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Technical Note: COMPUTATION OF ELECTRIC FIELD STRENGTH NECESSARY FOR ELECTROSTATIC SCREENING OF UNDERGROUND METALLIC GAS PIPELINE

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Abstract

The potential difference between conductors of a transmission line causes them to be charged, so that they become capacitive. Thus the capacitance between the conductors is the charge per unit of potential difference (p.d). Charging current flowing in the conductors is the result of alternate charging and discharging of a line due to an alternating voltage impressed on the line. Obviously, electric field is established by this charge. The effects of this field on the objects lying within its vicinity depend on its intensity. In this paper, the electric field of 33kV overhead line is considered. The aim of the paper is to determine the maximum electric field strength or potential gradient, E of the 33kV overhead line at the surface of the ground above an underground metallic gas pipe line located 2 metres away. Computation of E is carried out and if the calculated value of E is higher than the maximum permissible value, corona discharge could occur, and so electrostatic screening or cathodic protection of the pipe line against the electric field will be necessary.

Keywords: transmission line, charge, electric field, potential gradient, electrostatic screening

1. Introduction

A metallic electrode in the proximity of high-intensity electric field of a high-voltage supply can be charged by electrostatic induction [1]. In other words leakage between the power lines and the electrode results. The ionic charging process of a cylinder in an electric field perpendicular to its axis is based on the equation [2]:

$$\frac{dQ}{dt} = -\int_s kqEdS$$

Where Q = space charge, S = lateral surface of the cylinder (the surface into which the charging current can flow), k = mobility of the ions, q = space charge density, E = total electric field around the cylinder.

As shown in Figure 1, the route of a proposed 33kV overhead line is about 2m from an underground gas pipe line owned by Nigerian Gas Company (NGC). Parameters of transmission line are:

1. Nominal voltage level - 33KV
2. Number of phase - 3
3. Operating frequency - 50Hz
4. Type of suspension - Steel cross arm (100cm × 50cm × 7.5cm × 2.8m long)
5. Mounting height - 8.56m above ground
6. Conductor used - 150mm^2 ACSR WOLF
7. Distance between conductors - 1.2m
8. Earthing scheme - Each cross-arm separately earthed by a copper conductor (95mm^2)

Details of Gas Pipe: 1. 6inch Diameter steel pipe 2. Buried 1m deep and covered with sand

The strong electric field in the air space above the gas pipe creates high potential at the gas surface. If this surface potential exceeds some threshold value in the range of 0.01 0.2 kV/m, a spark discharge, energetic enough to ignite inflammable vapour, may occur. Reliable prediction of the time duration of electrostatic hazards is critically important to safe industrial practice [3]. Electrical discharge phenomena occurring

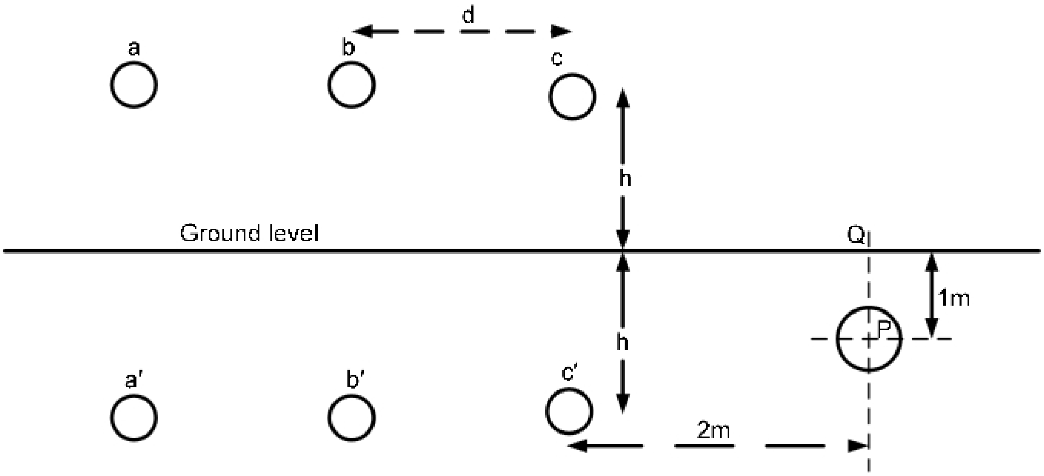

Figure 1: 33-kV line conductors and their mirror images.

from a space-charge might be responsible for electrostatic hazards such as the explosion of a super tank, gasoline tank and so on [4].

