Simulation of interferences between power lines and gas pipelines in unbalanced phase currents state

Ştet Denisa, Micu Dan Doru, Czumbil Levente,
Darabant Laura and Ceclan Andrei
Department of Electrotechnics, Technical University of Cluj-Napoca, Cluj-Napoca, Romania

Abstract

Purpose – The purpose of this paper is to compute the values of induced voltages and currents in an underground gas pipeline, which shares the same right of way with a high voltage power line (HVPL) in unbalanced phase currents regime, in order to detect the possibility of the AC corrosion occurring in the pipeline.

Design/methodology/approach – The analysis of the induced voltages in metallic structures (gas pipeline) was done using a professional analysis and modeling software which uses the electromagnetic field method.

Findings – It was shown that during fault conditions, large currents and voltages are induced on the pipelines, which may pose a threat to operating personnel and equipment. Induced voltages also occur in cases of unbalanced phase currents of the HVPL, which may pose a threat voltage that could lead to damages of the underground gas pipeline due to corrosion phenomena.

Practical implications – Because the electromagnetic field approach involves complicated analytical expression and introduces serious computational difficulties, among which matrix of coefficients representing the set of simultaneous linear equations, the use of professional analysis and modeling software is justified.

Originality/value – The paper reveals that even in unbalanced phase currents regime of the HVPL, the nearby metallic structures that share the same right of way with the transmission line are in danger of degradation because of the induced voltages, whose values exceed the values imposed by regulation.

Keywords Pipelines, Electric power transmission, AC interference, High voltage power lines, Unbalanced regime, Metallic gas pipeline

Paper type Research paper

Introduction

The situations where a buried gas pipeline and one or more high voltage power line share proximal rights-of-way for considerable lengths is a common situation in practice. In this situation, the pipelines located near power lines may capture a portion of the energy encompassed by the conductors' paths, particularly under unfavorable circumstances such as long parallel exposures, unbalanced phase currents and power fault conditions.

The authors are grateful to the Romanian Minister of Education and Research for the financial support in the frame of CABDIAG 22122/2008 Research Programs and TE_253/2010_CNCSIS Project.

COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering
Vol. 31 No. 4, 2012
pp. 1178-1189

0332-1649
DOI 10.1108/03321641211227447

The interference between power transmission lines and pipeline generally consists of an inductive, a conductive and a capacitive part. The capacitive component is ignored for buried pipelines, whereas the conductive part is present only under fault conditions and affects the part of the pipeline that is close to the faulted structure. The inductive component, which is the result of the magnetic field generated by a power line, is present during faults and normal operating conditions or in case of unbalanced phase currents. Due to the inductive interference, voltages and currents are induced in a buried metallic pipeline (Christoforidis *et al.*, 2004). The high quality of present pipeline coatings results in higher induced voltages. These voltages should be kept below certain levels imposed by various standards and regulations.

A recent NACE standard suggests that under normal operating conditions the induced voltage on a pipeline should not exceed 15 V, in order to minimize the possibility of AC corrosion and to ensure personnel safety (NACE Standard, 1995).

The objective of this study is to obtain the values of induced voltages and currents in an underground gas pipeline, by a high voltage transmission line, using a professional analysis and modeling software, in order to detect the possibility of the AC corrosion occurring in the pipeline.

It will pursue a comparison between the induced currents and voltages obtained in normal operating conditions and in case of unbalanced phase currents.

Main section

Field theory approach

There are generally two ways of analyzing electromagnetic interference between transmission lines and parallel pipelines:

(1) by using the conventional circuit method (CCM) along with grounding analysis; or

(2) by using the electromagnetic field method (EFM) (Ma and Dawalibi, 2006).

The procedure of an EFM analysis is as follows. A conductor network which includes the pipeline, the power line phase conductors, and the overhead ground wires together with the towers and grounding systems is modeled. All the conductors in the conductor network are subdivided into short segments and the potential and current on each segment are the unknowns. A numerical method is used to build the matrix which is then solved to yield the unknowns. The EFM produces the total interference effect in a single step, avoiding the separation of the inductive and conductive components which is necessary in the CCM. The limitation of the EFM is that when the common corridor is very long and consists of many circuits, the modeling and computation time can be very long.

