A comprehensive review: Evaluation of AC Induced Voltage on Buried Pipeline Near Overhead Transmission Lines and Mitigation Techniques Comparison

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Abstract – *Metal pipelines used to transport gas and other chemical products are protected by insulating coatings as well as cathodic protection systems. These pipelines sometimes are passed near the power lines, causing induced AC voltage on them. Increasing the AC voltage amplitude on the buried pipelines will increase the risk of electric shock, electric sparking between the equipment connected to the pipeline and the ground or adjacent metal structures, increasing the rate of insulation damage to the pipelines, disrupting the functioning of the cathodic protection system as well as increasing the AC corrosion of pipelines. Therefore, it is necessary to study and evaluate the factors affecting the inductive AC voltage level and provide effective solutions to reduce its destructive effects. In this paper, the inductive voltage of overhead lines on the buried metal pipeline has been investigated under normal conditions of the power system. The amount of induced voltage on the pipelines depends on some factors such as the current of the transmission line, the number of transmission line circuits, the arrangement of the phases, and the distance between the transmission line and the underground pipeline.*

Keywords*: Electromagnetic Interference, Normal Induced AC Voltage, Buried Pipeline, Overhead Transmission Line*

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I. Introduction

Considering the nature and role of the reliable energy transmission networks in today's life and the need to expand the transmission lines, and also taking into account considerations such as lack of space, in many cases, electricity power lines and buried metal pipelines are passed on adjacent corridors. The presence of electromagnetic fields around the power lines induces alternating voltage on the buried metal pipelines. As shown in Fig. 1, power lines in different ways induce a voltage on the adjacent buried metal pipelines [1].

Transmission line can affect its adjacent metal pipelines in three ways: capacitive coupling (electrostatic coupling), resistive coupling (conductive coupling) and inductive coupling (electromagnetic coupling) [2]. The induced voltage by capacitive coupling is created only on above ground metal pipelines that are adjacent to the overhead transmission line. This induced voltage amplitude on the pipeline (not grounded) depends on several factors such as the characteristics of the power line (phase arrangement, frequency and line voltage amplitude) and the characteristics of the pipeline (pipeline length, pipeline distance from the transmission line) [3]-[4].

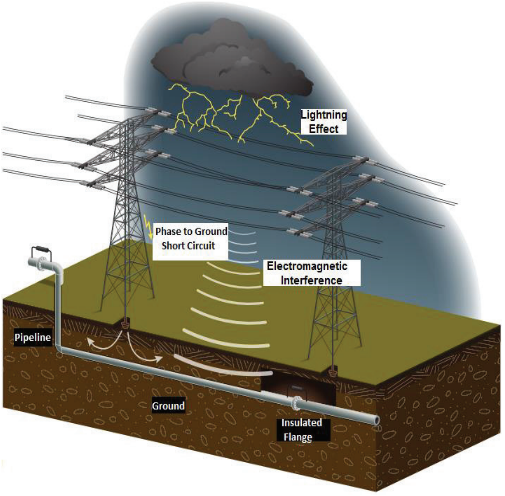

Fig. 1. Different kind of power line effects on adjacent metal pipeline

The conductive coupling overvoltage occurs in the event of a short circuit fault to the ground or direct lightning strike to the power network towers. In fact, due to the discharge of the current to the adjoining ground of the pipeline, the ground potential around the pipeline increases and induces a voltage on the pipeline.

The electromagnetic coupling overvoltage on the pipeline is due to the effect of the AC current passage (load or short circuit) through the transmission line conductors. This factor is the most important reason for inducing AC voltage on the buried metal pipeline (not grounded) [3]-[5]. The highest amount of induction voltage is produced in sections of the pipeline which are in parallel with the high voltage line. The imbalance between the electromagnetic fields of the transmission lines (due to the position of the phases, the imbalance of the three-phase circuit, so on and so forth), the distance between the pipeline and the power line, the length of the parallel pipeline with the transmission line and the angle between the pipeline route and the electricity network line are the factors affecting the AC induction voltage amplitude and peak on the pipeline [5]-[6]. Increasing the distance between the pipelines and the power line, increasing the quality of the pipe's insulation and reducing the parallel length of the pipelines with the power line are the most effective ways to reduce the amount of AC overvoltage induced by the inductive coupling.

