Modelling and evaluation of electromagnetic field of urban high-voltage power line

Atanas G. Chervenkov

Theoretical Electrical Engineering Department
Technical University of Sofia
Sofia 1700, Bulgaria
E-mail: acher@tu-sofia.bg

***Abstract*—An electromagnetic field EMF generated by high voltage overhead transmission line in an urban environment is presented. The electromagnetic interference generated by overhead high-voltage HV line is considered. The levels of the electric field and magnetic field around HV urban lines are investigated. They are calculated analytically and simulated numerically for various realistic cases like normal mode and short circuit mode. The magnetic field of a high-voltage power line under lightning strike is also simulated. An impact of electromagnetic field in electrical devices in adjacent building and people, which is located nearby urban HV line, is being studied. Model validation of numerical simulation with measuring results of electric field of an existing transmission line 110 kV is done. Results of the electric and magnetic field analysis of the overhead urban line were assessed to check the compliance exposure limits with the existing requirements. The presented method for the electromagnetic field modeling could be used for the evaluation of the impact on the human body by simulations of different, unusual situations like lightning strike.**

Keywords—electromagnetic field, electromagnetic interference, finite-element method, high-voltage, power line, urbanization

I. Introduction

Main purpose of this investigation is modelling the electromagnetic field around of 110 kV power line located in urban area and evaluation of the influence of the electromagnetic field on the environment area. An additional attention should be addressed for determination of the electromagnetic field at height of 1.8 m over the ground, to evaluate the impact on the human. Modelling gives it possibility for analysis of existing urban overhead HV line and predicting electromagnetic field levels.

Due to the increase in urban population, infrastructure is being built near power lines. This violating conditions of electromagnetic compatibility. The influence of electromagnetic fields created of HV lines on the electrical facilities has paid attention to scientific researcher's long time ago. The results of many studies have shown that the relationship between humans health and electromagnetic field exposure is non-existent directly or it is too weak [1]. In subsequent studies prove specific facts and justify the need for further studies for the impact of the low frequency fields on human health. Long-term low-level exposure of EMF from HV lines there could be a negative influence on children neuro function. Nevertheless, due to differences in results only in a few tests can be reached statistical significance of possible limitations. More research are needed to investigate the exposure effects of extremely low frequency EMF on neuro function and children development [2]. However the interpretation of the available evidence by many public organizations led to the proposition that exposure to low frequency electric and magnetic fields "is not a human health hazard". So, a working group under the protection of the US National Institute of Environmental Health Sciences (NIEHS) concluded that there was a possible low risk associated with certain exposures to ELF magnetic fields [3]. The main evidence for a risk in epidemiological aspect is shown in several investigations and analyses. But, small number of highly exposed children is studied and besides, the results could be due to a combination of selection bias, confused and stochastic [4].

International Commission on Non-Ionizing Radiation Protection (ICNIRP) gives recommendations on the influence of the electromagnetic field on humans. However accordance of these guidelines may not necessarily exclude interference on medical devices: cardiac pacemakers; implanted defibrillators; metallic prostheses; and etc. Interference with pacemakers may occur at levels below the recommended reference levels [5].

The 110 kV overhead power lines distribute the electricity from the electrical systems of the Republic of Bulgaria to the 110kV/20 kV city substations. They were built 30 years ago in sparsely populated areas of cities. Then, the requirements for electromagnetic compatibility have been not taken into account. Now, due to the massive construction of big cities in Bulgaria, it is necessary to monitor the levels of interference, which these power lines have. A high voltage line located in an urbanized environment is being considered. The power line is located in one of the districts of Burgas with the geographical coordinates 42.5205822 ° N, 27.4552999 ° E. A snapshot of a part of the urban line in Fig.1 is shown. The area in tower vicinity of the investigated 110 kV urban line is being considered, in which there are residential buildings.

II. Electromagnetic Fild Modelling of Overhead Urban Line

A. Electrical Field Analytical Model

For the evaluation of electrical field an algorithm for the capacitive penetration is used [6]. A principal geometry of the studied urban line in Fig. 2 is shown. The conductors of the HV line are pleased at the appropriate heights from the ground. The charges of the conductors have linear density λ. The low voltage conductor in point M is considered [6].

The fourth conductor can be conductor of low voltage or of communication line, placed in near building, or conductor in a vehicle, located under the HV urban line [6].