The ground conductors are first subdivided into segments of length "small enough" with respect to both wavelength and overall length of the ground network.

Suppose that the modeled network consists of n segments, each one characterized by its internal impedance and coating admittance. Consider that any segment A_k of this group of segments has a total earth leakage current of S_k amperes which is assumed to be uniformly distributed over its surface. Therefore, the following equation gives the longitudinal current at any point $u = v$ of the conductor segment (Dawalibi *et al.*, 1999; Li *et al.*, 2000; Dawalibi and Southey, 1989):

$$I_k(v) = a_k v + b_k \tag{1}$$

where a_k and b_k are constants.

If $A_k(v)$, $E_k(v)$ and $V_k(v)$ are the vector potential, the electric field and the scalar potential at point $u = v$ on the conductor surface, respectively, $A_e(x,y,z)$, $E_e(x,y,z)$ and $V_e(x,y,z)$ are the corresponding quantities at a point $M(x,y,z)$ of the surrounding media. The following fundamental electromagnetic equations can be written:

$$E_e = -j\omega A_e - gradV_e \tag{2}$$

and:

$$E_e = \frac{-j\omega A_k - \partial V_k}{\partial v} \tag{3}$$

Because the vector potential and electric field on the surface of a conductor are parallel to the conductor's axis, only the magnitudes of the vectors need to be shown in equation (3).

Consider that E_{ek} and A_{ek} are the component of the vector with respect to the u axis at the same point $u = v$ of segment k. If we can assume that the conductor insulation thickness is small (or nonexistent), then $A_{ek} = A_k$ (since there is no magnetic flux between the conductor and the earth adjacent to it). Therefore, the following expression is valid:

$$E_{ek} = -j\omega A_k - \frac{\partial V_{ek}}{\partial \nu} \tag{4}$$

which in turn, based on the preceding equations, can be rewritten as:

$$E_{ek} = E_k + \frac{\partial}{\partial \nu}(V_k - V_{ek}) \tag{5}$$

The electric force along the conductor is also given by:

$$E_k = Z_k I_k(\nu) \tag{6}$$

where Z_k is the unit length internal impedance of the conductor.

The difference of potential between the conductor and an adjacent point in earth can be computed with the following expression:

$$V_k - V_{ek} = -Y_k^{-1}\frac{dI_k(\nu)}{d\nu} \tag{7}$$

where Y_k is the unit length admittance of the conductor insulation.

Elementary operations on equations (3)-(7) lead to the following equation:

$$Z_k I_k - Y_k^{-1}\frac{d^2 I_k}{\partial \nu^2} = -j\omega A_{ek} - \frac{\partial V_{ek}}{\partial \nu} \tag{8}$$

This is the fundamental equation which can provide the required information. A_{ek} is the u component of the vector potential caused by all conductor segments on a point $u = v$ of segment k. If A_{ik} and V_{ik} are used to represent the vector and scalar potential contribution of segment i on segment k, the equation (8) can be written as:

$$Z_k I_k - Y_k^{-1} \frac{d^2 I_k}{\partial \nu^2} + j\omega \sum_{i=1}^{n} A_{ik} + \sum_{i=1}^{n} \frac{\partial V_{ik}}{\partial \nu} = 0 \qquad (9)$$

The scalar potential V_{ik} is easily deduced from the vector potential A_i at point $u = \nu$ of segment k. The vector potential A_i caused by a short conductor segment at an observation point M is also easily calculated. This vector potential is a function of longitudinal current I_i flowing in segment i. Therefore, equation (9) contains n unknown functions represented by the longitudinal currents $I_1, I_2, I_3, \ldots, I_k, \ldots, I_n$ on the n conductor segments (Dawalibi *et al.*, 1999; Li *et al.*, 2000; Dawalibi and Southey, 1989).

If the longitudinal current function is assumed to be constant, then equation (9) represents the general form of a set of simultaneous linear equations which can be solved in order to obtain the unknown values of the longitudinal currents. The earth potentials and magnetic field at any observation point are then computed from the expression of the vector potential.

On the other hand, if it is assumed that the expression of longitudinal current is given by equation (1), then equation (9) will generate *2n* unknowns represented by the coefficients a_k and b_k. In this case, *2n* equations of the same type as equation (9) are required to uniquely define the problem which is done by applying the mentioned equation twice, once to the section of the segment on each side of the current injection node (Dawalibi and Southey, 1989).

