The Influence of Nonhomogeneous Earth on the Inductive Interference Caused to Telecommunication Cables by Nearby AC Electric Traction Lines

Kostas J. Satsios, *Student Member, IEEE*, Dimitris P. Labridis, *Member, IEEE*, and Petros S. Dokopoulos, *Member, IEEE*

***Abstract*—This work investigates the inductive interference caused by ac electric traction lines to nearby buried telecommunication cables, in the presence of a nonhomogeneous earth. The two dimensional, quasi stationary electromagnetic field diffusion equation has been numerically solved by using the Finite Element Method (FEM), in a system involving an ac electric traction line of the Greek Railways Organization and a buried cable of the Greek Telecommunications Organization. Using FEM results, magnetic vector potential in the cross-section of the examined system, as well as the longitudinal electromotive force induced in the circuit formed by the telecommunication cable and earth, are calculated. A rigorous parametric analysis concerning various nonhomogeneous earth models has shown a significant influence of the depth and resistivity of the first earth layer, as well as of the resistivities of the different earth layers, on the electromagnetic field and on the inductive interference caused to the buried telecommunication cable.**

***Index Terms*—Electric traction lines, finite element methods, nonhomogeneous earth, telecommunication cables.**

I. Introduction

ANALYSIS of electrical interaction effects between electric traction lines, power transmission lines and nearby telecommunication networks has been a topic of growing interest, due to the restrictions currently imposed to public utilities in the use of right-of-ways. These restrictions have resulted in situations in which power lines, pipelines, railroads, telecommunication lines etc. have to be laid in close distance for several kilometers. However, electrical interference problems among these systems must be carefully examined, before the sharing of a common right-of-way may be finally decided.

A telecommunication cable, even below ground, following an ac power transmission line or an ac electric traction line over a certain distance, is subjected to a significant interference. This interference consists of an inductive, a conductive and a capacitive component. Inductive interference, generated by the magnetic field, is present during both normal operating conditions and fault conditions. Conductive interference arises when a power transmission line or an electric traction line injects a large current into the earth during a fault and the telecommunication cable is located near this fault. Capacitive interference, which is generated by the electric field, influences only cables above ground, having no earth-connected sheath.

The inductive interference caused by an energized ac power transmission line is significant in cases of single-phase faults. In normal operating conditions, the balance of the three-phase currents causes no substantial effect. In this case only a small electromagnetic force is induced, due to the geometrical asymmetry of the electromagnetic field. On the other hand the inductive interference generated by ac electric traction lines is significant even in normal operating conditions, since these lines are by definition asymmetrical.

Electrical interference problems have been examined by many scientific organizations and research institutes, leading to various research reports, papers and books [1]–[10]. Although the mechanisms by which inductive, conductive and capacitive interferences arise are well understood, the determination of interaction effects in a typical right-of-way is a complex procedure. This procedure requires a good knowledge of electrical and geometrical properties as well as an accurate earth representation.

The earth model is particularly important for the determination of interaction levels and of the performance of mitigation systems. Without an adequate modeling, the mitigation designs have to be conservative in order to ensure a sufficient protection. When the earth structure is accurately modeled, effective and cost-efficient mitigation designs may be evaluated.

In this paper the influence of the nonhomogeneous earth on the inductive interference caused by an ac electric traction line to a nearby telecommunication cable has been examined. The use of finite elements method (FEM) for the solution of Maxwell's equations which describe complex electromagnetic field problems leads always to useful conclusions [11]. Therefore, a procedure based on finite element method (FEM) has been proposed to solve the electromagnetic field problem of an ac electric traction line, in the presence of a buried telecommunication cable and a nonhomogeneous earth.

II. System Arrangement and Assumptions Justification

To investigate the influence of nonhomogeneous earth on the inductive interference caused to telecommunication cables by nearby ac electric traction lines, a typical system shown in Fig. 1 has been chosen. This system consists of a typical ac electric traction line of the Greek Railways Organization,

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The authors are with Power Systems Laboratory, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Thessaloniki, GR-54006 Greece.

