# Induced Voltage on Buried Oil Pipelines Caused by High Voltage Power Lines

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*Abstract*—The electromagnetic interference caused by power transmission lines to oil and gas buried pipelines is under investigation for many years. Especially during fault conditions, large currents and voltages are induced on the pipelines that may pose danger to working personnel or may accelerate the corrosion of the pipeline's metal. In this research, the induced voltage in the oil buried pipelines due to the magnetic fields produced by nearby 400kV transmission lines have been computed. This effect results in a corrosion process which we have proposed some solutions

*Key-Words*— AC Interference, Induced Voltages, Electric Power Transmission Lines, pipeline, corrosion, cathodic protection.

## I. INTRODUCTION

AC interference in a pipeline sharing a corridor with a power line consists of an inductive component and a conductive component. Inductive interference, which is occurred by the magnetic field generated by the power line, is present during both normal load conditions and fault conditions on the power line. Conductive interference arises when a power line structure injects a large magnitude current into the earth during a phase to- ground fault and the pipeline is located near the faulted structure [1]-[3].

Previous researches tackled the phenomenon of electromagnetic induction due to high voltage power lines. Many of them used computer software to simulate these effects [8]-[10]. On the other hand, in many papers, the effects of high voltage power lines were calculated using the image method [11], [12]. A general guide on the subject was issued later by CIGRE [4], while CEOCOR [5] published a report focusing on the AC corrosion of pipelines due to the influence of power lines.

This paper presents a method for analysis of the electromagnetic interferences created on pipeline networks by the High Voltage (HV) power lines working on normal or fault conditions. This effect results in a corrosion process to which we proposed some solutions.

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 ( ) =0.85 and a tension U (tension phase-phase) = 380 KV



Figure 1 : Geometry of the HV line

## II. PHYSICAL APPROACH

### A. Electric Field

Every electrical circuit powered, produces an electric field at frequency of 50 Hz. Value or the intensity of this field depends on various parameters. In the case of power transmission line, the electrical field varies with the electrical characteristics and geometry of the line.

Consider a conductor at a height h above the ground and its image at a depth h below the ground, (figure2).
Using the image method, the horizontal and vertical components of the electric field at point M of coordinates (x, y) are:
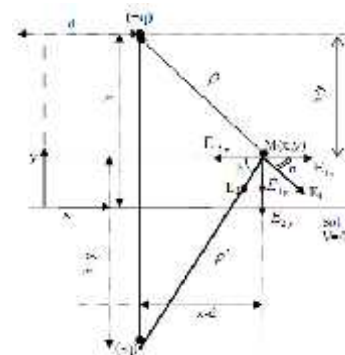


Figure 2: image method

The horizontal component can be written as:

$$E_x = \frac{q}{2\pi\varepsilon_0}\left(\frac{x-d}{r_1^2} - \frac{x-d}{r_2^2}\right) \qquad (1)$$

The vertical component can be written as:

$$E_y = \frac{q}{2\pi\varepsilon_0}\left(\frac{h-y}{r_1^2} - \frac{h+y}{r_2^2}\right) \qquad (2)$$

Where, q is the charge of the conductor

$$\begin{cases} r_1^2 = (x-d)^2 + (h-y)^2 \\ r_2^2 (x-d)^2 + (h+y)^2 \end{cases}$$

The total electric field is the square root of the sum of the squares of both horizontal and vertical components, it is written as follows:

$$E = \sqrt{(E_x)^2 + (E_y)^2} \qquad (3)$$

For a three phase system, the electric field is given as follows:

$$E = \sqrt{(E_{xi})^2 + (E_{yi})^2} \qquad (4)$$

With:

$E_{xi}$ : Sum of all the horizontal components, and

$E_{yi}$ : Sum of all the vertical components.

### B. Magnetic Field

A magnetic field will be created by the current going through the conductors. As in the electric field, each point charge will produce a magnetic field having a horizontal and a vertical component. The image method is used to determine the magnetic field.

$$B = \sqrt{(B_h)^2 + (B_v)^2}$$

Where $B$ is the magnetic field, $B_h$ and $B_v$ are the horizontal and vertical components respectively.

$$\begin{cases} B_h = \frac{\mu I}{2\pi}\left(\frac{x-d}{(x-d)^2+(h-y)^2} - \frac{x-d}{(x-d)^2+(h+y)^2}\right) \\ B_v = \frac{\mu I}{2\pi}\left(\frac{h-y}{(x-d)^2+(h-y)^2} - \frac{h+y}{(x-d)^2+(h+y)^2}\right) \end{cases} \qquad (5)$$

Where

$I$ : The current through the conductor.

$$I = \frac{P}{\sqrt{3}U.\cos\varphi} \qquad (6)$$

P: Active power carried by the line;
U: Voltage applied;
$\varphi$: Angle between the voltage and current.

