Indonesian Journal of Electrical Engineering and Informatics (IJEEI)
Vol. 10, No. 2, June 2022, pp. 292~301
ISSN: 2089-3272, DOI: 10.52549/ijeei.v10i2.3572

The Influence of the Mixed Electric Line Poles on the Distribution of Magnetic Field

Ghanim Thiab Hasan[1], kamil JaduAli [2], Ali Hlal Mutlaq [3]
[1,2] Electrical Department, Shirqat Engineering College, Tikrit University / Iraq
[3] Medical Devices department, Engineering Technical College, Alkitab University, Kirkuk / Iraq

Article Info

Article history:

Received Nov 7, 2021
Revised Apr 5, 2022
Accepted Apr 20, 2022

Keyword:

Reinforced concrete pillar Steel lattice column
Magnetic field
Mixed lines.

ABSTRACT

With the wide spread of transmission lines and distribution networks, there is a higher exposure to magnetic fields generated by those lines, leading to more cases of human health impacts. The aim of this paper is to conduct a comparative analysis of magnetic field levels in the vicinity of a three-phase overhead line, which mounted on a steel lattice and a reinforced concrete columns. The analysis includes the influence of the change in phase position of all currents, both in low and medium voltage system of the considered mixed lines. Emphasis have been consented on investigate the influence on distribution of magnetic fields of the currents induced in the ferromagnetic and conductive parts of the columns. The mathematical calculations were conducted numerically by using “COMSOL“Multiphysics software package, which is based on application of the finite element method, on two-dimensional mixed lines model. The obtained results indicate that the intensity of magnetic induction vector decreases in the area around the columns due to the induced currents in ferromagnetic conductive parts of columns. This phenomenon is more pronounced in steel lattice columns, while it is less pronounced in the reinforced concrete columns.

Corresponding Author:

Ghanim Thiab Hasan
Department of Electrical Engineering,
Al-shirqat Engineering college ,
Tikrit University.
Email: ganimdiab@yahoo.com

1. INTRODUCTION

Over the last decades, many questions have been raised about the possibility of the potential health hazards caused by electric and magnetic field [1]. The interactions of such fields with the human body may affect the functioning of living cells by inducing currents which flow inside human organisms. These currents result from the electric and magnetic fields induced in humans subjected to high voltage [2].

Power systems are a complex network for the production, transmission and distribution of electricity and have the task of providing reliable, economical and quality power to consumers. The transmission of electricity is conducted by lines, in a wide range of voltage levels [3].

Overhead lines are most present in transmission and distribution networks, especially in suburban areas. In urban areas, human security and reduced space capacity justify the installation of cable lines despite much higher investment costs [4]. In many rural and suburban areas, in order to distribute electricity more economically, electricity is distributed using mixed overhead lines [5]. The World Health Organization (WHO) is making significant efforts and resources to establish a causal link between the effects of electromagnetic (EM) fields and potential diseases in people living or permanently residing in areas around power plants [6].

To validate these assumptions, several numerical and laboratory studies have been conducted. Based on the results obtained, the cancer is the most dangerous epidemic that may arise from human exposure to electric and magnetic fields. The risk can be doubled for children [8]. While, other studies, however, completely denied such risks [7].

In the majority of studies that we have found in the literature, the evaluation of electric and magnetic has been determined below a single power line. Only three recent papers have investigated the electric and magnetic field distribution below only two parallel transmission lines [8].

In recent decades, various measurement and calculation methods have been developed to determine the strength of the electric and magnetic fields in the vicinity of power plants such as overhead lines and transformer stations (SS). Calculation methods can be divided into analytical and numerical methods. Magnetic field calculations using direct Maxwell equations are only possible for simple configurations because of the complexity of the model [9]. The advantage of analytical model is in the ability to express the field level depending on the transmission line parameters and simplify the analysis of new configurations. The disadvantage of these models is that they are based on many assumptions [10].

The multi pole expansion can be used for analytical calculation of electric and magnetic fields, and the procedure based on the discrete approximation of Biot-savart law for the magnetic fields [11].For the numerical calculations of the electromagnetic fields in the vicinity of power lines, the following methods can be used:

1. Finite-difference method (FDM),
2. Finite element method (FEM),
3. Boundary element method (BEM),
4. Charge simulation method (CSM), and
5. The surface charge simulation method (SCSM) [12].