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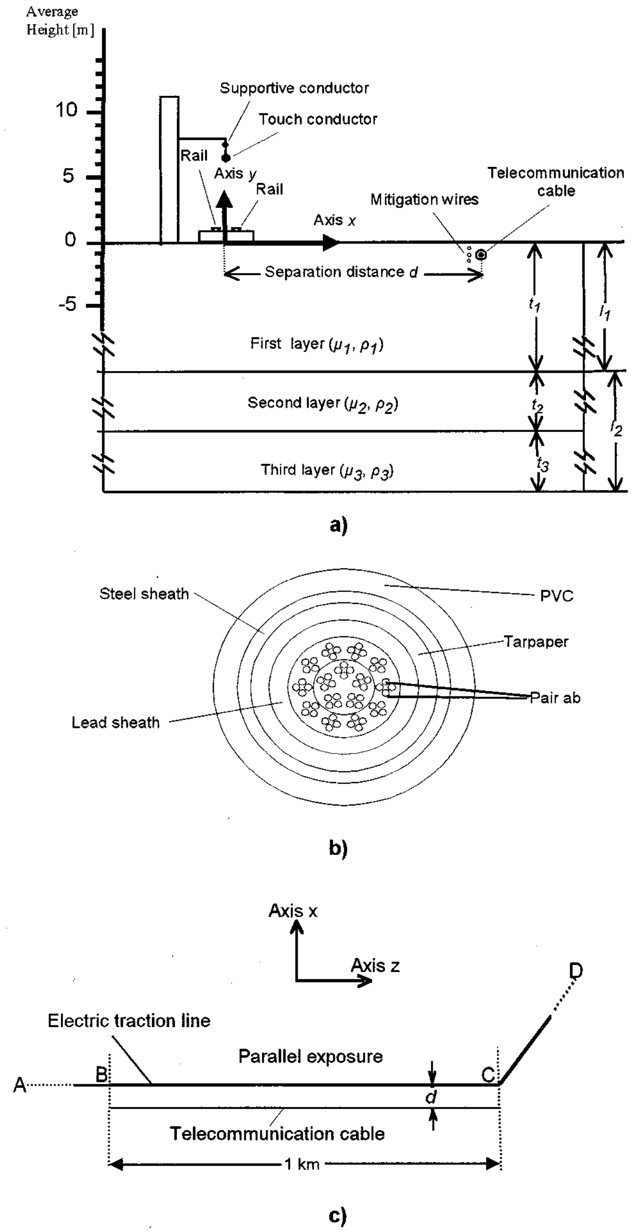

Fig. 1. (a) Cross-section of the system under investigation (b) Detailed telecommunication cable cross-section (c) Top view of the parallel exposure.

running parallel to a typical shielded buried cable of the Greek Telecommunications Organization, as shown in Fig. 1(c). The parallel exposure is equal to 1 km. The assumption that the traction line is parallel to the buried telecommunication cable is valid for many practical applications, when both are located in straight narrow corridors.

As shown in Fig. 1(a), the electric traction line consists of a copper touch conductor, which supplies the electric locomotive with alternating current at 50 Hz. The touch conductor is connected with the electric traction line through a supportive bronze conductor. The current of the touch conductor returns to the traction power substation partially through the rails and partially through the earth. There are two traction power substations, one in point A and one in point D.

The cross-section of the examined telecommunication cable is shown in Fig. 1(b). The cable consists of thirty copper paper insulated pairs. The diameter of the conductor of each pair is equal to 0.8 mm. An internal lead sheath encloses the pairs, which are isolated with tarpaper from an external steel sheath, The external sheath has a PVC insulation.

Aluminum mitigation wires shown in Fig. 1(a) are bare. In order to avoid possible corrosion problems, a system to protect these bare mitigation wires against corrosion may be required. The earth is subdivided in layers with different resistivities, while their relative permeabilities are $\mu_{r1} = \mu_{r2} = \mu_{r3} = 1$. These layers, shown in Fig. 1(a), are assumed to be homogeneous across the x-dimension, although this is not a necessity for the method developed.

The maximum expected supply current I_s flowing in the electric traction line section BC of Fig. 1(c), which is parallel to the telecommunication cable, is assumed equal to 1 kA. In this case conductive and capacitive interference are negligible and the inductive interference, due to the magnetic field, prevails. End effects are neglected for the inductive interference calculations, leading to a two dimensional problem. The assumption concerning the ignorance of the end effects is valid for the inductive interference calculations and for the lengths of parallel exposures encountered in practical applications.

