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Assessment of Electromagnetic Interference (EMI) Effects in High-Voltage AC OHLs Adjacent to Underground Pipelines

Mohammed A. AlAqil[1]
[1]*Department of Electrical Engineering, College of Engineering, King Faisal University, AlAhssa, Saudi Arabia*
Email: malaqil@kfu.edu.sa

Abstract:- The interaction between high-voltage transmission lines and nearby buried metallic pipelines can create electromagnetic fields that induce potentially dangerous voltages, posing safety risks. This paper explores the impact of electromagnetic interference on underground water pipelines located near a high-voltage transmission line (up to 380 kV) in Riyadh, part of the Saudi national grid. The study found that certain sections of the pipelines did not experience voltages beyond the standard safety limits under normal operating conditions. However, during Line-to-Ground fault scenarios (such as short circuits), the induced voltages exceeded safe thresholds. To mitigate this risk, gradient control wires were implemented to reduce the induced voltage and maintain compliance with safety standards. The research showed that adjusting the wire resistance could effectively lower these voltages, with a 10mΩ resistance proving adequate for this specific line. The findings and recommendations may vary depending on the specific design of the overhead line and the local geography.

Keywords*: Electromagnetic Fields, Electromagnetic Interference, Gradient Control Wires, Induced Voltage, Overhead Transmission Lines, Buried Pipelines, Voltage Safety.*

1. Introduction & Background Knowledge

The co-location of water, gas, and oil pipelines with overhead power transmission lines (OHLs) along shared right-of-ways is increasingly prevalent. The proximity of electrical conductors and cables to these buried pipelines can induce voltages within the pipeline system, particularly in areas where both infrastructures occupy the same ground space. Such induced voltages may pose risks to operational personnel, damage pipeline components, and interfere with the effectiveness of cathodic protection systems. Consequently, the structural integrity and safety of the pipeline may be compromised, resulting in heightened maintenance and repair costs for pipeline operators, as well as potential damage to corrosion mitigation equipment.

In order to lessen the harmful consequences of high-voltage transmission OHLs crossing adjacent to subterranean pipes, there is a need for to gain good understanding of such cases industry-wide. Recently, sophisticated computer modeling software has been used to study the Electromagnetic Interference (EMI) problems in the case of High-Voltage AC (HVAC) OHL crossings over buried subterranean pipes, as shown in [1-4].

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Additional protective wires beneath the power line conductors are being investigated in an effort to lower the induced voltages to the high-voltage power conductor under direct and indirect lightning strikes. Indeed, using the well-known Electromagnetic Transient Program (EMTP), the work provided in [5-6] demonstrated the effect of various OHL configurations next to the gas pipeline on the level of induced voltages.

An accurate electromagnetic interference (EMI) analysis is essential for evaluating Ultra-High-Voltage (UHV) OHLs, such as the one examined in Riyadh, Saudi Arabia. This analysis must be based on a precise prediction of soil resistance along with the resistance of the metallic pipeline and its protective coating [7]. It has been observed that the depth at which anode is buried does not significantly affect pipeline corrosion [8]. Additionally, as noted in previous studies as in [9], the risk of AC-induced corrosion is assessed using Carson's method, which calculates mutual coupling impedances between buried pipelines and high-voltage OHLs. However, the Graphical User Interface (GUI) model developed for this purpose is currently specific to the case study conducted in Strydpan, South Africa, and may not be universally applicable.

This study presents a practical case analysis of a 380 kV Ultra-High-Voltage OHL located near buried water pipelines. The investigation focuses on the effects of electromagnetic interference (EMI) caused by induced line voltages, with the implementation of gradient control wires to mitigate these effects. The primary goal is to ensure that the induced UHV levels resulting from mutual inductance between the OHLs and underground pipelines during short-circuit conditions do not reach damaging levels, thus protecting the pipeline's corrosion prevention system. The effectiveness of the proposed mitigation model is assessed through multiple short-circuit scenarios, incorporating shunt resistance at the pipeline nodes and considering variations in soil resistivity.

Studying the electromagnetic coupling effects between UHV transmission lines and underground pipelines is a standard approach to assess the potential risks associated with both normal operating conditions and fault scenarios, ensuring that dangerous or detrimental voltages are prevented. The metallic pipelines located beneath high-voltage transmission lines are typically subject to three primary types of coupling: (i) inductive coupling, (ii) capacitive coupling, and (iii) resistive coupling.

1.1. Reviewing EMI Effects on Buried Pipelines under High-Voltage OHLs

Inductive coupling, represented by *L* in Figure 1, arises when a metallic pipeline is situated within the alternating magnetic field of a high-voltage transmission line. The induced voltage at the pipeline terminations is expected to vary linearly with the length of the pipeline section and is notably influenced by the soil resistivity. This type of coupling impacts both aboveground and underground pipelines. Under normal operating conditions, the

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electromagnetic fields generated by the three phases of the overhead transmission line typically counterbalance one another, leading to a significant reduction in the net induced voltage on the pipeline.

In the case of an asymmetric fault in the energy system, where the power flow becomes non-uniform, the voltage generation is more pronounced due to the uneven distribution of electromagnetic fields (EMF) across the line phases. In such scenarios, the risk of damaging the corrosion protection system increases. Therefore, it is crucial to ensure that the induced voltages remain within safe limits to prevent harm to the pipeline's protective measures.

Capacitive coupling, represented by *H* in Figure 1, affects only the aboveground pipelines. In this case, the induced voltage remains constant regardless of the pipeline's length. Typically, capacitive coupling plays a secondary role in the overall voltage induced in a pipeline, being most significant for pipelines running parallel to overhead transmission lines (OHLs). Underground pipelines, however, are shielded from the OHL's electric field and are unaffected by capacitive coupling.

Resistive coupling between a high-voltage OHL and a buried pipeline occurs when current leaks into the ground. A common example of this is a line-to-ground fault occurring near a buried pipeline, which can result in a higher potential voltage at the base of the OHL towers, leading to an increased local ground potential. This elevated potential poses a risk to the pipeline, particularly when combined with the heightened inductive coupling effects that arise in such fault conditions.