The induction voltage on the pipeline can increase the risk of electric shock, electric sparking between the equipment connected to the pipeline and the ground or adjacent metal structures, increasing the rate of insulation damage to the pipeline, disrupting the operation of the cathodic protection system and increasing the AC corrosion of the pipeline. Hence, NACE SP0177 standard has defined the maximum permissible value of the AC induction voltage on the pipelines less than 15 Volts [7]. Although the corrosion caused by the AC current compared to the DC current is very small (less than 2 to 3 percent), if the current density of the AC (i_{ac}) due to the induction voltage is greater than 30 $\frac{A}{m^2}$, the resulting corrosion can be significantly increased [8]. In accordance with equation (1), the value of the AC induction current density, which passes through the defective pipeline cover to ground, depends on the AC induction voltage amplitude, the specific electrical resistance of the soil around the pipe, and the non-insulated area of the pipelines [8].

$$i_{ac} = \frac{8V_{ac}}{\rho \pi d} \qquad (1)$$

where:

i_{ac} : AC density

V_{ac} : AC voltage of pipeline to remote earth

ρ : Soil resistivity

d : Diameter of a circular holiday having an area equal to that of the actual holiday

According to EN 12954, the effect of AC current amount on the corrosion rate of buried metal pipelines is according to Table I [9].

TABLE I
AC CORROSION RATE ACCORDING TO THE INTENSITY OF THE CURRENT DENSITY

current density passes through the pipelines to ground (A/m^2)	Corrosion of the pipeline	consideration
$\leq 20-30$	Insignificant	If the ratio of AC current density to DC is less than 5, and the induction voltage amplitude on the pipeline is less than 15 Volts. Also, the DC current density should be less than $1A/m^2$.
$30 \leq i_{ac} \leq 100$	Medium or unpredictable	-
$i_{ac} \geq 100$	Very high	-

In [2], the electromagnetic interference effects caused by the power lines are investigated on living organisms and metal objectives. In reference [9], authors considered a split factor of overhead transmission line impacts the amount of the induced voltage. The direct effect of lightning on buried cable due to the electric field are modelled in [10]. In reference [11], the induced voltage of transmission line under short circuit fault considering the mutual impedance between the power line and pipeline is evaluated. The safety distance between th pipeline and power line to protect the pipeline's coating from the lightning overvoltage is discussed in [12]. In this paper, the transmission line and pipeline are simulated in different conditions in electromagnetic transient program-rebuilt version (EMTP-RV) software and the number of induced voltage is compared, and finally, effects of some mitigation approaches are compared with each other. Based on comparison, the AC grounding of the pipeline is concluded as the best mitigation method.

II. Case Study Details

The understudied transmission line nominal voltage is 230 kV with nominal current of 650 Ampere. In addition to this information, soil resistivity is considered at $50\,\Omega.m$. The understudied pipeline dimension is 32 inches in diameter and has insulation coating thickness of 3 millimetres.

III. Investigation of the factors affecting the induction voltage on buried pipelines

A. The effect of the parallel length of the transmission line and pipeline

The alternating voltage that is induced along the pipeline is proportional to the length of the path that the transmission line and pipeline are aligned in parallel [13]. Fig. 2 shows the amount of induction voltage on a pipeline at distance of 30 meters from the center of the vertical transmission line. With an increase of parallel path from 200 m to 1,000 m with 200 meters increment steps, the induction voltage also increases with the same ratio.

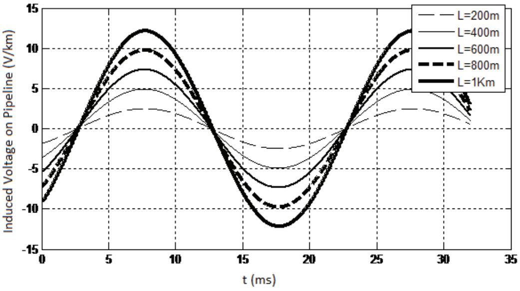

Fig. 2. The effect of path length increasing on the induction voltage on the pipeline

B. The Transmission Lines Configuration

Electromagnetic field changes around the transmission lines depends on the tower's geometrical configuration. In line with the horizontal configuration in the center of the transmission line due to the neutralization of the fields, the inductive voltage is insignificant [14], [15]. As the distance from the center increases, the pipeline is affected by one of the phases and becomes induced to more voltage on it, and then with increasing distance from the transmission line, the amount of inductive voltage will decrease. In networks with vertical configuration, the intensity of the field and the inductive voltage at the center of the transmission line are very high and then decreases with increasing distance from the center of the transmission line. The triangular configuration line's behaviours are between the vertical and horizontal configurations. Fig. 3 shows the different types of 230 kV transmission line. The height of the tower in all configurations is 22 meters and the distance between the phases is 7 meters.

