Electromagnetic field evaluation in building located close to high-voltage overhead line

Atanas G. Chervenkov

*Technical University of Sofia, Department of Theoretical Electrical Engineering, 1000 Sofia, Bulgaria, e-mail: acher@tu-sofia.bg

***Abstract*—The magnetic and electric fields created of overhead line located in a densely populated area, near a residential building are investigated. The goal of this study is to model the fields created of 110 kV distribution line, located in highly urbanized environment and to evaluate the field impact on the residential building, situated very close after new construction. The electromagnetic compatibility of high-voltage line is considered. To find the electromagnetic field components, a method using numerical solution of Maxwell's equations by finite-element method FEM is used. The magnetic field model is based on Poisson's equation and on using of magnetic vector-potential. A modeling and simulation makes it possible to analyze real configuration and evaluate magnetic field levels and to establish electromagnetic compatibility. The electric and magnetic field levels in areas of the building are evaluate to verify the requirements of necessary exposure. The electromagnetic field has been investigated, taking into account the closer vicinity, where located a building recently built near the power line and it is possible to obtain high levels of the field. A magnetic flux density has relatively large values in a several areas of the building. The obtained electrical intensity levels are low, relative to the permissible norms for public exposure and ensure necessary safety requirements. The study allows the influence determination of the magnetic field and electric field of humans and can be evaluated risks of human health.**

Keywords — electromagnetic compatibility, FEM, magnetic field, new construction, overhead line, health risk.

I. INTRODUCTION

The goal of many studies is the discussion and evaluation of possible effects on humans. Usually, they have the assumption, that the current and induced field explain the negative effects of electromagnetic field (EMF) exposure [1]. Safety, environmental damage and property impacts of high voltage overhead transmission lines are less feared of the more people [2, 3, and 4]. The population in the big cities of Bulgaria is increasing more and more. The infrastructure is expanding and is located even near overhead power lines. This makes it possible to change the electromagnetic environment.

High voltage HV (110 kV) distributive overhead power lines are built about 30-40 years ago [4]. The places in the cities where they were built were sparsely. At present these areas of cities are very populated. Therefore, it is now necessary to be explored the conditions of electromagnetic compatibility [4]. You even have to, by reason of the large construction of new buildings in some big cities in our country, it is necessary to make a preliminary study of the interference levels, created by close power lines.

The goal of this study is to model the fields created of 110kV distribution line, which is located in highly urbanized environment and to evaluate the field impact on the residential building, situated very close after new construction. The power line is located in one neighborhood of Sofia with 42.645257° N, 23.333487° E coordinates. A snapshot of the investigated building and high voltage line is shown in Fig. 1.

Fig. 1. A snapshot of the investigated building and line

The close surrounding area in the immediate environment of the overhead line is studied. A new residential building has been built near the power line. The principal scheme for the electromagnetic field determination of the investigated overhead HV power line is shown in Fig.2.

The investigated line is for voltage of 110kV and consists of two triples of conductors A, B, C and A', B' C', respectively, and grounding conductor N. The building is built on 5 floors next to power line. The distance of the lowest conductor to the ground is h_{min} and d is distance to the building.

II. ELECTROMAGNETIC FIELD MODELLING

A. Model of the Magnetic Field with Magnetic Vector Potential $\vec{A}_\mu$

To find the electromagnetic field components, a method using numerical solution of Maxwell's equations by finite-element method FEM is used [3, 4]. The current density $\vec{J}$ in the HV line conductors, with AC current, creates the

978-1-6654-3581-9/21/$31.00 ©2021 IEEE

magnetic field in the close area [3, 4]. The first Maxwell's equation for determination of magnetic field $\vec{H}$ is applied [4]