It is evident that the accuracy of the solution will depend on the number n of ground network segments and/or on the degree of the polynomial used to represent the distribution of the longitudinal current within a conductor segment.

Despite the simplicity and flexibility of the methodology, this approach involves complicated analytical expression and introduces serious computational difficulties among which the $2n \times 2n$ size of the matrix coefficients representing the set of simultaneous linear equations is the most restrictive.

For the above reasons and the fact that the emphasis of the research work is on power line frequency performance, the use of professional analysis and modeling software is justified (Dawalibi *et al.*, 1999).

Description of the problem

A plan view of the gas pipeline and nearby transmission circuit, as we propose to model them electrically, from an inductive interference perspective, could be shown in Figure 1.

Figure 2 shows a side view section and a top view of the system consisting in transmission line and pipeline. The tower of the transmission line is 35 m high and is made of steel. The transmission line phase conductor are 36/7 ACSR conductors and the shield wires are 7-strand, 1.27 cm diameter galvanized high strength steel conductors. The grounding system consists of a 16×16 loop buried at a depth of a 0.5 m and four vertical ground rods which are driven to a depth of 10 m cooper conductors of radius 7 mm are used (SES, 2006) (Figures 3-6).

Different energization conditions on the phase wire are investigated. Tables I and II present the currents and scalar potential of the phase conductors for normal operating conditions and the case of unbalanced phase currents with an unbalance factor $k_I = I_- / I_+ = 7\%$.

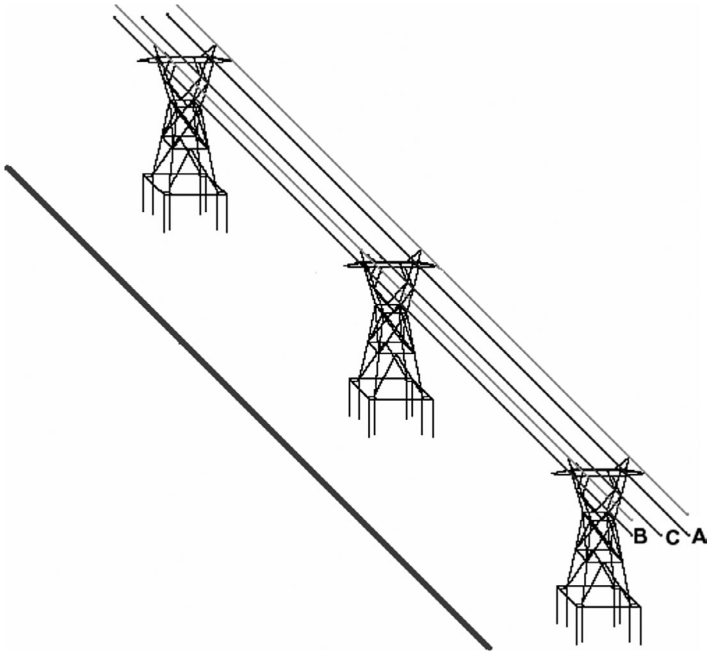


Figure 1.
General view of the studied of the studied model

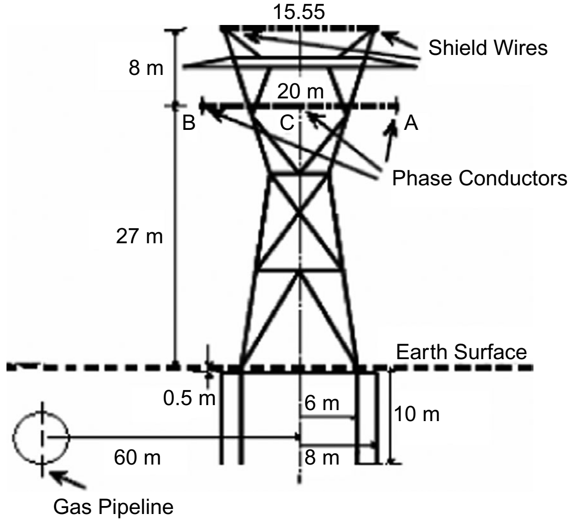
The plot in Figure 7 shows that the induced potential may reach about 20 V during normal operating condition, and about 25 V in case of an unbalanced phase currents.