Fig. 1. A snapshot of the considered urban overhead HV line

The electric field in investigated point M is determined. Mirror images method is used [6]. In this case we use the equations of Maxwell [6]. For the voltages $\dot{V}$ we have system of four equations [6]:

$$\begin{cases} \dot{V}_1 = \alpha_{11}q_1 + \alpha_{12}q_2 + \alpha_{13}q_3 + \alpha_{14}q_4 \\ \dot{V}_2 = \alpha_{21}q_1 + \alpha_{22}q_2 + \alpha_{23}q_3 + \alpha_{24}q_4 \\ \dot{V}_3 = \alpha_{31}q_1 + \alpha_{32}q_2 + \alpha_{33}q_3 + \alpha_{34}q_4 \\ \dot{V}_4 = \alpha_{41}q_1 + \alpha_{42}q_2 + \alpha_{43}q_3 + \alpha_{44}q_4 \end{cases}. \quad (1)$$

In equation first three equations of system (1) q_1, q_2, q_3 are the charges of HV line wires and q_4 - the low voltage line charge of the object located in point M and $\alpha_{kk}, \alpha_{km}, k = 1{,}4, m = 1{,}4$ are potential's coefficients. For convenience it can be accepted, that the fourth conductor has no charge i.e. $q_4 = 0$ [6].

Therefore, a system (1) in new form is obtained. The new system has been solved. The charges q_1, q_2, q_3, and voltage of the forth conductor $\dot{V}_4$ are determined. To de conductor geometry respectively, the coefficients α_{km} in system (1) are received. As a result after solution of system (1) searching voltage V_4 is determined. The three-phase voltages $\dot{V}_1, \dot{V}_2$ and $\dot{V}_3$ of the HV (110kV) line are a symmetrical system. For determination of the electric field the voltage gradient is determined ($\dot{E} = grad\,\dot{V}$) [7].

B. Numerical Model of the Magnetic Field

For determination of the magnetic field finite-element method is used, by numerical solution of corresponding equations of Maxwell. The Poisson equation is achieved [7]. The flux density lies in the plane parallel of plane model *xOy.* In this case the vector of electric current density $\vec{J}$ and the vector potential $\vec{A}_\mu$ are orthogonal to it and have components only in one z - direction.

The electromagnetic field is modelled using complex magnetic potential $\dot{A}_{\mu z}$ and Poisson equation is

$$\frac{\partial^2 \dot{A}_{\mu z}}{\partial x^2} + \frac{\partial^2 \dot{A}_{\mu z}}{\partial y^2} - j\omega\mu\gamma\dot{A}_{\mu z} = -\mu\dot{J}_z\ , \quad (2)$$

where: $\vec{A}_\mu$ is magnetic vector potential, j is imaginary unit; ω is angular frequency, γ is electric conductivity, J is current density, μ is magnetic permeability. The magnetic permeability is $\mu_{rx} = \mu_{ry} = \mu_{rz} = 1$ and in this case magnetic permeability of air is equal to those of the space $\mu = \mu_0$ [7].

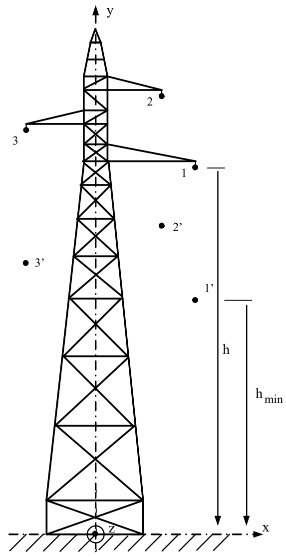

Fig. 2. Tower geometry of the investigated HV line

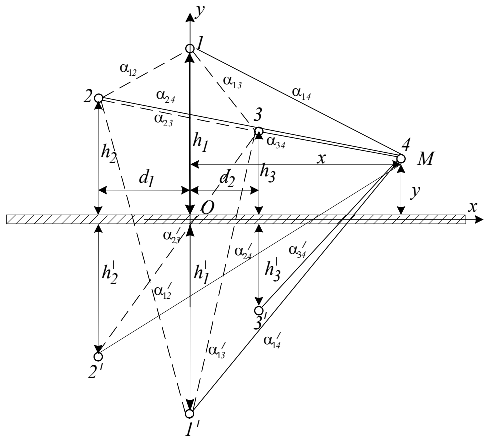

Fig. 3. A conductor geometry scheme of the power line

The Poisson equation is solved numerically. For the magnetic vector-potential we have finite element expression [7]

$$\{A_\mu\} = [N_A]^T.\{A_N\} \quad (3)$$

We find the matrix N_A of the shape functions in nodes of square and triangle finite elements and magnetic vector-potential A_N [7].