### C. Induced Voltage

#### 1) Soil resistivity

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)[13].
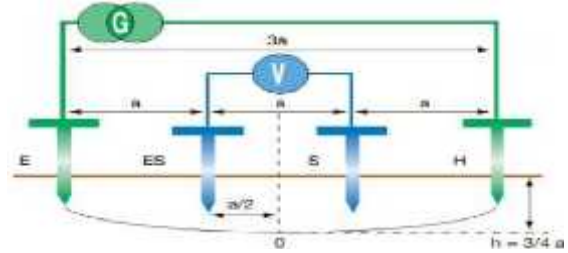


Figure 3: Soil Resistivity Calculation Using the Four Pin Method

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:

$$\rho = 2\pi.a.R \quad [\Omega.m] \qquad (7)$$

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) 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.

$$V = \frac{\rho I}{4\pi}\left(\frac{1}{\sqrt{x^2+y^2+(z-h)^2}} + \frac{1}{\sqrt{x^2+y^2+(z+h)^2}}\right) \qquad (8)$$

Where $\rho$ 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.

#### 3) 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:

$$V = \frac{\rho_1 I}{4\pi} \left( \frac{1}{\sqrt{x^2+y^2+(z-h)^2}} + \frac{1}{\sqrt{x^2+y^2+(z+h)^2}} + K \left( \frac{1}{\sqrt{x^2+y^2+(2H+h-z)^2}} + \frac{1}{x^2+y^2+(2H+h+z)^2} + \frac{1}{\sqrt{x^2+y^2+(2H-h-z)^2}} + \frac{1}{x^2+y^2+(2H-h+z)^2} \right) \right) \tag{9}$$

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

Where x, y, z represent the coordinates of the point where the voltage potential should be found, $\rho_1$ is the soil resistivity of the first layer, $\rho_2$ 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[11],[14].

## III. RESULTS AND DISCUSSION

The graphical representation of the resultant electric field obtained for the power line as a function of the distance to the center of the line is shown in figure 4. The maximum value of the electric field (9KV/m) is obtained at 7 meter of the center of the power line. This field decreases as the distance from the power line.
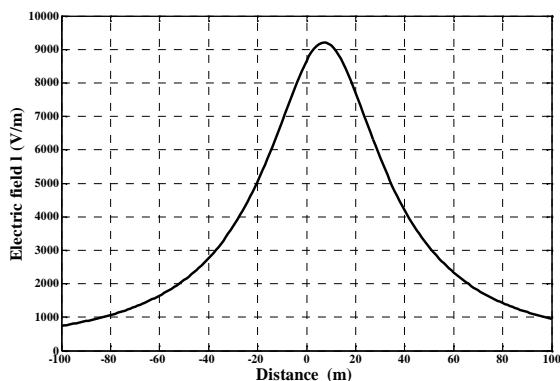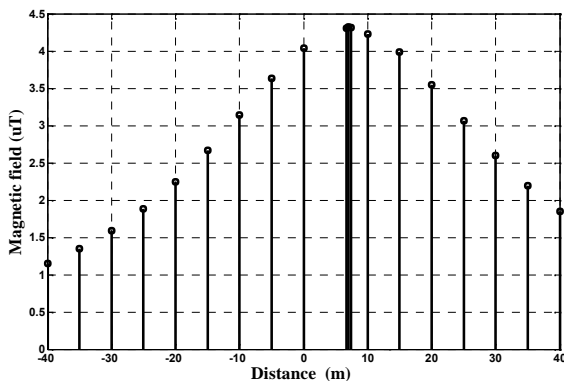


Figure 4: Electric Field



Figure 5: Magnetic Field

The result concerning the profile of the magnetic field is illustrated by the curve in Figure 5. The same for the electric field, the magnetic field has a symmetric distribution.

The maximum value occurs at 7 meter of the center of the power line, with a value of 4.3µT. The magnetic field decreases as the distance from the source increases.
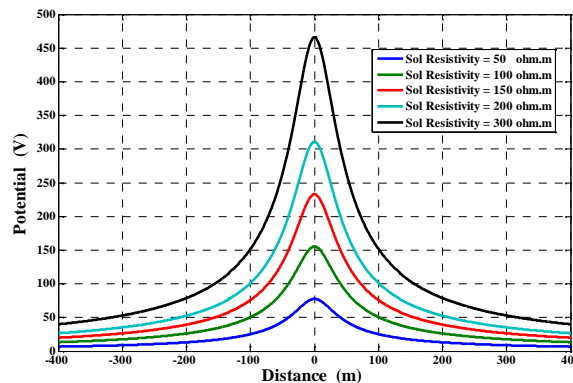


Figure 6: Voltage Induced in the Pipeline in a Homogeneous soil

Figure 6 shows the voltage induced in the pipe for a homogeneous soil for different values of the resistivity of soil. The simulation results have shown that the voltage levels are directly proportional to the soil resistivity.
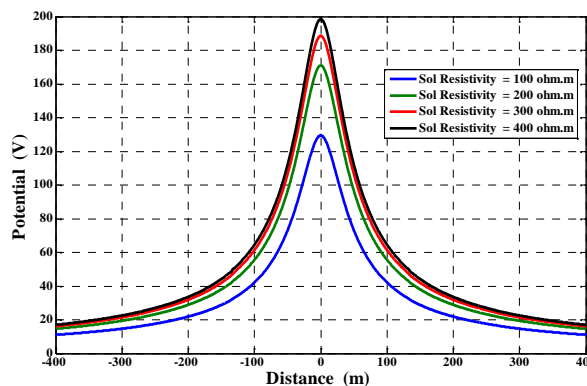


Figure 7: Voltage Induced in the Pipeline in a non-Homogeneous soil

Figure 7 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 $\rho_2$ increases, the reflection coefficient increases and the voltage magnitude also increases.