It is required to determine the electric field strength at the surface of the gas pipeline and then decide whether it is harmful or not. If the value obtained exceeds the acceptable value as per International Electro-technical Commission (IEC) standard, electrostatic screening would have to be provided for the pipeline. The effect of earth on the capacitance of the transmission line may be compensated for by the method of images. The presence of ground below a charged conductor may be replaced by a fictitious conductor having equal and opposite charge and located as far below the surface of ground as the overhead conductor above, as shown in Figure 1. The fictitious conductor is known as the mirror image of the overhead conductor [5].

2. Determination of Voltage Gradient

Basically, according to Gauss's law, the total electric charge on a conductor equals the total electric flux emerging from the conductor. In other words, the total charge within the closed surface equals the integral over the surface of the normal component of the electric flux density. To start with, let us consider a long straight cylindrical conductor in air - Figure 2. The radius of the conductor is r [m]. The flux density per unit length at a distance x meters from the axis of the conductor is given as:

$$D_x = \frac{q}{2\pi x} \; [\mathrm{C/m^2}] \tag{1}$$

q = the charge on the conductor in C/m. The potential gradient is,

$$E_x = \frac{q}{2\pi x \epsilon_o} \; [\mathrm{V/m}] \tag{2}$$

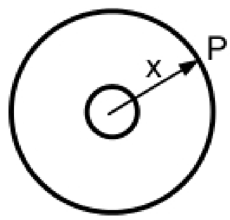

Figure 2: Electric field x meters around a conductor.

ϵ_o = permittivity of free space.

The conductor is an equipotential surface with uniformly distributed charge on the wire, equivalent to charge concentrated at the center for calculating flux external to the wire Positive charge on the wire exerts repelling force on a positive charge placed in the field. Thus energy is expended in moving a charge from the conductor to a point P which is x[m] from the conductor. This energy is the amount of work done per coulomb of charge moved and it is numerically equal to the potential difference between the two points [6]. Therefore the potential difference between the conductor and P is given by:

$$V_{rx} = \frac{q}{2\pi\epsilon_o} \ln\frac{x}{r} \; [\mathrm{V} \tag{3}$$

In the case of the three conductors in Figure 1, conductors a, b and c are carrying charges q^a, q^b and q^c respectively. The mirror images of the conductors are carrying charges $q^{a'}$, $q^{b'}$ and $q^{c'}$ By the principle of superposition, the total potential on conductor a due to the sinusoidal charges, q^a, q^b and q^c, as well as their mirror images $q^{a'}$, $q^{b'}$ and $q^{c'}$ is given as:

$$\begin{aligned} V_a = -\frac{1}{2\pi\epsilon_o} [q_a \ln r_a + q_b \ln d + q_c \ln 2d \\ + q_{a'} \ln 2h + q_{b'} \ln y + q_{c'} \ln z] \end{aligned} \tag{4}$$

Similarly, the potential on conductor b is:

$$V_b = -\frac{1}{2\pi\epsilon_o}\left[q_a \ln d + q_b \ln r_b + q_c \ln d + q_{a'} \ln y + q_{b'} \ln 2h + q_{c'} \ln y\right] \tag{5}$$

and the potential on conductor c is:

$$V_c = -\frac{1}{2\pi\epsilon_o}\left[q_a \ln 2d + q_b \ln d + q_c \ln r_c + q_{a'} \ln z + q_{b'} \ln y + q_{c'} \ln 2h\right] \tag{6}$$