The Heuristic algorithm has been used in the conjunction with one of the previously numbered calculation methods for optimizing some parameters that are part of electric and magnetic field calculations close to transmission lines [13].
Most heuristic algorithms can be applied for optimizing the number and positions of the simulating charges in CSM method. Heuristic algorithms are also can be applied to the transmission line geometry optimization [14].

EM fields of industrial frequency belong to the field of non-ionizing low frequency radiation The reference limit levels of the population exposure , determined by the ordinance on the limits of exposure to non-ionizing radiation are stricter than the reference limit levels proposed by ICNIRP [15]. Many European Union countries also use lower thresholds than those given by ICNIRP. The reference limit levels of exposure of the population to electric and magnetic fields, proposed by ICNIRP and the Regulations in the European Union at a frequency of 50 Hz, are given in Table 1.

Table 1. Reference limit levels for population exposure at a frequency of 50Hz.

Standard	E [V/m]	H [A/m]	B [μT]
European Union	2000	32	40
ICNIRP	5000	160	200

The aim of this paper is to analyze the distribution of the magnetic field in the vicinity of steel lattice and reinforced concrete columns of mixed overhead power distribution systems, at the maximum allowable current intensities and the minimum allowable heights of phase conductors. The influence of the distribution of phase positions and the presence of ferromagnetic, conductive parts of columns on the distribution of the magnetic field have been investigated.

The calculations were performed numerically, using the “COMSOL” software package multiphysics [16], observing a simplified, two-dimensional model of the system. The results are presented graphically, by representing the intensity of the magnetic induction vector at a standard defined height (1 m) above the ground in a symmetrical area around the column.

1.1. Overhead mixed line

The pole is an integral part of every overhead line and serves for air conduction. Overhead line poles are usually made of reinforced concrete or as a steel lattice structure. Nowadays, wooden poles are less and less in use. The choice of poles depends on the voltage level, their function, mechanical forces and climatic conditions. Mixed lines are always placed on steel lattice or reinforced concrete columns [17].

There are some common rules in the formation of a mixed line, regardless of the type of the column. The low voltage line is always placed on a horizontal console and below the medium voltage line. The neutral line is located next to the line conductors. Medium voltage (MV) three-phase conductors can be above the line in the same plane or in two, parallel planes forming a triangle, when the two lower conductors are in one plane, and the third above them [18]. Non-insulated allucel conductors are always used for medium voltage lines, while allucel conductors or self-supporting cable bundles can be used for low voltage (LV) lines.

In Iraq, a mixed line is formed at voltage levels of (20 kV / 400 V) by using strands of the same nominal cross section 50/8 mm^2 for conductors of both systems. The conductors are attached with soft wire to the supporting insulators of different shapes and sizes for the low voltage (LV) and medium voltage (MV) line systems. When using supporting cable bundles, the bundle of insulated ropes is fastened to the pole with appropriate clamps [19].

1.2. Steel lattice column

Steel lattice poles are used at all voltage levels, most often in transmission and sub-transmission networks, but they also used in distribution. They are usually four-legged, connected to the ground by a concrete foundation, which should be higher than the surrounding terrain for safety reasons. Steel lattice columns used in mixed lines are 10.5 m high. It should be noted that when using a steel lattice column, horizontal steel brackets are always used to receive both LV and MV lines [20].

1.3. Reinforced concrete column

Reinforced concrete columns have the longest service life and do not require special maintenance. They are used in low voltage (LV), medium voltage (MV) and mixed systems. Reinforced concrete pillar in mixed above-ground systems has a standard prescribed height of 12 m, of which the above-ground part is 10 m high.The top consoles are placed on the pillars, which can be made of reinforced concrete or are metal constructions. The lines of the MV system can be placed in a horizontal plane as well as in two parallel planes, forming a triangular configuration of lines [21].

2. METHODOLOGY

2.1. Theoretical setting of the problem

When conductive bodies are found in the immediate vicinity of the lines, the induced electric field occurs due to electromagnetic induction, which is superimposed on the electric field caused by the system conductors. In addition, since bodies are conductive, the induced electric field creates induced currents, which create an additional magnetic field, so that both fields, are a consequence of the action of the conductor field, but also induced charges and currents.