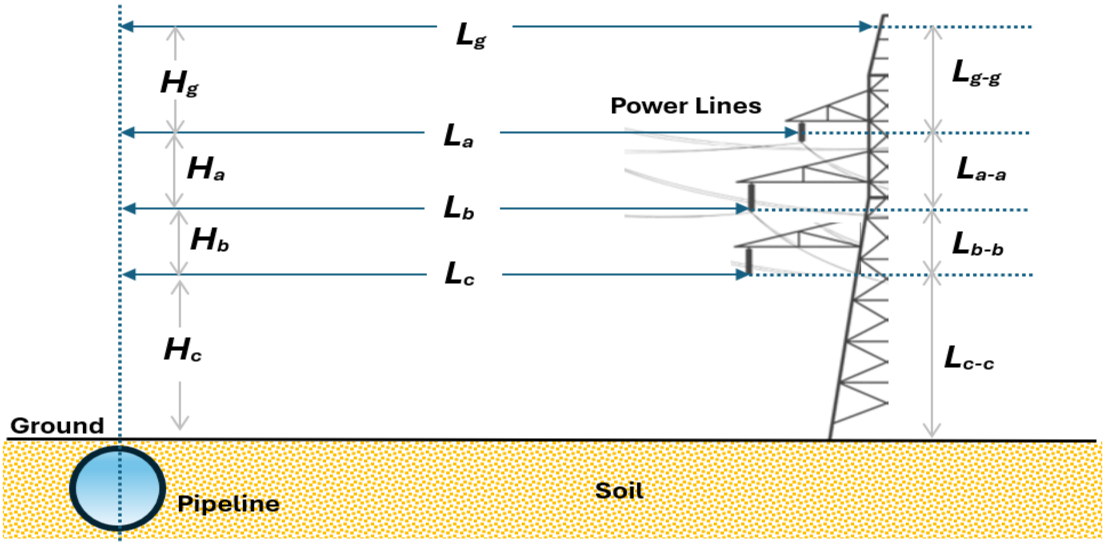

Figure. 1 A schematic diagram representing the transmission OHL and the underground pipeline buried in the ground soil.

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1.2. Permissible EMI Levels and their Associated Safe Voltage Limits

Over the past few decades, the issue of induced voltages on pipelines has been examined by several organizations, including the National Association of Corrosion Engineers (NACE), which was among the first to issue guidelines concerning corrosion and safety measures. Notably, these standards were updated multiple times, with significant revisions occurring as recently as 2007. The revisions introduced in standards [14-15] aimed at mitigating the effects of induced AC and lightning on metallic structures, ensuring the effectiveness of corrosion control systems. These reports provided recommendations for instrumentation, safety protocols, and methods to predict voltage drops across structural electrolytes. Additionally, standard [16] focuses on electrical coordination between pipelines and overhead transmission lines. All of these standards emphasize the importance of monitoring and reducing induced potential voltages, particularly those exceeding 15 V, in pipelines within UHV electrical networks.

There is an enormous amount of literature on the issue of 50/60 Hz EMI caused by high-voltage power lines on nearby pipelines or telecommunication cables with metallic elements; if only handbooks and technical reports that provide general and comprehensive information on the problem are considered, one can refer to [1-5]. Nonetheless, practically all of the aforementioned research focuses on the EMI produced by high-voltage OHLs, with only a few references referring to the equivalent problem using high-voltage power conductors. Furthermore, in the great majority of calculation methods, such as [2, 7, 8], the ground is assumed to be homogeneous with constant resistivity; this is another constraint because a two-layer soil model is more realistic.

Thus, the major goal of the work reported in this paper is to develop an algorithm capable of computing earth current while simultaneously accounting for conductive influence on the pipeline. It also enhances soil representation by transitioning from a homogenous model to a multilayer one. It also allows for some comparisons of interference results when only inductive coupling is considered, as opposed to both inductive and conductive coupling.

2. Methodology

Figure 1 shows a schematic diagram which illustrates the regions where a 1kA lightning impulse is assumed as well as the general OHL–Pipeline model that is taken into consideration in this study. The OHL conductor of the suspended UHV 380 kV for the selected tower sections is tested by the system using the lightning current and frequency flows in the model. An Optical Fiber Ground Wire (OPGW) conductor and an ACSR conductor are used in the OHL transmission structure. A grounding foundation resistance of 3 Ω will be sufficient at each

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tower to assess whether the pipeline will have higher induced voltages than allowed by the standard.

2.1. Modelling of the Capacitive Coupling Effect

When electrical OHLs are constructed close to subsurface metallic constructions (such as pipes), electrostatic interference creates a capacitive effect. Capacitive coupling from OHL conductors only affects pipes that are erected above ground, as shown in Figure 2. In fact, Figure 2 illustrates the so-called Parallelism Exposure, in which the pipeline physically runs parallel to the power line's phases [18].

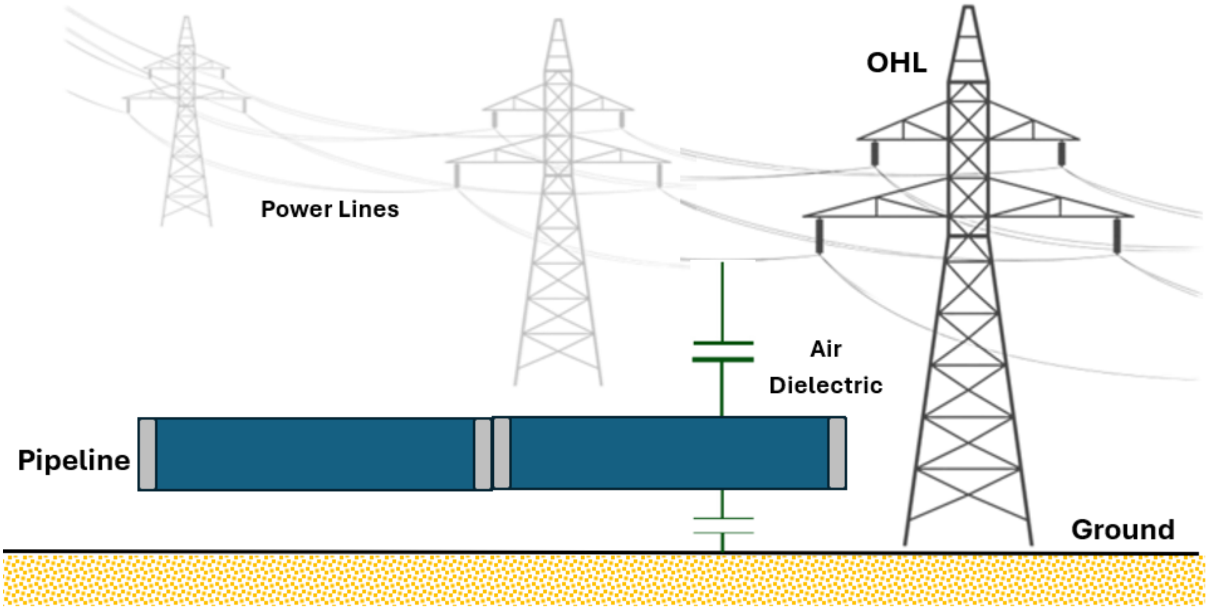

Figure.2 Power lines interference with pipelines through electrostatic/capacitive coupling.