In both cases the pipeline is subjected to possible corrosion phenomena due to the fact that the induced potentials on the surface of the metallic pipeline exceed the imposed levels.

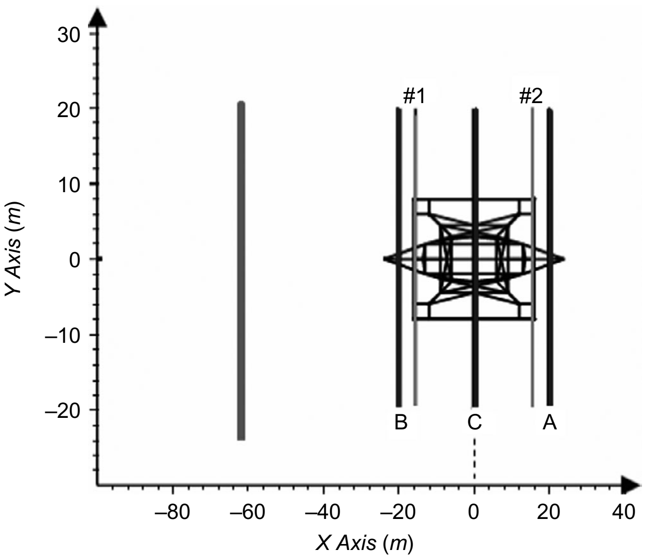
If voltages are induced in the metallic pipeline, the induced currents will pass through insulation defects to the metal surface. The values of these currents depend on the values of the total voltage of the electric system. Therefore, the induced currents increase with the induced voltages. In our case, the largest values are registered during the considered unbalance condition.

The current flowing from remote earth to a pipeline runs through the soil (leakage current), hence the ohmic resistance provided by that soil is an important parameter in studying the AC induced voltage corrosion. The ohmic resistance provided by the soil is controlled by factors relating to the resistance of the soil solution itself, the porosity of the soil, and geometrical factors existing close to the interface between the soil and the segment of pipeline under consideration. The resistance of the soil solution itself is inversely related to the conductivity of the solution and it determines the amount of AC voltage being lost across the soil resistance (magnitude of the IR drop related to the AC voltage). This means that if the resistance of the soil is very high, a high degree of the AC voltage is lost across the soil resistance, thus decreasing the amount of AC voltage reaching the pipe, and vice versa (Zhang *et al.*, 2008).

The distribution of the electric and magnetic field around the tower and at the surface of the pipeline shows that the biggest values of these quantities are registered



(a)