$$rot\vec{H} = \vec{J} \quad (1)$$

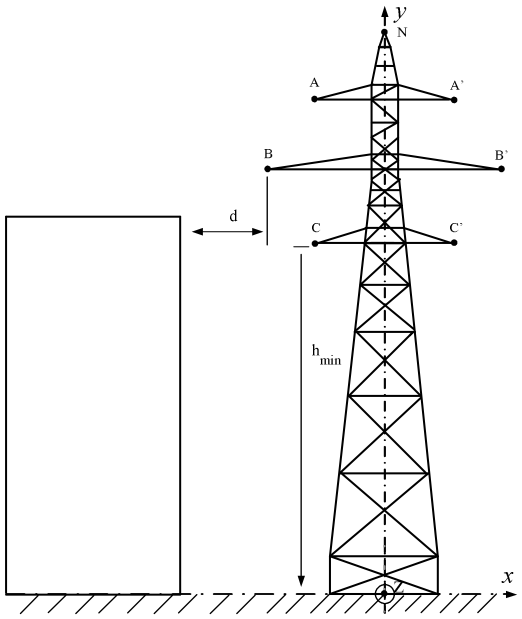

Fig. 2. Principal scheme of the investigated HV line and building location

In this case, the magnetic vector - potential $\vec{A}_\mu$ is used [3, 4], which is introduced by magnetic flux density (magnetic induction) $\vec{B}$ [3, 4]

$$\vec{B} = rot\vec{A}_\mu , \quad (2)$$

Coulomb calibration is used [3]

$$div\vec{A}_\mu = 0 \quad (3)$$

The *rot* is a vector operator that describes too little rotation of a magnetic vector potential $\vec{A}_\mu$ in three-dimensional space. The alternative terminology rotation and alternative notations *rot* $\vec{A}_\mu$ and $\nabla \times A$ are often used the former especially in many European countries and the latter, using the nabla operator and the cross product, is more used in other countries in the world. The *rot* $\overrightarrow{A_\mu}$ is equal of $curl\vec{A}_\mu$.

The electrical intensity *E* (briefly named electric field) can be determined by magnetic vector potential with the expression [3, 4]

$$\dot{E} = \frac{\partial A_\mu}{\partial t} - grad\ V , \quad (4)$$

where *V* is scalar electric potential.

Around the tower, the magnetic permeability is $\mu = \mu_r \mu_0 = 4\pi 10^{-7}\ H/m$, because the surrounding environment (air) is with relative magnetic permeability close to $\mu_r = 1$.

A Poisson's equation is solved [3]

$$\nabla^2 \vec{A}_\mu = -\mu \vec{J} \quad (5)$$

The magnetic flux density is in parallel plane to plane of studied object (Fig.2). Therefore, the magnetic vector - potential $\vec{A}_\mu$ and electric current density vector $\vec{J}$ are orthogonal to plane of the object and they have only one component, in the *z*-direction [4]. In this case, the vectors of magnetic field and electric field can be determinate from Poisson's equation of magnetic vector - potential $\dot{A}_{\mu z}$. [4]

$$\frac{\partial^2 \dot{A}_{\mu z}}{\partial x^2} + \frac{\partial^2 \dot{A}_{\mu z}}{\partial y^2} - j\omega\mu\gamma \dot{A}_{\mu z} = -\mu \dot{J}_z \ , \quad (6)$$

where: imaginary unit is j ; angular frequency is ω and conductivity of the surrounding space is γ [4].

For variable electromagnetic fields at low angular frequencies ω (frequency *f*=50 Hz) the imaginary component $j\omega\mu\gamma \dot{A}_{\mu z}$ can be neglected for E-field exposure [4, 5].

In case of idle mode or case with minimal conductor current, the HV line conductors can be defined like sources of the electrical field, which is created by phase voltages [3, 4] $\dot{V}_A, \dot{V}_B$ and $\dot{V}_C$, and voltages $\dot{V'}_A, \dot{V'}_B$ and $\dot{V'}_C$, respectively, of two triples conductors. The voltages are a symmetrical system.

In this case equivalent Laplace equation is solved

$$\nabla^2 \dot{V} = 0 \quad (7)$$

The electric field intensity *E* in this case is determined only through the relation [3, 4]

$$\dot{E} = -grad\ \dot{V} \quad (8)$$

B. Numerical Model of the Electomagnetic Field

A numerical procedure, which use the finite element method is applied to determine the electromagnetic field vectors. The magnetic vector - potential is solved through the matrix operation [3]

$$\{A_\mu\} = [N_A]^T . \{A_N\}, \quad (9)$$

where the matrix of shape functions on elements is N_A and the magnetic vector - potential in the mesh of finite element nodes is A_N [3, 4 and 5].

