

# DIAGNOSIS OF AC CORROSION ON THE BURIED PIPELINE DUE TO THE HIGH VOLTAGE POWER LINE

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**Abstract:** *This paper studies the electromagnetic effect of the high voltage power line on the X70 Steel pipeline and the factors affecting this interference. The induced voltage onto the pipeline was calculated for different separation distance between conductors, the existence of the earth wire, separation distance between transmission line and pipeline and the parallelism length. The induced AC current density was calculated function to the induced voltage, the soil resistivity, and the holiday diameter. The electrochemical characters of the X70 steel with and without influence of the alternating currents were studied in simulated soil solution. The results indicate that the AC density accelerate the corrosion degree of X70 steel in simulated soil solution comparing with that in the absence of the AC density.*

**Keywords** —Pipeline, power lines, interference, induced voltage, induced current density, AC corrosion.

## 1. Introduction

The electromagnetic interference study between high voltage power transmission lines (HVPTL) and nearby buried metallic pipelines (BMP) importance is given by the induced voltages and current densities. Electrical energy from a high voltage power transmission power line (HVPTL) can be transferred to a metallic pipeline by three possible mechanisms—capacitive coupling, conductive coupling, and electromagnetic or inductive coupling [1-8]. With electrostatic coupling, energy is transferred through the electrical capacitance that exists between the power line and the pipeline.

In the conductive coupling, a large currents and voltages are directly transmitted to earth during HVPL faults.

In the electromagnetic coupling, the effect is similar to the coupling in a transformer, with the high voltage line acting as the primary coil, and the pipeline as the secondary coil. Voltages can be induced on the pipelines from HVPTL in the areas where they run in parallel together. The level of the induced voltages is due to various parameters such as: distance between conductors, distance between the power line and the pipeline, over head earth wire, overhead line operating current and length of the parallelism between power line and pipeline. These induced voltages may be dangerous for working personnel, pipeline due to corrosive effects (AC corrosion) and the cathodic protection installations [9-18].

There has been a considerable amount of research into interference effects between power line and pipeline including computer modeling and simulation [19-21]. 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.

This paper studies the electromagnetic effect of the high voltage power line on the X70 Steel pipeline and the factors affecting this interference. In this object, the induced voltage onto the pipeline was calculated for different separation distance between conductors, the existence of the earth wire, separation distance between transmission line and pipeline and the parallelism length. Then the induced AC current

density was calculated function to the induced voltage, the soil resistivity, and the holiday diameter. Thereafter, the electrochemical characters of the X70 steel with and without influence of the AC density were studied in simulated soil solution. The results indicate that the superposed of AC densities accelerates the corrosion degree of X70 steel in simulated soil solution comparing with that in the absence of the AC density.

## 2. Induced voltage and current density

The induced voltage ( $V_p$ ) 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 HVPTL parameters and the mutual impedance with earth return in ( $\Omega/m$ ) between pipeline and phase conductors of HVPTL.

$$V_p = \sum_{i=1}^n Z_{PH(i)-P} I_i \quad (1)$$

where:  $V_p$  is the induced voltage on the pipeline due to full load currents and  $Z_{PH(i)-P}$  is the mutual impedance with earth return in ( $\Omega/m$ ) between pipeline and the (i) phase conductor of HVPTL. The mutual impedance can be found using Carson's equation as in (2) [24-25].

$$Z_{PH-P} = (\mu_0 \cdot \frac{1}{8}) + j((\mu_0 \cdot \frac{1}{2}) \cdot \ln(\frac{D}{D_{PH-P}})) \quad (2)$$

$$= 1.85 / \sqrt{(\mu_0 / \rho_{soil})} \quad (3)$$

where  $\rho_{soil}$  in ( $\Omega \cdot m$ ) is the depth of the earth return path with soil resistivity  $\rho_{soil}$  in ( $\Omega \cdot m$ ), space permeability ( $\mu_0$ ), angular frequency and distance between pipeline and phase conductors  $D_{PH-P}$ . With overhead earth wire, the impedance of earth wire with earth return  $Z_E$  for the earth wire resistance  $R_E$  and geometric mean radius of  $R_{GM}$  is given as in (4),

$$Z_E = R_E + \frac{\mu_0 \cdot \tilde{S}}{8} + j \frac{\mu_0 \cdot \tilde{S}}{2} \left( \frac{1}{4} + \ln \frac{D}{R_{GM}} \right) \quad (4)$$

