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EMF Analysis for a 380kV Transmission OHL in the Vicinity of Buried Pipelines

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ABSTRACT The induction of Electromagnetic Fields that are generated through the interaction of high-voltage transmission lines with neighboring buried metallic pipelines produce uncontrolled hazardous potential voltages, which can infringe safety limits. The paper presents the findings of the electromagnetic interference effects on water buried pipelines constructed within the vicinity of an Extra High-Voltage 380 kV transmission overhead line (OHL) in Riyadh-Salboukh route within the Saudi national grid power network. The presented case study showed that some segments of the buried pipelines under this line have not experienced voltages that exceeded the standard limits for the steady-state condition. However, in the event of L-G fault currents (short circuits), the pipelines experienced a voltage level that is above the local electric utility safety limits. Therefore, the work produced implemented the mitigation method of gradient control wires to reduce the potential voltages experienced by the pipelines to enforce the safety limit. The variation of wire resistance has been proven to be a feasible solution to reduce the excessive induced voltages. The comparison has shown that a 0.1 Ω is sufficient to maintain the safe limit for at least this line. These findings may vary depending on the OHL design and site topology.

INDEX TERMS Electromagnetic field, EM interference, gradient control wires, induced voltage, mitigation system, transmission lines, water pipelines.

I. INTRODUCTION

Sharing of normal passageways by water, gas, and oil buried pipelines and power transmission overhead lines (OHLs) is becoming quite common. Voltages can be initiated in such covered pipelines because of the nearness of electrical cables in regions where they share the environmental corridor. These voltages can influence the working personnel, pipeline-related hardware, and pipeline cathodic security frameworks. Therefore, the integrity and safety of the pipeline may be jeopardized, leading to high maintenance and repair costs to the pipeline owners and destroying the corrosion protection equipment.

There is an industry-wide need to increase the understanding of the process of high-voltage transmission OHLs crossings nearby the buried pipelines to mitigate their negative effects. As of late, the Electromagnetic Interference (EMI) problem in the case of high-voltage OHL crossings over buried pipelines has been investigated using advanced computer modelling software as found in [1]–[4].

Further extra protecting wires underneath the power line conductors are explored for reducing the induced voltages under direct and indirect lightning strikes to the high-voltage power conductor. In fact, the work presented in [5], [6] presented the impact of different OHL configurations nearby gas pipeline on the induced voltage using Electromagnetic Transient Program (EMTP).

The contextual analysis of the Extra-High-Voltage (EHV) 380kV transmission OHL (as the one studied here and located in the Eastern Province of Saudi Arabia) requires a precise EMI study relying upon predicting a proper soil resistance for the existing fragments within the metallic pipeline and its normal coating resistance [7]. The buried depth anode has no impact on the corrosion of the pipeline [8]. In [9], AC induced corrosion risk assessment indices are calculated using Carson's concept of mutual coupling impedances between the buried pipelines and high-voltage transmission OHLs. However, the developed Graphical User Interface (GUI) model is only applicable to the case study site at Strydpan in South Africa.

In this work, a practical case study is established for the EHV 380kV transmission OHL in the vicinity of water buried

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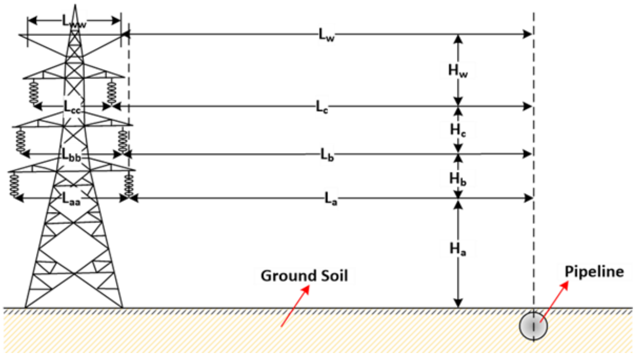


FIGURE 1. **The schematic of the transmission line and a buried pipeline.**

pipelines using CONduction and INDuction (CONIND) computer software to investigate the EMI effect due to the induced line voltages. The study is of significant importance to ensure that the induced EHVs due to the mutual inductance between OHLs and pipelines during short circuit conditions is not very high to, therefore, avoid the damage of the corrosion protection on the water pipelines. The feasibility of the mitigation of the developed CONIND model over induced-voltage on the water pipeline is examined via various short circuit case studies with shunt resistance added at the pipeline nodes while taking into account the soil resistivity variation.