The vectors of the electromagnetic field are determined through the magnetic vector - potential as its derivatives.

Magnetic flux density *B* is defined by rotation of magnetic vector potential (2) by the numerical expression [3, 4]

$$\{B\} = \Delta \times [N_A]^T \{A_N\} \quad (10)$$

III. NUMERICAL RESULTS

As already mentioned, only the plane perpendicular to the power line direction can be considered [4].

For the numerical solution the ANSYS software is used [3, 4]. It is finite element method package. The finite element mesh has vector type deformed element with 8 nodes.

The overhead power line was built with metallic towers [1, 3 and 4], with two triples of phase conductors (six phase conductors) and one ground conductor - double three-phase 110kV, 50 Hz power line , shown in Fig. 2. It has six steel – aluminum conductors of the three phases (two triples of conductors) and one grounding conductor. The phase conductors have circular cross section. The currents in the phases conductors conduct are time varying. They are symmetrical system, shifted by 120^0 degree, relative to each other. The phases conductors have a heights h_A, h_B and h_C and h'_A, h'_B and h'_C, respectively from the ground. The cross-section of the phases conductors is $300mm^2$. h_{min} is the suspension of conductors due to sagging and it is 7m for this studied line. The electrical power line has been investigated with the dimensions and current loads prescribed by the manufacturer [1, 3, 4, and 6].

The numeric simulations are made with next data: h_A=23m; h_B=19.5m; h_C=16m; d=5 m; x= -50 ÷ +20 m. The distribution of magnetic field intensity and electric field close to the HV overhead line is observed [3, 4]. The levels of magnetic field and electric field of HV line are determined by the appropriate current density in the conductors in different cases of an operating mode [3, 4 and 6]. Three modes of the power line operation are considered [3, 4] - normal operation, idle mode and short circuit.

Initially, a normal mode is considered. In normal mode the phase conductors can be carrying current up to 690A [6].

The graphics of the magnetic field distribution B around the studied line for 2 elevations in Fig.3 are shown. The perpendicular plane of the investigated line is being considered [1, 4]. Results with current of 300A are made.

In a several areas of the building a magnetic flux density values are relatively large. Unfortunately, obtained values of magnetic field are small higher than recommended maximum values for continuous magnetic exposure. The induction levels, obtained from the calculations, in the rooms located very close to the HV line, are not satisfactory, according to permissible levels of public exposure [7].

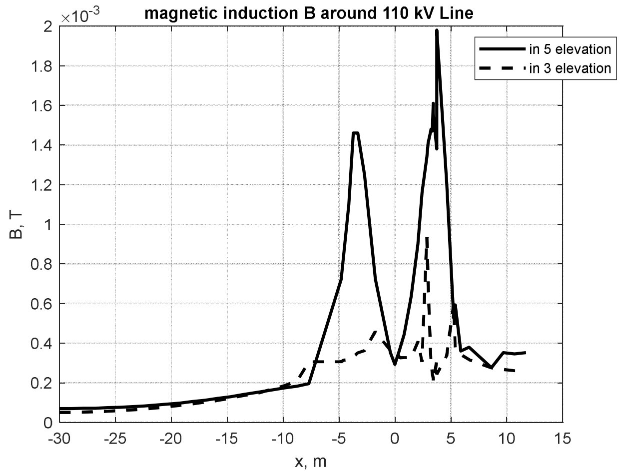

Fig. 3. A magnetic field distribution at the highest and middle elevation in normal mode

Next, the short circuit mode in the line is observed. In this case the phase conductors can be carrying current up to 5000 A, short time - only 2 seconds.

The graphic of the magnetic field distribution B around the studied line in case of short circuit in Fig.4 is shown.

2 D flux line in perpendicular plane to the power line direction [3, 4] for short circuit case in Fig.5 is shown.

The levels of magnetic field, found by simulations are critical, very close to the recommendable levels of magnetic exposure in case of short-term exposure from high intensity magnetic field with low frequency.