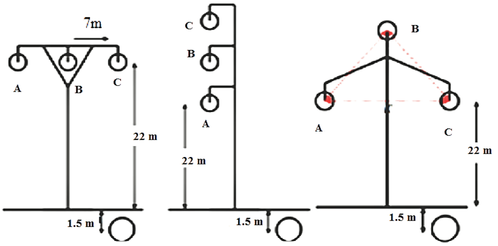

Fig. 3. Different configurations of transmission line

Fig. 4 shows the induced voltage on the pipeline in different configurations of transmission line with different distances from the center of the transmission line [16].

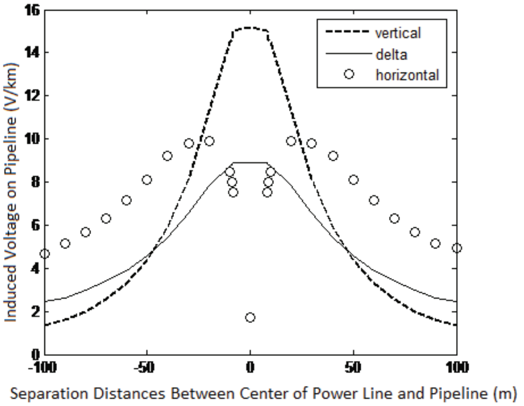

Fig. 4. The inductive voltage on pipeline due to transmission lines with different configurations

C. The effect of distance between phases on the induction voltage amplitude on the pipeline

As the distance between the phases increases, the mutual effect between the phases decreases and the pipeline is more affected by one phase; as a result, greater voltages will be induced on the pipeline. Fig. 5 shows the induced voltage owing to the 230 kV vertical transmission line with phases distance of 6, 7, and 8 meters.

In the case of lines with triangular configuration, as shown in Fig. 6, phases distance may be unequal, in which case the symmetry of the induction voltage on both sides of the transmission line is disturbed and the maximum induction of voltage occurs at distances close to the lower phase, and then, by increasing the pipeline distance from the transmission line, the amount of induced voltage will decrease.

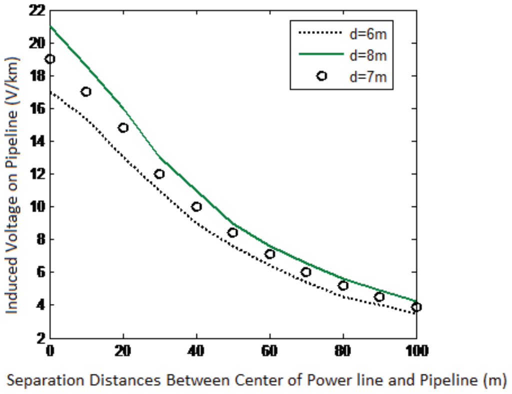

Fig. 5. The effect of phases distance in the vertical configuration on the amount of induction voltage on the pipeline

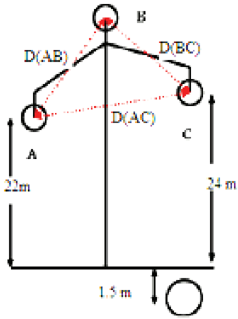

Fig. 6. A triangular shape transmission line with asymmetric phase distances

As can be found from Fig. 7, the amount of induced voltage on the triangle arrangement of transmission line with unequal sides is less than the equal spacing side. This may be due to the coupling effect of phases on each other.

