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AC Corrosion Induced by High Voltage Power Line on Cathodically Protected Pipeline

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Abstract — The implications of the influence of alternating currents on buried pipelines are of great concern to all pipeline owners in world. The relevance of the interference is always increasing for operational personnel and for the protection of buried metallic structures from corrosion. The paper studies the electromagnetic interference problem between an existing high voltage power line and a newly designed underground pipeline cathodically protected. Induced voltages and currents are evaluated for steady state operating conditions of the power line. It is found that on pipelines suffering from A.C. interference traditional pipe-to-soil potential measurements do not guarantee efficient cathodic protection against corrosion. A specific approach to assess the effectiveness of cathodic protection should be adopted.

Keywords— AC Interference, Induced Voltages, Electric Power Transmission Lines, pipeline, AC Corrosion, cathodic protection, soil resistivity.

I. INTRODUCTION

A new corrosion phenomenon has been added to the list of corrosion phenomena, and it is related to A.C. currents. These usually result from A.C. voltages induced into the pipeline where the pipeline route is in parallel with, or crosses, high voltage power lines [1].

AC Corrosion is caused by current exchange between soil and metal. This exchange of current depends on the voltage induced on pipelines. The amplitude of induced voltage is due to various parameters such as: the distance between phase cables, the distance between the high voltage electricity lines and the pipeline and the overhead line operating current. Corrosion is mainly influenced, or associated with the A.C. current density, size of coating defect and the local soil resistivity [2], [3] and [4].

The interference between a power system network and neighboring gas pipeline 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.

This piper evaluates and analyzes the electromagnetic interference effects on buried pipelines cathodically protected created by the nearby high voltage transmission lines. We calculate the various parameters of the sacrificial anode cathodic protection system, then we analyze the problem of interference between the power line and pipeline by the calculation of the magnetic field, induced voltage and current density during both normal conditions on the power line and finally we evaluate the AC corrosion likelihoods of pipelines. It is found that on pipelines suffering from A.C. interference traditional pipe-to-soil potential measurements do not guarantee efficient cathodic protection against corrosion. A specific approach to assess the effectiveness of cathodic protection should be adopted.

II. CATHODIC PROTECTION

To protect buried pipelines against corrosion, a noncorrosive coating is used and additional protection is applied by means of cathodic protection (CP) in order to control galvanic current in such a way as to avoid anodic current flow from the pipe to the soil. Though large voltage differences are an efficient protection, this is limited by the thickness of the coating. The usual rule is to maintain the pipeline at a constant potential between 0.850 V to 1.3 V (with respect to a copper/saturated copper sulfate electrode Cu/$CuSo_4$) [13], [14].

There are two main CP system types:

A first method consist of connecting a galvanically more active metal to the pipeline, in this case the metal will behave as the anode (typically Zn, Al or Mg); 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 figure1.

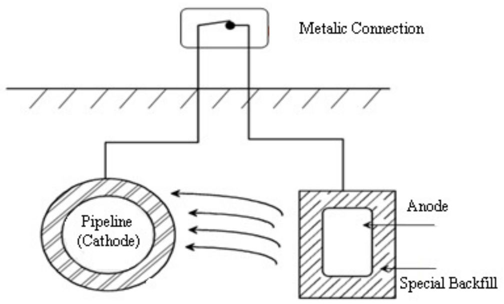

Fig.1. sacrificial anode cathodic protection System

As shown in figure.2, 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.

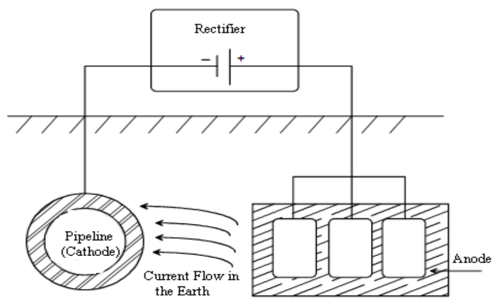

Fig.2. Impressed current cathodic protection System

III. INDUCTIVE INTERFERENCE

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. Figure 3 shows the components of the electric field at the observation point M(x,y) due to one phase conductor and its image.

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

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.

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

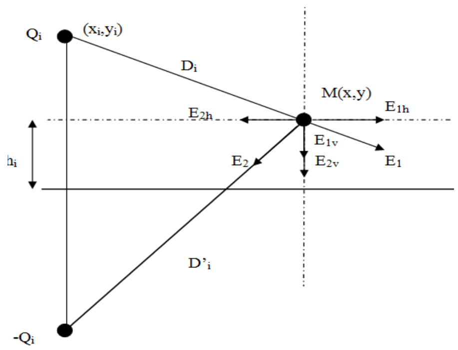

Fig.3: Components of electric field due to HVPL

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.