As it is a system of transmission of low frequency electrical power, the electromagnetic field can be considered quasi-static, so the electric and magnetic fields can be observed separately, so, their mutual influence is negligible, except through electromagnetic induction. The medium (air) in which the mixed line is located is linear and can be considered homogeneous. In the immediate vicinity of the system, as well as in the conductors of the system, there are often steel, Ferro-magnetic, conductive materials, lattice poles with appropriate brackets, reinforced concrete poles and brackets for receiving conductors on them.

The magnetic field generated by currents in mixed line conductors is of relatively low intensity, so it certainly does not lead to saturation of nearby ferromagnetic parts. In most ferromagnetic materials, the saturation occurs at about (0.6 - 0.8 T), which is of the order of (104 – 105) times the value of the intensity of the magnetic induction vector in the ferromagnetic parts of the columns. Therefore, it is not necessary to take into account the nonlinearity of these materials, these materials can be treated as homogeneous, constant permeability.

As the time changes of voltage and current are simple - periodic, for the calculation of the distribution of electric and magnetic fields in the vicinity of mixed lines, it is possible to use complex notation. In order to determine the distribution of electric and magnetic fields, the simplest is the vector of electric field strength $\vec{E}$ and complex vector of magnetic induction $\vec{B}$, are defined as follows [22]:

$$\vec{E} = -gradv - j\omega\vec{A} \quad (1)$$

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

Where: $\vec{E}$ represent the vector of electric field, $\vec{B}$ represent the vector of magnetic field, $\vec{A}$ is the vector of magnetic potential Since there are no volume-distributed charges in the observed space, the complex electric scalar potential satisfies the Laplace differential equation in the complex domain as follows:

$$\Delta v = 0 \quad (3)$$

Earth-induced charges are represented by figures, and the earth is usually treated as perfectly conductive, which greatly simplifies calculations. Charges induced in the present conductive configurations are already taken into account when defining complex partial differential equations for potentials. A complex magnetic vector potential is a solution of a complex partial differential equation [23] as follows:

$$\Delta\vec{A} - j\omega\mu\sigma\vec{A} = -\mu j \tag{4}$$

Where: $\Delta\vec{A}$ is the vector of the potential gradient, $\vec{A}$ is the magnetic potential vector, ω, is the angular frequency, σ is the conductivity related to ferromagnetic material, μ represent the magnetic permeabitity of free space , j is the magnetic polarization .

To solve (2) and (3), it is necessary to define the boundary conditions and select the reference point of the complex electric scalar potential. Despite the fact that, by choosing to treat the problem as 2D, it is assumed that the line is infinitely long and thus has finite charges at infinity, the reference point of complex electric scalar potential can be chosen at infinity in the plane of water observation. By applying approximate methods for solving the Laplace differential equation, this means the assumption that the field disappears far enough from the line itself, which again means that neither the electric nor the magnetic field exists far enough from the line itself. The complex vector of the density of induced currents $\vec{J}_{ind}$ is a consequence of the induced electric field $\vec{E}_{ind}$ as shown in the following equation [24]:

$$\vec{J}_{ind} = \sigma\vec{E}_{ind} = -j\omega\mu\sigma\vec{A} \tag{5}$$

When calculating the magnetic field, the magnetic field of induced currents is superimposed on the magnetic field of the currents in the conductors, so that the resulting magnetic field is the vector sum of these two fields.

2.2. Model analysis

In his paper, a comparative analysis of mixed lines was performed which firstly placed on a reinforced concrete and then placed on a steel lattice column. In both cases, the MV brackets are used to receive the insulator in one plane, due to the fact that, only horizontal brackets can be used on the lattice column. The cross section of the analyzed system, with the dimensions of the steel brackets used, is shown in Figure 1. The medium voltage (MV=20KV) line was marked with S_1, S_2 and S_3, while the low voltage (LV=400V) line was marked with N_1, N_2 and N_3, while the neutral line is marked with n.