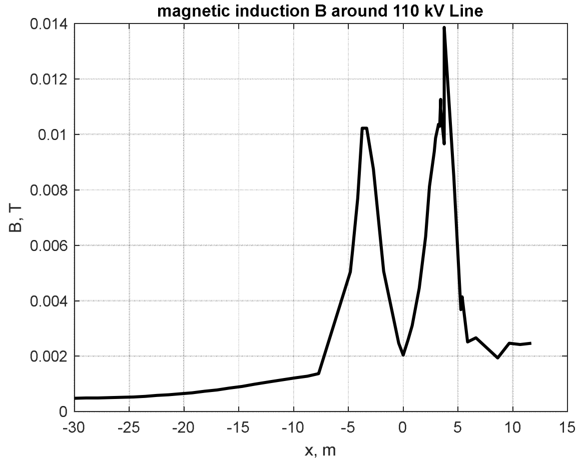

Fig. 4. A magnetic field distribution at the middle elevation in short circuit case

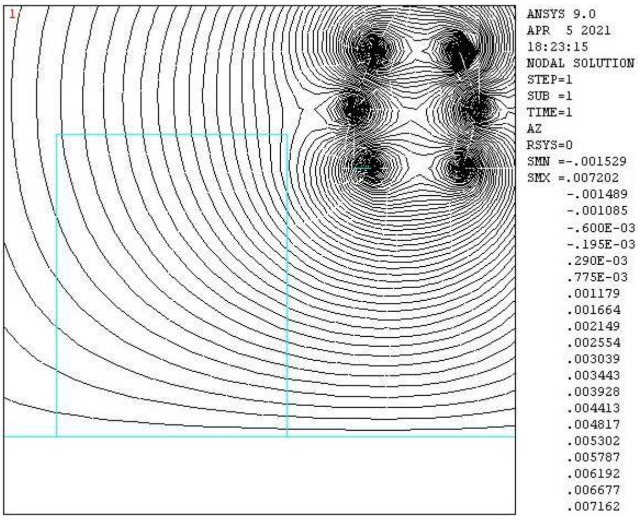

Fig. 5. 2-D magnetic flux lines around overhead power line in case of short circuit

Due to the short duration of the short circuit, until the overcurrent protection of the power line is switched off, these exposure levels may not be taken into account when examining electromagnetic radiation, because they do not have a significant effect on the human body, but they can have effect on the sensitive electronic equipment.

The magnetic field density in the nearby area around the high voltage power line, where the new building was built, is quite high on the top floors of the building.

There are still no studies that can reliably prove the influence of the magnetic field in short-term exposure to strong magnetic fields.

Finally, idle mode of studied line is investigated. The level of electric field intensity around 110 kV power line is searched.

In Fig. 6 the electric intensity vectors (vector field) in perpendicular plane to the HV line [4] in idle mode are shown.

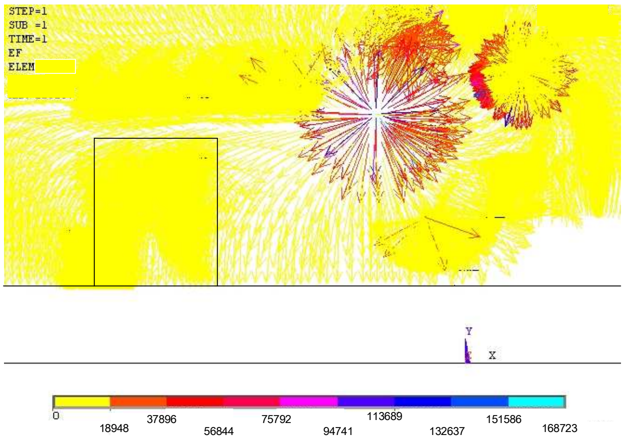

Fig. 6. Electric vector field around studied line in idle mode

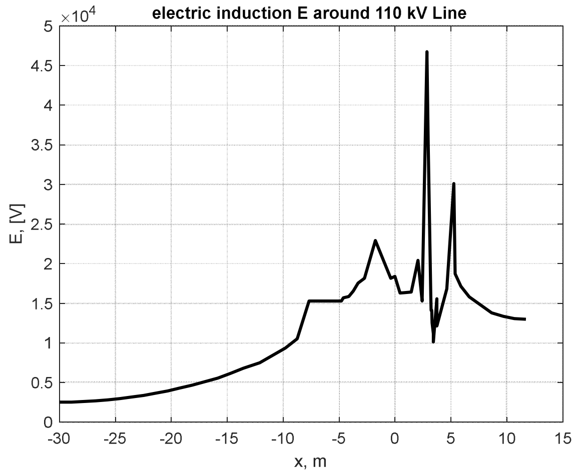

Fig. 7. A electric field distribution in idle mode of the line

A profile of the electric intensity in idle mode around the studied line in Fig.7 is shown. The perpendicular plane to the overhead line direction is being considered also [1, 4].

