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Analysis and Mitigation of the Interference Between High Voltage Power Line and Buried Pipelines

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Abstract — **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, cathodic protection, soil resistivity.

I. INTRODUCTION

The electromagnetic fields generated by high voltage power lines (HVPL) result in AC interference to nearby metallic structures [1], [2], Therefore, in many cases nearby metallic pipelines (MP) are exposed to the effects of induced AC currents and voltages [3]. These induced voltages and currents may be dangerous for both operating personnel and pipeline structural integrity due to corrosion effects [4].

The interference has been traditionally divided into three main categories: capacitive, conductive and inductive coupling [5], [6], [7], and [8].

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.

There has been a considerable amount of research into interference effects between AC power line and pipeline including computer modeling and simulation. [9], [10]. A general guide on the subject was issued later by CIGRE [11], while CEOCOR [12] published a report focusing on the AC corrosion of pipelines due to the influence of power lines.

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 [13],[14],[15] and [16].

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, and then we study the effect of the soil conductivity in the level of the induced voltage in the pipeline during both normal conditions on the power line. Finally we evaluate the AC corrosion likelihoods of pipelines and suggest proper mitigation solutions.

I. PHYSICAL APPROACH

A. *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. Fig.1 shows the components of the electric field at the observation point M(x,y) due to one phase conductor and its image.

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

Where:

Q is the charge of the conductor, ε_0 is the relative permittivity. Resultant of horizontal and vertical components of the field gives the total electric field at the desired locations as shown in equation given below.

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

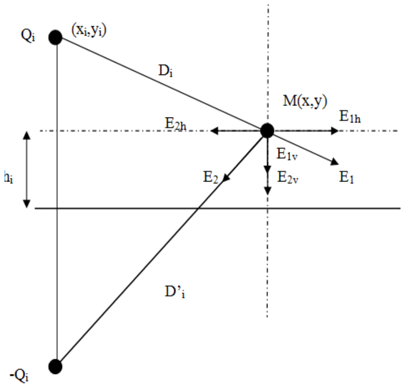

Fig.1: Components of electric field due to HVPL

B. *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.

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

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

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

Where:

μ is the air relative permeability, Iis the current through the conductor.

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

P is the active power carried by the line, U is the voltage applied;

C. *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)[17].

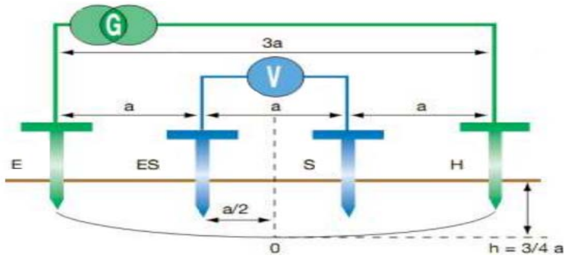

Fig 2: Soil Resistivity Calculation Using the Four Pin Method

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:

$$\rho=2\pi.a.R \quad [\Omega.m] \qquad (3)$$

Where:

A is the probe spacing in meters, R is 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.

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 [18].

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

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.

II. RESULTS AND DISCUSSION

We carried out within the context of this work the calculations carried out on a high voltage power line having the following characteristics (figure 3). P = 750 MW under a cos (θ) =0.85 and U = 400 KV.

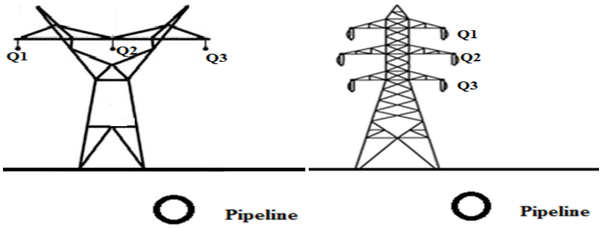

Fig.3: Horizontal Vs. vertical configurations

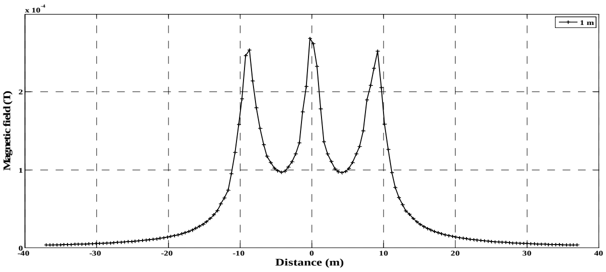

Fig.4: Magnetic field for horizontal configuration

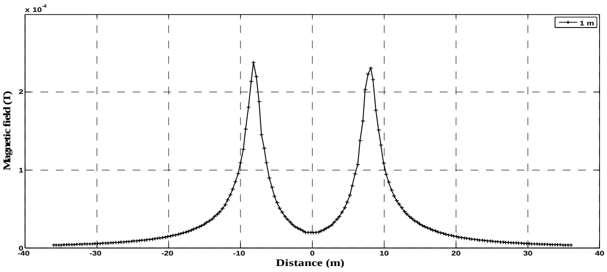

Fig.5: Magnetic field for vertical configuration

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.