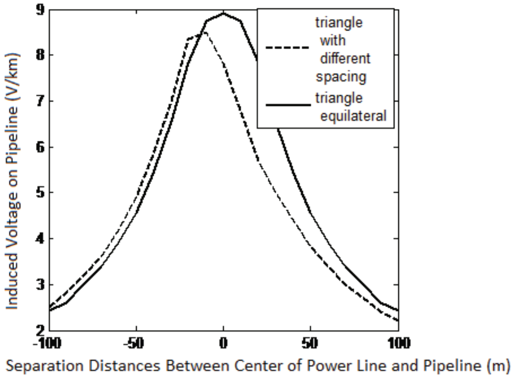

Fig. 7. Comparison of induction voltage in a triangular transmission line with asymmetric and symmetric phases [16]

D. Guard wire's effect on the induction voltage on the pipeline

The disturbance in the magnetic field balance due to the presence of guard wire causes more voltage to be induced on the pipeline. In the case of lines with horizontal configuration, the presence of guard wires leads to loss of symmetry between the two sides of the transmission line at the induction voltage. Fig. 8 shows the induction voltage induced by the 230kV transmission line along with a guard wire on a buried pipeline.

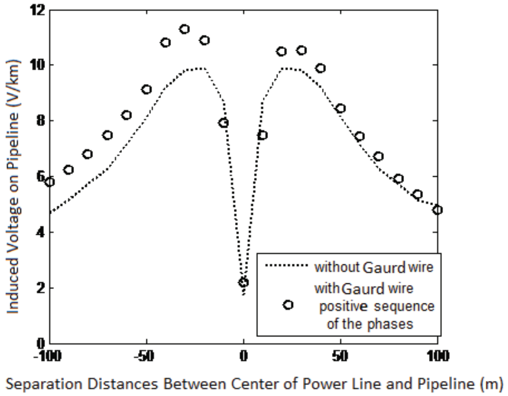

Fig. 8. The effect of guard wire on the amount of induced voltage on the pipeline with the horizontal structure of the transmission line and positive phase sequence

E. The effect of the number of transmission lines on the induction voltage on the pipeline

One of the factors influencing the amount of induction voltage is the number of transmission lines. The arrangement of phases in double circuit transmission lines plays an important role in the amount of the induced voltage. There are four types of phase arrangement for double circuit transmission lines. Fig. 9 shows the different states of phase placement in a double circuit vertical line. The different arrangement of the phases causes variation in the magnetic field around the transmission lines and different values on the induced voltages.

In the first case, double circuit transmission line behaves as same as the single-circuit line, where the magnetic field intensity and the induced voltage are twice the single-circuit line. In the second case, the phases are arranged in such a way that they neutralize each other's fields in the center of the two circuits and reduce the amount of the induced voltage. By increasing the distance from the center of the two circuits, the pipeline is affected by one of the circuits and the amount of th induced voltage increases. Finally, by increasing the distance from the center of the transmission line, the induced voltage will decrease. Fig. 10 shows the effect of phase arrangement in a double circuit line on the induced voltage.

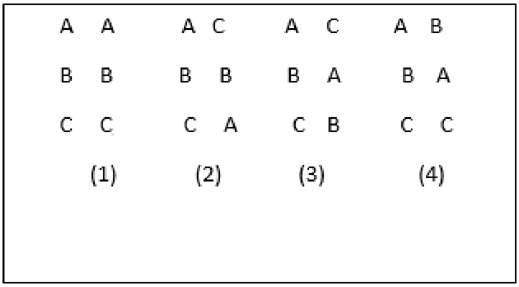

Fig. 9. Different modes of phase's arrangement

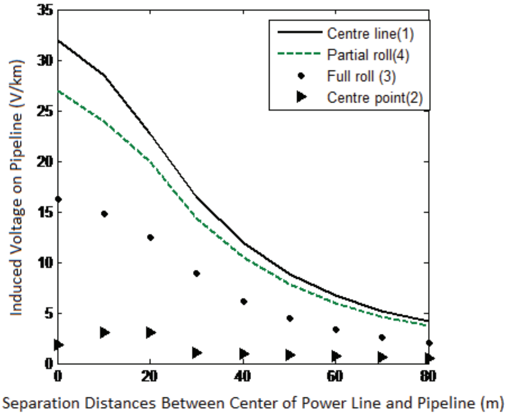

Fig.10. Influence of phase's arrangement in two circuit transmission line on the amount of induction voltage on the pipeline

F. The effect of the transmission line's current on the induction voltage on the pipeline

In order to study the effect of phase current, two transmission lines with different voltage levels have been considered and the induced voltages of them are compared. Specifications of the transmission lines are presented in Table II.