III. FEM Calculations

A. Field Equations and FEM Formulation

The previous assumption lead to a linear two-dimensional electromagnetic diffusion problem for the z-direction components of the magnetic vector potential (MVP) A_z and of the total current density vector J_z. This problem is described [11] by the system of equations

$$\frac{1}{\mu_0 \mu_r}\left[\frac{\partial^2 A_z}{\partial x^2} + \frac{\partial^2 A_z}{\partial y^2}\right] - j\omega\sigma A_z + J_{sz} = 0 \quad (1a)$$

$$-j\omega\sigma A_z + J_{sz} = J_z \quad (1b)$$

$$\iint_{S_i} J_z \, ds = l_i \quad (1c)$$

where

- σ is the conductivity,
- ω is the angular frequency,
- μ_0 and μ_r are the vacuum and relative permeabilities respectively,
- J_{sz} is the source current density in the z-direction and
- l_i is the current flowing through conductor i of cross section S_i.

The matrix equation obtained [12] from the finite element formulation of equations (1a)–(1c) is solved using the Crout variation of Gauss elimination. MVP values in every node of the discretization domain as well as the unknown source current densities are calculated using the matrix equation solution. Consequently, the eddy current density J_{ez}^e of element e is obtained from the relation [11]

$$J_{ez}^e(x, y) = -j\omega\sigma A_z^e(x, y) \quad (2a)$$

and the total element current density J_z^e will be the sum of the conductor-i source current density J_{szi} and of the element eddy current density J_{ez}^e given by (2a), i.e.

$$J_z^e(x, y) = J_{ez}^e(x, y) + J_{szi} \tag{2b}$$

Integration of (2b) over a conductor cross-section will give the total current flowing through this conductor.

The solution domain of our problem is subdivided in first order triangular finite elements. The complicated geometry of the examined problem requires an optimal grid generator which provides triangular finite elements, each of which contribute very nearly the same error to the overall solution. Therefore a Delaunay based [13] adaptive mesh generation algorithm has been developed for the original discretization. The continuity requirement of the flux density B on the interface between neighboring elements has been chosen as the criterion for an iteratively adaptive mesh refinement.

B. Calculation of the Longitudinal Electromotive Force E.M.F.

A measure of the inductive interference caused to the telecommunication cable by the ac electric traction line is the longitudinal electromotive force (e.m.f.) induced in the circuit formed by a pair ab of the cable and the earth. This e.m.f. is calculated from the following equation

$$\text{e.m.f.} = -j2\pi f\phi \tag{3}$$

where:

- f is the frequency of the inducing current in Hz (in the examined case $f = 50$ Hz);
- ϕ is the flux of the electromagnetic field through the parallel section of the telecommunication cable and the ground.

In a two-dimensional problem, the flux of the electromagnetic field through the parallel section of the telecommunication cable and the ground is given by

$$\phi = A_z l \tag{4}$$

where A_z is the MVP, derived from FEM calculations, in the telecommunication cable and l is the length of this cable.

IV. Investigation of Nonhomogeneous Earth Influence

A. Two Earth Layers Without Mitigation Wires

Suppose that in the system of Fig. 1(a) the second earth layer has the same resistivity as that of the third earth layer, leading to a model with two earth layers. The depth of the first earth layer is equal to l_1, while second earth layer thickness is equal to $l_2 = 2 \text{ km} - l_1$. The layers extend across x-axis up to 2 km from the electric traction line axis of symmetry, in both directions. Initially it is assumed that no mitigation wires are present. The influence of each earth layer resistivity on the electromagnetic field and on the inductive interference depends on the depth of the first earth layer. It may be interesting to estimate the depth l_1 from which the first earth layer resistivity determines almost exclusively the electromagnetic field and the inductive interference.

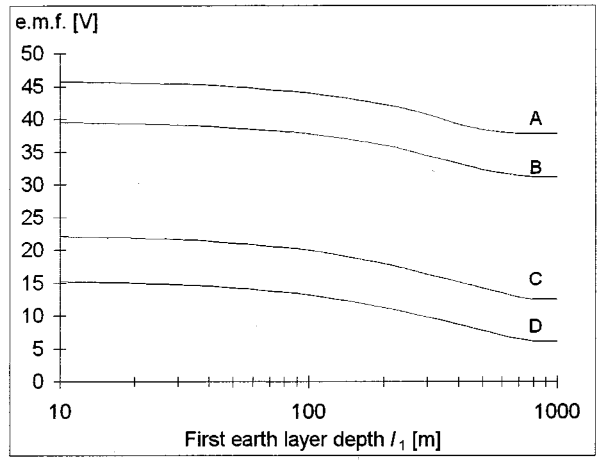

Fig. 2. Longitudinal electromotive force e.m.f. induced in the telecommunication cable as a function of the depth of the first earth layer of Fig. 1(a), for a two earth layer model with resistivities $\rho_1 = 100\ \Omega$ and $\rho_2 = 1000\ \Omega$. Curve A corresponds to separation distance 60 m, curve B to 100 m, curve C to 500 m and curve D to 1000 m.

