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Pipelines Corrosion Due to the Electromagnetic Pollution caused by the High Voltage Power Lines

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***Abstract* — This paper studies the effect of the electromagnetic pollution caused by the high voltage power lines on the corrosion of the buried pipeline. In this objective, the finite element method (FEM) was used to calculate the magnetic field distribution and the induced current densities in the buried pipeline caused by both horizontal and vertical configuration of the HVPL during steady state conditions. In order to diagnose the effect of the electromagnetic pollution on the corrosion of the pipeline, the electrochemical impedance spectroscopy (EIS) measurements were used to characterize the corrosion polarization properties of X70 steel in simulated soil at various AC current densities. The results show that, the electromagnetic pollution caused by the high voltage power lines affect the electrochemical characteristics of the X70 steel pipeline and accelerate the corrosion of the pipeline.**

Keywords— Electromagnetic pollution, high voltage power line, induced current density, X70 steel pipeline , corrosion, Finite element method, electrochemical impedance spectroscopy.

I. INTRODUCTION

Electromagnetic radiations from the high voltage power lines are something that can affect the electric and electrochemical properties of the pipelines in the soil. These radiations from a high voltage power transmission power lines (HVPLs) can be transferred to a metallic pipelines by two possible mechanisms (1) capacitive or electrostatic coupling, and (2) electromagnetic or inductive coupling [1,2].

With electrostatic coupling, energy is transferred through the electrical capacitance that exists between the power line and the pipeline. In the electromagnetic coupling, the electromagnetic induction caused by the HVPLs on the buried pipelines is the primary effect during steady state conditions. This induction occurs when alternating current flowing power line conductors generates an electromagnetic field around the conductors, which can couple with adjacent buried pipelines, inducing a current. This induced current may be dangerous for working personnel, the buried steel pipeline due to corrosive effects and cathodic protection installation performances [3-12].

Several researchers studied the interference effects between power line and pipeline [13-21]. A general guide on the subject was issued later by CIGRE [22], while CEOCOR [23] published a report focusing on the AC corrosion of pipelines due to the influence of power lines.

In recent years, electrochemical impedance spectroscopy (EIS) has found widespread applications in the field of characterization of materials. It is routinely used in the characterization of coatings, batteries, fuel cells, and corrosion phenomena. It has also been used extensively as a tool for investigating mechanisms in electro electro-dissolution, passivity, and corrosion studies [24-28].

This paper studies the effect of the electromagnetic pollution caused by both horizontal and vertical configuration of the high voltage power line on the corrosion of the buried pipeline. First, the finite element method (FEM) was used to calculate the magnetic field distribution and the induced current densities in the buried pipeline during steady state conditions. In order to diagnose the effect of the electromagnetic pollution on the corrosion of the pipeline, the electrochemical impedance spectroscopy (EIS) measurements were used to characterize the corrosion of X70 steel in simulated soil at various AC current densities. The results show that, the electromagnetic pollution caused by the high voltage power lines affect the electrochemical characteristics of the X70 steel pipeline and accelerate the corrosion of the pipeline.

II. ELECTROMAGNETIC POLLUTION

In this paper, the calculation method in order to study the electromagnetic coupling between a HVPL and buried steel pipeline is based on the finite element method (FEM).The required input data for the model are the HVPL and the pipeline geometrical characteristics, the magnetic and the electric characteristics of the pipeline, the soil resistivity and finally the electric characteristics of the HVPL[2,29]. The schematic representation of the HVPLs used to identify the impact of electromagnetic coupling on the buried steel pipeline is shown in Fig. 1.

The high voltage power lines under study having the following characteristics: P = 162MW under $\cos(\theta)$ =0.85, the operating frequency is 50Hz, U = 220KV and the electric conductivity of the phase wires is $4 \cdot 10^7$S/m.