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

Where:

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

C. Induced Voltage

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.

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

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.

IV. RESULTS

A. Design details for the sacrificial anode CP system

The pipeline under study is buried. Table.1 lists the characteristics for the buried pipeline such as radius, wall thickness, length, coating thickness. The anode material should not be located at three meter from the pipeline and must be surrounded by a backfill. Table .2 lists the characteristics for the Mg sacrificial anode. The following eight steps are required when designing galvanic cathodic protection systems.

Tab.1. Pipeline characteristic

Material	X42
Length	10 (Km)
Pipe diameter	219.1 (mm)
Coating thickness	6.4 (mm)

Tab. 2. Anode characteristic

Constituents	90% Mg,6%Al 3%Zinc
Consumption Rate	7 (Kg/A an)
Dimension	3 inch x3 inch x14 inch
Potential	-1.7 (V)
Current efficiency	1100 (Ah/Kg)
Weight	20 (kg)
backfill material	75% hydrated gypsum, 20%bentonite and 5% sodium sulfate.
Backfill resistivity	3 (Ω.m)
Efficiency (%)	50

1. Review soil resistivity

If resistivity variations are not significant, the average resistivity will be used for design calculations. The soil resistivity measurements are given in table3.

$$\rho_{soil}=\frac{1}{N}\sum_{1}^{N}\rho_i=72.5\ \Omega.m$$

Tab. 3. Soil resistivity measurements

PK(km)	Resistivity (Ω.m)	PK(km)	Resistivity (Ω.m)	PK(km)	Resistivity (Ω.m)
00.000	65	04.980	45	06.900	90
01.000	70	05.000	55	07.250	90
01.500	80	05.750	70	07.560	85
02.000	65	05.950	70	07.850	85
02.500	65	06.100	70	08.100	90
03.000	60	06.350	90	08.500	90
03.500	45	04.500	50	09.150	90
04.000	50	06.450	90	09.255	80

2. Area to be protected

The area to be protected by is calculated by:

$$A=\pi(d+2tc)L=0.7281*10^4\ m^2$$

Where:
d is the pipe diameter (m), tc is the coating thickness (mm) and L is the length of pipe (m).

3. Current to protect the steel structure

Using a design current density of J=0.15 mA/m2, the current demand required to protect the steel structure from corrosion is determined by the following formula:

$$I=A*J_{dc}=1.09\ A$$

4. Calculate net driving potential for anodes

The average potential of the pipeline system is -0.67 V. Hence the net initial driving potential (E) is given by:

$$E=-1.70-(-0.67)=-1.03\ V$$

5. Anode-to-electrolyte resistance

The anode to electrolyte resistance is an important parameter in order to predict the current output of an anode. To determine the resistance of a single vertical anode, the following relationship is applied (Dwight's equation): [15]

$$R_{anode}=R_{anode/backfill}+R_{backfill/soil}$$

$$R_{anode/backfill}=\frac{0.00521\rho_{backfill}}{L_{anode}}\left(\ln\frac{8L_{anode}}{d_{anode}}-1\right)$$

$$R_{backfill/soil}=\frac{0.00521\rho_{soil}}{L_{backfill}}\left(\ln\frac{8L_{backfill}}{d_{backfill}}-1\right)$$

Where:

$\rho_{backfill}$: Resistivity of backfill in ohm-m;
ρ_{soil} : Soil resistivity in ohm-m;
L_{anode} : Length of anode in meters;

L_{anode} : Length of backfill in meters;
d_{anode} : Diameter of anode in meters;
$d_{backfill}$: Diameter of backfill in meters.

$$R_{anode} = 1.58\ \Omega$$

6. Current per anode

To predict the current output of protective current from a sacrificial anode the voltage between anode and cathode (driving voltage) is divided by the resistance of the anode to the electrolyte. The maximum output current from each anode is given by:

$$I_{max} = E/R = 0.65\ A$$

7. Number of anodes needed

The number of galvanic anodes required to protect the pipeline is given by

$$N = I_{total}/I_{max} \simeq 2 \text{ anode}$$

8. Net driving force of the anodes

This implies that the anodes should be spaced at 3.3 km intervals. Because the pipeline will be polarised to at least a potential of (-0.850 V/Cu-cuSo4), the net driving force of the anodes is given by;

