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Abstract

The Analysis of electromagnetic interference between high voltage overhead power transmission lines and nearby gas/oil pipeline has been a topic of growing interest for many years. When pipelines are located in shared row with power lines, the pipeline can incur high induced voltages and currents due the AC interference. The induced voltage on pipeline can be dangerous for operator to touch the pipeline as well as pipe corrosion can result from AC discharge. This research evaluates and analyzes the electromagnetic interference effects on oil and gas buried pipelines created by the nearby high voltage transmission lines. The aim is to evaluate the AC corrosion likelihoods of pipelines and suggest proper mitigation solutions.

Keywords: AC Interference, Induced Voltages, Electric Power Transmission Lines, pipeline, AC corrosion, Corrosion protection.

1. Introduction

The electromagnetic fields generated by high voltage power lines (HVPL) result in AC interference to nearby metallic structures. Therefore, in many cases nearby metallic pipelines (MP) are exposed to the effects of induced AC currents and voltages. These induced voltages and currents may be dangerous for both operating personnel and pipeline structural integrity due to corrosion effects [1].

Interferences due to a high voltage line on a metallic pipeline in close vicinity could be due to any of the three types of couplings shown below [2-5].

Capacitive Coupling: Affects only aerial pipelines situated in the proximity of HVPL. It occurs due to the capacitance between the line and the pipeline. For underground pipelines the effect of capacitive coupling may not to be considered, because of the screening effect of earth against electric fields.

Inductive Coupling: Voltages are induced in nearby metallic conductors by magnetic coupling with high voltage lines, which results in currents flowing in a conducting pipeline and existence of voltages between it and the surrounding soil. Time varying magnetic field produced by the transmission line induces voltage on the pipeline.

Conductive Coupling: When a ground fault occurs in HVPL the current flowing through the grounding grid produce a potential rise on both the grounding grid and the neighboring soil with regard to remote earth. If the pipeline goes through the “zone of influence” of this potential rise, then a high difference in the electrical potential can appear across the coating of the pipeline metal.

Underground steel pipelines are in permanent contact with the electrolyte solution from the soil, so proper protection measures are necessary in order to limit the induced current densities, which are the cause of electrochemical corrosion.

There are more than one method applied to power lines and pipeline to reduce induced voltage and current on pipelines. This include increasing the separation distance between them, the configuration of tower, number of the conductor per phase, the distance between conductors, soil structure , the type of coating for pipe , and the pipe grounding [6-7].

There has been a considerable amount of research into interference effects between AC power line and pipeline including computer modeling and simulation. [8], [9]. A general guide on the subject was issued later by CIGRE [10], while CEOCOR [11] published a report focusing on the AC corrosion of pipelines due to the influence of power lines.

This piper evaluates and analyzes the electromagnetic interference effects on oil and gas buried pipelines created by the nearby high voltage transmission lines. First we analyze the magnetic field for horizontal and vertical configurations, then we study the effect of the soil conductivity in the level of the induced voltage in the pipeline during both normal conditions and fault conditions on the power line and finally we evaluate the AC corrosion likelihoods of pipelines and suggest proper mitigation solutions.

2. Physical Approach

2.1. Electric Field

To calculate the electric field under the power line, phase conductors are considered as infinite line charges. The horizontals and verticals components of the electric field due to the three phase conductors at the desired locations are calculated separately using equation (1) given below. Figure.1 shows the components of the electric field at the observation point M(x,y) due to one phase conductor and its image.

$$\begin{cases} E_{hi} = \dfrac{Q_i}{2\pi\varepsilon_0}(x - x_i)\left[\dfrac{1}{(D_i)^2} - \dfrac{1}{(D_i')^2}\right] \\ E_{vi} = \dfrac{Q_i}{2\pi\varepsilon_0}\left[\dfrac{(y - y_i)}{(D_i)^2} - \dfrac{(y + y_i)}{(D_i')^2}\right] \end{cases} \tag{1}$$

Where: Q is the charge of the conductor resultant of horizontal and vertical components of the field gives the total electric field at the desired locations as shown in equation given below.