TABLE I
LONGITUDINAL ELECTROMOTIVE FORCE E.M.F. INDUCED IN THE TELECOMMUNICATION CABLE FOR HOMOGENEOUS EARTH (I.E. WHEN RESISTIVITIES OF THE THREE LAYERS SHOWN IN FIG. 1(a) ARE $\rho_1 = \rho_2 = \rho_3 = \rho$) FOR VARIOUS SEPARATION DISTANCES d

	$\rho = 100\ \Omega$m	$\rho = 1000\ \Omega$m
Separation distance d [m]	e.m.f. [V]	e.m.f. [V]
60	37.754	45.774
100	31.165	39.555
500	12.505	22.145
1000	6.083	15.229

First and second earth layers are initially assumed to have resistivities $\rho_1 = 100\ \Omega$m (dry earth) and $\rho_2 = 1000\ \Omega$m (rocky earth) respectively. The parametric analysis for l_1, concerning the e.m.f. induced in the telecommunication cable, is shown in Fig. 2. The application of the proposed method for the same separation distances of Fig. 2 but for homogeneous earth (i.e. when the resistivities of the earth layers of Fig. 1 are $\rho = \rho_1 = \rho_2 = \rho_3$) having resistivity $\rho = 100\ \Omega$m or $\rho = 1000\ \Omega$m has given the results shown in Table I. Comparing e.m.f. values of Table I with the corresponding values obtained from Fig. 2 it is evident that:

- when the depth l_1 of the first earth layer varies between 10 m and 50 m, the electromagnetic field and the inductive interference is determined properly from the resistivity of the second earth layer.
- for depth $l_1 = 600$ m and greater, the resistivity of the first earth layer plays the dominant role in the electromagnetic field and inductive interference influence.

The above conclusions may be also explained with the help of Fig. 3. From this figure it is evident that when l_1 is equal to 600 m, the induced e.m.f. derived for the earth model with

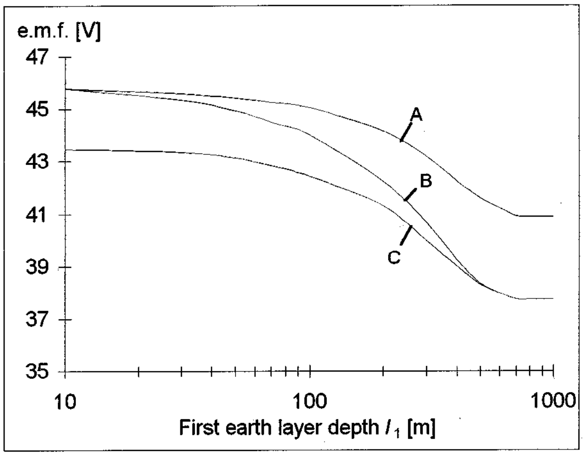

Fig. 3. Longitudinal electromotive force e.m.f. induced in the telecommunication cable as a function of the depth of the first earth layer, for a two earth layer model and a separation distance $d = 60$ m. Curve A corresponds to resistivities $\rho_1 = 200\ \Omega$ and $\rho_2 = 1000\ \Omega$, curve B to $\rho_1 = 100\ \Omega$ and $\rho_2 = 1000\ \Omega$ and curve C to $\rho_1 = 100\ \Omega$ and $\rho_2 = 500\ \Omega$.