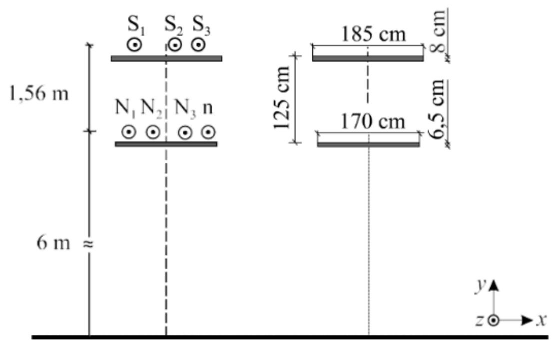

Figure.1. Configuration of phase conductors of mixed overhead line.

Since the ecological aspect of the influence of the magnetic field of mixed line is observed in the paper, all calculations were performed for the most unfavorable configuration at the lowest allowable conductor heights. Accordingly, the LV line is set at a safety height of 6 m, and the MV line at 6 m + 1.56 m = 7.56 m, adhering to the prescribed allowable distances between LV and MV lines. The heights of the receiving insulators are 5.1 cm for the LV line and 36.2 cm for the MV line. Instead of real strands, their simplified models were used in the paper. The first approximation enabled the real strands to be replaced by a model in the form of two, concentrically placed layers, of appropriate, equivalent radii. Based on the second approximation, strand can be considered as a conductor made of aluminum through the entire equivalent cross section, because the variations in the EM field distribution due to the presence of the ferromagnetic core are insignificant.

The electrical and magnetic properties of the materials from which the model elements are made are illustrated in Table (2).

Table 2. Electrical and magnetic properties of the material [25].

Material property	Aluminum	Fitting	Column
σ (S/m)	$3.55x10^7$	$0.46x10^7$	$3.55x10^7$
ε_r	-------	1	1
μ_r	-------	850.	1

It was adopted that the lines are loaded with the maximum allowable effective value of the nominal current, I_N = 170 A. The mixed overhead lines (20 kV / 400 V) or (20 KV / 0.4 KV) placed on a steel column, as well as reinforced concrete poles, used in rural and suburban areas in Iraq. Due to the use of allucel strands of the same, nominal cross section 50/8 mm^2 , the complex maximum values of the currents of three-phase conductors in medium voltage (MV) line have the following values:

$$I_0^{20KV} = 170\sqrt{2}\, e^{j\theta^0} \tag{6}$$

$$I_4^{20KV} = 170\sqrt{2}\, e^{-j120^o} \tag{7}$$

$$I_8^{20KV} = 170\sqrt{2}\, e^{-j240^o} \tag{8}$$

And the complex maximum values of the currents of three-phase conductors in low voltage (LV) line are:

$$I_0^{400V} = 170\sqrt{2}\, e^{j\theta^0} \tag{9}$$

$$I_4^{400V} = 170\sqrt{2}\, e^{-j120^o} \tag{10}$$

$$I_8^{400V} = 170\sqrt{2}\, e^{-j240^o} \tag{11}$$

The two-dimensional models of the system consist of a steel-lattice and reinforced concrete column, taken from AutoCad in „COMSOL“ Multiphysics and placed on the modeled surface of the earth. Earth and air are represented by rectangular areas of sufficiently large dimensions in relation to the pillars (air 60 m × 30 m), (earth 60 m × 20 m), so that the boundary condition applies at the boundaries of the area, the intensity of the magnetic vector potential is zero ($\vec{B}$ = 0). The parameters of the environment are illustrated in Table (3).

Table 3. Parameters of the environment.

Parameters	Free space.	Earth
ε_r	1	1
μ_r	1	1
σ (S/m).	10^{-6}	1/50

It is assumed that the ground surface is flat, that the conductors within one system (LV and MV) are parallel and placed at the same height, as shown in Figure 1. In the areas around the conductors and the poles themselves, the network was the densest, while it became rarer, approaching the edges of the domains. The network formed in this way best covered the areas where the most intense changes in the magnetic vector potential occur.

Equations (2) and (3) have been solved by a numerical procedure, after which a graphical representation of the quantities of interest was performed; in this paper, the intensity distributions of the magnetic induction vector, in the plane normal to the direction of propagation of the line containing the column itself, at a height of 1 m above the ground, in the area ± 30 m from the column axis.