$$E = \sqrt{(E_{hi})^2 + (E_{vi})^2} \tag{2}$$

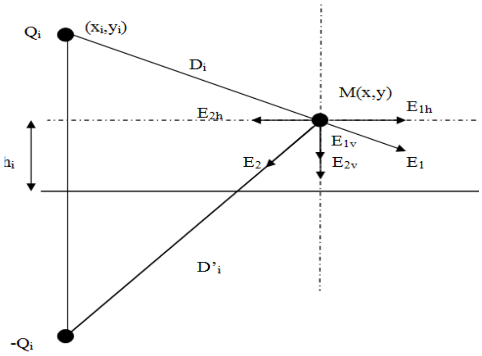

Figure1. Components of electric field due to HVPL

2.2. Magnetic Field

A magnetic field will be created by the current going though the conductors. As in the electric field, each point charge will produce a magnetic field having a horizontal and a vertical component.

$$B = \sqrt{(B_{hi})^2 + (B_{vi})^2} \tag{3}$$

Where B is the magnetic field, B_{hi} and B_{vi} are the horizontal and vertical components respectively

$$\begin{cases} B_{hi} = \dfrac{\mu I}{2\pi}(x - x_i)\left[\dfrac{1}{(D_i)^2} - \dfrac{1}{(D_i')^2}\right] \\ B_{vi} = \dfrac{\mu I}{2\pi}\left[\dfrac{(y - y_i)}{(D_i)^2} - \dfrac{(y + y_i)}{(D_i')^2}\right] \end{cases} \tag{4}$$

Where:

ε_0 : Relative permittivity of Air and μ: Air relative permeability.

I : The current through the conductor.

$$I = \frac{P}{\sqrt{3}U\cos\theta}$$

P : Active power carried by the line, : Voltage applied ; and θ is the angle between the voltage and current.

2.3. Induced Voltage

One of the main elements in the study of the induced voltage as a result of HV lines is the determination of soil resistivity of the surrounding area of pipeline, There are many ways to measure the soil resistivity, The most commonly used method of measuring soil resistivity is the four-pin method (Wenner)[12].

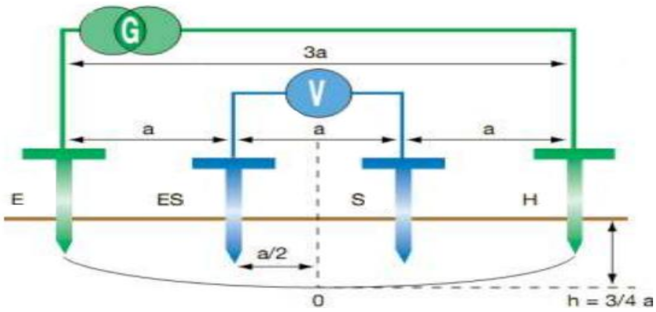

Figure 2. Soil Resistivity calculation using the four pin method

Wenner method employs four pins. The two outer electrodes will used to inject current into the ground and the two inner electrodes will used to measure earth potentials. All four electrodes will placed in a straight line. The apparent resistance is directly readable from the instrument (R = V/I). Approximating the current electrodes by hemispheres, the soil resistivity is then obtained by:

$$\rho = 2\pi a R\ [\Omega \cdot \mathrm{m}] \tag{5}$$

Where:

a: The probe spacing in meters, R: The resistance measured in Ohms.

By using this method, the soil resistivity approximately at a depth of three quarters of the distance between two electrodes can be assessed.

2.3.1. Homogeneous Soil

The induced voltage on the pipeline is generated by the electromagnetic field in the soil. The level of induced voltage from a high voltage power transmission line on an adjacent pipeline is a function of geometry, soil resistivity and the transmission line operating parameters. The image method was used to calculate the induced voltage in a pipeline, in a single soil resistivity layer [13].

$$V = \frac{\rho I}{4\pi}\left(\frac{1}{\sqrt{x^2 + y^2 + (z-h)^2}} + \frac{1}{\sqrt{x^2 + y^2 + (z+h)^2}}\right) \tag{6}$$

Where, ρ is the soil resistivity, I is the current in the line, h is the depth of the pipeline in the soil and x, y, z represent the point where the voltage potential should be found.