II. GENERAL BACKGROUND ON HIGH-VOLTAGE INDUCED EMFs

It is a common practice to study the impact of electromagnetic coupling effects for EHV lines built above-buried pipelines to predict the line risks for steady-state conditions and in the event of fault currents to guarantee omitting hazardous or harmful voltages. The metallic structures (e.g., pipelines) that run within the area of constructed high-voltage lines are normally exposed to three types of coupling effects, namely: (i) *Inductive*, (ii) *Capacitive*, and (iii) *Resistive* couplings.

A. EFFECT ON PIPELINES EXPOSED TO HIGH-VOLTAGE EMFs

The *inductive* coupling (indicated as L in Figure 1) occurs when the metallic pipeline is located within the alternating magnetic field. The mutual perpendicular coupling between the pipeline and the three-phases and ground are indicated in Figure. 1 with subscripts 'a', 'b', 'c', and 'w', respectively. The voltage within the terminations of the pipeline section is expected to linearly change with its parallel length and is significantly changing concerning the soil resistivity. Inductive coupling affects both the pipelines above and below ground. When the power line operates in a steady state, the electromagnetic field generated by the three AC phases of the OHL usually balances one another and considerably reduces the induced voltage on pipeline's net capacity.

This is not the situation if the OHL phases and ground experience asymmetrical fault conditions (i.e., non-uniform power flow). It is more likely that more voltages can be generated in the event of imbalanced EMF distribution with the line phases. In both cases, one should ensure that such induced voltages would not be too high.

The *Capacitive* coupling (indicated as H in Figure 1) only impacts the above-ground pipelines. The capacitive coupling between the ground surface and three-phases and ground are indicated in Figure. 1 with subscripts 'a', 'b', 'c', and 'w', respectively. For this case the induced voltage does not show any variation with line length. Capacitive coupling is generally a secondary impact in terms of the complete voltage range induced into a pipeline and is important for those parallel to OHLs. Pipelines buried beneath the ground are shielded from the transmission line's electrical field and cannot be influenced by the capacitive coupling.

The *Resistive* coupling between the high-voltage OHL and the buried pipeline exists in the occasion of current leakage into the ground. A good example of that is the occurrence of a line-to-ground (L-G) fault near the location of the buried pipeline, which might cause an increased potential voltage near the bases of the OHL towers (i.e., increased ground local potential). This brings the pipeline to danger in combination with the elevated rate of inductive bonding that is taking place in such scenario.

B. STANDARDIZATION OF EMF AND VOLTAGE LIMITS

Since the early 1970s, the problem of induced voltages on pipelines has been investigated by NACE, which is one of the first to provide recommendations regarding corrosion and safety measures. Multiple attempts and revision of this standard code of practice took place in 1995, 2000, and lately in 2007. These revisions have introduced the NACE SP0177 entitled as "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems" [14], [15]. This report contains recommendations and guidelines for instrumentation and safety measures.

The standard also provides a method to predict the voltage drops that can be performed through structure-electrolyte. Another standard is the well-known CAN/CSA-C22.3 No. 6-M91 that is used by the Canadian authorities as an official document for electrical coordination between pipelines and overhead transmission lines [16]. Both of the abovementioned standards (NACE and CAN/CSA-C22.3 No.6-M91) strongly recommend monitoring and reducing the induced potential voltage (if more than 15 V) into pipelines for EHV electrical networks.

III. DESCRIPTION OF CONIND MODEL TO PERFORM EMF ANALYSIS

A schematic diagram is depicted in Figure. 1 to illustrate the overall OHL – Pipeline model that is constructed in CONIND. In this model, it is assumed that a 1kA lightning impulses should is assumed. The model utilizes the lightning current and frequency flows. The system tests the OHL conductor of the suspended EHV 380 kV for tower sections 221 – 228. The transmitting scheme uses ACSR conductor and