The mutual impedance between the phase conductor, earth wire and the pipeline is given as in (5)

$$Z_{PH-P-E} = Z_{PH-P} - ((Z_{E-P} \cdot Z_{PH-E}) / Z_E) \quad (5)$$

Then the induced voltage  $V_p$  on the pipeline is given by:

$$V_p = \sum_{i=1}^n Z_{PH(i)-P-E} I_i \quad (6)$$

The induced AC current density ( $J_{AC}$ ) at a circular holiday is a function of the induced voltage on the pipeline ( $V_p$ ), the soil resistivity ( $\rho_{soil}$ ), and the holiday diameter ( $D$ ), and can be calculated as follows[19]:

$$J_{AC} = \frac{8 \cdot V_p}{\rho_{soil} \cdot D} \quad (7)$$

## 3. Results

We carried out within the context of this work the calculations carried out on two configurations of HVPTL (horizontal and vertical) with and without over head earth wire. The power lines having the following characteristics:  $P = 400$  MW under  $\cos(\phi) = 0.85$ ,  $U = 220$  KV, distance between conductors  $d = 6$  m and 5 Km of the parallelism between HVPTL and BMP. Fig.1, shows the plan view of the HVPTL-BMP common distribution corridor

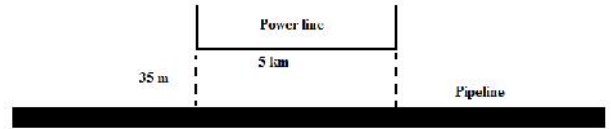


Fig.1 Plan view of the HVPTL-BMP common distribution corridor

### 1. Induced voltage

#### 1) Existing of the over head earth wire (OHEW)

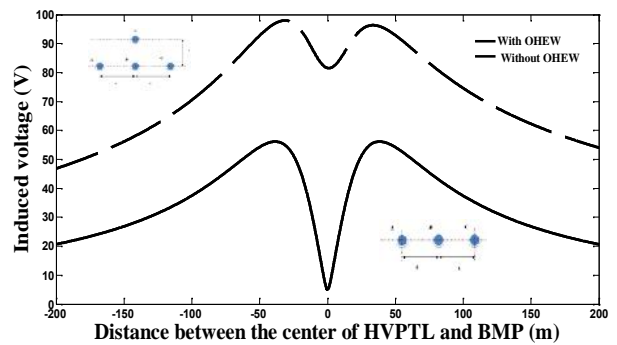


Fig.2 Induced pipeline voltage with and without OHEW for horizontal configuration

Fig.2 shows the induced pipeline voltage with and without over head earth wire. It is clearly seen that the presence of the OHEW increases the induced voltage.

This may be due to the fact that the presence of the OHEW breaks the magnetic field balance of the system and leads to higher induced voltage on the pipeline.

### 2) Distance between conductors of HVPTL

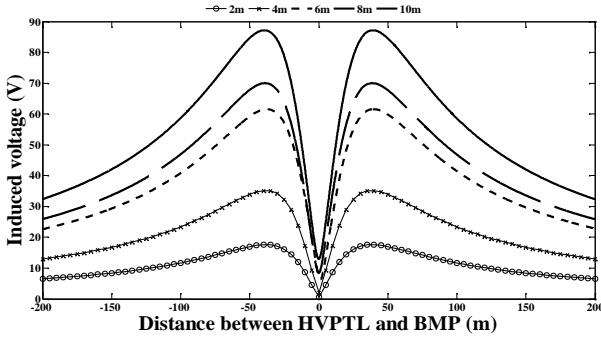


Fig.3 Induced pipeline voltage for different separation distance between conductors for vertical configuration

Fig.3 shows the induced voltages for separation distance between conductors of 5m, 6m, 7m, 8m, 9m and 10m for the horizontal and vertical configuration. It is clearly seen that the increase of the separation distance between conductor increases the induced voltage pipeline. This may be due to the fact that the mutual effect of the two neighbor conductors is reduced as they get separated from each other.