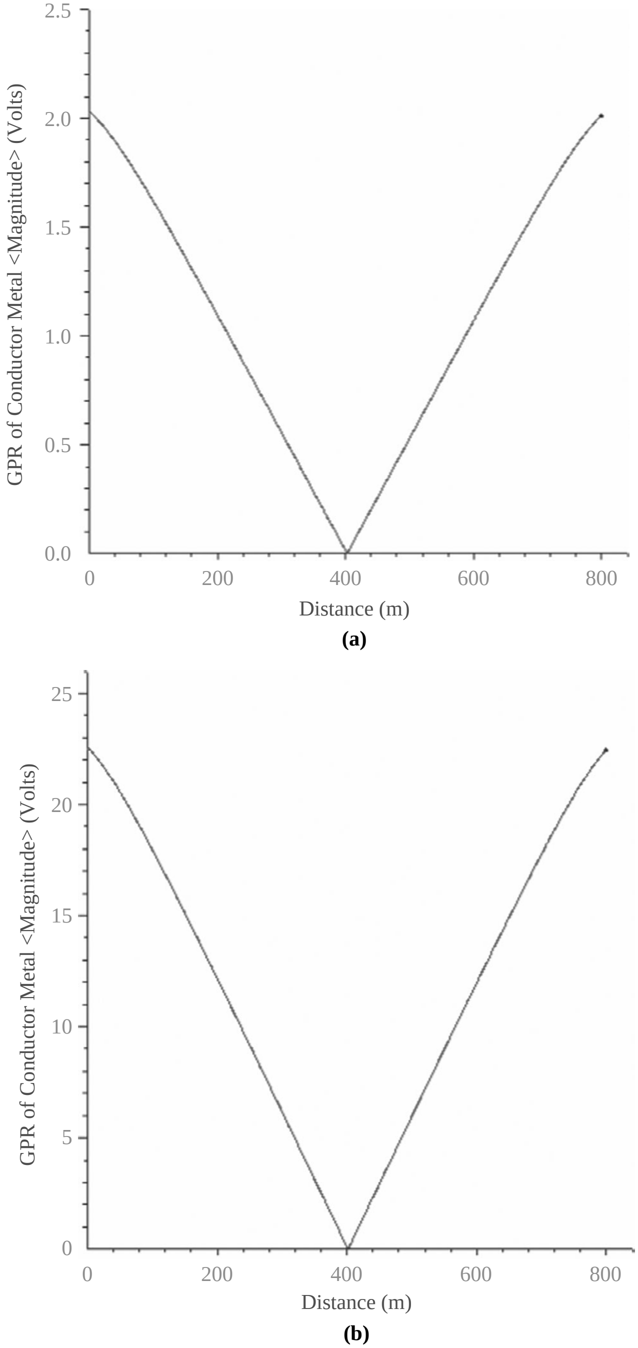


(b)

Figure 2.
Side view and top view of the geometry

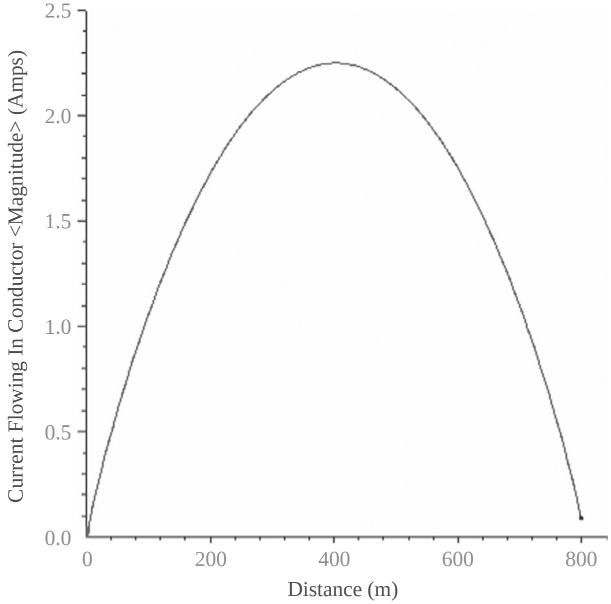
near the metallic tower of the transmission line. This could lead to problems regarding the personnel safety.

Therefore, like in the case of induced voltages, the values of the electric and magnetic field should be kept below certain levels imposed by various standards and regulations (IRPA/INIRC, 1993; ICNIRP, 2010).