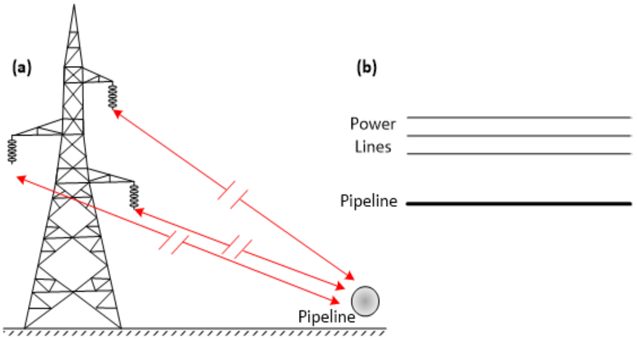


FIGURE 2. Electrostatic or capacitive coupling interference from a power line to a pipeline: (a) capacitive coupling and (b) parallel exposure [18].

an Optical Fiber Ground Wire (OPGW) conductor. At each tower, grounding footing resistances of 3Ω will be adequate to determine whether such pipeline will have greater voltages than permitted in the standard.

A. FORMULATION OF THE ELECTROSTATIC INTERFERENCE (CAPACITIVE EFFECT)

The electrostatic interference imposes a capacitive effect in the case of building electrical OHLs near to underground – buried metallic structures (e.g., pipelines). Only pipelines installed above the earth are subject to capacitive coupling from the conductors of OHLs as illustrated in Figure 2 (a). The so-called Parallelism Exposure is shown in Fig. 2 (b) where the pipeline runs physically in parallel with the phases of the power line [18].

The main phenomenon behind this effect is that such buried structures absorb a relative voltage due to the nature of the ground soil type. Electric utilities tend to ground underground pipelines when it is expected to pass under an EHV transmission line (i.e., rated more than 115kV). The nature of constructing and installing pipelines requires welding the individual section of the pipes, which might reach a total length of 300 m. The effect of electrostatic interference resulting from the capacitive coupling with the transmission line voltage is not of concern after completion of the pipeline due to the leakage of electric charges to earth, which can be minimized through metal coating [18]. The pipeline voltages for a given pipeline exposure with the power line can be calculated using matrix analysis techniques [18]. The self – potential coefficient of a pipeline close to the earth is given by (1) where h_p is the pipeline's height above ground measured from the pipe's center, and r_p is the pipeline's radius, both are in m.

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

The partitioned matrix form for a multi-conductor system that consists of power lines and pipelines can be expressed as shown in (2).

$$\begin{bmatrix} V_C \\ V_P \\ V_E \end{bmatrix} \begin{matrix} C \\ = P \\ E \end{matrix} \begin{bmatrix} P_C & P_{Cp} & P_{CE} \\ P_{pE} & P_P & P_{pE} \\ P_{EC} & P_{Ep} & P_E \end{bmatrix} \begin{bmatrix} Q_C \\ Q_P \\ Q_E \end{bmatrix} V \quad (2)$$

where V subscripts and multiples 'C', 'P', and 'E' represent the power lines' phase conductors, pipelines and power lines' earth wires, respectively.

The equation is general and allows for the presence of more than one power line with more than one earth wire and more than one pipeline. All potential coefficients in (2) are matrices. The earth wires can be eliminated by substituting $V_E=0$ in (2) which therefore gives the expression in (3).

$$\begin{bmatrix} V_C \\ V_P \end{bmatrix} = \begin{matrix} C \\ P \end{matrix} \begin{bmatrix} P_C' & P_{cP}' \\ P_{pC}' & P_P' \end{bmatrix} \begin{bmatrix} Q_C \\ Q_P \end{bmatrix} V \quad (3)$$

where,

$$P_C' = P_C - P_{CE}P_E^{-1}P_{EC} \quad P_{Cp}' = P_{Cp} - P_{CE}P_E^{-1}P_{Ep}$$
$$P_{pC}' = P_{pC} - P_{pE}P_E^{-1}P_{EC} \quad P_p' = P_p - P_{pE}P_E^{-1}P_{Ep} \quad (4)$$

The next step is to apply the pipelines' earthing constraint to (3). For an insulated pipeline, Q_p is equal to 0 and, hence, from (3) the pipelines' voltages to earth due to capacitive coupling with the power lines can be given by (5).

$$V_P = P_{pC}'P_C'^{-1}V_C V \quad (5)$$

where V_C is the known phase voltages to the earth of the power lines. If a person touches the pipeline i whose voltage is $Vp_{(i)}$, the current that would flow through the person's body is determined by the series combination of his contact resistance to earth and the pipeline's capacitive reactance. In practice, the latter is much greater than the person's resistance and therefore the discharge current is given by (6).

$$I_{P(i)} = j2\pi f 10^3 C_{p(i)} L_i V_{p(i)} \text{ mA} \quad (6)$$
$$C_{p(i)} = \frac{1}{P_{p(i)}} \quad {}^{F}\!/_{km} \quad (7)$$

where L_i is the length of pipeline exposed to capacitive coupling in km. If the pipelines are solidly earthed or earthed through a very low impedance, then V_p becomes 0 and, from equation (3), QP cann be expressed as in (8).