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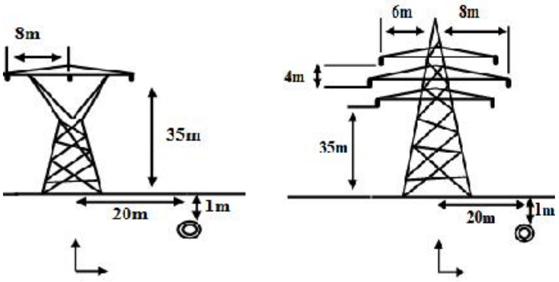
The pipeline is buried in the soil at the depth of 1m and the lateral distance between the pipeline and the centre of the HVPLs is 20m. The material of the pipeline employed in this study is API X70 high strength low alloy steel.The pipeline having the following electrical characteristics: the electric conductivity $\sigma = 8 \cdot 10^6$ S/m and the relative permeability $\mu_r = 6700$.



a/ Horizontal configuration b/ Vertical configuration

Fig.1. Schematic representation of the HVPTLs used to identify the impact of electromagnetic coupling on the buried X70 steel pipeline

The analyzed system as it is presented in Fig.1 has been simulated by finite elements method in order to calculate the distribution of the magnetic field and the induced current densities in the buried X70 steel pipeline for both horizontal and vertical configurations of the HVPL during steady state conditions.

Figs. 2 and 3 show the magnetic field distribution as a function of lateral distance from the centre of the HVPLs, at various heights (4m, 8m, 12m, 16m and 20m) for the horizontal and vertical configurations, respectively. We can see that both horizontal and vertical configurations are symmetric in magnetic field distribution along the vertical axis. Also, we can see that the height of the HVPLs constitutes an importance factor influencing the magnetic field level.

Figs. 4 and 5 show the magnetic field distribution as a function of lateral distance from the centre of the HVPL, at the pipeline level, for both horizontal and vertical configuration of the HVPL, respectively. We can see that the power line configuration has the key effect on the induced magnetic field in the steel pipelines. For the horizontal configuration the induced magnetic field in the steel pipeline is 2.5µT, while the vertical configuration has 3.7µT.

The permanent influence of the steel pipeline from the magnetic field caused by the HVPL during steady state conditions leads to the exchange of current between the metal of the pipeline and the soil that surrounds it. For a soil resistivity of 100Ω.m, the induced current density distribution in the steel pipeline due to the electromagnetic induction caused by the HVPL for the horizontal and vertical configuration of the HVPL during steady state condition are shown in Figs. 6 and 7, respectively.

For the horizontal configuration the maximum induced current density is 166A/m^2 while in the vertical configuration the maximum is 242A/m^2.

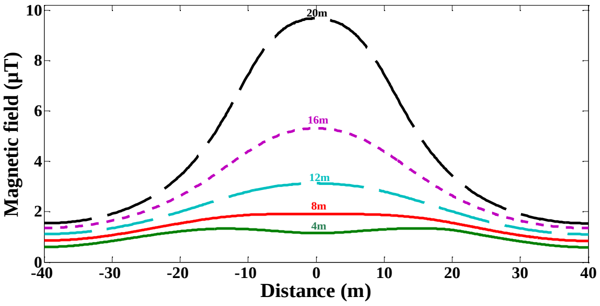


Fig.2. Magnetic field distribution as a function of lateral distance from the centre of the HVPL, at various heights for horizontal configuration

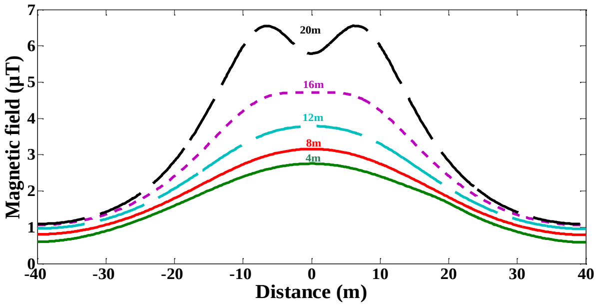


Fig.3. Magnetic field distribution as a function of lateral distance from the centre of the HVPL, at various heights for vertical configuration

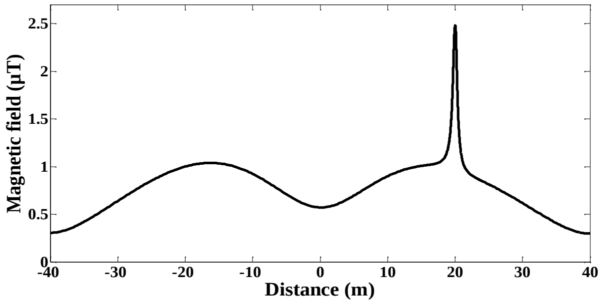


Fig.4. Magnetic field distribution as a function of lateral distance from the centre of the HVPL, at pipeline level in the horizontal configuration