2.3.2. Non Homogeneous Soil

In this case, two layers soil resistivity are considered. Using the image method, the conductor will have a corresponding image due to each layer. The formula used to calculate this voltage is [13]:

$$V = \frac{\rho_1 I}{4\pi}\left(\begin{array}{c} \dfrac{1}{\sqrt{x^2+y^2+(z-h)^2}} + \dfrac{1}{\sqrt{x^2+y^2+(z-h)^2}} + \\ K \cdot \left(\begin{array}{c} \dfrac{1}{\sqrt{x^2+y^2+(2H+h-z)^2}} + \dfrac{1}{x^2+y^2+(2H+h+z)^2} + \\ \dfrac{1}{\sqrt{x^2+y^2+(2H-h-z)^2}} + \dfrac{1}{x^2+y^2+(2H-h+z)^2} \end{array}\right) \end{array}\right) \tag{7}$$

$$K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \tag{8}$$

Where x, y, z represent the coordinates of the point where the voltage potential should be found, ρ_1 is the soil resistivity of the first layer, ρ_2 is the soil resistivity of the second layer (which was varied), K is the reflection coefficient, H is the depth of the first soil layer, h is the depth of the pipeline in the soil.

3. Results and Discussions

3.1. Study State

We carried out within the context of this work the calculations carried out on a high voltage power line having the following characteristics (Figure 1). P = 750 MW under a cos (θ) =0.85 and U = 400 KV.