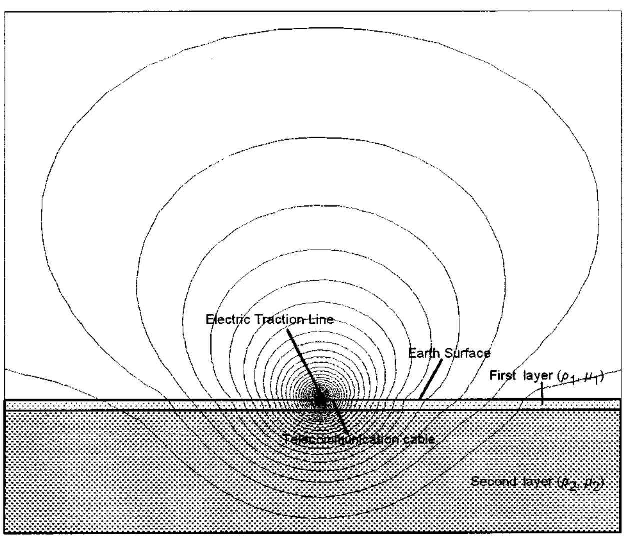

Fig. 4. Flux lines (A = const) of the electromagnetic field, for a two earth layer model with resistivities $\rho_1 = 100\ \Omega$ and $\rho_2 = 1000\ \Omega$. The depth of the first earth layer is $l_1 = 50$ m while separation distance is $d = 100$ m.

resistivities $\rho_1 = 100\ \Omega$m, $\rho_2 = 1000\ \Omega$m is equal to the induced e.m.f. calculated for the earth model with resistivities $\rho = 100\ \Omega$m, $\rho_2 = 500\ \Omega$m.

The influence of the depth of the first earth layer may be easily understood from Figs. 4 and 5, in which flux lines are shown for two cases with $l_1 = 50$ m and $l_1 = 400$ m respectively. From the MVP distribution of Fig. 4, which is valid for a first earth layer depth $l_1 = 50$, it is clear that the influence of the resistivity of the first earth layer on the electromagnetic field is negligible. In this case, the field is almost exclusively influenced by the resistivity of the second earth layer. On the other hand, from the MVP distribution of Fig. 5, which is valid for a first earth layer depth $l_1 = 400$ m, the influence on the electromagnetic field due to the resistivity of the first earth layer is evident, since the field lines are now compressed in that layer.

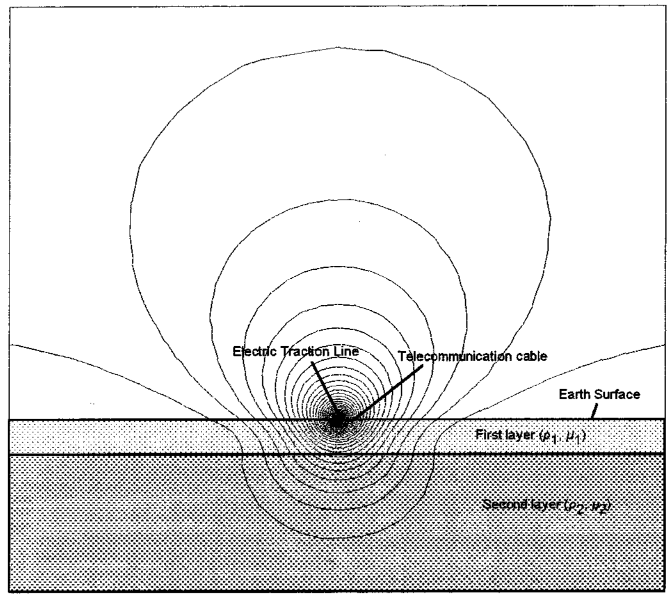

Fig. 5. Flux lines (A = const) of the electromagnetic field, for a two earth layer model with resistivities $\rho_1 = 100\ \Omega$ and $\rho_2 = 1000\ \Omega$. The depth of the first earth layer is $l_1 = 400$ m while separation distance is $d = 100$ m.

Finally, the first and second earth layers are assumed to have $\rho_1 = 1000\ \Omega$m and $\rho_2 = 100\ \Omega$m respectively. The corresponding parametric analysis for the depth of the first earth layer, concerning the e.m.f. induced in the telecommunication cable, is now shown in Fig. 6. Comparing the results shown in Fig. 6 and in Table I, it can be concluded that when the depth of the first earth layer is greater than $l_1 = 900$ m, the electromagnetic field and the inductive interference are determined solely from the first earth layer.

B. Two Earth Layers with Mitigation Wires

The previous examined model is further extended to include mitigation wires near the buried telecommunication cable, as shown in Fig. 1(a). The reduction of induced e.m.f. obtained by installing progressively more bare mitigation wires, made of a low resistivity and permeability material such as aluminum, is shown in Table II. From this Table it is clear that buried mitigation wires are very effective.