The searched vectors of magnetic field are defined as the derivatives of the magnetic vector-potential. Magnetic induction B (magnetic flux density) is determined by the expression

$$\{B\} = \Delta \times [N_A]^T\{A_N\} \quad (4)$$

The vectors of electromagnetic field are located in perpendicular plane to the urban line direction. For the numerical solution of Poisson equation we apply ANSYS package. The used finite element is magnetic vector quad with eight nodes. It is with refined deformed mesh. The investigated urban HV line was built metallic towers for three linear conductors plus ground conductor. They have been implemented by the FEM model. The tower configuration has been included with real characteristic and sizes of the investigated urban line. The line conductors have $300mm^2$ cross-section [7]. The smallest height of conductors, because of sagging, h_{min} is 7m. The relative magnetic permeability of the environment (air) is - $\mu_0 = 4\,\pi\,10^{-7}\ {}^{H}/_{m}$.

A 3 phase 110kV urban line (Fig. 2) is considered. It consists of 3 aluminum conductors with circular cross section, carried time varying currents, with frequency of 50 Hz, shifted by 120^0 phase degree. The conductors are located at a heights from the ground h_1, h_2 and h_3 , respectively.

III. Computantional Results

A. *Analysis of the Electrical Field*

The calculations are performed with corresponding sizes [6]: l=1m; h_2=20.5m; h_3=17.5m; h_1=15.5m; y=1 m; x=-50 ÷ +50 m. The investigated electric field vector in the perpendicular plane of urban high-voltage line is observed [6]. Model validation by comparing with measuring results of electric field with a similar line [8] is done. In Fig. 4 the intensity profiles of the electric field of the urban power line [6] are shown.

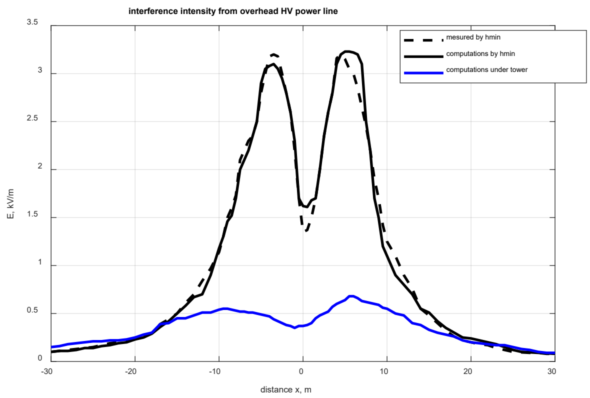

Fig. 4. Profiles of the electric intensity at 1.8 m height from the ground

The calculations by extremal positions above ground of conductor were done. In Fig. 4 computations with minimal conductor height h_{min}, when there is a sag (usually in the middle between the towers), with solid are given. A numerical computation under tower, when the conductors are at their highest position, with blue solid line is given. In this case, electrical field intensity has smaller values, when conductors are more elevated. Measuring results [8] with dashed line are given. They have a symmetry regarding the vertical axis. The obtained intensity levels by calculations are satisfactory, below the admissible levels for public exposure, according to the safety requirements [5].

B. *Analysis of the Magnetic Field*

The calculations with same sizes by extremal positions of the conductor above the ground were done.

The values of magnetic flux density and magnetic field intensity in vicinity of the HV urban line depends on many factors like the current density in line, the operating mode and etc. [7].

Initially, the high-voltage urban line in a normal mode has been studied. The conductors a current of 130A are conducted. The magnetic flux density distribution B_x on the x-axis, in the vicinity of the urban line, in Fig.5 is shown. Results are performed by the smallest height h_{min} of the conductors [7]. In normal mode the magnetic field has relatively small values in a large area around the line. However, these values are much smaller than the maximum permissible for continuous exposure to a magnetic field.