TABLE II
TRANSMISSION LINES PARAMETERS

Nominal Voltage (kV)	Phase Nominal Current (A)	Phases Distances (m)	Tower height (m)
230	650	7	22
400	850	9	24

The simulation results of these two transmission lines are presented in Fig. 11. As it is seen, more voltage is induced on the pipeline as more current passes through the phases due to the increasing magnetic field intensity.

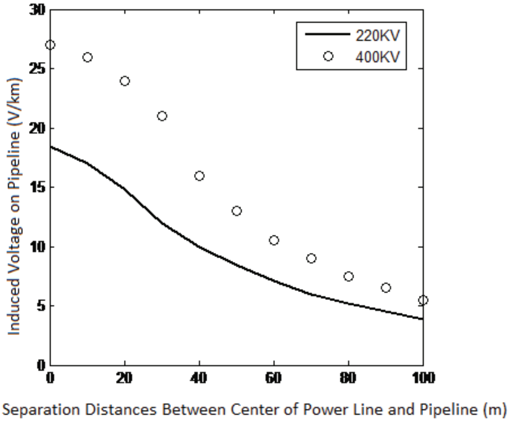

Fig. 11. Comparison of the induction voltage of two transmission lines with different voltage levels (various phases' current) on the pipeline

G. Soil resistivity effect on the amount of induced voltage level

Table III shows the variation in the amount of induced voltage on a pipeline due to soil resistance changes of a 230 kV vertical transmission line with a guard wire. The pipeline is located 30 meters from the center of the transmission line.

TABLE III
THE EFFECT OF SOIL RESISTANCE VARIATION ON THE AMOUNT OF INDUCTION VOLTAGE ON THE PIPELINE

Soil Resistivity (Ω.m)	Induction Voltage amount (V/Km)
100	18.3
200	19.2
300	19.33
400	19.65
500	19.89
600	20.09
700	20.26
800	20.4
900	20.52
1000	20.63

As can be seen, increasing soil resistance does not have much effect on the amount of the induced voltage. Soil resistivity has a monumental effect on the induced voltage in phase to ground fault or lightning strike conditions, so with increasing soil resistance, the induced voltage will increase [16].

IV. AC grounding of the pipeline as the most effective method of induction voltage mitigation, simulation and results

One of the ways to mitigate the amount of induced voltage is frequent earthing of buried pipelines which do not pass the DC current of cathodic protection to earth but passes all AC current in different frequency and various amplitudes [17].

As mentioned in sub-section G of section III, soil resistivity does not have a significant impact on the amount of induction voltage, so two scenarios have been considered and simulated. At first, the condition without earthed pipeline simulated and in the second scenario, the pipeline has been earthed by 1-ohm resistor throughout the pipeline.

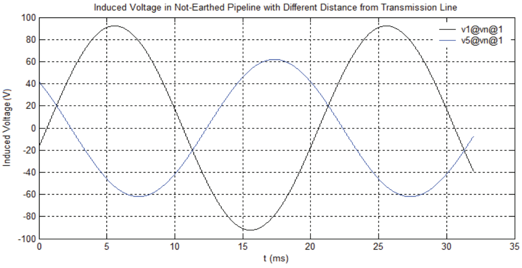

Fig. 12. Induced Voltage amount on Not-Earthed Pipeline

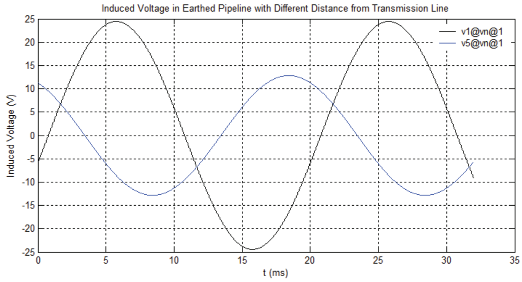

Fig. 13. Induced Voltage amount on Earthed Pipeline

In these two outputs, V1 and V5 represent the effect of pipeline distance from transmission line on the amount of induced voltage which V1 illustrates near distance while V5 depicts faraway distance. From Fig. 12 and 13, it is clearly shown that pipeline earthing is one of the most effective methods to mitigate the induced voltage level on the buried pipeline. As can be seen, frequent effective earthing can reduce the induced voltage amount to a quarter of the non-earthed condition. Furthermore, with the increase in the distance between pipeline and power network transmission line, the amount of induced voltage will decrease.