This effect is primarily caused by the fact that the type of ground soil causes these buried structures to absorb a relative voltage. When underground pipelines are anticipated to cross beneath a UHV transmission OHL (i.e., rated over 115kV), electric utilities often ground them. Due to the nature of pipeline construction and installation, each pipe segment, which may total up to 300 meters, must be welded together. Due to the leakage of electric charges to earth, which may be reduced by metal coating, the effect of electrostatic interference caused by the capacitive coupling with the transmission line voltage is not a worry once the pipeline is completed and operated [18]. Matrix analysis approaches can be used to determine the pipeline voltages for a specific pipeline exposure within the power line [18]. The self-potential coefficient of a pipeline near the earth is determined by (1), where r_p is the pipeline's radius, in meters, and h_p is the pipeline's height aboveground, measured from the pipe's center.

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$$P_p = 17.975109 \times 10^6 \times \log_e \left[h_p + \frac{\sqrt{{h_p}^2 - {r_p}^2}}{r_p} \right] \quad \boldsymbol{km/F} \tag{1}$$

A multi-conductor system with pipelines and power lines can be represented using the partitioned matrix form as shown in (2). where the multiples "C," "P," and "E," as well as the V subscripts, stand for the power lines' ea,th wires, pipelines, and phase conductors, respectively.

$$\begin{bmatrix} \boldsymbol{V_C} \\ \boldsymbol{V_P} \\ \boldsymbol{V_E} \end{bmatrix} = \begin{array}{c} \boldsymbol{C} \\ \boldsymbol{P} \\ \boldsymbol{E} \end{array} \begin{bmatrix} \boldsymbol{P_C} & \boldsymbol{P_{Cp}} & \boldsymbol{P_{CE}} \\ \boldsymbol{P_{pE}} & \boldsymbol{P_P} & \boldsymbol{P_{pE}} \\ \boldsymbol{P_{EC}} & \boldsymbol{P_{E_P}} & \boldsymbol{P_E} \end{bmatrix} \begin{bmatrix} \boldsymbol{Q_C} \\ \boldsymbol{Q_P} \\ \boldsymbol{Q_E} \end{bmatrix} \boldsymbol{V} \tag{2}$$

Because the equation is generic, many power lines with multiple earth wires and various pipelines may exist. Each potential coefficient in (2) is a matrix. The expression in (3) can be obtained by removing the earth wires by altering VE = 0 in (2).

$$\begin{bmatrix} \mathrm{V_C} \\ \mathrm{V_P} \end{bmatrix} = \begin{array}{c} \mathrm{C} \\ \mathrm{P} \end{array} \begin{bmatrix} \mathrm{P'_C} & \mathrm{P'_{cP}} \\ \mathrm{P'_{pC}} & \mathrm{P'_P} \end{bmatrix} \begin{bmatrix} \mathrm{Q_C} \\ \mathrm{Q_P} \end{bmatrix} \mathrm{V} \tag{3}$$

Where,

$$\begin{aligned} \mathrm{P'_C} &= \mathrm{P_C} - \mathrm{P_{CE}} \mathrm{P_E^{-1}} \mathrm{P_{EC}} & \qquad \mathrm{P'_{Cp}} &= \mathrm{P_{Cp}} - \mathrm{P_{CE}}\, \mathrm{P_E^{-1}}\, \mathrm{P_{Ep}} \\ \mathrm{P'_{pC}} &= \mathrm{P_{pC}} - \mathrm{P_{pE}} \mathrm{P_E^{-1}} \mathrm{P_{EC}} & \qquad \mathrm{P'_p} &= \mathrm{P_p} - \mathrm{P_{pE}}\, \mathrm{P_E^{-1}}\, \mathrm{P_{Ep}} \end{aligned} \tag{4}$$

The earthing limitation for the pipelines must then be applied to (3). Since Q_p is zero for an insulated pipeline, (5) can be used to determine the voltages to earth from (3) caused by capacitive coupling with the power lines.

$$\mathrm{V_P} = \mathrm{P'_{pC}}\, \mathrm{P'^{-1}_C}\, \mathrm{V_C}\ \mathrm{V} \tag{5}$$

Where V_C stands for the power lines' known phase voltages to the ground. The current that would flow through a person's body if they touched a pipeline with a voltage of $V_p(i)$ is dictated by the capacitive reactance of the pipeline and the person's contact resistance to earth. In actuality, the latter is far higher than the individual's resistance; as a result, equations (6) and (7) provide the discharge current and capacitiance, respectively.

$$\mathrm{I_{P(i)}} = \mathrm{j2\pi f10^3 C_{p(i)} L_i\, V_{p(i)}}\ \ \mathrm{mA} \tag{6}$$

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$$C_{p(i)} = \frac{1}{P_{p(i)}} \quad {}^{F}\!/_{km} \tag{7}$$

Where L_i is the pipeline's exposed capacitive coupling length in kilometers, V_p becomes 0 if the pipelines are earthed solidly or through a very low impedance, and Q_P can be written as in equation (8) using equation (3).

$$Q_p = -P_P'^{-1} P_{pC}' \left(P_C' - P_{Cp}' P_p'^{-1} P_{pC}'\right).^{-1} V_C \ \frac{C}{km} \tag{8}$$

The charging currents of the pipelines are determined by equation (9), since the phasor equivalent of the current $i=dq/dt$ is $I = j\omega Q$. Therefore, expression (10) provides the discharge current that passes through the body of a person who contacts pipeline *I*.

$$I_p = j\,2\pi f\,Q_p \quad {}^{A}\!/_{km} \tag{9}$$

$$I_{p(i)} = -j2\pi f 10^3 L_i Q_{p(i)} \quad mA \tag{10}$$

The distance between the pipeline and the line phases is no longer constant if the pipeline or a portion of it is not parallel to the power line. Figure 3(a) and (b), respectively, depict two such scenarios. A parallelism exposure condition, in which the pipeline is parallel to the power line with an analogous distance from the power line provided by (11) and under the condition in (12), can be created in both situations from the non-parallel pipeline exposure. In both equations, x_{Eq} is the geometric mean distance between the pipeline and the power line, where x_1 and x_2 are the pipeline's minimum and maximum distances, respectively.