Finally, flux lines of the electromagnetic field near the electric traction line are shown in Fig. 7, when the three aluminum wires are located near to the telecommunication cable. The effect of mitigation of inductive interference level due to the aluminum wires is here easily understood, since the electromagnetic field is compressed toward the electric traction line. In the absence of mitigation wires, the magnetic field would have a y-axis symmetry and flux lines in the telecommunication cable region would be similar to those of the left part of y-axis of Fig. 7.

C. Three Earth Layers

Consider now a model with three earth layers, as shown in Fig. 1(a), having layer thicknesses $t_1 = 100$ m, $t_2 = 300$ m and $t_3 = 1600$ m respectively. The separation distance d between the electric traction line and the telecommunication cable

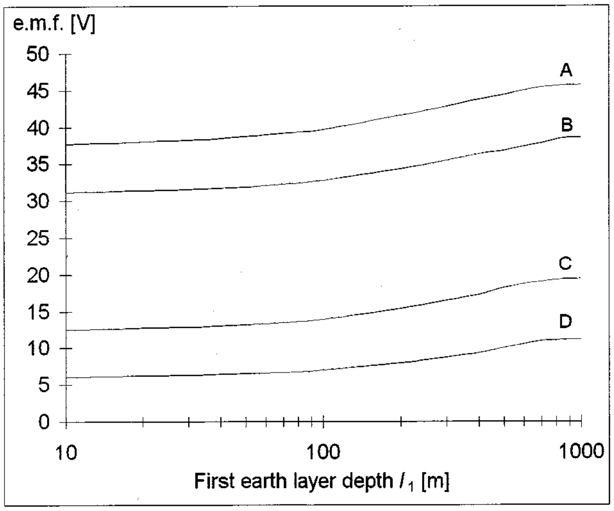

Fig. 6. Longitudinal electromotive force e.m.f. induced in the telecommunication cable as a function of the depth of the first earth layer of Fig. 1(a), for a two earth layer model with resistivities $\rho_1 = 1000\ \Omega$ and $\rho_2 = 100\ \Omega$. Curve A corresponds to separation distance 60 m, curve B to 100 m, curve C to 500 m and curve D to 1000 m.

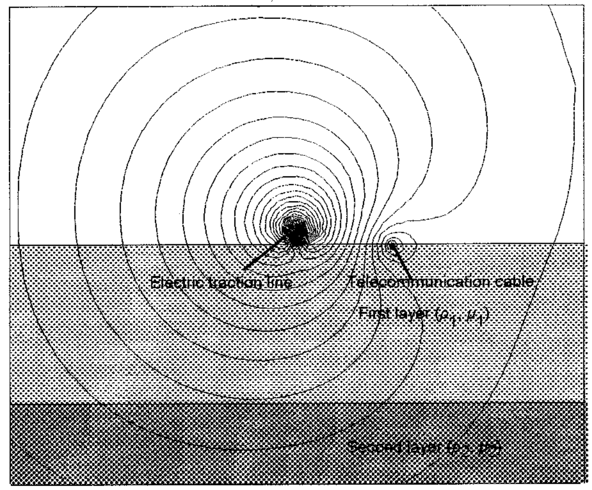

Fig. 7. Flux lines (A = const) of the electromagnetic field near the electric traction line, for a two earth layer model with resistivities $\rho_1 = 100\ \Omega$ and $\rho_2 = 1000\ \Omega$. The depth of the first earth layer is $l_1 = 150$ m, the separation distance is $d = 60$ m and three aluminum mitigation wires are located near the telecommunication cable.

TABLE II
EFFECT OF THE BURIED MITIGATION WIRES ON THE E.M.F. INDUCED IN THE TELECOMMUNICATION CABLE, FOR A TWO EARTH LAYER MODEL. THE DEPTH OF THE FIRST EARTH LAYER l_1 IS EQUAL TO 600 m, THE SEPARATION DISTANCE IS EQUAL TO 60 m, THE BARE MITIGATION WIRES HAVE A RADIUS EQUAL TO 5 mm AND THEY ARE LOCATED AT A DISTANCE EQUAL TO 1 m LEFT TO THE TELECOMMUNICATION CABLE