$$E = -1.70V-(-0.85V) = -0.85V$$

Current (I) per anode 0.54A

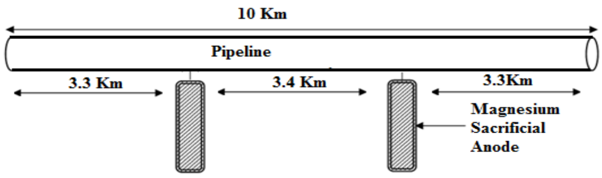

Fig.4. Schematic of the distribution of galvanic anodes along the pipeline

B. Interference Problem

We carried out within the context of this work the calculations carried out on a high voltage power line (HVPL) having the following characteristics. P = 750 MW under a cos (θ) =0.85 and U = 400 KV. Metallic pipeline (MP) Crossings with power lines at the points PK00.970 Km and PK01.170 Km (Figure5)

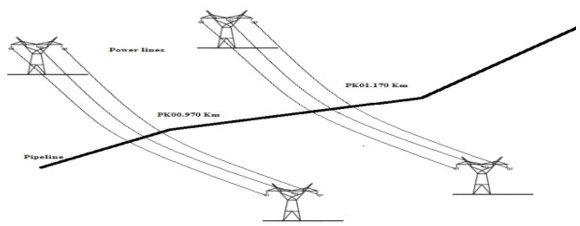

Fig.5. Plan view of the HVPL-MP common distribution corridor.

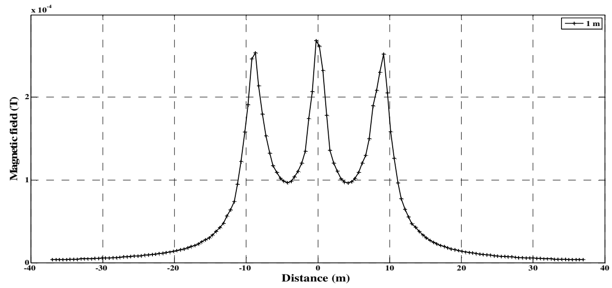

Fig.6. Magnetic field

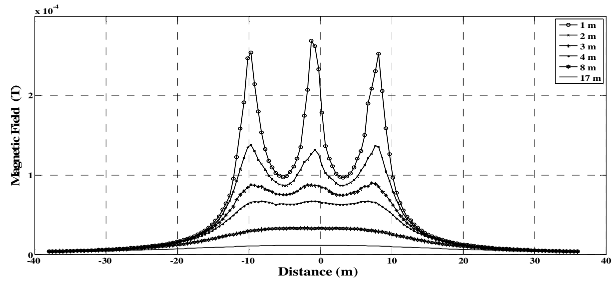

Fig.7. Magnetic field with varying height

Figure 6 shows the magnetic field profile for the horizontal configuration less than 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.
Figure7 shows the magnetic field for horizontal configuration of the power line 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.

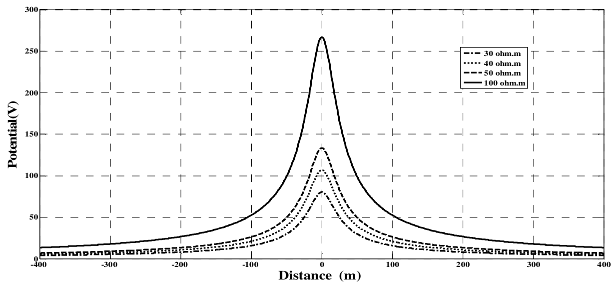

Fig.8. Induced voltage

The resultant pipeline induced voltages are calculated with the variation of the soil resistivity (soil resistivity varied from 30 to 100 Ω.m). In Fig.8, 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).

V. 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:

$$R=\frac{\rho_{soil}}{2.D}.\left(1+\frac{8t_c}{D}\right) \quad (4)$$

Thus the current density J_{ac} (A/m^2) through the coating defect is:

$$J_{ac}=\frac{8.U_{ac}}{\rho_{soil}.\pi(8t_c+D)} \quad (5)$$

U_{ac} is the induced voltage, t_c is the thickness of the coating, ρ_{soil} is the soil resistively, D is the diameter of the coating defect.

Based on actual investigation in the field of AC corrosion, as well as to the actual European technical specifications [16] 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 [17].