### 3) High distance between HVPTL and BMP

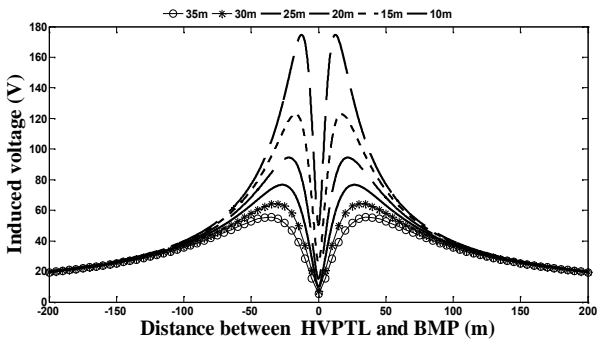


Fig.4 Induced pipeline voltages with varying height for horizontal configuration

Increasing the distance between the pipeline and the high voltage line reduces the level of induced voltage on the pipeline. Fig.4 shows the induced pipeline voltage with varying height (10m, 15m, 20m, 25m, 30m and 35m) of the HVPTL. As the height increases, the electromagnetic field seen by the pipeline decreases causing a decrease in the magnitude of the induced voltage.

### 4) Length of parallelism between HVPTL and BMP

The magnitude of induced voltage on pipeline is affected by the parallelism section of the pipeline and power line. Fig. 5 shows the induced voltages on pipeline for 5km, 10km, 20km, 30km and 40km length of parallel section. As the parallel section increases, the induced voltage on pipeline increases too.

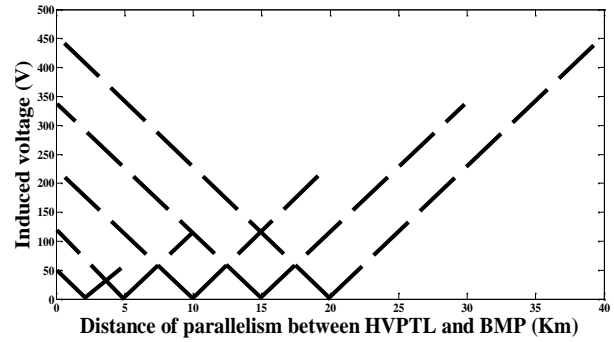


Fig.5 Induced pipeline voltages for different parallelism length

## 2. Induced current densities

In Fig.6, 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.

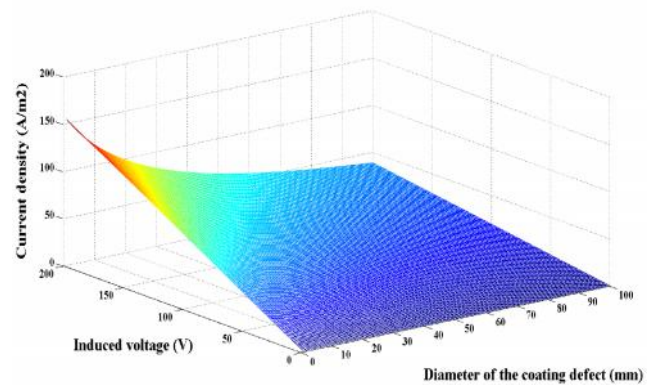


Fig.6 Induced current densities

According to the studies in the field of AC corrosion, as well as to the actual European technical specifications [26] the alternating corrosion risk can be estimated from current densities at coating holidays among  $30 \text{ A/m}^2$ . For current densities between  $30 \text{ A/m}^2$  and  $100 \text{ A/m}^2$  there exists medium AC corrosion likelihood. For current densities upper 100

A/m<sup>2</sup> there is a very high A/m<sup>2</sup> corrosion likelihood [27].