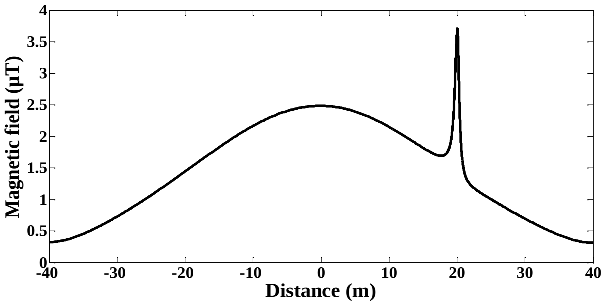


Fig. 5. Magnetic field distribution as a function of lateral distance from the centre of the HVPL, at pipeline level in the vertical configuration

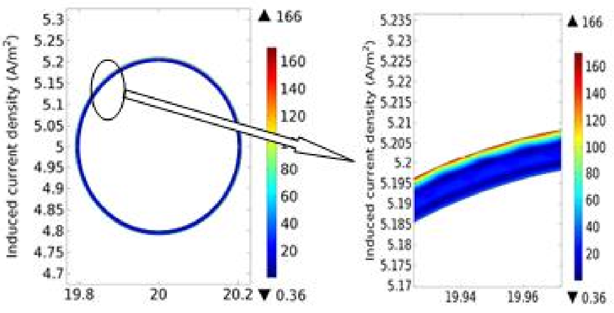


Fig.6. Induced current density distribution in the steel pipeline for horizontal configuration (A/m^2)

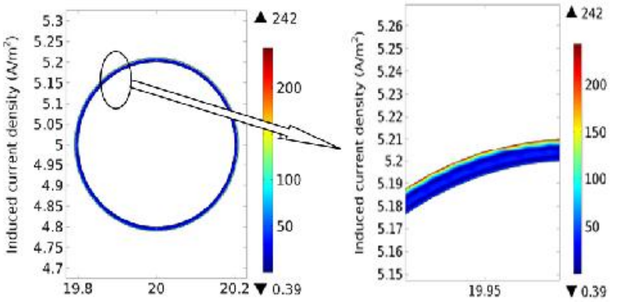


Fig.7. Induced current density distribution in the steel pipeline for vertical configuration (A/m^2)

III. EFFECT OF THE ELECTROMAGNETIC POLLUTION

In this context and in order to diagnoses the effect of these induced current densities on the X70 steel pipeline, the corrosion behavior of X70 steel specimens at various AC current densities was investigated using electrochemical impedance spectroscopy measurements in simulated soil solution. The EIS measurements were performed using on a Bio-Logic SP-150 electrochemical workstation driven by a PC. The three-electrode system was used: X70 steel specimen was utilized as working electrode (WE). A saturated calomel electrode has served as reference electrode (RE), and a platinum wire as counter electrode (CE). The electrolyte used in this study is the simulated soil solution [30]. The current densities were applied on the X70 electrode by two electrodes which were connected to the interference source, as shown in Fig. 8.

Fig.8. Experimental test bench

The fundamental approach of all impedance methods is to apply a small amplitude sinusoidal excitation signal to the system under investigation and measure the (current or voltage) .The electrochemical impedance spectroscopic of the X70 steel in simulated soil solution is recorded in the frequency range from 200 kHz to 50 mHz using a 10 mV peak-to-peak signal amplitude. The plot of the imaginary part of impedance against the real part gives the electrochemical impedance spectroscopy plot, as shown in Fig.9.

The electrical equivalent circuit of the steel in the soil in the point of view to the electrochemistry of the pipe-soil interface is presented in Fig.10, where Rs is the solution resistance, C is the double-layer capacitance and R is the charge-transfer resistance (R is proportional to the corrosion resistance of the electrode. With the increase of R, the resistance to the corrosion increases.)