A simplified 2D system model can provide a satisfactory approximation of the magnetic field distribution in the environment of the observed configuration in case of the observed system does not have significant specifics, such as changes in terrain configuration, changes in conductor deflection, the need to observe a real pole model and / or mutual position. When the stated characteristics of the system change along the route, it is desirable to perform analyzes by observing a realistic 3D model of the system. Calculations in this case require much more computing resources and take much longer, but their accuracy also increases. The obtained results then more accurately reflect the distribution of the magnetic field in the environment of the system than in the case of the 2D model.

3. RESULTS AND DISCUSSION

In order to obtain quantitative indicators of the influence on the distribution of the magnetic field of phase positions of currents, as well as the presence of poles that contain conductive ferromagnetic parts, the following scenario was conducted.

The influence of the MV line phase distribution on the distribution of the magnetic field in the absence of LV line and the column itself was first examined. In the next step of the calculation, in addition to the MV system, the LV line is included in the circuit, still in the absence of column.

After the phase positions in both systems that give the highest values of the intensity of the magnetic induction vector were determined, the procedure was repeated in the presence of a column. Finally, the obtained results were compared, observing the graphs of the intensity of the magnetic induction vector of the most unfavorable phase positions, from the point of view of ecology, without column and in the presence of column, and appropriate conclusions were made.

3.1. Influence of the presence of a steel lattice column

Calculations have shown that the deviations of the intensity of the magnetic induction vector when changing the phase position of currents in the MV system, in the absence of LV systems and columns, are negligibly small, so in the further calculation we used arbitrarily chosen phase position SN 048 (S1 - I0, S2 - I4 and S3 - I8).

From Figure 2, it can be noted that the distribution of the magnetic field is also influenced by the phase position of LV line. Figure 2 also shows the influence of LV line phase attitudes on the intensity distribution of the magnetic induction vector in the presence of a steel lattice column, at the SN 048 phase attitude.

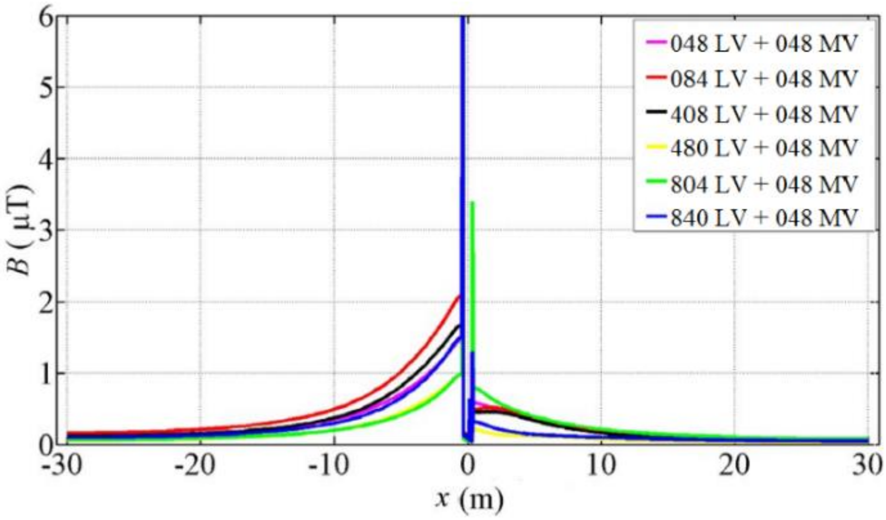

Figure 2. Intensity of magnetic induction vector in the presence of steel column at different phase positions of LV line (SN 048).

Figure (2) shows that the highest values of the intensity of the magnetic induction vector in the space outside the column were obtained by arranging the phases SN 048 + NN 048. In the column itself, the values of the intensity of the magnetic induction vector, due to large differences in steel and air permeability, are much higher than in the surrounding area. In order to more clearly observe the influence of phase attitudes on the intensity distribution of the magnetic induction vector, the values of the intensity of the magnetic induction vector that occur in the column reinforcement (B_{max} in the column = 10.5 µT) were artificially cut on the graph.

3.2. Results validation

The influence of the presence of a steel lattice column on the intensity distribution of the magnetic induction vector is presented in Figure (3), which shows a comparative graph of the "worst" phase positions for a system without a column and in the presence of a steel lattice column in the column plane. Ignoring the significant jump in the value of the magnetic induction vector in the steel column, it can be even better seen from Figure 4 that the presence of a lattice column introduces significant changes in the intensity distribution of the magnetic induction vector in the area to the left and right of the column.