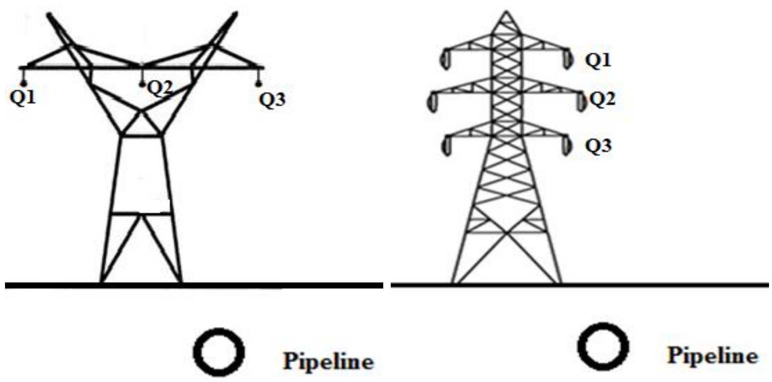

Figure 3. Horizontal Vs. vertical configurations

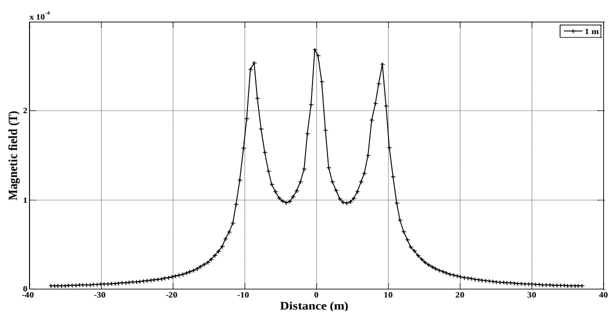

Figure 4. Magnetic field for horizontal configuration

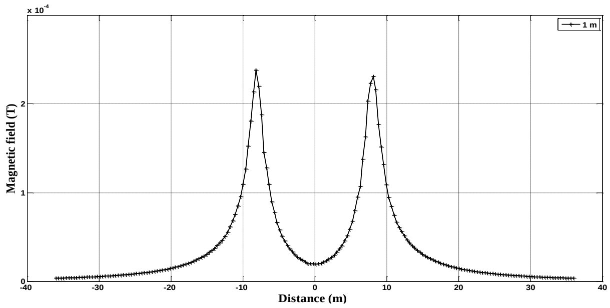

Figure 5. Magnetic field for vertical configuration

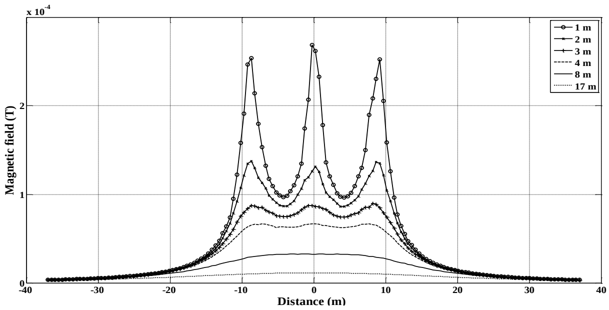

Figure 6. Magnetic field for horizontal configuration with varying height

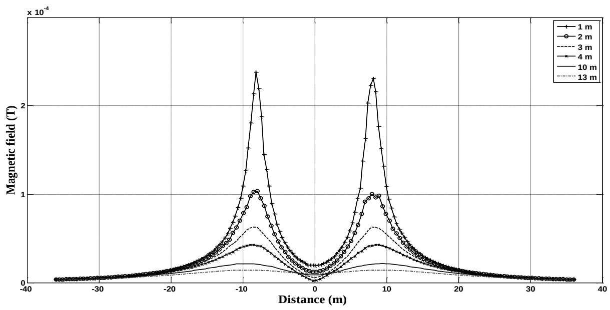

Figure 7. Magnetic field for vertical configuration with varying height

Figure 4, shows the magnetic field profile for the horizontal configuration under one meter of the high voltage power line. Three peaks corresponding to the location of the three phase conductors. The peak at the center of the right of way has a slightly larger magnitude than the two peripheral peaks. The magnetic field profile in figure 5, presents a two peak configuration.

Figures.6 and 7 show the magnetic field for horizontal and vertical configuration respectively with varying height. As the height increases, the distance between the charges and the pipe line increases causing a decrease in the magnitude of the magnetic field.

In order to know which configuration gives the lowest field under the transmission line, magnetic fields at one meter height above the ground for various configurations have been calculated.

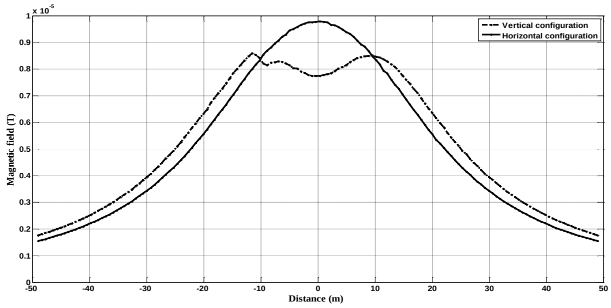

Figure 8. Magnetic Field for horizontal and vertical configurations

In Figure.8, the resulting magnetic fields corresponding to each of the configurations are shown. In the center of the right of way, the horizontal configuration gave the lower magnitude, whereas, as we move laterally away from the center, the vertical configuration gives the lower magnitude.

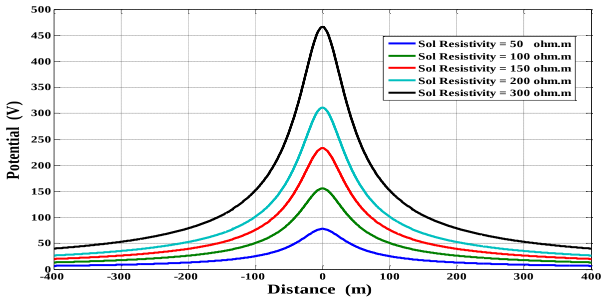

Figure 9. Induced pipeline potentials under different soil resistivity

The inductive interference effect has been analyzed at different soil resistivity (the soil resistivity varied from 50 to 300 Ω.m). In Figure.9, it is clear that the soil resistivity has an influence on the induced voltage. The pipeline induce-voltage reduces by reducing the soil resistivity (i.e. high soil resistivity gives high induced voltage).