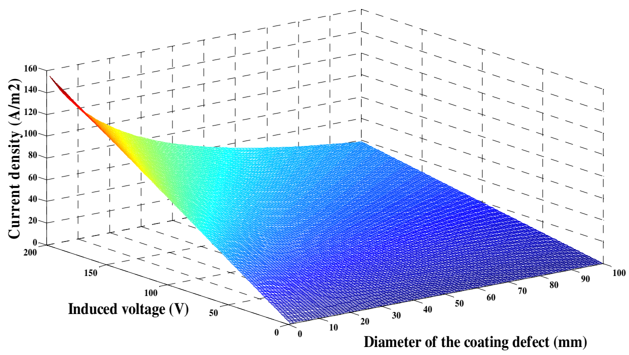

Fig.9. Current density

In Fig.9, 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.

VI. 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 configuration. The voltage profiles for normal operation conditions have been simulated. It is found that on pipelines suffering from A.C. interference traditional pipe-to-soil potential measurements do not guarantee efficient cathodic protection against corrosion.

REFERENCES

[1] CIGRE Joint Working Group C4.2.02, “AC Corrosion on Metallic Pipelines due to Interference from AC Power Lines”, CIGRE Technical Brochure no. 290, 2006.

[2] F. P. Dawalibi, R. Da. Southey, “Analysis of electrical interference from power lines to gas pipelines, part I - Computation methods,” IEEE Trans. Power Del., vol. 4, no. 3, pp. 1840-1846 July 1989.

[3] F. P. Dawalibi, R. Da. Southey, “Analysis of electrical interference from power lines to gas pipelines, part II - Parametric analysis,” IEEE Trans. Power Del., vol. 5, no. 1, pp. 415-421 Jan. 1990.

[4] Hanafy M. Ismail, Effect of Oil Pipelines Existing in an HVTL Corridor on the Electric-Field Distribution, IEEE Transactions on Power Delivery, VOL. 22, NO. 4, pp.2466-2471, 2007.

[5] G. Christoforidis, D. Labridis, Inductive Interference on pipelines buried in multilayer soil due to magnetic fields from nearby faulted power lines, IEEE Transaction on Electromagnetic Compatibility, Vol. 47, No. 2, pp. 254-262, May 2005.

[6] A. Gupta and M. J. Thomas, "Coupling of High Voltage AC Power Lines Fields to Metallic Pipelines," in 9th International Conference on Electro Magnetic Interference and Compatibility, INCEMIC, Bangalore, India, February 23-24, 2006.

[7] Mohamed M. Saied, The Capacitive Coupling Between EHV Lines and Nearby Pipelines, IEEE Transactions on Power Delivery, VOL. 19, NO. 3, pp.1225-1231, 2004.

[8] R. Braunstein, E. Schmautzer, M. Oelz, “Impacts of inductive and conductive interference due to high-voltage lines on coating holidays of isolated metallic pipelines”, 21st International Conference on Electricity Distribution, June 2011, Frankfurt, Germany, paper 13.

[9] George Filippopoulos and Dimit ris Tsanakas , Analytical Calculation of the Magnetic Field Produced by Electric Power Lines, IEEE Transactions on Power Delivery, VOL. 20, NO. 2, pp 1474, APRIL 2005.

[10] G. M. Amer, “Novel technique to calculate the effect of electromagnetic field of HVTL on the metallic pipelines by using EMTP program,” The Int. Journal for Computation and Mathematics in Electr. and Electron. Eng., vol. 29, no. 1, pp. 75-85 2007.

[11] CIGRE Working Group 36.02, “Guide on the Influence of High Voltage AC Power Systems on Metallic Pipelines”, CIGRE Technical Brochure no. 095, 1995.

[12] AC corrosion on cathodically protected pipelines – Guidelines for risk assessment and mitigation measures, CEOCOR, 2001.

[13] W. von Baeckmann, W. Schwenk, W. Prinz, Handbook of Cathodic Corrosion Protection, Theory and Practice of Electro-chemical Protection Processes, 3rd ed., Gulf Publishing Co, Houston, TX, 1997

[14] W.Von Baeckmann, W.Schwenk, W.Prinz, Handbook of Cathodic Corrosion Protection - 3Ed, 1997.

[15] National Association of Corrosion Engineers (NACE) International Cathodic Protection Training Manual, vol. 2, Corrosion Control; 1976. p. 12.21-21-25 and 15.24-32.

[16] “CEN/TS15280: Evaluation of a.c. corrosion likelihood of buried pipelines - Application to cathodically protected pipelines”, CEN, March 2006.

[17] R. Braunstein, E. Schmautzer, G. Propst, “Comparison and Discussion on Potential Mitigating Measures Regarding Inductive Interference of Metallic Pipelines”, Proceedings of ESARS, October 2010, Bologna, Italy.