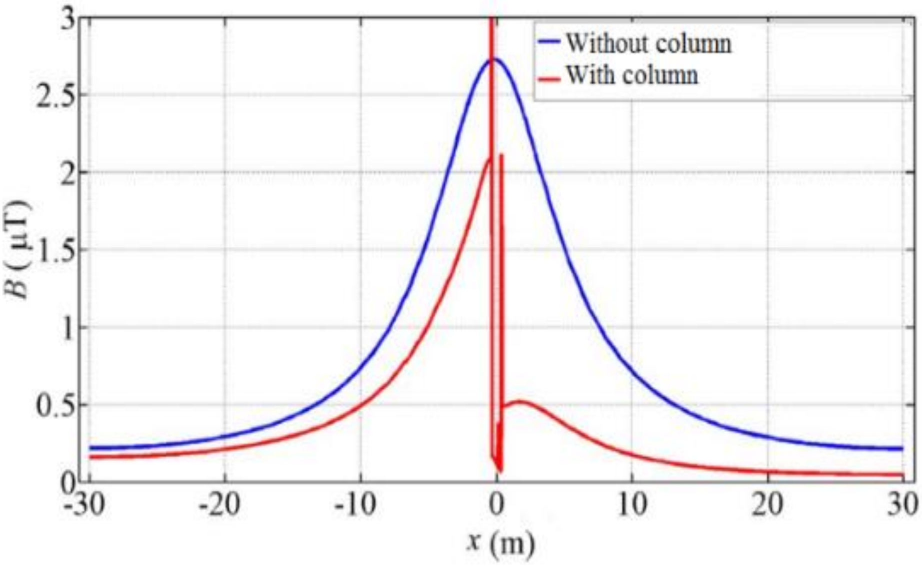

Figure 3. Intensity distribution of magnetic induction vector with and without the presence of a steel lattice column.

The presence of a pole creates an asymmetric distribution around the pole, which is attributed to the asymmetric position of the LV lines. The two phase conductors are on the left side of the pole, while on the right side there is only one phase conductor, with neutral conductor, through which no current is established under symmetrical load. More importantly, the values of the intensity of the magnetic induction vector are lower in the presence of a column than without a column.

The decrease in the intensity of the magnetic induction vector is the result of the action of induced currents in the steel column and receiving brackets of the supporting insulators, whose field is superimposed on the magnetic field of currents in phase conductors of mixed line. Asymmetrically placed LV lines cause uneven distribution of induced currents in the supporting brackets and the column, as a result of which, as can be seen in Figure 4, the asymmetry is expressed only in the presence of the column.

3.3. Influence of reinforced concrete column

In the analysis of the influence of reinforced concrete column on the intensity distribution of the magnetic induction vector, the steps from the previous consideration were repeated, when the mixed line was placed on a steel lattice column. In accordance with the described series of procedures, Figure 5 shows the influence of the phase attitudes of LV line currents on the intensity distribution of the magnetic induction vector in the presence of a reinforced concrete column. As in the case of the steel lattice column, the change in the phase arrangement of the MV system did not significantly affect the intensity of the magnetic induction vector in this case, so that further calculations were performed for the MV line phase layout, 048 MV.

Looking at Figure (4), similar conclusions can be seen as in the case of mixed line placed on a steel column. Due to the high permeability of steel, much higher values of the intensity of the magnetic induction vector occur in the fitting of the sub than in the surrounding space in the air. Due to a clearer presentation of changes in the intensity of the magnetic induction vector in free space, the values per ordinate are lay in the range up to 6 μT. The influence of the presence of a reinforced concrete column on the intensity distribution of the magnetic induction vector is shown in Figure (5).

3.4. Results validation

The graph in Figure (5) shows the "worst" phase positions for the system with and without the presence of a reinforced concrete column in the plane of the column. Form Figure (5) , we can see that the presence of a reinforced concrete column introduces asymmetry in the distribution of the magnetic field around the column, and reduces the intensity values of the magnetic induction vector, as in the case when the mixed line was placed on a steel column. Comparing the graphs in Figures (3),(4) and (5), it can be concluded that the presence of a steel column significantly reduced the intensity of the magnetic field induced in the space around the column than in case of the alone reinforced concrete column.