$$x_{Eq} = \sqrt{x_1\, x_2} \quad m \tag{11}$$

$$ {}^{1}\!/_{3} \le {}^{x_1}\!/_{x_2} \le 3 \tag{12}$$

In order to maintain adequate accuracy when calculating the mutual parameters between the pipeline and the power line, the restriction of equation (11) is used. The length of a non-parallel pipeline section is essentially limited by this constraint, requiring the pipeline to be divided into multiple pieces, each of which is transformed into a parallel segment to the power line. Using the formula in (13), the total pipeline voltage to earth for an insulated pipeline with several parallel and non-parallel exposure portions can be computed as the mean of the voltages in each section weighted by its length to the pipeline's overall length. The current that would pass through a person's body if they touched or came into contact with the pipeline may be calculated using this voltage. Additionally, double-circuit power lines can be subjected to an extension of the matrix analysis method previously described.

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$$V_P = \frac{1}{L} \sum_{I=1}^{N} V_{P(J)} \, L_j \quad V \tag{13}$$

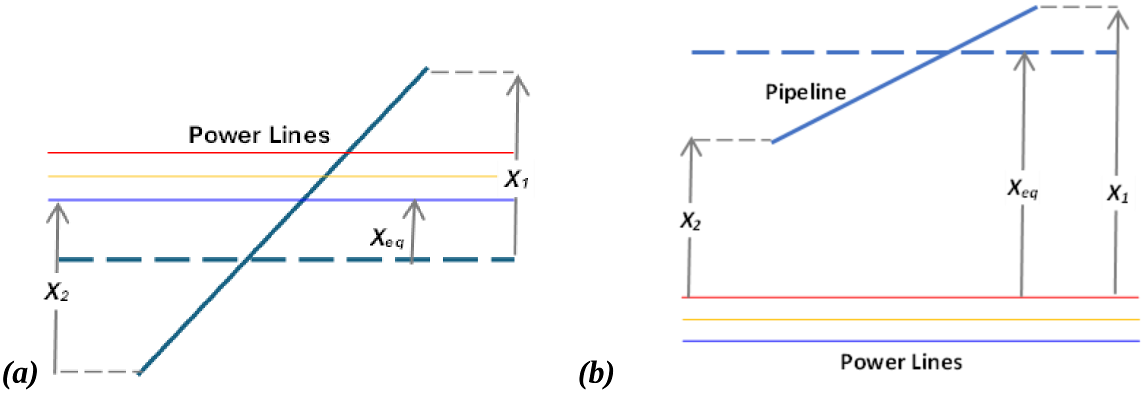

Figure. 3. In cases of oblique exposure close to a power line (a) and crossing a power line (b), non-parallel exposures are converted to parallel exposures between the pipeline and power line.

2.2. Modelling the Resistive Interference

In the event of a line-to-ground fault on the transmission line or a lightning strike, resistive interference is more likely to happen. During such occurrences, a massive cone-shaped voltage is produced inside the tower's grounding system. Pipelines within this "cone" shaped voltage cloud may cause voltage to be transferred to their metallic structures, especially where coating flaws are present. Because of the possible voltage generated between the pipeline structure and the ground soil in the vicinity of the voltage cone-shaped cloud above the underground pipe section, this allows a high risk of worker safety when in touch with the stroked portion of the pipeline. Consequently, for contact voltages above 65 V or 1000 V for long-term and short-term interference, respectively, it is crucial to adopt high levels of structural and personnel protection [11–12]. Electric utilities provide high-voltage shock protection equipment as part of their on-site safety protocols. Pipelines built next to high-voltage transformers or electric substations may occasionally be subject to additional regulations.

2.3. Modelling of the Inductive Coupling Effect

Another problem that occurs when metallic structures are present in or near the UHV transmission OHLs is inductive electromagnetic interference. The pipeline segments shown in Figure 4 are inside the zone of influence namely sections A-B, B-C, and C-D. Figure 4 depicts the inductive coupling mechanism and zone of influence. The inductive effect, or induced

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voltage linked with nearby metallic pipeline structures, is what causes the EMI. The following situations increase the likelihood of observing elevated amounts of electromagnetic interference:

- • Overhead lines carrying high electrical currents
- • Use of inadequate pipeline coatings
- • Proximity of pipelines to UHV transmission lines

A potential voltage difference between the metallic underground pipeline sections and ground soil is caused by the resulting magnetic inductive link between the UHV transmission lines and the pipeline, which produces an electromagnetic interference (EMI) and consequently induces electric charges to flow within the pipe sections. This contact voltage, also known as inductive coupling, necessitates the implementation of proper grounding systems and the enforcement of high-standard grounding instructions to workers in situ in order to prevent any unintended losses and damages to personnel or assets [13].