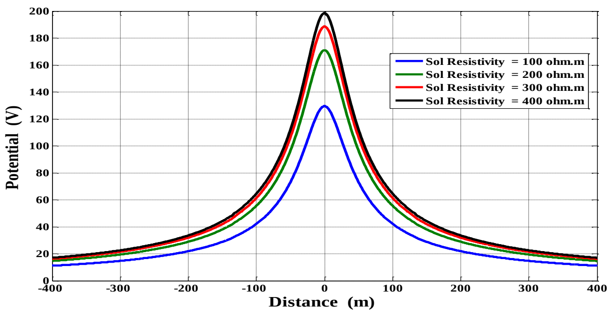

Figure 10. Voltage induced in the pipeline in a non-homogeneous soil

Figure 10 shows the variation of the induced voltage in a two layer soil resistivity. While varying the soil resistivity of the bottom layer, as the resistivity ρ2 increases, the reflection coefficient increases and the voltage magnitude also increases.

3.2. Fault Condition

The high AC potentials generated on the adjacent pipeline during a fault are a result of the very high fault current in the faulted conductor (inductive coupling) and ground current near the faulted tower (conductive coupling). Figure 11 presents the induced voltage obtained for a fault current to ground of 3KA as a function of the distance. The maximum value occurs at the defect, with a value of 160KV.

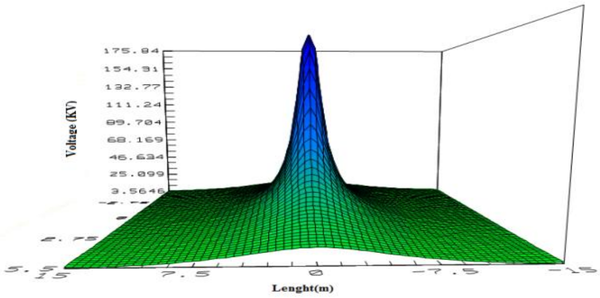

Figure 11. Distribution of ground potential

The coatings typically used are never perfectly homogeneous. There are cavities with different forms. They are the main cause of aging and destruction of solid insulation. The pipeline is located five meters of the fault, the value of the voltage induced in the pipeline is about 20KV. For a coating of polyethylene type with no default, the value of the dielectric strength is 18KV/mm. In this case, the coating remains intact. Figure 12 shows the electric field in the coating with two rectangular cavities.

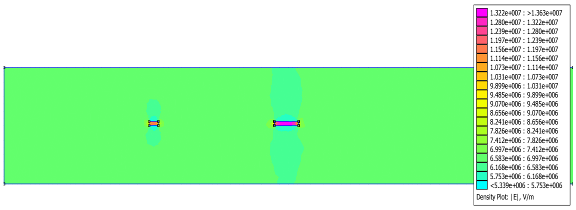

Figure 12. Electric Field

Dielectric breakdown occurs when a charge buildup exceeds the electrical limit or dielectric strength of a material. The dielectric strength of air is approximately 30 kV/cm. The electric field in the cavities exceeds 120 kV/cm, we'll have a breakdown in the cavities. This causes a rapid aging of the coating.

4. AC Corrosion

The risk of AC corrosion of the metallic structures is closely linked with the pipeline isolation defects, which might occur, for instance during construction work. From an electrical point of view, coating holidays can be seen as a small, low impedance AC earthing system connected to the pipeline. If the coating holiday size for example exceeds a certain dimension, corrosion risk likelihood neutralizes according to the relevant current density.

We consider a situation where a pipeline is buried near a High Voltage Power Lines, and let us assume that the pipeline coating has a single defect. At the defect point, the pipeline has a resistance to earth whose approximate value is:

$$R' = \frac{\rho}{2D}\left(1 + \frac{8d}{D}\right) \tag{9}$$

Thus the current density J (A/m2) through the coating defect is:

$$J = \frac{8U}{\rho\pi(8d + D)} \tag{10}$$

U: Induced voltage, d: Thickness of the coating, Soil resistively, D: Diameter of the coating defect.