### 3. AC corrosion

In this section, we use the electrochemical tests to diagnosis the effect of the AC currents densities on the X70 steel pipeline. The electrochemical measurements were performed using on a Bio-Logic SP-150 electrochemical workstation driven by a PC. The three-electrode system was used (Fig.7): X70 steel specimen was utilized as working electrode (WE). The geometric exposed area corresponding to the working electrode was 1 cm<sup>2</sup>. The working electrode (Fig.8) was polished successively with emery paper of increasing fineness up to 400, 600, 800, 1200 and 4000 grade, then degreased with acetone and thoroughly rinsed with distilled water. A saturated calomel electrode (SCE) was served as reference electrode (RE), and a platinum wire as counter electrode (CE). AC current density was applied on the X70 specimen by two electrodes which were connected with the alternating voltage source, shown as in Figure.9. All the experiments were accomplished at room temperature and under aeration conditions. The chemical composition of the simulated soil solution, the PH and the conductivity are given in Table 1.



Fig.7 Electrochemical cell

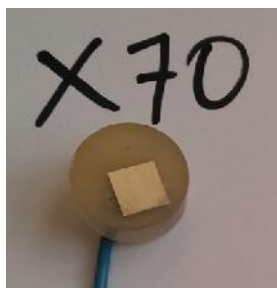


Fig.8 X70 steel specimens (Working electrode)

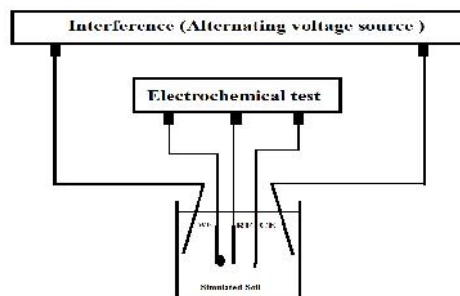


Fig.9 Alternating voltage source

Table1. simulated soil solution				
Composition	MgSO <sub>4</sub> , 7H <sub>2</sub> O	CaCl <sub>2</sub> , 2H <sub>2</sub> O	KCl	NaCO <sub>3</sub>
Weight (g)	0.131	0.18	0.122	0.483
PH	8.1			
T (°C)	23			

The polarization curves of X70 steel with and without AC density were obtained at scanning range between -1.6 to 0.2 V.SEC using a scan rate of 1 mV/s from cathodic to anodic direction. Fig.10, shows the polarization curves of the X70 steel in simulated soil solution for AC density of 0 A/m<sup>2</sup>, 100 A/m<sup>2</sup> and 200 A/m<sup>2</sup>. The electrochemical parameters such as: corrosion potential, corrosion current density, tafel slops and corrosion rate revealed by the polarization curves with and without AC density are gathered in Table 2.

In Figs 11 and 12 respectively, an increase in corrosion potential ( $E_{corr}$ ) and corrosion current density ( $I_{corr}$ ) can be seen at the curves without AC compared to those with AC. The corrosion current density for the sample without AC density is about 12.64μA/cm<sup>2</sup> and the corrosion potential is about -769.39 mV. For the samples exposed to AC density, the corrosion current densities are 31.41μA/cm<sup>2</sup> and 46.36μA/cm<sup>2</sup> and the corrosion potential are 731.39 V.SEC and 710.26 V.SEC respectively for AC densities of 100 A/m<sup>2</sup> and 200 A/m<sup>2</sup>.

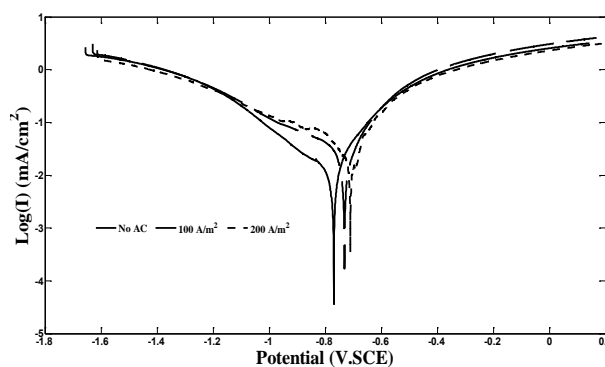


Fig.10 Polarization curves of the X70 steel in simulated soil with and without AC density

