2 Advantages of Corona

It reduces the magnitude of high voltage steep fronted waves due to lighting or switching by partially dissipating as a corona loss. In this way it acts as a safety valve to some extent.

6.4 RADIO INTERFERENCE

Radio interference is the adverse effect introduced by corona on wireless broadcasting. The corona discharges emit radiation which may introduce noise signals in the communication lines, radio and television receivers. It is mainly due to the brush discharges on the surface irregularities of the conductor during positive half cycles. This leads to corona loss at voltages lower than the critical voltages. The negative discharges are less troublesome for radio reception. Radio interference is considered as a field measured in microvolts per metre at any distance from the transmission line and is significant only at voltages greater than 200 kV. There is gradual increase in *RI* level till the voltage is such that measurable corona loss takes place. Above this voltage there is rapid increase in *RI* level. The rate of increase is more for smooth and large diameter conductors. The amplitude of *RI* level varies inversely as the frequency at which the interference is measured. Thus the services in the higher frequency band *e.g.*, television, frequency modulated broadcasting, microwave relay, radar etc. are less affected. Radio interference is one of the very important factors while designing a transmission line.

6.5 INDUCTIVE INTERFERENCE BETWEEN POWER AND COMMUNICATION LINES

It is a common practice to run communication lines along the same route as the power lines since the user of electrical energy is also the user of electrical communication system. The transmission lines transmit bulk power at relatively higher voltages. These lines give rise to electromagnetic and electrostatic fields of sufficient magnitude which induce currents and voltages respectively in the neighbouring communication lines. The effects of extraneous currents and voltages on communication systems include interference with communication service *e.g.*, superposition of extraneous currents on the true speech currents in the communication wires, hazard to person and damage to apparatus due to extraneous voltages. In extreme cases the effect of these fields may make it impossible to transmit any message faithfully and may raise the potential of the apparatus above the ground to such an extent as to render the handling of the telephone receiver extremely dangerous.

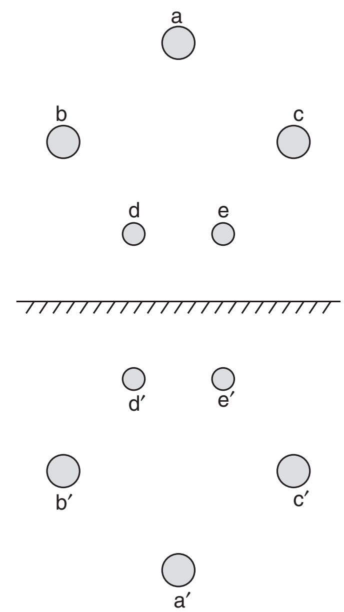


Fig. 6.3 3-phase single circuit power line, communication line and their images.

Electromagnetic Effects: Consider Fig. 6.3. a, b and c are the power conductors of a 3-phase single circuit line on a transmission tower and d and e are the conductors of a neighbouring communication line running on the same transmission towers as the power conductors or a neighbouring separate line. Let the distances between power conductors and communication conductors be D_{ad}, D_{ae}, D_{bd}, D_{be}, D_{cd} and D_{ce} respectively and the currents through power conductors be I_a, I_b and I_c respectively such that $I_a + I_b + I_c = 0$. The flux linkage to conductor d due to current I_a in conductor a will be $\psi_{ad} = 2 \times 10^{-7} I_a \ln \frac{\infty}{D_{ad}}$. Similarly, the flux linkage to conductor e due to current I_a in conductor a

$$\psi_{ae} = 2 \times 10^{-7} I_a \ln \frac{\infty}{D_{ae}}$$

∴ Mutual flux linkage between conductor d and e due to current I_a will be

$$\psi_{ad} - \psi_{ae} = 2 \times 10^{-7} I_a \ln \frac{D_{ae}}{D_{ad}}$$

or mutual inductance $M_a = \frac{\psi_{ad} - \psi_{ae}}{I_a} = 2 \times 10^{-7} \ln \frac{D_{ae}}{D_{ad}}$ H/metre

Similarly M_b and M_c the mutual inductances between conductor b and the loop de and between conductor c and the loop de respectively are given as

$$M_b = 2 \times 10^{-7} \ln \frac{D_{be}}{D_{bd}} \text{ H/metre}$$

$$M_c = 2 \times 10^{-7} \ln \frac{D_{ce}}{D_{cd}} \text{ H/metre}$$

These mutual inductances are due to fluxes which have a phase displacement of 120°; therefore, the net effect of the magnetic field will be

$$M = M_a + M_b + M_c$$

where **M** is the net mutual inductance which is the phasor sum of the three inductances.

If I is the current in the power conductors and f is the supply frequency, the voltage induced in the communication conductors d and e will be $V = 2\pi f\, MI$ volts per m.

It is to be noted that larger the distance between the power conductors and the communication conductors, smaller is the value of mutual inductance and since the current through the power conductors is displaced by 120°, there is appreciable amount of cancellation of the power frequency voltages. But the presence of harmonics and multiples of third harmonics will not cancel as they are in phase in all the power conductors and, therefore, are dangerous for the communication circuits. Also, since these harmonics come within audio frequency range, they are dangerous for the communication circuits.

Electrostatic Effects: Consider again Fig. 6.3. Let q be the charge per unit length of the power line. The voltage of conductor d due to charge on conductor can be obtained by considering the charge on conductor a and its image on the ground. Let conductor a be at a height h_a from the ground. Therefore, the voltage of conductor d will approximately be

$$V_{ad} = \frac{q}{2\pi\varepsilon_0} \int_{h_a}^{D_{ad}} \left[\frac{1}{x} + \frac{1}{(2h_a - x)} \right] dx$$

$$= \frac{q}{2\pi\varepsilon_0} \left[\ln \frac{2h_a - x}{x} \right]_{D_{ad}}^{h_a} = \frac{q}{2\pi\varepsilon_0} \left[\ln \frac{2h_a - D_{ad}}{D_{ad}} \right]$$

Now from the geometry the voltage of conductor a is $V_a = \frac{q}{2\pi\varepsilon_0} \ln \frac{2h_a}{r}$, where r is the radius of conductor a.

∴ Substituting for q in the expression for V_{ad} above, we get

$$V_{ad} = \frac{2\pi\varepsilon_0 V_a}{\ln \frac{2h_a}{r}} \cdot \frac{1}{2\pi\varepsilon_0} \ln \frac{2h_a - D_{ad}}{D_{ad}}$$

$$= V_a \cdot \frac{\ln \frac{2h_a - D_{ad}}{D_{ad}}}{\ln \frac{2h_a}{r}}$$

Similarly, we can obtain the potential of conductor d due to conductors b and c and hence the potential of conductor d due to conductors a, b and c will be

$$V_d = V_{ad} + V_{bd} + V_{cd}$$

Similarly, the potential of conductor e due to conductors a, b and c can be obtained.

PROBLEMS

6.1. Determine the corona characteristics of a 3-phase, 50 Hz, 132 kV transmission line 100 km long running through terrain at an altitude of 600 metres, temp. of 30°C and barometric pressure 74 cm. The conductors are 1.5 cm diameter and spaced with equilateral spacing of 2.75 metres. Assume surface irregularity factor of 0.9 and m_v = 0.75.

6.2. A 3-phase, 50 Hz, 132 kV transmission line consists of conductors of 1.17 cm dia and spaced equilaterally at a distance of 3 metres. The line conductors have smooth surface with value for m = 0.96. The barometric pressure is 72 cm of Hg and temperature of 20°C. Determine the fair and foul weather corona loss per km per phase.