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

Since the phasor equivalent of the current $i = dq/dt$ is $I = j\omega Q$, the pipelines charging currents are given by (9).

$$I_p = j2\pi f Q_p \quad {}^{A}\!/_{km} \quad (9)$$

And so, the discharge current through the body of a person that touches pipeline i is given by expression (10).

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

If the pipeline or some of its sections are not in parallel to the power line, the distance between the pipeline and the line phases is no longer constant. Two such situations

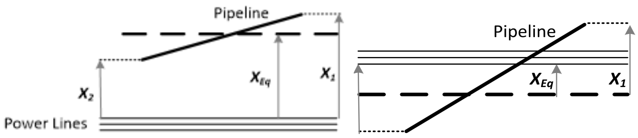


FIGURE 3. **Conversion of non-parallel exposures to parallel exposures between a power line and a pipeline: (left) oblique exposure near a power line and (right) crossing power line [18].**

are illustrated in Figure 3 (a) and (b), respectively. In both cases, the non-parallel pipeline exposure can be converted to a Parallelism condition - where the pipeline is parallel to the power line-, with an equivalent distance from the power line given by (11) and under the condition in (12).

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

$$1/3 \leq x_1/x_2 \leq 3 \tag{12}$$

where x_{Eq} is the geometric mean distance to the power line with x_1 and x_2 as the minima and maximum distances of the pipeline to the power line.

The constraint of (11) is applied in order to maintain sufficient accuracy in calculating the mutual parameters between the pipeline and the power line. This constraint effectively places a limit on the length of a non-parallel pipeline section, which necessitates dividing the pipeline into a number of sections each of which are converted to a parallel section to the power line.

For an insulated pipeline having a number of sections of both parallel and non-parallel exposures, the total pipeline voltage to earth can be calculated as the mean of the voltages in each section weighted by its length to the pipeline's total length as expressed in (13).

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

This voltage can be used to calculate the current that would flow through the body of a person that touches or comes into contact with the pipeline. The matrix analysis technique presented above can be extended and applied to double-circuit power lines.

B. FORMULATION OF THE RESISTIVE IINTERFERENCE

Resistive interference is more likely to occur in the case of either lightning strikes or in the event of a L – G fault on the transmission line. At such events, an enormous amount of voltage is generated within the towers grounding system in the form of a cone. The presence of pipelines within this cone – shaped voltage cloud might incur voltage being transmitted to their metallic structures, particularly in areas of coating defects. This permits a high-risk of personnel safety being in contact with the stroked portion of the pipeline due to the potential voltage created among the pipeline structure and the ground soil in the area of the voltage cone-shaped cloud above the pipe section.

Therefore, it is important to implement high-levels of structure and personnel protection for contact voltage above 65 V or 1000 V for long-term and short-term interference, respectively [11], [12]. Electric utilities enforce the protection measures for their workers on-site by providing high-voltage shock protection gear (e.g., insulated rubber boots, insulated gloves). In some occasions, there are special requirements for pipelines constructed in the vicinity of electric substations or high-voltage transformers.