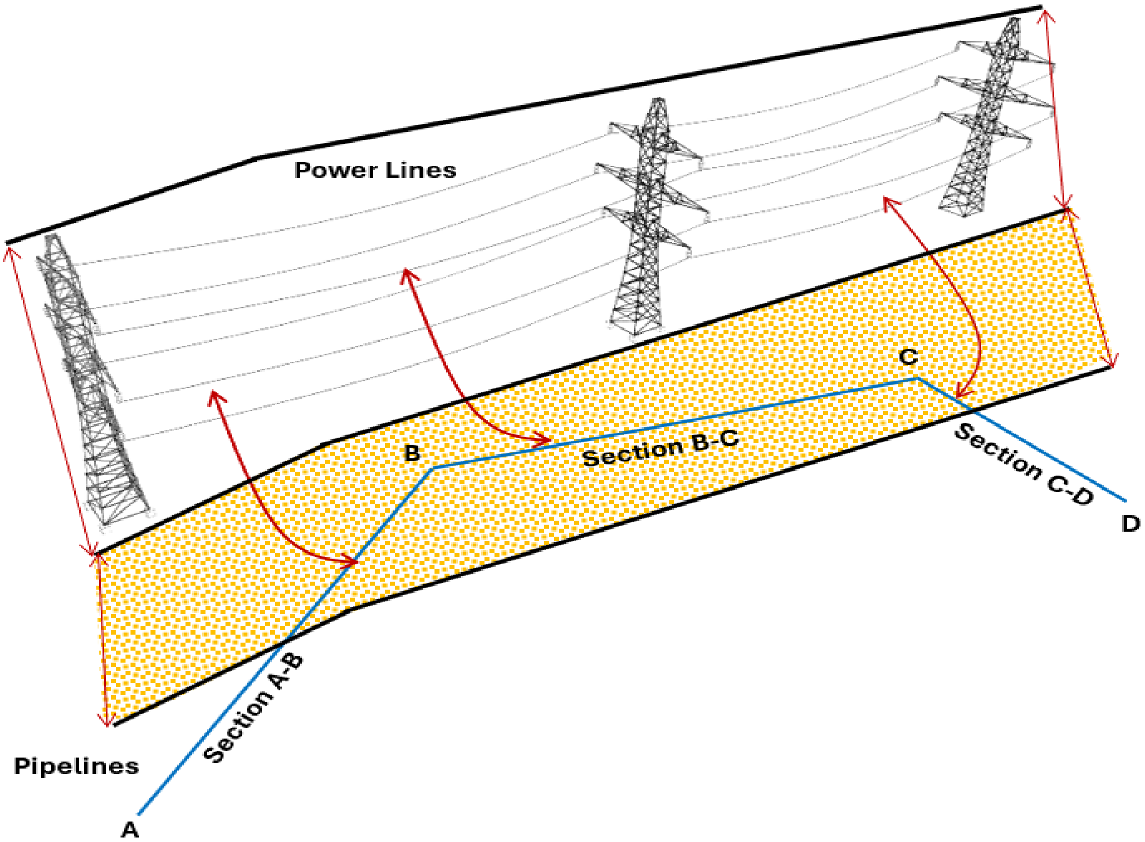

Figure. 4 Electromagnetic interference (EMI) entering the subterranean pipeline sections from the OHL power line.

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Two types of analytical methods are used to determine the voltage produced on the submerged pipeline due to the power line currents: the system of numerical analysis, which includes methods of finite elements and methods of boundary elements; and the study of the nodal network, which uses the condensed analogous circuit impedance matrix of π-form. While the study of the nodal network using matrices yields more reliable results, the calculation may take a long time depending on the computer capacity and accurate analysis if the length that parallels becomes long. Due to the power line, the latter method is used to measure the induced voltage on the pipeline [19].

2.4. Description of the Studied System

An advanced approach to evaluating electrical interference in gas or oil pipelines involves analyzing the nodal network [17]. This method assesses the voltage induced in pipelines by electrical transmission lines under both steady-state and fault conditions. Unlike matrix-based solution methods, this approach uses an iterative process to model the pipeline segments through Thevenin equivalents. Data input is required to define each pipeline segment and the interaction between each segment and the parallel conductors of nearby power lines carrying current. Figure 5 illustrates the process for calculating the induced voltage on the pipeline.

The impedance of the Thevenin equivalent, denoted by voltage V or impedance Z, is measured from the left side looking into the pipeline. As the system progresses, the next section of the pipeline is characterized by its own Thevenin equivalent, represented as V_L and Z_L. Due to the influence of other pipeline sections and external field electrodes, the Thevenin equivalent may need to be combined with additional counterparts. Key parameters such as pipeline diameter, wall thickness, coating resistance, soil resistivity, and other factors are represented by the characteristic impedance Z_o and propagation constant γ [20].

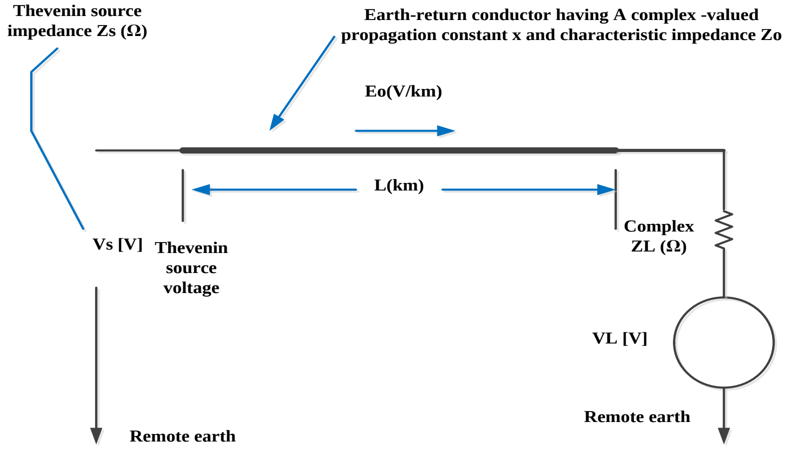

Figure 5. Thevinine equivalent of the induced voltages into the underground pipeline [20]

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2.5. EMI Analysis Using the proposed Modelling Approach

Located along the Riyadh-Salboukh highway, the 380 kV system is suspended in the northern ring road of Saudi Arabia's capital, Riyadh. It so happens that this power transmission OHL is where the pipeline runs. Table 1 provides an overview of the buried pipeline and power line structure requirements. Based on the tower structure dimensions, distances, and spans between towers listed in Table I, this double circuit OHL section is rated at 380 kV with 760 A per circuit. The technical parameters of the ACSR Conductor type (54/7 x 3.08 mm) used in this OHL are listed in Table 1. It should be noted that for single line-to-ground faults, the fault current is set at 62 kA. The physical attributes of the transmission line ACSR conductor and the OPGW conductor are included in Table 1, which also provides a summary of the pipeline's characteristics. According to the standards, 1500 V is permitted in fault situations [10–11]. A study model of the transmission system and parallel water pipeline with nodes 1-6 is depicted in the schematic in Figure 6.