	ρ_1=100, ρ_2=1000 [Ωm]	ρ_1=1000, ρ_2=100 [Ωm]
Number of Aluminum Mitigation Wires	e.m.f. [V]	e.m.f. [V]
none	37.97	44.99
1	24.62	29.22
2	17.72	19.47
3	14.38	15.67

is equal to 60 m and no mitigation wires are present. A parametric analysis for various resistivities of the three earth layers, concerning the e. m. f. induced in the telecommunication cable, is presented in Table III. This table, in the case of $\rho_1 = \rho_2 = \rho_3 = 100\ \Omega$m shows induced e.m.f. equal to 37.754 V, while in the case of $\rho_1 = \rho_2 = \rho_3 = 1000\ \Omega$m equal to 45.774 V. These two cases lead to the minimum and maximum e.m.f. values and correspond to the minimum and maximum inductive interference levels respectively. From the other results of Table III it can be concluded that e.m.f. is mainly influenced by the resistivities of the second and the third earth layer. The corresponding influence of the resistivity of the first earth layer is negligible, because t_1 is only 100 m.

All the above calculations have been made for a supply current I_s. equal to 1000 A. However, MVP distribution and therefore eddy current values are proportional to the supply current, so the presented results may be easily used for any given supply current I_s.

TABLE III
LONGITUDINAL ELECTROMOTIVE FORCE E.M.F. INDUCED IN THE TELECOMMUNICATION CABLE, FOR VARIOUS RESISTIVITIES OF THE THREE EARTH LAYER MODEL OF FIG. 1(a) HAVING LAYER THICKNESS $t_1 = 100$ m, $t_2 = 300$ m AND $t_3 = 1600$ m. THE SEPARATION DISTANCE IN ALL CASES IS $d = 60$ m

ρ_1 [Ωm]	ρ_2 [Ωm]	ρ_3 [Ωm]	e.m.f. [V]
100	100	100	37.754
100	100	500	38.957
100	100	1000	39.229
100	500	100	42.894
100	500	500	43.223
100	500	1000	43.567
100	1000	100	44.508
100	1000	500	44.732
100	1000	1000	45.014
500	100	100	37.859
500	100	500	39.883
500	100	1000	40.015
500	500	100	42.240
500	500	500	43.462
500	500	1000	43.987
500	1000	100	42.756
500	1000	500	43.867
500	1000	1000	45.494
1000	100	100	37.945
1000	100	500	40.008
1000	100	1000	40.598
1000	500	100	43.456
1000	500	500	44.246
1000	500	1000	44.698
1000	1000	100	44.236
1000	1000	500	44.639
1000	1000	1000	45.774

From all the previous results it is evident that resistivity measurements in relative small depths, in an attempt to simulate the inductive interference problem using a homogeneous earth, may lead to an erroneous earth model. This model may lead to an inaccurate determination of the inductive interference problem.

V. Conclusions

The electromagnetic field problem of an ac electric traction line in the presence of nonhomogeneous earth and a telecommunication cable has been numerically solved, using the finite element method. Magnetic vector potential distribution in the cross-section of the parallel exposure and the longitudinal electromotive force induced i n the telecommunication cable may be easily computed with the proposed method, for any nonhomogeneous earth model. Many different earth models have been examined. Useful conclusions concerning the influence of the earth structure on the inductive interference levels are presented. Mitigation wires performance has also been investigated. It is concluded that a nonhomogeneous earth model is essential for the accurate computation of the inductive interference levels and for the effective design of mitigation systems.

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References

[1] J. R. Carson, “Wave propagation in overhead wires with ground return,” *Bell System Technical Journal*, vol. 5, pp. 539–554, October 1926.

[2] J. Pohl, “Beeinflussung von umhullten Rohrleitungen durch Hochspannungsfreileitungen,” in *CIGRE-Conference*, Bericht, 1966, 326.

[3] E. D. Sunde, Ed., *Earth Conduction Effects in Transmission Systems*. New York, NY: Dover Publications, 1968.

[4] “Arbitration agency for problems of interference between installations of the German Federal Railways, the German Federal Post Office and the Association of German Power Utilities,” Verlags und Wirtschaftsgesellschaft der Elektrizitatswerke mbH - VWEW, Technical Recommendation No 7, May 1982.

[5] M. Frazier, “Mutual design—HVDC transmission lines and railroads,”, EPRI Project 1902-3, c/o SAIC. 1984 tests at Yermo, CA and Delta,U .