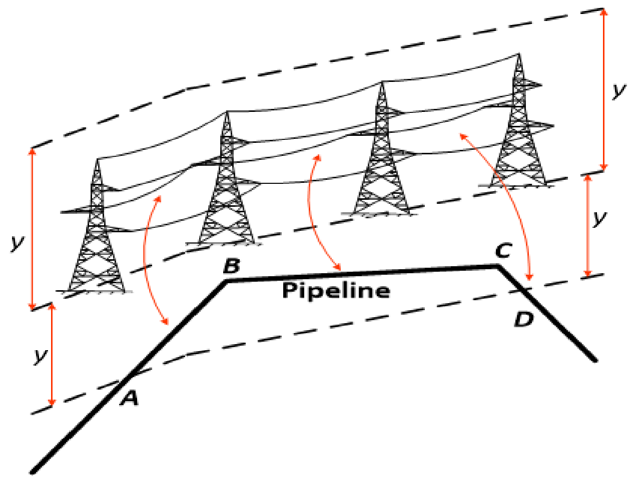


FIGURE 4. **Illustration of EMFs from the power line to the pipeline [18].**

C. FORMULATION OF THE INDUCTIVE EFFECT AND CONTACT VOLTAGES

The inductive interference (i.e., Electromagnetic) is another phenomenon that arises when metallic structures are present within or close to the EHV transmission line. The inductive coupling mechanism and zone of influence are illustrated in Figure. 4 where the sections of the pipeline that fall within the zone of influence are A-B, B-C and C-D. The electromagnetic interference is the result of voltage being induced and coupled with neighboring pipeline metallic structures (inductive effect).

It is more likely to observe increased levels of the electromagnetic interference in the following cases: (i) Overhead lines operating at high electric current, (ii) Utilizing improper pipeline coating, and (iii) Locating pipelines close to the EHV transmission lines. The resultant magnetic inductive link among the EHV transmission line and the pipeline creates electromagnetic interference and hence induces electric charges flowing within the pipe sections. As a result, these induced electric charges in the form of the electric current cause a potential voltage difference between the metallic pipelines and ground soil [12]. This contact voltage (inductive coupling) requires enforcing high-standard grounding instructions to worker in situ and proper grounding system to avoid any undesirable personnel or assets losses and damages [13].

IV. MODELLING AND SIMULATIONS: NODAL NETWORK ANALYSIS

Due to the power line currents, two different types of analytical methods are used to determine the voltage produced

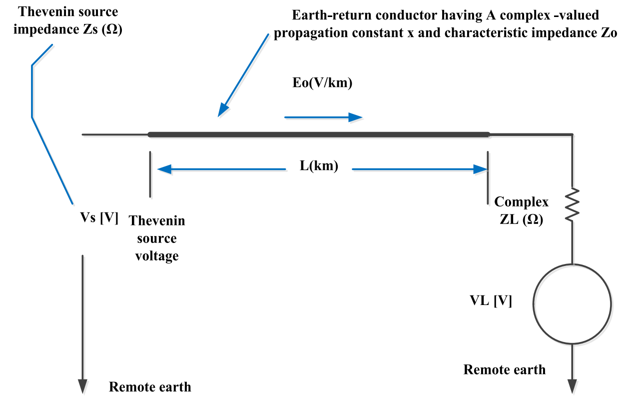


FIGURE 5. Pipeline Thevenin calculation [20].

on the submerged pipeline. One is the system of numerical analysis, which comprises methods of finite elements and methods of boundary elements. The other is the study of the nodal network. When using the numerical analysis method, the calculation may take a long time depending on the computer capacity and accurate analysis if the length that parallels becomes long. On the other side, the study of the nodal network uses the condensed analogous circuit impedance matrix of pi-form which provides more reliable results. Because of the power line, it is therefore commonly used to measure the induced voltage on the pipeline [19].

A. DESCRIPTION OF THE STUDIED SYSTEM

CONIND is an advanced software for electrical interference evaluation of oil or gas pipelines [17]. This software is utilized to assess the severity of the voltage induced from the electrical transmission power lines into pipelines that are exposed to steady-state and fault conditions. The calculation of the program is based on an iterative growth of the pipeline segment equivalents of Thevenin. It does not use a solution technique based on a matrix. To describe each segment of the pipeline and the coupling between that segment and each current-carrying parallel conductor of the power line, data entry is required. The calculation of induced voltage on the pipeline is illustrated in Figure 5.

The impedance of Thevenin with voltage V or impedance is measured from the left side looking into the pipeline side. The latest version of Thevenin becomes V_L and Z_L for the next section of the system. Because of other pipeline sections and field electrodes, it may need to be paired with other Thevenins. The pipeline diameter, wall thickness, coating resistance, soil resistivity and other parameters are represented by the characteristic impedance Z_o and propagation constant γ [20].

B. EMF ANALYSIS OF THE CONIND MODEL

The 380 kV system is along the Riyadh-Salboukh route and suspended in the north ring road of the capital city of Riyadh, Saudi Arabia. The pipeline happens to be routed below this transmission system. The specifications of the power line structure and buried pipeline are summarized in the Table 1 and Table 2, respectively while considering the following description of the OHL system. The OHL section is of the 380 kV Salbouk-Riyadh OHL is a double circuit line (760 Amps per circuit) with tower structure dimensions, distances and spans between towers as specified in Table 1. The line employs an ACSR Conductor (54/7 × 3.08 mm) with the technical specifications tabulated in Table 2. It is worth mentioning that the fault current is 62 kA for Single line to ground faults.