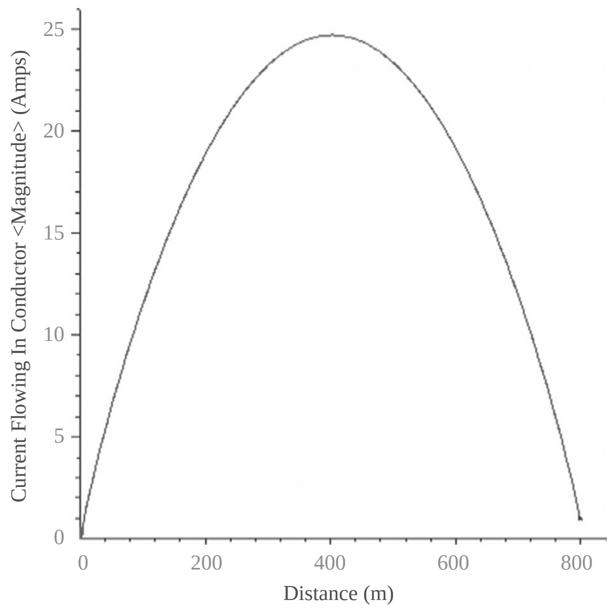


Notes: (a) Normal conditions; (b) 7 percent unbalanc

Figure 3.
Induced potentials in the gas pipeline



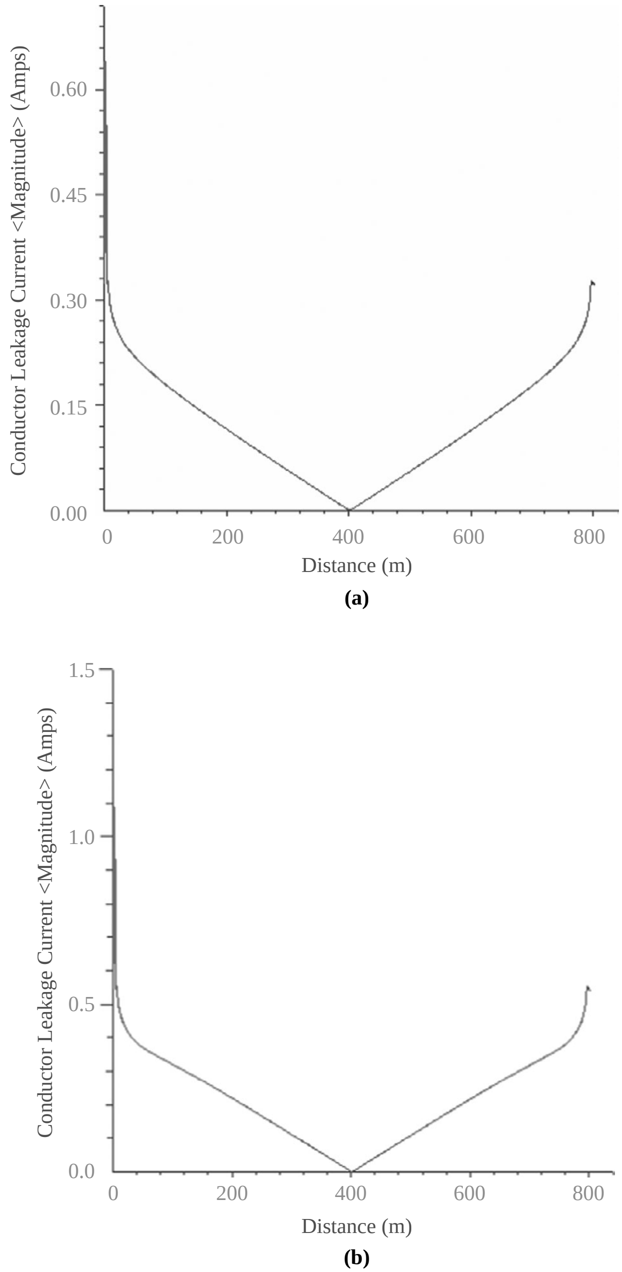
(a)



(b)