Table 2. Corrosion potential and corrosion current densities with and without alternating voltages

AC (A/m <sup>2</sup> )	E <sub>corr</sub> (mV)	I <sub>corr</sub> (μA/cm <sup>2</sup> )	Ba (mV)	Bc mV	Corrosion rate (mmpy)
0	-769.39	12.64	173.1	247.1	0.1193
100	-731.39	31.41	175.5	466.3	0.2635
200	-710.26	46.36	204.0	671.6	0.4039

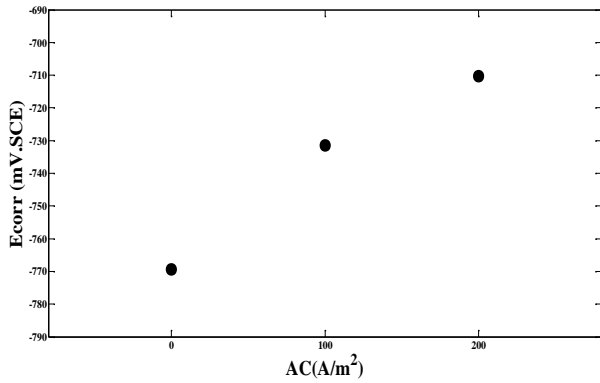


Fig.11 Corrosion potential

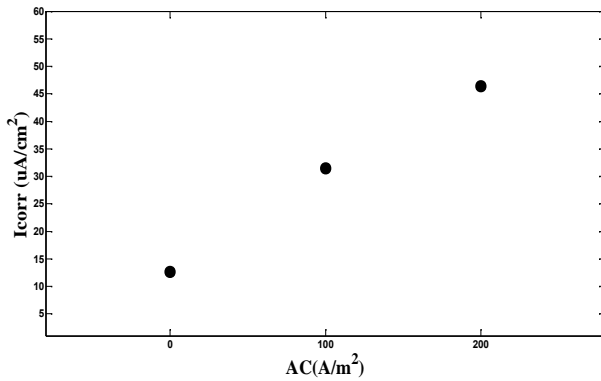


Fig.12 Corrosion current density

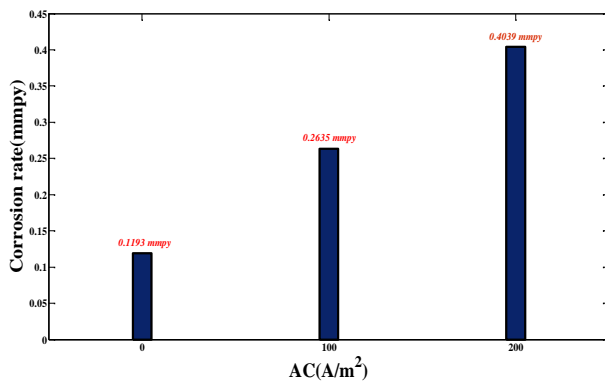


Fig.13 Corrosion rate

The corrosion rate (Fig.13) increase with the increase of the AC densities , these indicate that superposed AC density accelerate the corrosion degree of X70

steel in simulated soil solution comparing with that in the absence of the AC density.

These results can be explained by the fact that applied AC density affect double layer chemical composition with consequent change of the corrosion potential and the growth of the corrosion films on the surface. The change on the metal/electrolyte interface and the continuous alternation of anodic and cathodic cycles may also lead to an increase in the exchange current density.

#### 4. Conclusions

The important conclusions reached to this study are:

- As the parallel section increases, the induced voltage on pipeline increases too,
- The structures with a coating defect of small size may have a higher risk of AC corrosion,
- An increase in corrosion potential and corrosion current density can be seen at the curves without AC compared to those with AC.
- The corrosion rate increase with the increase of the AC densities , these indicate that superposed AC density accelerate the corrosion degree of X70 steel in simulated soil solution comparing with that in the absence of the AC density.
- The X70 steel under AC densities is more susceptible to corrosion in simulated soil solution,

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