The following Table summarizes the pipeline characteristics while Table 2 shows the physical characteristics of the transmission line ACSR conductor and the OPGW conductor.

TABLE 1. The specification of the pipeline.

Parameters	Dimension
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
Pipeline Service type	Water Pipeline
Diameter of the pipe (m)	0.6
Thickness of pipe (m)	0.015
Material GR. of pipe	X60
Affected Length of pipeline (km)	3.5
Total Length of pipe Line (km)	20
Flange rating	300
Coating thickness (m)	0.005
Max. operating pressure (PSI)	900
Design temperature (°C)	54.4
Coating thickness (m)	0.01
Coating resistance (Ωm^2)	6003
ρ-conductor (ρcu)	17.0
μ-conductor (μ0)	250
ρ-coating (Ωm)	604558
Y-coating (Siemens/m)	7.36 x 10^4
Soil resistivity (Ω)	1000

TABLE 2. Transmission line specifications utilizing ACSR and OPGW.

Parameter	ACSR	OPGW	
		OPGW (25C48z)	OPGW (62L83z)
Cross sectional Area (mm$^{2)}$	455.03	96	96
Overall diameter (mm)	27.72	12.5	16.2
Overall radius (mm)	13.86	6.25	8.1
Conductor weight (kg/m)	1.5348	480	825
Ultimate tensile strength (kN)	125.5	71.5	120.8
Maximum sag (m)	15m	-	-
Outer Conductive Strands	54 (Aluminum) (1.54mm)	13 (Aluminum clad steel) Outer aluminum tube (3.9mm)	13 (Aluminum clad steel) Outer aluminum tube (5.05mm)
Inner Core Strands	7 (Steel)	36 (Optical fibers)	36 (Optical fibers)

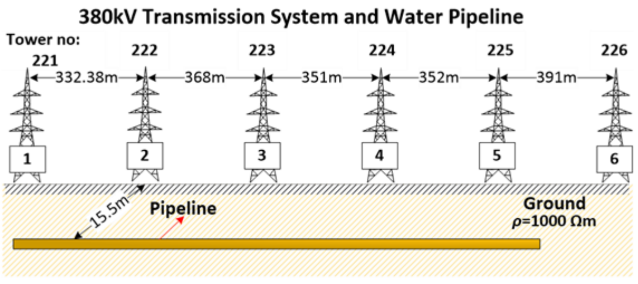


FIGURE 6. Schematic diagram of the study model showing the transmission system and parallel water pipeline.

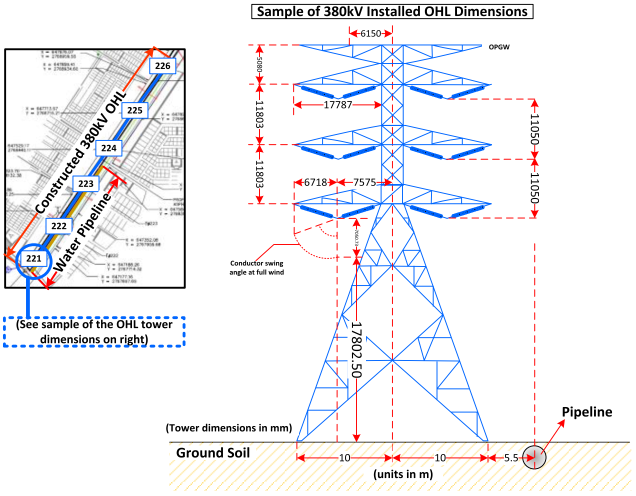


FIGURE 7. Study case transmission system route, model, configuration, and the OHL tower structure dimensions.

While the study is aimed to determine the induced voltages on the pipeline of Riyadh-Salboukh route, it is of high safety precaution to determine such voltages when the transmission line runs parallel to the pipelines where the effect of EMIs is higher. Modeling and simulation of the completely involved parameters and data are used under steady-state and fault conditions and compared with acceptable standard limits.