OHL Section	1-2	2-3	3-4	4-5	5-6
Span length (m)	332.4	368	351	352	391

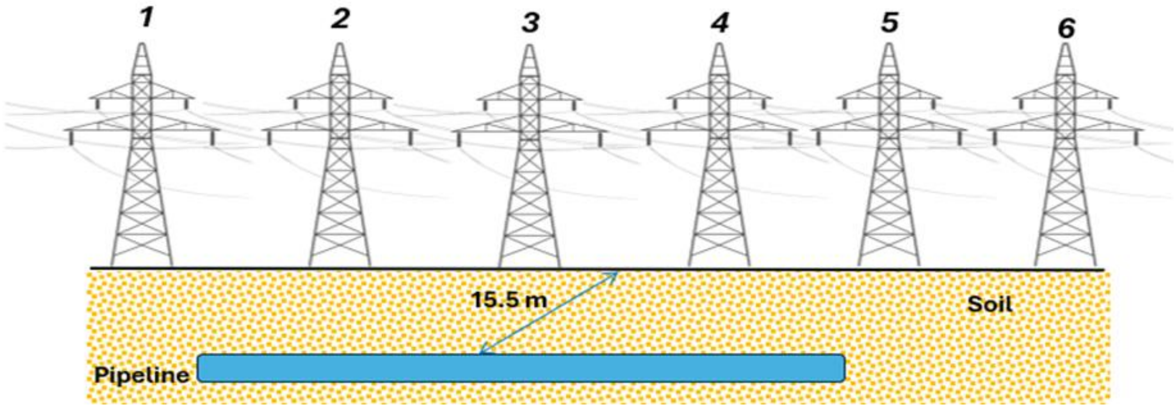

Figure 6. Schematic representation of the study model displaying the parallel water pipeline and OHL system section.

Parameters	Dimension
Specification of the Underground Pipeline	
Distance of the nearest concrete duct wall of the pipeline from the center of OHL (m)	15.5
Width of the concrete duct (m)	1.5
Thickness of the duct wall (mm)	150
Depth of concrete duct, from ground (m)	1.8
Depth of water pipeline in the duct from GL (m)	1.5

<table>
<tr><td colspan="3">Pipeline Service type</td><td>Water Pipeline</td></tr>
<tr><td colspan="3">Diameter of the pipe (m)</td><td>0.6</td></tr>
<tr><td colspan="3">Thickness of pipe (m)</td><td>0.015</td></tr>
<tr><td colspan="3">Material GR. of pipe</td><td>X60</td></tr>
<tr><td colspan="3">Affected Length of pipeline (km)</td><td>3.5</td></tr>
<tr><td colspan="3">Total Length of pipeline (km)</td><td>20</td></tr>
<tr><td colspan="3">Flange rating</td><td>300</td></tr>
<tr><td colspan="3">Coating thickness (m)</td><td>0.005</td></tr>
<tr><td colspan="3">Max. operating pressure (PSI)</td><td>900</td></tr>
<tr><td colspan="3">Design temperature (°C)</td><td>54.4</td></tr>
<tr><td colspan="3">Coating thickness (m)</td><td>0.01</td></tr>
<tr><td colspan="3">Coating resistance (Ωm^2)</td><td>6003</td></tr>
<tr><td colspan="3">ρ-conductor (ρcu)</td><td>17.0</td></tr>
<tr><td colspan="3">μ-conductor (μ0)</td><td>250</td></tr>
<tr><td colspan="3">ρ-coating (Ωm)</td><td>604558</td></tr>
<tr><td colspan="3">Y-coating (Siemens/m)</td><td>7.36 x 10^4</td></tr>
<tr><td colspan="3">Soil resistivity (Ω)</td><td>1000</td></tr>
<tr><th colspan="4">Specification of the OHL and Power Conductor</th></tr>
<tr><th rowspan="2">Parameter</th><th rowspan="2">ACSR</th><th colspan="2">OPGW</th></tr>
<tr><th>OPGW (25C48z)</th><th>OPGW (62L83z)</th></tr>
<tr><td>Cross sectional Area (mm$^{2)}$</td><td>455.03</td><td>96</td><td>96</td></tr>
<tr><td>Overall diameter (mm)</td><td>27.72</td><td>12.5</td><td>16.2</td></tr>
<tr><td>Overall radius (mm)</td><td>13.86</td><td>6.25</td><td>8.1</td></tr>
<tr><td>Conductor weight (kg/m)</td><td>1.5348</td><td>480</td><td>825</td></tr>
<tr><td>Ultimate tensile strength (kN)</td><td>125.5</td><td>71.5</td><td>120.8</td></tr>
<tr><td>Maximum sag (m)</td><td>15m</td><td>-</td><td>-</td></tr>
<tr><td>Outer Conductive Strands</td><td>54 (Aluminum) (1.54mm)</td><td>13 (Aluminum clad steel) Outer aluminum tube (3.9mm)</td><td>13 (Aluminum clad steel) Outer aluminum tube (5.05mm)</td></tr>
<tr><td>Inner Core Strands</td><td>7 (Steel)</td><td>36 (Optical fibers)</td><td>36 (Optical fibers)</td></tr>
</table>

Table 1. The design of pipeline system and the OHL-conductor system.

Although the study's goal is to identify the induced voltages on the Riyadh-Salboukh pipeline, it is extremely prudent to do so where the transmission line passes parallel to the pipelines, as this is where EMIs have the most impact. Under both steady-state and fault scenarios, modeling and simulation of all associated parameters and data are employed, and the results are compared with acceptable standard limits. Only 15V of induced AC voltage is permitted on the pipeline in steady-state, according to NACE Standard (No. RP0177). This indicates that the water pipeline needs some kind of mitigation. The water pipeline is subjected to a number of mitigation options. Regarding the fault conditions, one end of the pipeline would experience, for instance, above 2000 V. This illustrates why the pipeline requires induced voltage mitigation.

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3. Results

According to the Saudi Electricity Company's (SEC) standard, a 1 kΩ-m soil resistivity has been taken into account in this study. Real data is used to create the study model, and proposed model is used to run simulations. It should be noted that the shunt, which is a 5 Ω resistance that can be inserted at pipeline nodes 3 and 4 (shown in Figure 6), can help reduce the induced voltages on the pipeline, which in this instance were higher than the permitted norm. Except in cases when the currents are fault current (62 kA), the same approach is applied when modeling the fault current.

3.1. EMI Analysis without Mitigation

At first, the Riyadh-Salboukh transmission system examination was carried out without any EMI mitigation on the OHL. In order to properly mitigate the seriousness of operating this 380kV system in conjunction with the water pipelines, this analysis is seen to be crucial. The transmission system and the induced voltages at various nodes are displayed in Figure 7.

According to the previously mentioned standards, the voltages above 15 V should be mitigated. Figure 7 shows that the induced voltages on nodes 3 and 4 have a lower induced voltage, while the other nodes at nodes 1 and 2 still have a higher induced voltage than allowed standards. Initially, a shunt resistance (15 Ω) was added at the pipeline nodes 1 to 6 (in Figure 6) to mitigate the induced voltages on the pipeline, which in this case were above the value of the allowed standard. Additional mitigation should be done with different resistances besides taking 40 kA fault current, which is thought to be more reasonable.