Notes: (a) Normal conditions; (b) 7 percent unbalance

Figure 4.
Induced currents in the gas pipeline



Notes: (a) Normal conditions; (b) 7 percent unbalance

Figure 5.
Leakage currents

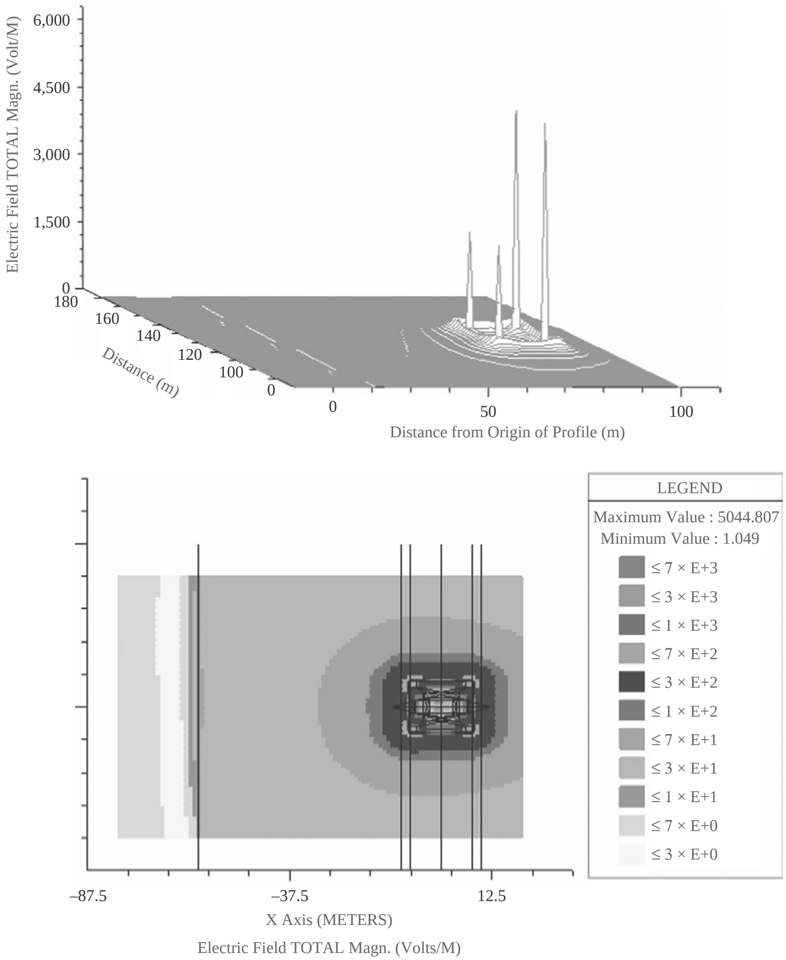


Figure 6.
Distribution of the electric field around the tower

Energization	Phase currents (A) Phase A	Phase B	Phase C
Normal operating conditions	$430 \cdot e^{+j120}$	$430 \cdot e^{-j120}$	$430 \cdot e^{j0}$
7 percent unbalance	$400 \cdot e^{+j119}$	$425 \cdot e^{-j123}$	$430 \cdot e^{j0}$

Table I.
The values of the phase currents

Energization	Phase potentials (kV) Phase A	Phase B	Phase C
Normal operating conditions	$303 \cdot e^{+j120}$	$303 \cdot e^{-j120}$	$303 \cdot e^{0}$
7 percent unbalance	$297 \cdot e^{+j120}$	$298 \cdot e^{-j121}$	$303 \cdot e^{j0}$