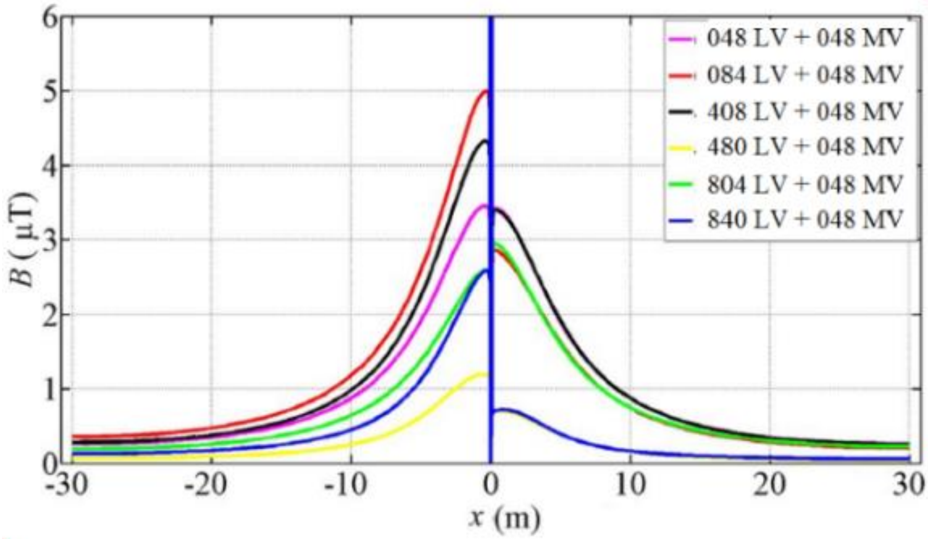

Figure 4. Intensity of magnetic field induced in the presence of steelof column at different phase positions of LV line (SN 048).

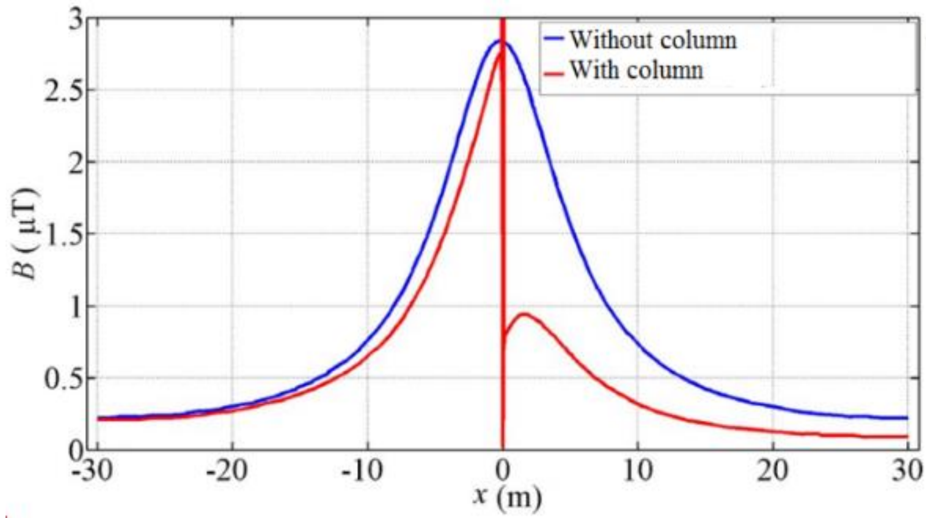

Figure 5. Intensity vector distribution of magnetic induction with and without the presence of a reinforced concrete column.

4. CONCLUSION

Through the analyzing of the the intensity distribution of magnetic induction vectors in the vicinity of mixed overhead line 20 kV / 400 V that placed on a steel column, as well as reinforced concrete poles, used in rural and suburban areas in Iraq, it was noted that the presence of ferromagnetic parts of poles reduce the intensity of the magnetic induction vector in the free space around the poles. The influence of steel lattice column on the reduction of the magnetic field is somewhat more pronounced in relation to the presence of reinforced concrete column, where all obtained values are much below the limit reference values proposed by European Union and ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (B_{max} in the vicinity of the column < 3 µT< $B_{permitted}$ = 40 µT).