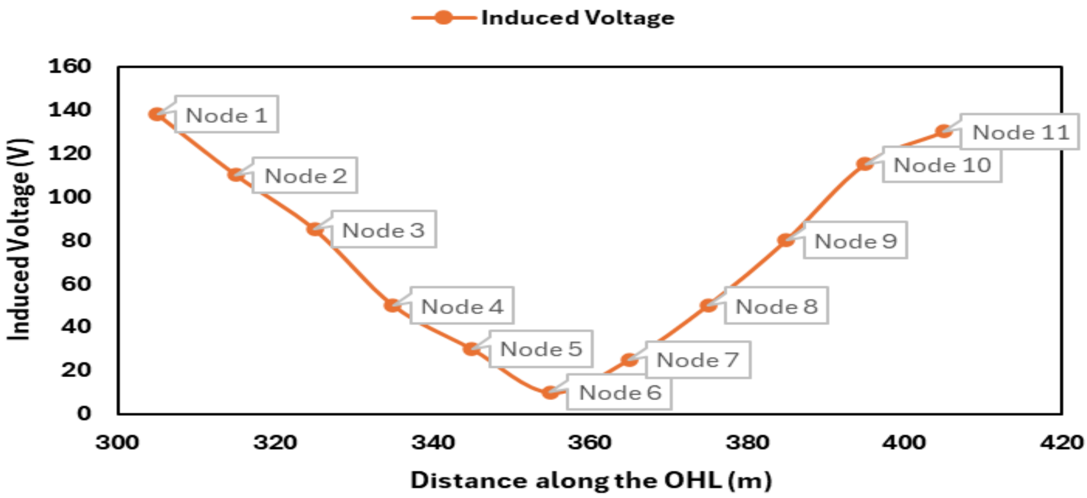

Figure 7. Induced voltages (without mitigation) at different nodes along the OHL system.

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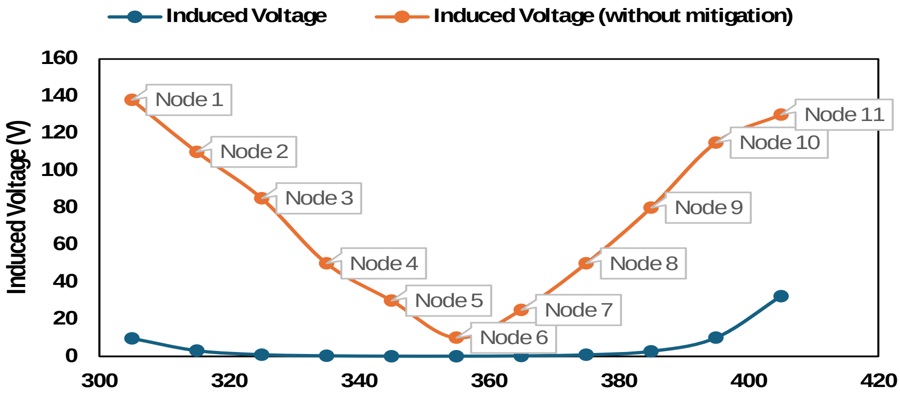
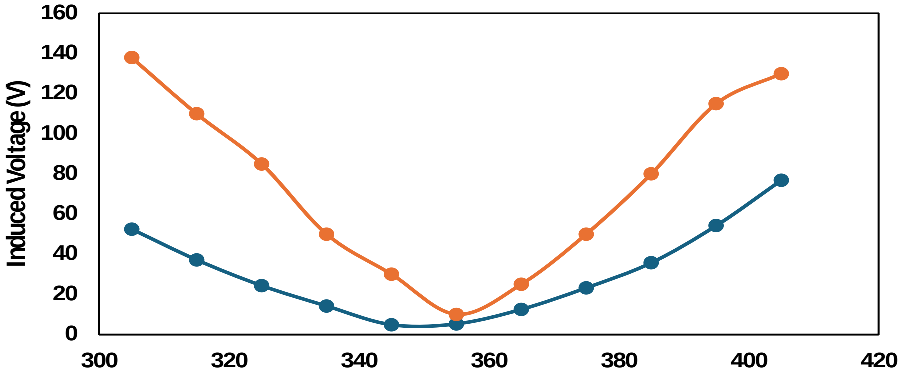
3.2. EMI Analysis with Resistance Mitigation

The prior case's analysis demonstrated that the maximum allowable limit was surpassed, necessitating the mitigation of the EMI issue in the OHL system that is the subject of this study. The authors suggest using resistances as a mitigating strategy. To see how the various resistance values affect the induced voltages, this solution has been investigated. The induced voltages at various node distances with mitigation wire resistances are displayed in Figure 9(a)–(c). With the exception of node 11, the results of Figure 9(a) unequivocally demonstrate that 0.1Ω wire resistance restricts the induced voltage at all nodes to the conventional level (below 15 V). With the exception of nodes 1-3 and 8-11, Figure 9(b) demonstrates that the induced voltage is limited by 0.5Ω in every node. At nodes 4–7, the 1Ω restricts the induced voltage to the standard limit, whereas at the other nodes, the induced voltage falls short of the standard value, as shown in Figure 9(c). The comparison in Figure 9 makes it clear that the best value to reduce the induced voltage on the pipeline is 0.1Ω wire resistance based on the results obtained.



(a)



(b)

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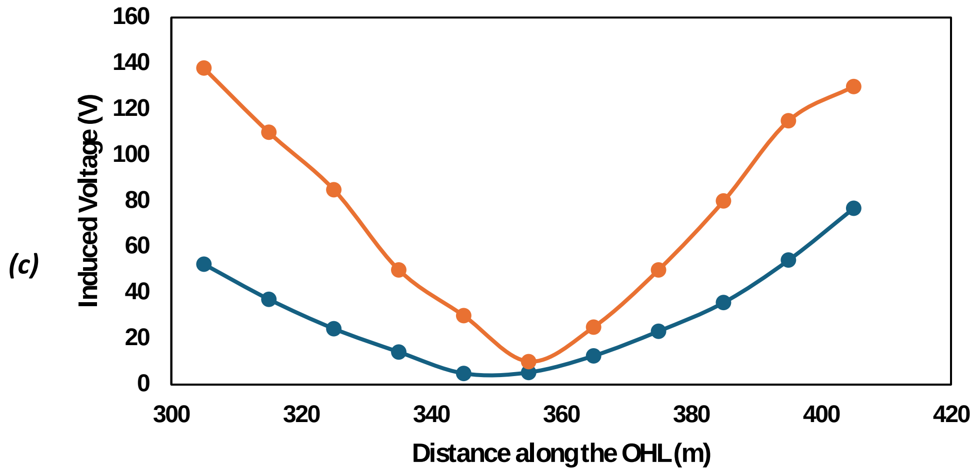

Figure 9. Induced voltages (with mitigation) at different nodes along the OHL using: *(a)* 0.1Ω *(b)* 0.5Ω *(c)* 1Ω.