Table II.
The values of the phase potentials

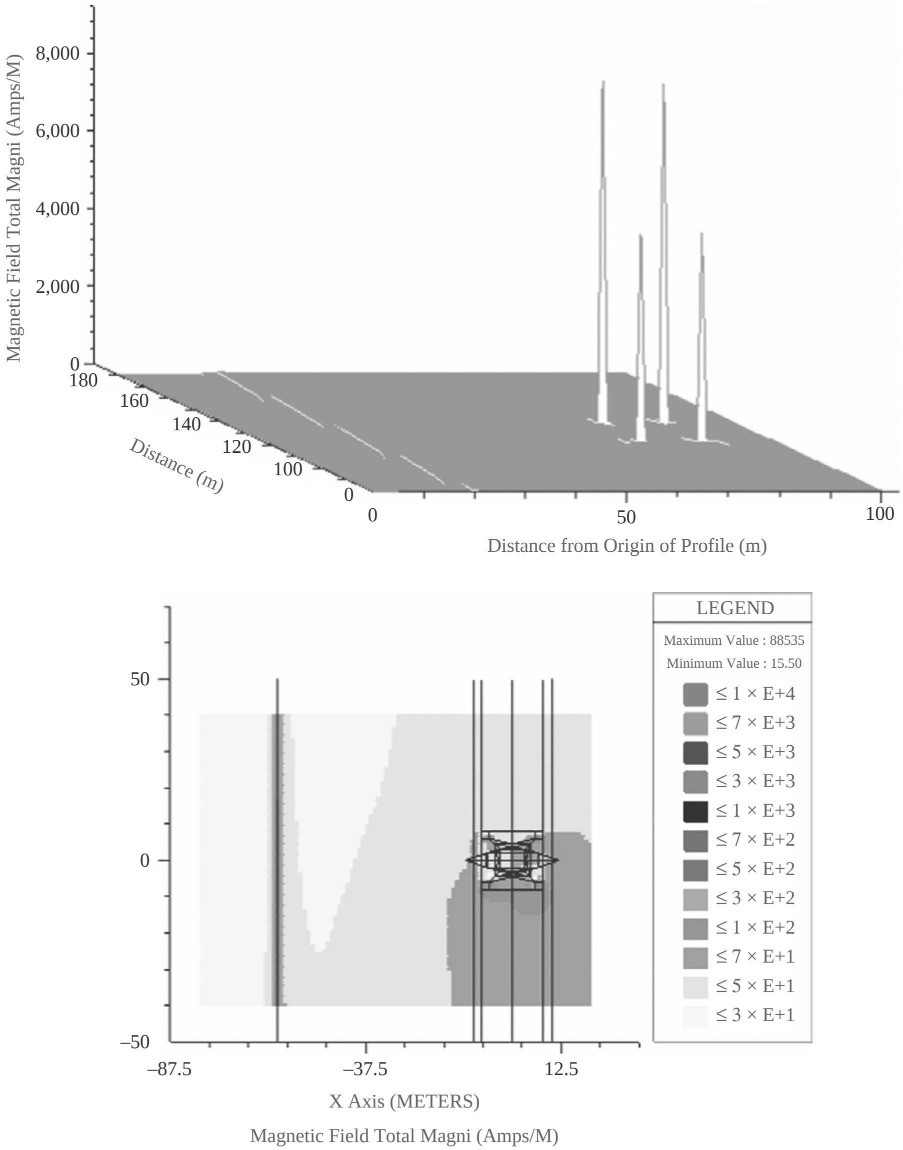


Figure 7.
Distribution of the magnetic field around the tower

Conclusion

An analysis of the interferences between an electric transmission line and a buried metallic pipeline was achieved. The obtained result shows that not only in critical situation regarding the transmission line functioning condition (fault condition) the nearby metallic structures could be in danger but also in unbalance phase currents conditions, important induced voltages could occurs and lead to corrosion of the metallic surfaces.

References

Christoforidis, G.C., Labridis, D.P. and Dokopoulos, P.S. (2004), "AC interference on a gas pipeline caused by nearby power lines in a complex right-of-way. Comparison between measurements and calculations", paper presented at CEOCOR, Dresden, Germany, 15-17 June, available at: www.desfa.gr/files/dimosieyseis/2004kioupis.pdf

Dawalibi, F.P. and Southey, R.D. (1989), "Analysis of electrical interference from power lines to gas pipelines", *IEEE Transaction on Power Delivery*, Vol. 4 No. 3, pp. 1840-6.

Dawalibi, F.P., Ma, J. and Li, Y. (1999), "Mechanisms of electromagnetic interference between electrical networks and neighboring metallic utilities", *Proceedings of the 61st Annual Meeting of the American Power Conference, Chicago, IL, USA*, pp. 150-5.

ICNIRP (2010), "Guidelines for limiting exposure to time varying electric and magnetic fields (1 Hz-100 KHz)", *Health Physics*, Vol. 99, pp. 818-36.

IRPA/INIRC (1993), "Guidelines on limits of exposure to 50-60 Hz electric and magnetic fields", *Health Physics*, Vol. 58, pp. 113-22.

Li, Y., Dawalibi, F.P. and Ma, J. (2000), "Electromagnetic interference caused by a power system network and a neighboring pipeline", *Proceedings of the 62nd Annual Meeting of the American Power Conference, Chicago, IL, USA*, pp. 311-6.

Ma, J. and Dawalibi, F.P. (2006), "Recent advances in electromagnetic analysis in common corridors", *Proceedings of 4th Asia-Pacific Conference on Environmental Electromagnetic* (*CEEM*), *Dalian, China, August 1-4*, pp. 409-18.

NACE Standard (1995), "Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems", NACE Standard RP0177-95.

SES (2006), *Electromagnetic Fields Near a Transmission Line Tower Subjected to Unbalanced Currents and a Phase-to-Ground Fault. How to … Engineering Guide*, Toolbox Edition 2006 Release, SES, Laval.

Zhang, R., Vairavanathan, P.R. and Lalvani, S.B. (2008), "Perturbation method analysis of AC-induced corrosion", *Corrosion Science*, Vol. 50, pp. 1664-71.

Further reading

Ştet, D., Simion, E., Micu, D.D., Darabant, L., Czumbil, L. and Ceclan, A. (2010), "Analysis of electrical interference from power lines to gas pipelines", paper presented at 6th International Conference on Electrical & Power Engineering, Iasi, Romania, 28-30 October, available at: www.epe.tuiasi.ro/2010/

Corresponding author

Ştet Denisa can be contacted at: Denisa.Stet@et.utcluj.ro