NACE Standard (No. RP0177) states that only 15V allowed of induced AC voltage on the pipeline in steady-state. This means that some sort of mitigation is required on the water pipeline. Several mitigation scenarios are applied to the water pipeline. The schematic of the transmission line tower is illustrated in Figure 7 showing the tower structure dimensions. As for the fault conditions results of, for example, over 2000 V would be induced at one end of the pipeline. This demonstrates the need for induced voltage mitigation on the pipeline. Standards state that 1500 V is allowed during fault conditions [10], [11]. The schematic shown in Figure 6 demonstrates study model showing the transmission system and parallel water pipeline with node 1-6. Figure 7 shows the Study case transmission system route, model, configuration, and OHL tower structure dimensions.

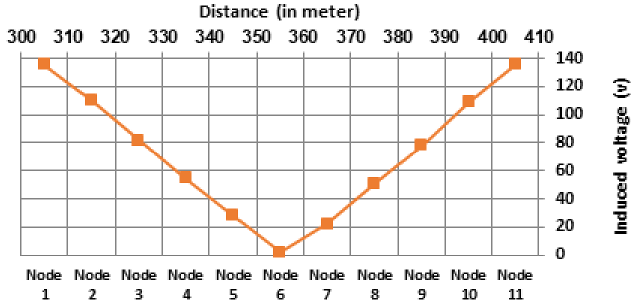


FIGURE 8. Induced voltages at different nodes along with the transmission system without mitigation.

V. RESULT AND DISCUSSIONS

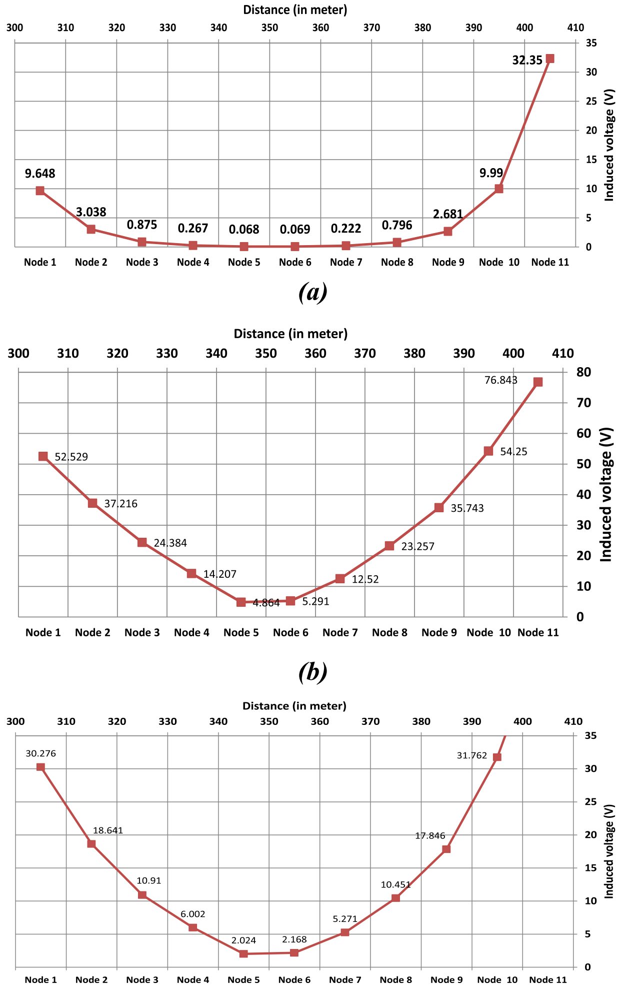
In this study, soil resistivity of 1000 Ω-m has been considered as per the standard used in Saudi Electricity Company (SEC). The Study model is developed using the real data and simulations are carried out using CONIND software. It must be noticed that the shunt is a resistance of 5 Ω that can be added at the pipeline nodes 3, and 4 (in Figure 6) to mitigate the induced voltages on the pipeline, in this case, was above the value of the allowed standard. In the case of modeling the fault current, the same model is used except the currents are of fault current (62 kA). At first, a shunt resistance (15 Ω) that is added at the pipeline nodes 1 to 6 (in Figure 6) to mitigate the induced voltages on the pipeline, in this case, was above the value of the allowed standard. More mitigation should be carried out with different resistances as well as considering 40 kA fault current, which considered more reasonable. According to the previously mentioned standards, the voltages above 15 V should be mitigated. From Table 3, it is noticed that induced voltages on nodes 3 and 4 have a lower induced voltage, the other nodes at node 1, 2 and 6 still at a higher induced voltage than allowed standards.