Based on actual investigation in the field of AC corrosion, as well as to the actual European technical specifications [14] the AC corrosion risk can already be expected from current densities at coating holidays among 30 A/m^2 . For current densities between 30 A/m^2 and 100 A/m^2 there exists medium AC corrosion likelihood. For current densities upper 100 A/m2 there is a very high A/m2 corrosion likelihood [15].

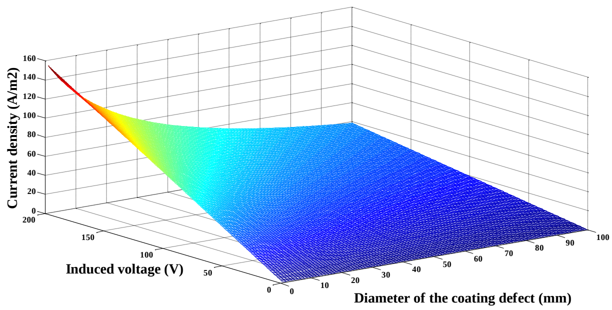

Figure 13. Current density

In Figure.13, the current density varies linearly with induced voltage and depends on soil characteristics by its resistivity, i.e. current density is greater in soil with low electrical resistivity. Moreover, current density increases by decreasing the dimension of the coating defect. The structures with a coating defect of small size may have a higher risk of AC corrosion.

5. Corrosion Protection

A first method consist of connecting a galvanically more active metal to the pipeline, in this case the metal will behave as the anode; thus the galvanically more active metal (anode) sacrifices itself to protect the pipeline (cathode). A galvanically more active metal is a metal that is able to lose its peripheral electrons faster other than other metals. The first method is described in figure14 [16].

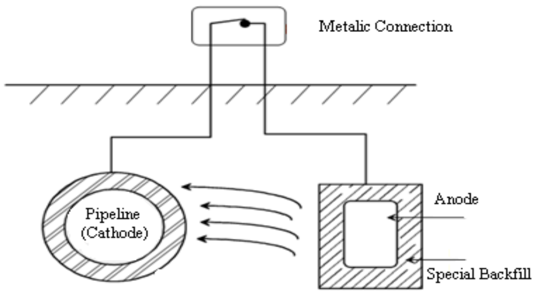

Figure 14. Galvanic anode cathodic protection

As shown in figure.15, in the second method a DC current source is connected which will force the current to flow from an installed anode to the pipeline causing the entire pipeline to be a cathode. This method is called impressed current cathodic protection where the DC power supply may be a rectifier, solar cell or generator [16].

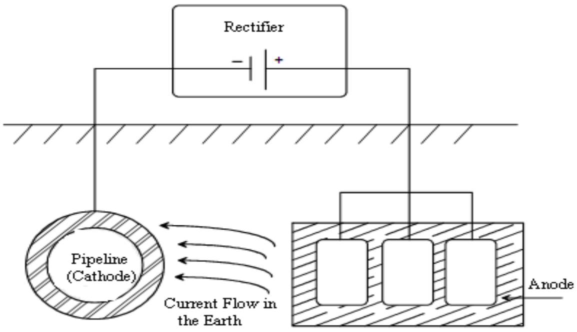

Figure 15. Impressed current cathodic protection System

6. Conclusion

The interference problems that affect pipelines near high voltage AC power (HVAC) transmission lines have been well defined .The magnetic field on the pipeline in the vicinity of a high voltage power line have been calculated for horizontal and vertical configurations. By comparing the magnetic field profiles for the horizontal and vertical configurations, it was found that in the center of the right of way, the horizontal configuration gave the lower magnitude, whereas, as we move laterally away from the center, the vertical configuration gives the lower magnitude.

The voltage profiles for normal operation and during fault conditions have been simulated. Finally, the AC corrosion effect on metals was studied and the method of mitigation of AC corrosion was proposed. In the first method, a metal is connected to the pipeline sacrificing itself to protect the pipeline whereas in the second method, a DC source is connected to the pipeline forcing it to act as a cathode.

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