4. Conclusion

This article investigates the EMI problem produced by the ultra-high voltage transmission OHL on the subterranean water pipeline using gradient control wire installation method. Interference issues affecting pipelines in common right of ways or near ultra-high voltage transmission lines have been resolved for important sections of the underground pipeline to the transmission line using the most cost-effective wire resistance reduction approach. The suggested solution met the majority of the known requirements, including the standards in [14-17]. For subterranean pipelines that run in parallel segmented lengths of up to 10 km, the pipeline encounters an induced voltage that creates inductive coupling at steady-state and fault circumstances, similar to how an overhead line flows.

The soil resistance applied to the pipeline's segmented portion has a significant impact on the EMI analysis. As a result, defining appropriate ground soil resistance is critical for predicting acceptable results. The advice for mitigating the influence of EMI caused by transmission OHLs on buried metallic pipes, as well as other associated dangers that can be minimized or avoided. Soil resistance measurements along the pipeline's physical route and laterals must be taken into account at all points along the pipeline. In addition, the average pipeline coating resistance is used and measured, which improves accuracy. When conducting an EMI evaluation, numerous assumptions are typically made due to a lack of field data and missing acquired data, such as the bonding of metallic pipeline information to the distribution network. The case study offered suggests paying special attention to the following:

- Contractors working to construct and bury pipelines near high-voltage lines must be closely monitored to guarantee complete commitment and compliance with the local electric utility's shock risks restrictions.

- Implementing coating fragments and corrosion analysis on segmented pipe sections near high-voltage lines with increased potential. It is advised to enforce a cut-off voltage (2V) until the soil resistance around the towers is less than 1 kΩ-m.

- Examine voltages caused by fault currents in pipelines, even if no steady-state operation is seen.

- Prevent personal and asset harm by monitoring potential and electromagnetics to prevent corrosion and coating damage.

Refrences

[1] P. Czarnywojtek, W. Machczynski, “Computer simulation of responses of earth-return circuits to the AC and DC external excitation,” European Transactions on Electrical Power, vol. 3, pp. 173-83, 2003.
[2] K. Kopsidas, I. Cotton, “Induced voltages on long aerial and buried pipelines due to transmission line transients,” IEEE Transactions on Power Delivery, vol. 23, pp. 1535-1543, 2008.
[3] M. M. Saied, “The capacitive coupling between UHV lines and nearby pipelines,” IEEE Transactions on Power Delivery, vol. 19, pp. 1225-1231, 2004.
[4] A. I. Metwally, F. Heidler, “Mitigation of the produced voltages in AC overhead power-lines/pipelines parallelism during power frequency and lightning conditions,” European Transactions on Electrical Power vol. 15, pp. 351-69, 2005.
[5] H. Isogai, A. Ametani, “Hosokawa, Y. Basic investigation of induced voltages to a buried gas pipeline from an overhead transmission line,” ICEE Proceedings, PP. 361-365, 2004.
[6] M. G. Amer, “Novel technique to calculate the effect of electromagnetic field of HVTL on the metallic pipelines by using EMTP program,” COMPEL International Journal of Computations and Mathematics in Electrical Engineering, vol. 26, pp. 75-85, 2007.
[7] M. H. Shwehdi, U. M. Johar, “Transmission line EMF interference with buried pipeline: Essential & Cautions,” Proceedings of the International Conference on Non-Ionizing Radiation, UNITEN, Malaysia, 2003.
[8] L. Liu, Z. Yu., J. Zhe, H. Jianhong, W. Liu., "Observation Research on the Effect of UHVDC Grounding Current on Buried Pipelines," Energies, vol. 12, pp. 1279, 2019.
[9] A. B. Kazeem, A. Akinlolu, T. Bolanle, A. Adisa, M. Adnan, H. Yskandar, “AC Induced Corrosion Assessment of Buried Pipelines near HVTLs: A Case Study of South Africa,” Progress in Electromagnetics Research, vol. 81, pp.45-61, 2018.
[10] “Electrical Coupling Study, Pacific Northern Gas, Prince George to Prince Pupate Gas Pipeline”. Technical Report, 1995.
[11] CIGRE: Guide on the influence of high voltage AC power systems on metallic pipelines, 1995.
[12] J. Ma, F. P. Dawalibi, “Computation and measurement of electrical Interference Effects in Aqueducts Due to a Nearby Parallel Transmission Line,” International Symposium on Electromagnetic Compatibility, Beijing, pp. 215-218, 1997.
[13] Y. Li, F. P. Dawalibi, J. Ma, “Electromagnetic Interference caused by a power system Network and a Neighboring Pipeline,” Proceedings of the 62nd Annual Meeting of the American Power Conference, Chicago, pp. 311-316, 2000.
[14] NACE RP0177: Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems, 2000.

Received: 06-10-2024 Revised: 15-11-2024 Accepted: 10-01-2025

[15] NACE TM0497 (No. 21231): Measurement techniques related to criteria for cathodic protection on underground or Submerged Metallic Piping Systems, 2012.
[16] CAN/CSA-C22. 3 (No. 6-M91): Principles and Practices of Electrical Coordination between Pipelines and Electric Supply Lines, Canadian Standards Association, 1991.
[17] http://www.ground-it.com/software.htm (accessed on 10-01-2019).
[18] Power Systems Modelling and Fault Analysis Theory and Practice Newnes Power Engineering Series, pp. 74-199, 2008.
[19] R.D Southey, F. P. Dawalibi, “Computer Modelling of AC Interference Problems for the Most Cost-Effective Solutions,” NACE International, pp. 564, 1998.
[20] F. P. Dawalibi, “Analysis of Electrical Interference from Power Lines to Gas Pipelines”, IEEE Transactions on Power Delivery, Vol. 4, No. 3, pp. 415-421, 1989.