## IV. FAULT CONDITIONS

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 8 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.
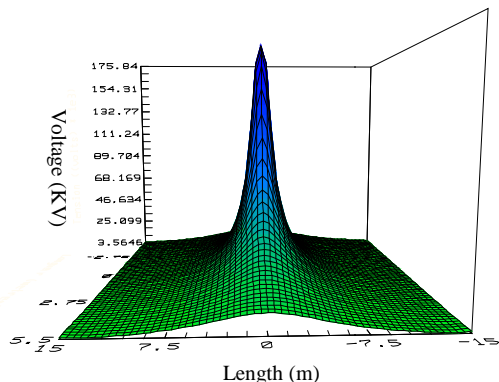
Figure 8: Distribution of ground potential

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 9 shows a schematic representation of two rectangular cavities enclosed in a solid insulation (coating).The electric field inside in the cavities is given in the figure 10.
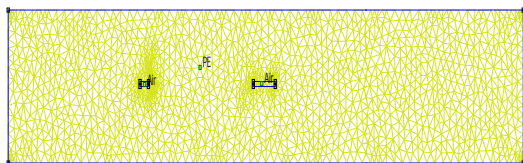


Figure 9: Schematic representation of a rectangular cavity enclosed in a solid insulation (coating)
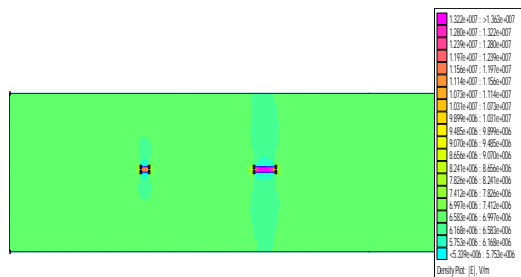


Figure 10: Electric Field

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. From Figure 10, 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.

By inductive coupling, pipelines placed in this environment during normal operation or fault conditions are driven by currents. We must limit the intensity of this current to prevent corrosion of the pipeline's metal.

## V. CORROSION

The corrosion of metals is an electrochemical process. At the anode, the metal atom gives up one or more electrons and becomes metal ions. Oxidation reactions (corrosion) occur at the surface of the anode and reduction reactions occur at the surface of the cathode. In chemical shorthand the general formula for this reaction is:

$$M \rightarrow M^{n+} + ne^-$$

Where, M is a metal atom such as iron or copper in a metallic structure such as a pipeline. When the pipeline behaves as an anode, it starts losing its metallic atoms.

The three general types of electrochemical reactions that occur depend on the cause of the potential difference between the anode and the cathode. The potential difference can be caused by differences in the environment, differences in the metal, or by external electrical sources. These three types are concentration cell corrosion (electrochemical cell caused by differences in the electrolyte), galvanic corrosion (Electrochemical cell caused by differences in the metal), and Stray current corrosion (electrochemical cell caused by external electrical sources) [11], [15], [17].

he stray current corrosion is a type of electrochemical corrosion cell caused by an electromotive force from an external source affecting the structure by developing a potential gradient in the electrolyte or by inducing a current in the metal, which forces part of the structure to become an anode and another part a cathode [14].

## VI. 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 figure12 [18].
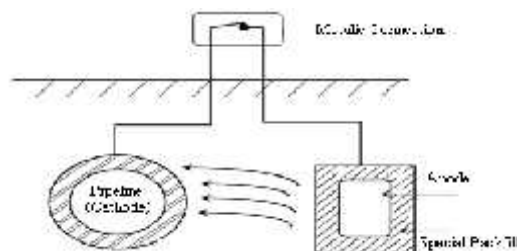


*Figure12: Galvanic Anode Cathodic Protection*

As shown in figure.13, 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[18].
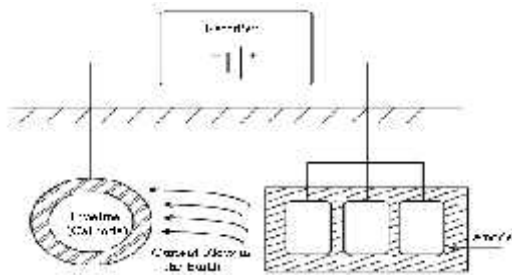
Fig.13: Impressed Current Cathodic Protection System

## VII. CONCLUSION

The interference problems that affect pipelines near high voltage AC power (HVAC) transmission lines have been well defined .The electric and magnetic fields on the pipeline in the vicinity of a high voltage power line have been calculated. The methods for measuring the soil resistivity have been discussed.

The voltage profiles for normal operation (in a homogeneous soil and two soil resistivity layers) and during fault conditions (damage of the coating), have been simulated.

Finally, the corrosion effect on metals was studied and two solutions were 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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