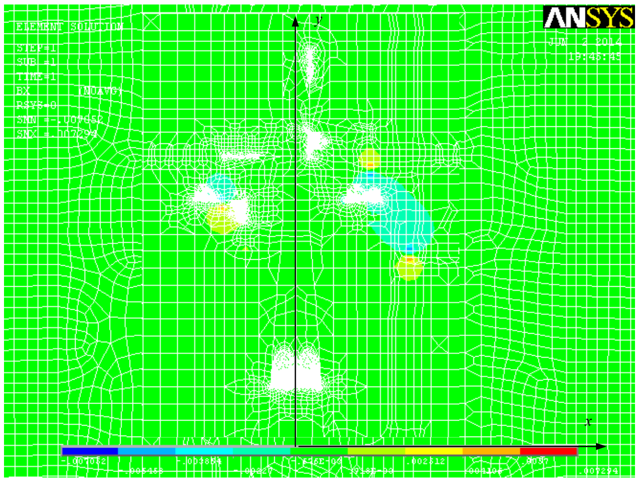

Fig. 5 Distribution of the magnetic induction on the x-axis by normal mode operation

Profiles of magnetic field density distribution “in a plane perpendicular to the direction” [6] of the urban HV power line by two positions of the conductors, in normal mode, in Fig. 6 are shown. The obtained by calculations magnetic field levels are satisfactory, below the admissible levels for public exposure.

The short circuit mode of the urban HV line is considered next. The conductors a current of 3000 A are conducted for a maximum of 3 seconds [7]. The distribution of magnetic flux density “in a perpendicular plane to the direction” [6] of the urban overhead HV power line, in short-circuit mode, in Fig. 7 is shown.

The lightning strike onto the urban HV line is considered as last case [7].

In the last years is possible the lightning current [7, 9, 10]. However, the magnetic field measurement by lightning strike is impossible. This is due to the fact, that the lightning currents have high frequency between 20 kHz and 20 MHz [7, 9]. The magnetic field only with the help of simulations can be determined [7]. The lightning current has a pulse shape with maximum current reaching values up to several kA over a few μs [7, 10]. The maximum lightning current by strike is conducted approximately 10.7 kA as regards 0.25 μs [7, 11].

The distribution of the magnetic field by lightning strike in a perpendicular plane of the urban HV line [7] in Fig. 8 is shown. The results with lightning current of 11 kA are made.

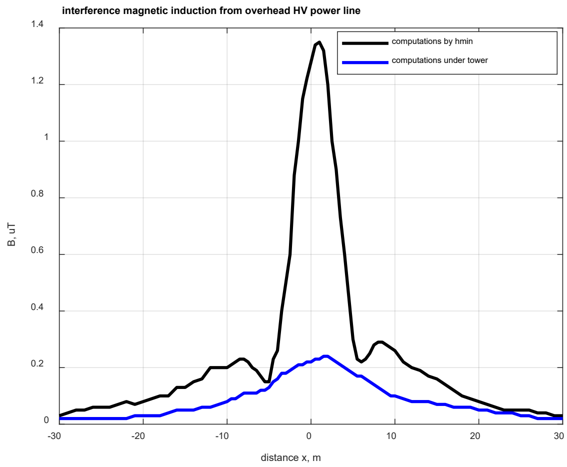

Fig. 6. Profiles of the magnetic flux density in normal mode at 1.8 m above the ground