[6] B. Mellitt, J. Allan, Z. Y. Shao, W. B. Johnston, and C. J. Goodman, “Computer-based methods for induced-voltage calculations in AC railways,” *IEE Proceedings*, vol. 137B, no. 1, pp. 59–72, January 1990.

[7] R. J. Hill and D. C. Carpenter, “Modeling of nonlinear rail impedance in AC traction power systems,” *IEEE Transactions on Power Delivery*, vol. 6, no. 4, pp. 1755–1761, October 1991.

[8] F. Dawalibi and R. D. Southey, “Analysis of electrical interference from power lines to gas pipelines Part I: Computation methods,” *IEEE Transactions on Power Delivery*, vol. 4, no. 3, pp. 1840–1846, July 1989.

[9] ——, “Analysis of electrical interference from power lines to gas pipelines Part II: Parametric analysis,” *IEEE Transactions on Power Delivery*, vol. 5, no. 1, pp. 415–421, January 1990.

[10] A. P. Sakis Meliopoulos, *Power System Grounding and Transients: An Introduction*. New York, NY: Marcel Dekker Inc., 1988, pp. 300–304.

[11] D. Labridis and P. Dokopoulos, “Finite element computation of field, losses and forces in a three-phase gas cable with nonsymmetrical conductor arrangement,” *IEEE Transactions on Power Delivery*, vol. PWDR-3, pp. 1326–1333, October 1988.

[12] J. Weiss and Z. Csendes, “A one-step finite element method for multiconductor skin effect problems,” *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-101, pp. 3796–3803, October 1982.

[13] Z. J. Cendes, D. Shenton, and H. Shahnasser, “Magnetic field computation using Delaunay triangulation and complementary finite element methods,” *IEEE Transactions on Magnetics*, vol. MAG-19, pp. 2551–2554, November 1983.

[14] J. Dabkowski and A. Taflove, *Mutual Design Considerations for Overhead AC Transmission Lines and Gas Transmission Pipelines—Volume 1: Engineering Analysis*, September 1978, ch. 3.

Kostas J. Satsios (S’94) was born in Serres, Greece, in May 1971. He received the Dipl. Eng. degree from the Department of Electrical Engineering at the Aristotle University of Thessaloniki in 1994. Since 1994 he is a Ph.D. candidate in the Department of Electrical and Computer Engineering at the Aristotle University of Thessaloniki. His research work is financially supported by the General Secretariat for Research and Technology of the Greek Ministry of Development and by the Greek Telecommunications Organization. His research interests are in finite elements and artificial intelligence methods development and their applications in power systems. He is a member of the Society of Professional Engineers of Greece.

Dimitris P. Labridis (S’87–M’90) was born in Thessaloniki, Greece, on July 26, 1958. He received the Dipl.-Eng. degree and the Ph.D. degree from the Department of Electrical Engineering at the Aristotle University of Thessaloniki, in 1981 and 1989 respectively.

During 1982–1993 he has been working, at first as a research assistant and later as a Lecturer, at the Department of Electrical Engineering at the Aristotle University of Thessaloniki, Greece. Since 1994 he has been an Assistant Professor at the same Department. His special interests are power system analysis with special emphasis on the simulation of transmission and distribution systems, electromagnetic and thermal field analysis, numerical methods in engineering and artificial intelligence applications in power systems.

Petros S. Dokopoulos (M’77) was born in Athens, Greece, in September 1939. He received the Dipl. Eng. degree from the Technical University of Athens in 1962 and the Ph.D. degree from the University of Brunswick, Germany, in 1967.

During 1962–1967 he was with the Laboratory for High Voltage and Transmission at the University of Brunswick, Germany, during 1967–1974 with the Nuclear Research Center at Julich, Germany, and during 1974–1978 with the Joint European Torus. Since 1978 he has been Full Professor at the Department of Electrical Engineering at the Aristotle University of Thessaloniki, Greece. He has worked as consultant to Brown Boveri and Cie, Mannheim, Germany, to Siemens, Erlagen, Germany, to Public Power Corporation, Greece and to National Telecommunication Organization and construction companies in Greece. His scientific fields of interest are dielectric’s, power switches, power generation (conventional and fusion), transmission, distribution and control in power systems. Professor Dokopoulos has 66 publications and 7 patents on these subjects.