V. Conclusion

In this paper, several factors which has impact on the amount of induced voltage on the pipeline have been evaluated. As mentioned, distance between the lines current and the pipeline, together with the transmission line corridor distance have a great influence on the induced voltage level. It is also found that soil resistivity is not as important as other factors. Finally, pipeline AC grounding method seems to be an effective method of mitigation as discussed and this idea has been verified based on the results from software.

References

[1] Al-Gahtani, Bander, 2009. *Electromagnetic Interference caused by a High voltage Transmission Network on Buried Pipelines & Communication Cables* (Doctoral dissertation, King Fahd University of Petroleum and Minerals).

[2] Hossam-Eldin, A., Mokhtar, W. and Ali, E.M., 2012. Effect of electromagnetic fields from power lines on metallic objects and human bodies. *International Journal of Electromagnetics and Applications*, *2*(6), pp.151-158.

[3] Ismail, H.M., 2007. Effect of oil pipelines existing in an HVTL corridor on the electric-field distribution. *IEEE Transactions on Power Delivery*, *22*(4), pp.2466-2472.

[4] Saied, M.M., 2004. The capacitive coupling between EHV lines and nearby pipelines. *IEEE Transactions on Power Delivery*, *19*(3), pp.1225-1231.

[5] Martinho, L.B., Silva, V.C., Pereira Filho, M.L., Palin, M.F., Verardi, S.L.L. and Cardoso, J.R., 2014. 3-D finite-element analysis of conductive coupling problems in transmission line rights of way. *IEEE Transactions on Magnetics*, *50*(2), pp.969-972.

[6] Hossam-Eldin, A.A. and Mokhtar, W., 2008, August. Electromagnetic interference between electrical power lines and neighboring pipelines. In *Systems Engineering, 2008. ICSENG'08. 19th International Conference on* (pp. 97-102). IEEE.

[7] SP0177, N.A.C.E., 2007. Standard practice mitigation of alternating current and lighting effects on metallic structures and corrosion control systems.

[8] NACE, T., 2010. 327, "*. AC Corrosion State-of-the-Art: Corrosion Rate, Mechanism, and Mitigation Requirements", NACE Report*, *35110*.

[9] Nassereddine, M., Rizk, J., Hellany, A. and Nagrial, M., 2014. AC interference study on pipeline: OHEW split factor impacts on the induced voltage. *Journal of Electrical Engineering*, *14*(1), pp.27-32.

[10] Klairuang, N., Pobporn, W. and Hokierti, J., 2004, November. Effects of electric fields generated by direct lightning strikes on ground to underground cables. In *Power System Technology, 2004. PowerCon 2004. 2004 International Conference on* (Vol. 2, pp. 1117-1121). IEEE.

[11] Amer, G.M., 2007. Novel technique to calculate the effect of electromagnetic field of HVTL on the metallic pipelines by using EMTP program. *COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, *26*(1), pp.75-85.

[12] Yuan, H., Qi, L., Wu, Y., Cui, X. and Wang, L., 2011, November. Lightning induced voltage on the underground pipeline near overhead transmission line. In *Lightning (APL), 2011 7th Asia-Pacific International Conference on* (pp. 411-415). IEEE.

[13] Frazier, M., Thomas, P., Robertson, H., Dunlap, J. and Morgan, T., 1986. Transmission line, railroad and pipeline common corridor study. *IEEE transactions on power delivery*, *1*(3), pp.294-300.

[14] Ponnle, A.A., Adedeji, K.B., Abe, B.T. and Jimoh, A.A., 2016. Variation in phase shift of multi-circuits HVTLs phase conductor arrangements on the induced voltage on buried pipeline: A theoretical study. *Progress in Electromagnetics Research*, *69*, pp.75-86.

[15] Ametani, A., Nagaoka, N., Baba, Y., Ohno, T. and Yamabuki, K., 2016. *Power system transients: theory and applications*. CRC Press.

[16] Junker, A. and Nielsen, L.V., 2017. Monitoring of the pH Evolution at a Cathodically Protected Steel Surface Subject to an AC Voltage Perturbation.

[17] Revie, R.W. ed., 2015. *Oil and gas pipelines: Integrity and safety handbook*. John Wiley & Sons.