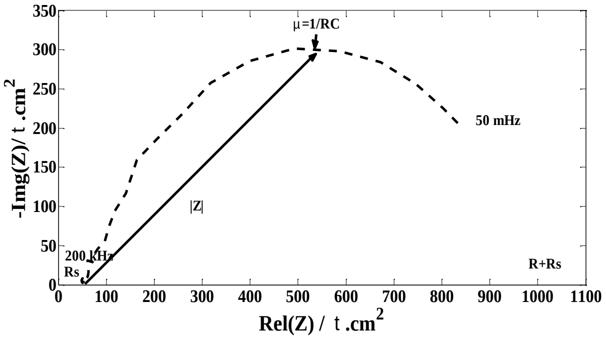


Fig.9. Electrochemical impedance spectroscopy of the X70 steel in simulated soil solution

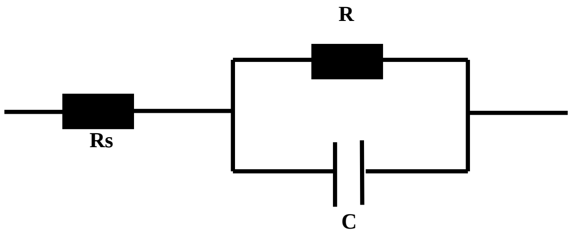


Fig.10. Electrical equivalent circuit of the X70 steel in the soil

Fig.11 shows the electrochemical impedance spectroscopy curves of X70 steel measured under current density of 0 A/m^2, 100 A/m^2 and 200A/m^2. The results of fitting the electrochemical impedance spectroscopy curves from Fig.11 are summarized in Table.1 which indicate the applied current density, charge-transfer resistance (R) and the double-layer capacitance (C). From Fig.11, it can be seen that the charge-transfer resistance decreased by increasing the AC current density. The charge-transfer resistance of X70 steel without influence of AC current density is 950Ω.cm^2. The resistance decreased after application of 100 A/m^2 (680 Ω.cm^2). Another decrease was observed for the AC current density of 200 A/m^2 to reach 500Ω.cm^2.

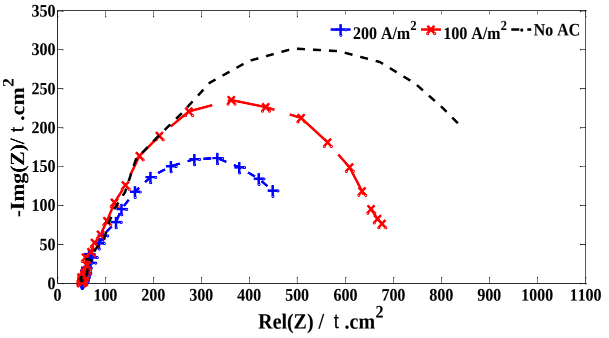


Fig.11. Electrochemical impedance spectroscopy of the X70 steel in simulated soil solution at various AC current densities

Table. 1. Electrochemical parameters of X70 steel at various applied current densities.

current density (A/m^2)	Rp (Ω.cm^2)	C (mF)
0	950	0.33
100	680	0.52
200	500	0.69

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According to electrochemical impedance spectroscopy results, the X70 steel pipeline without influence of AC current density showed the best corrosion resistance compared to cases where current densities were applied. We can conclude from these results that the electromagnetic pollution caused by the high voltage power lines affects the electrochemical characteristics of the X70 steel pipeline and accelerates the corrosion of the pipeline.

IV. CONCLUSION

This paper has studies the effect of the electromagnetic pollution caused by both horizontal and vertical configurations of the high voltage power lines during steady state conditions on the buried X70 steel pipeline. The more important conclusions reached in this study are the following:

- For both horizontal and vertical configurations are symmetric in magnetic field distribution along the vertical axis.
- The power line configuration has the key effect on the induced magnetic field and current density in the X70 steel pipelines. For the horizontal configuration the maximum induced current density is170A/m^2 while in the vertical configuration the maximum is 242A/m^2.
- The electromagnetic pollution caused by the high voltage power lines affects the electrochemical characteristics of the X70 steel pipeline and accelerates the corrosion of the pipeline.

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