The obtained electrical intensity levels are satisfactory, lower than required levels of public electric exposure, defined as safety requirements [7]. The building shields the electric field, unlike the magnetic one that passes through the walls.

IV. Discussion

The consideration of the cases, when it is possible to obtain high values of the electric intensity or magnetic intensity, is necessary due to the influence of the electromagnetic field on the person or the sensitive electronic equipment.

The frequency of investigated power lines is low, very low (50 Hz). In such cases, a quasi-static analysis could be applied and the unacceptable effects on the human body of the electric or magnetic fields can be determined separately [8].

The extremely low frequency electromagnetic field can excite electric potential on the human body, since the human tissues possess electromagnetic properties like conductivity, as a result of this is obtained so called AC hum.

It can be seen on Fig.5, that the building does not shield the magnetic field. However, the electric field has low values inside the building- Fig. 6. This is mainly due to the reinforced building structure, which provides weaker electric fields.

Therefore, the influence of the magnetic field of a nearby building on the people living inside is much greater than that of the electric field.

Cases of high frequency currents flowing through the high-voltage line conductors are less common. For instance, these are the cases of lightning striking on the overhead line whereby the frequencies of lightning current reach to 20MHz. In places where the activity of lightning is high, it is necessary to investigate this case of lightning. The studied high-voltage line is located next to substation, which has a reliable lightning protection and it is located at a higher level than power line. Therefore, lightning strikes are unlikely and it is not necessary to study them.

Conclusion

The present research performs field analysis of HV overhead power line by the FEM simulation. A modeling with simulations make a possibility to evaluate and analyze electromagnetic field in accordance with disturbing electromagnetic effects. The magnetic field has been studied in newly built building , taking into account that there, where located a existing HV the power line. In a several areas of the building a magnetic flux density values are relatively large. Thereby the influence of field effects on humans can be assessed and health risks can be avoided. The presented research can be continued for the simulation of the exposure level field on humans and on sensitive electronic devices by unusual situations like lightning strike.

Acknowledgment

The author would like to thank the Technical University of Sofia for the financial support.

References

[1] Chervenkov A. G., Chervenkova T., "Investigation of the capacitive interference of overhead multi-line power sisrtem",2017 15th International Conference on Electrical Mashines, Drives and Power Systems(ELMA), 2017, pp. 38-41.

[2] Wadleya D. A., Hanb J. H., Elliott P. G, „Risk hidden in plain sight: Explaining homeowner perceptions of electricity transmission infrastructure",Energy Policy, vol. 132, pp. 744-753, September 2019.

[3] Chervenkov A., Chervenkova T., "Investigation of the Influence of the Electromagnetic Field in the Vicinity of High Voltage Overhead Line", Materials Science Forum, vol. 856, 2016, pp. 190-195.

[4] Chervenkov A. G., "Modelling and evalution of electromagnetic field of urban high-voltage power line", 2020 7th International Conference on Energy Efficiency and Agricultural Engineering(EE&AE), 2020.

[5] Siauve, N., Scorretti, R., Burais, N., Nicolas, L. and Nicolas, A., "Electromagnetic fields and human body: a new challenge for the electromagnetic field computation", COMPEL, vol. 22 No. 3, 2003, pp. 457-469.

[6] Genkov N., Zahariev V., Ivanov P., Manual for the design of electrical systems and networks. Technica, Sofia, 1993 (In Bulgarian).

[7] 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, December 2010.

[8] Hoang, L.H.; Scorretti, R.; Burais, N.; Voyer, D., "Numerical dosimetry of induced phenomena in the human body by a three-phase power line". IEEE Transactions on Magnetics, vol.45, issue 3, March 2009, pp. 1666–1669.