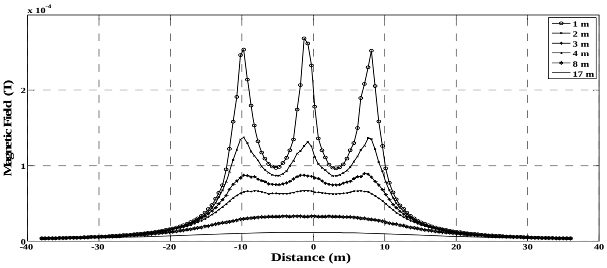

Fig.6: Magnetic field for horizontal configuration with varying height

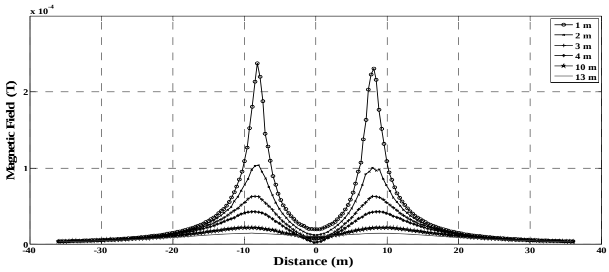

Fig.7: Magnetic field for vertical configuration with varying height

Figs.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.

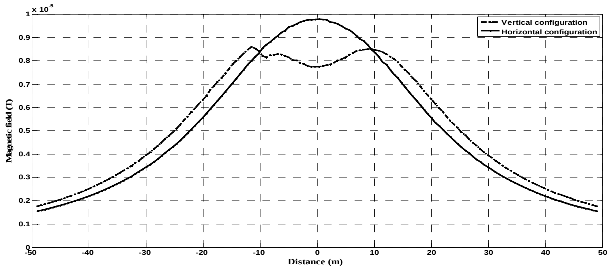

Fig.8: Magnetic Field for horizontal and vertical configurations

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

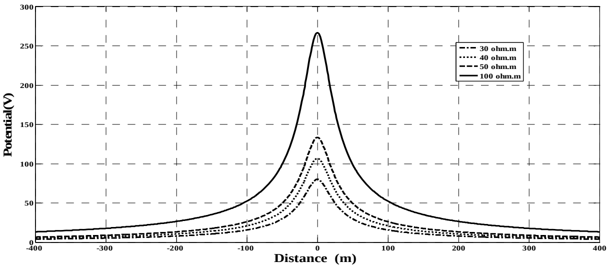

Fig.9: Induced pipeline potentials under different soil resistivity

The inductive interference effect has been analyzed at different soil resistivity (the soil resistivity varied from 30 to 100 Ω.m). In Fig.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).

III. 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 [19]:

$$R^{'}=\frac{\rho}{2.D}.\left(1+\frac{8d}{\pi D}\right) \quad (5)$$

Thus the current density J (A/m^2) through the coating defect is:

$$J=\frac{8.U}{\rho.\pi(8d+D)} \quad (6)$$

U is the induced voltage, d is the coating thickness, ρ is the soil resistively, D is the defect diameter.

Based on actual investigation in the field of AC corrosion, as well as to the actual European technical specifications [20], 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/m^2 there is a very high A/m^2 corrosion likelihood [21].

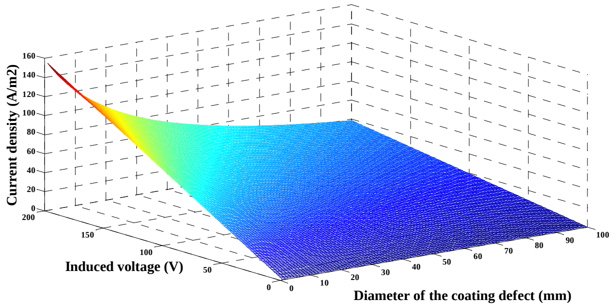

Fig.10: Current density

In Fig.10, 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.

IV. SUGGESTED SOLUTIONS

The close proximity of structures to power lines and their sharing parallel paths for relatively long distances is the principal cause of stray AC. If the structure is remote from the power lines, the interference can be virtually eliminated. Obviously, this method of mitigation is practical only at the preconstruction stage of either the power lines or the structure. Otherwise, the mitigation must be accomplished by alternative methods. One of these methods is grounding pipe using a metal such as zinc, magnesium. On short lines, this effect can be remedied by using distributed sacrificial anodes on the structure. The anodes will not only be sufficient to provide cathodic protection current but will also simultaneously lower the resistance of the structure with respect to earth.

V. 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 conditions have been simulated. Finally, the AC corrosion effect on metals was studied and the method of mitigation of AC corrosion was proposed. The method is grounding pipe using a sacrificial anodes such as zinc, magnesium. The anodes will not only be sufficient to provide cathodic protection current but will also simultaneously lower the resistance of the structure with respect to earth.

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