Where, $h = 8.56$m; $d = 1.2$m; $y = \sqrt{(2h)^2 + d^2}$; $z = \sqrt{(2h)^2 + (2d)^2}$ Noting that $q^{a'} = -q^a$; $q^{b'} = -q^b$; $q^{c'} = -q^c$, equations (4), (5) and (6) result in

$$V_a = \frac{1}{2\pi\epsilon_o}\left[q_a \ln\frac{2h}{r_a} + q_b \ln\frac{y}{d} + q_c \ln\frac{z}{2d}\right] \tag{7}$$

$$V_b = \frac{1}{2\pi\epsilon_o}\left[q_a \ln\frac{y}{d} + q_b \ln\frac{2h}{r_b} + q_c \ln\frac{y}{d}\right] \tag{8}$$

$$V_c = \frac{1}{2\pi\epsilon_o}\left[q_a \ln\frac{z}{2d} + q_b \ln\frac{y}{d} + q_c \ln\frac{2h}{r_c}\right] \tag{9}$$

In matrix form we have,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{2\pi\epsilon_o}\begin{bmatrix} \ln\left(\frac{2h}{r_a}\right) & \ln\left(\frac{y}{d}\right) & \ln\left(\frac{z}{2d}\right) \\ \ln\left(\frac{y}{d}\right) & \ln\left(\frac{2h}{r_b}\right) & \ln\left(\frac{y}{d}\right) \\ \ln\left(\frac{z}{2d}\right) & \ln\left(\frac{y}{d}\right) & \ln\left(\frac{2h}{r_c}\right) \end{bmatrix}\begin{bmatrix} q_a \\ q_b \\ q_c \end{bmatrix} \tag{10}$$

$$[V_{abc}] = [m][q_{abc}] \tag{11}$$

$$[q_{abc}] = [m]^{-1}[V_{abc}] \tag{12}$$

Therefore $[m]^{-1}$ = capacitance between phase conductors and between phase conductors and ground. Solving equation (12) yields: $q^a = 8.759 \times 10^{-8}$; $q^b = 7.593 \times 10^{-8}$; $q^c = 8.759 \times 10^{-8}$;

$$E_a = \frac{q_a}{2\pi\epsilon_o x_1}[\text{V/m}];$$

$$E_b = \frac{q_b}{2\pi\epsilon_o x_2} < -120^\circ[\text{V/m}];$$

$$E_c = \frac{q_c}{2\pi\epsilon_o x_3} < +120^\circ[\text{V/m}].$$

x_1, x_2, x_3 are the distances of conductors a, b, c respectively from the ground surface above the pipe line – point Q in Figure 1. Therefore,

$$E = E_a + E_b + E_c$$

$$E = -0.6492 + j25.7720 \text{ [V/m]}$$

$$|E| = 0.0258 \text{ kV/m}$$

3. Discussion

Electrostatic discharge is a phenomenon with considerable impact on the optimum operating condition of various installations. It has been shown that the electric field gradient on the ground surface at the location of the pipe due to the 33kV three-phase overhead line is approximately 0.0258kV/m. However, as per IEC standard, the standard permissible values of electric field gradients are: 0.01 - 0.05kV/m for 23kV-line and 0.10–0.20KV/m for 115kV line. Also, typical values of electric field gradient at ground level for voltages between 345kV and 1300kV range from 5kV/m to 16kV/m. According to IEC, the critical value of electric field gradient detrimental to surrounding objects is about 10kV/m. Meanwhile most of the studies carried out on the hazards related to electrostatic discharge (ESD) assume that the breakdown strength of air at atmospheric pressure is 30kV/cm [7].

4. Conclusion

From the foregoing, the electric field intensity due to the 33kV overhead line has not exceeded the dielectric strength of the medium (air), and so no hazardous electrostatic effect on the gas pipe line. Therefore no shielding/cathodic protection is required.

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