A. CASE 1: STEADY-STATE OHL (7m GROUND-CLEARANCE) - WITHOUT MITIGATION

The investigation of the Riyadh-Salboukh transmission system has been conducted initially without any mitigation of the EMI on the OHL. This analysis is deemed to be important to find the proper mitigation of the seriousness of operating this 380kV system in parallel with the water pipelines. The results in Figure 8 shows the induced voltages at different nodes along with the transmission system.

B. CASE 2: STEADY STATE (7m GROUND-CLEARANCE) – WITH RESISTANCE MITIGATION

The analysis in the previous case has shown that the maximum permissible limit is exceeded and there is a necessity of mitigating the problem of the EMI within the overhead line (OHL) systems are described in this study. The authors are proposing the mitigation solution through resistances. This solution has been examined to observe the effect of the different resistance values on the induced voltages. Figure 9 (a) -(c) shows the induced voltages at different node distances with



(a)

(b)

(c)

FIGURE 9. **Induced voltages at different nodes along with the transmission system with mitigation resistances of (a) 0.1Ω (b) 0.5Ω (c) 1Ω.**

mitigation wire resistances. The results of Figure 9 (a) clearly show that 0.1Ω wire resistance limits the induced voltage in the standard level (below 15 V) at all the nodes except node 11. Figure 9 (b) shows that the 0.5 Ω limit the induced voltage in all nodes except nodes 1-3 and 8-11. Figure 9 (c) illustrated that the 1Ω limit the induced voltage to the standard limit at nodes 4-7 whereas at the other nodes the induced voltage does not meet the standard value. From the obtained results, it is found that 0.1Ω wire resistance is the most optimum value to mitigate the induced voltage on the pipeline.

VI. CONCLUSIONS & RECOMMENDATIONS

In this paper, the EMI problem caused by the extra high voltage transmission line on the water-buried pipeline was investigated using CONIND software. The interference problems that affect pipelines in common right of ways or near extra-high voltage transmission lines has been solved for the critical location of the pipeline to the transmission line with most economical mitigation method of wire resistance.

TABLE 3. **Induced voltages on different node.**

	Node impedance		Node voltage		
Node no	Real	Imaginary	Real	Imaginary	Magnitude
1	3.296	0.236	21.006	28.262	35.213
2	3.262	0.062	11.834	15.642	19.614
3	3.240	-0.038	1.481	1.866	2.383
4	3.274	0.139	1.137	2.276	2.544
5	3.240	-0.044	-8.420	-11.246	14.048
6	3.277	0.153	-19.21	-26.087	32.400

The suggested solution satisfied most of the known standards such as CSA (6-M91) and NACE (No. RP0177). For buried pipelines, which runs in parallel segmented sections that might reach 10 km, the pipeline experiences an induced voltage that causes an inductive coupling at steady-state and fault conditions that flows along an overhead line.

The EMI analysis is highly influenced by the applied soil resistance for the segmented section of the pipeline. Therefore, it is important to define proper ground soil resistance to predict acceptable results. The recommendations to suppress the impact of EMI induced from transmission OHLs into buried metallic pipelines and the all the associated risks that can be minimized and evaded. Measurement of soil resistance along the physical route of the pipeline and its laterals must be carefully considered at all locations along the pipeline. Also, the average pipeline coating resistance used, and its measurement adds to the accuracy. When EMI evaluation is conducted, various assumptions usually are made due to lack of field data and missing gathered data such as bonding of the metallic pipeline information with the distribution network. The case study presented recommends paying extra attention to the following:

- It is essential to monitor contractors working to construct and bury pipelines near high-voltage lines to ensure full commitment and compliance with the local electric utility safety requirements for shock hazards limits.
- Implementing coating fragments and corrosion analysis on the segmented pipe sections close to the high-voltage line where potentials are expected to be intensified. It is recommended to enforce a cut-off voltage (2V) except that if the soil resistance in the vicinity of the towers is less than 1000 Ω-m.
- Investigate the voltages induced to the pipeline during the occurrence of fault currents even if no potential is observed for steady-state operation.
- Enforce mitigation and avoid personal and asset damages by monitoring the potentials and electromagnetics to control corrosion and possible coating damages.

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