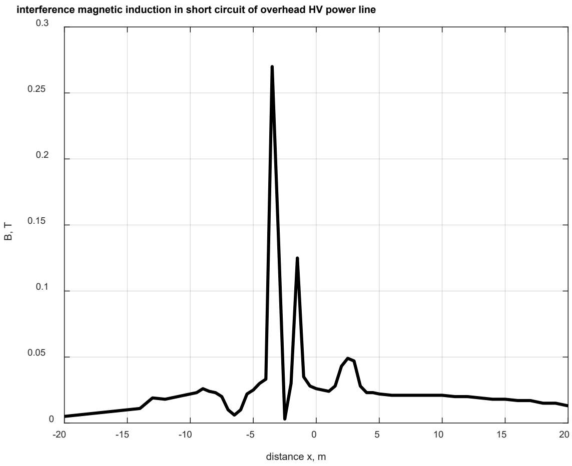

Fig. 7. Profile of the magnetic flux density in short circuit at 1.8 m

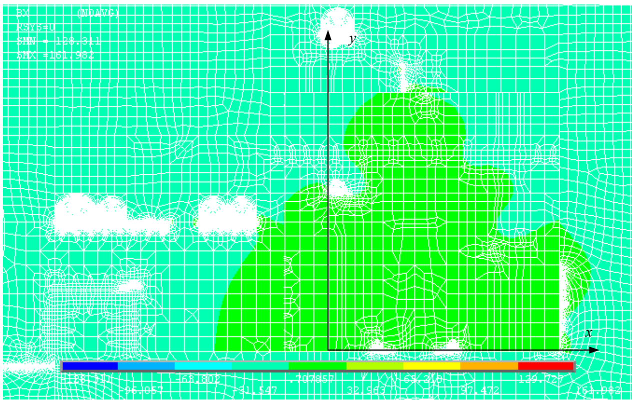

Fig. 8 Distribution of the magnetic field by lightning strike

The induction value a distance of 50 from the axis of the urban HV line, reaches to value of 15.7 *T*. These values are very high and can be dangerous for a person in the area around the power line. Therefore, it is necessary that the surrounding buildings in which people live reside, have to be located at greater distances from a high-voltage power line in an urban environment.

IV. Conclusion

The investigations present the analysis of electric and magnetic field of 110 kV urban power line, based on analytical modelling of electric field and FEM modeling of the magnetic field. A modeling gives possibility for analysis of existing lines and predicting electromagnetic field levels according to electromagnetic compatibility. The electromagnetic field is investigated, taking into account minimal level of the conductor line in the vicinity, where the field intensity is highest. Thus the impact of the level of the electromagnetic field on human body and health risks can be assessed. The electric and magnetic field levels around high voltage power line are investigated, calculated analytically and simulated numerically for various realistic cases of operation of urban lines. The simulation results are validated by comparison with published experimental real data.

Acknowledgment

The author would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

References

[1] M. T. Santini, G. Rainaldi, P. L. Indovina, “Cellular effects of extremely low frequency (ELF) electromagnetic fields”, Int. J. Radiat. Biol., Vol. 85, No. 4, pp. 294–313, April 2009.

[2] J. Huang, T. Tang, G. Hu, et al., “Association between Exposure to Electromagnetic Fields from High Voltage Transmission Lines and Neurobehavioral Function in Children”, Plos One, vol. 8, issue 7, article: e67284, July 2013.

[3] A. W. Preece, J. Hand, “Power frequency electromagnetic fields and health. Where's the evidence?”, Physics in Medicine and Biology, 45(9):R139-54, October 2000.

[4] M. Maslanyj, T. Lightfoot, J. Schüz, Z. Sienkiewicz, A. McKinlay, “A precautionary public health protection strategy for the possible risk of childhood leukaemia from exposure to power frequency magnetic fields”, BMC Public Health 2010, 10:673.

[5] International Commission on Non-ionizing Radiation Protection, “Guidelines for limiting exposure to time-varying electric and magnetic fields (1Hz to 100 kHz)”, Health Physics, vol. 99, No. 6, pp. 818-836, 2010.

[6] A. G. Chervenkov and T. V. Chervenkova, “Investigation of the capacitive influence of overhead multi-line power system”, 15th International Conference on Electrical Machines, Drives and Power System (ELMA), Sofia, 2017, pp. 38-41.

[7] A. Chervenkov and T. Chervenkova, “Investigation of the influence of the electromagnetic field in the visinity of High voltage overhead line”, Materials Science Forum, vol. 256, pp. 190-195, 2016.

[8] A. Lesov, V. Pehlivanova, V. Kirchev, A. Angelov, “Analysis of Electromagnetic Emission with Industrial Frequency of Overhead High Voltage Transmission Lines”, Journal of the Technical University of Plovdiv, vol. 13, pp. 71-92, 2006.

[9] U. Sonnadara, V. Cooray, and M. Fernando, “The Lightning Radiation Field Spectra of Cloud Flashes in the Interval From 20 kHz to 20 MHz”, IEEE Transactions on Electromagnetic compatibility, vol. 48, No. 1, pp.234-239, February 2006.

[10] J. Guo, Y. Xie and A. Qiu, “Calculation of Lightning Induced Voltages on Overhead Lines Using an Analytical Fitting Representation of Electric Fields”, IEEE Trans. on EMC, vol. 59, no. 3, pp. 879-886, June 2017.

[11] J. Paknahad, K. Sheshyekani and F. Rachidi, “Lightning Electromagnetic Fields and Their Induced Currents on Buried Cables. Part I: The Effect of an Ocean–Land Mixed Propagation Path”, IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 5, pp. 1137-1145, Oct. 2014.