Analyzes performed in this paper lead to the conclusion that when measuring the intensity of magnetic induction vectors in case of the most unfavorable conditions are observed, measurements should be performed as far as possible from the poles, in the space halfway between them. In that space, the smallest impact of the reduction of the magnetic field is expected due to the presence of poles, and thus the "worst" conditions are simulated, from the aspect of environmental protection. People who are concerned about the health effect caused by a radiation exposure of high-power electrical lines should keep in mind that the exposure intensity goes down significantly as get farther away from the radiation source.

REFERENCES

[1] J. Carlos Bravo-Rodríguez, Juan Carlos del-Pino-López and P. Cruz-Romero "A Survey on Optimization Techniques Applied to Magnetic Field Mitigation in Power Systems" Review paper, energies journal.2019. pp 1-20, doi :10.3390/en12071332.

[2] M. Talaat, "Calculation of electric and magnetic induced fields in humans subjected to electric power lines". J. Electrost. 72 (2014), 387–395. doi:10.1016/j.elstat.2014.06.008.

[3] Saied, M.M. "Canceling the Power Frequency Magnetic and Electric Fields of Power Lines". IETEJ.Educ. 2014, 54, 90–99. doi.org/10.1080/09747338.2013.10876111.

[4] Frezzi,P. Hug,R.Grant,J.Klingler,A."Passive magnetic field compensation of existing underground cables". In Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, Wroclaw, Poland, 5–9 September 2016; pp. 876–881.doi:10.1109/EMCEurope.2016.7739246.

[5] Hernández Jiménez, V.J.; Castronuovo, E.D.; Sánchez, I. "Optimal statistical calculation of power cables disposition in tunnels, for reducing magnetic fields and costs". Int. J. Electr. Power Energy Syst. 2018, 103, 360–368, doi: 10.1016/j.ijepes.2018.05.038.

[6] Bignucolo, F.Coppo, M. Savio, A, Turri, R. "Use of rod compactors for high voltage overhead power lines magnetic field mitigation". Energies 2017, 10, 1381. https://doi.org/10.3390/en10091381.

[7] Hedtke, S.Pfeiffer, M. Franck, C.M. Zaffanella, L. Chan, J. Bell, J. "Audible noise of hybrid AC / DC overhead lines: Comparison of different prediction methods and conductor arrangements'. Epri'sHigh-Volt. Direct Curr. Flex. Ac Transm. Syst. Conf. 2015, 1, 1–8. 17. doi.org/10.3929/ethz-b-000274041.

[8] "Council Recommendation on the Limitation of exposure of General Public to Electromagnetic Fields (0 to 300 GHz)," Official Journal of theEuropean Communities, 1999, L199/59.

[9] Rankovic´, A.; Mijailovic´, V.; Rozgic´, D. Optimization of electric and magnetic field emissions produced by independent parallel overhead power lines. Serb. J. Electr. Eng. 2017, 14, 199–216. https://doi.org/10.2298/SJEE161115002R.

[10] Ghanim Thiab Hasan[1], Ali Hlal Mutlaq[2], Kamil Jadu Ali[3] "Comparative evaluation of SiC/GaN "MOSFT" transistors under different switching conditions" Bulletin of Electrical Engineering and Informatics**.** Vol. 11, No. 2, April 2022, pp. 1111-1120.DOI: 10.11591/eei.v11i2.3445.

[11] El Dein, A.Z. A Survey on Optimization Techniques Applied to Magnetic Field Mitigation in Power Systems, energies journal. 2019, 39, pp 1-20. Doi.org/10.3390/en12071332

[12] Giaccone, L. "Optimal layout of parallel power cables to minimize the stray magnetic field". Electr. Power Syst. Res. 2016, 134, 152–157. DOI:10.1016/j.epsr.2016.01.014.

[13] Rabah Djekidel, Sid Ahmed Bessedik, Pierre Spiteri, Djillali Mahi. "Passive mitigation for magnetic Between HV power line and aerial pipe line using PSO algorithms optimization". ElectricPowerSystems Research, Elsevier, 2018, 165, pp.18-26. Doi:10.1016/j.epsr.2018.08.014.

[14] International Commission on Non-ionizing Radiation Protection: "ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz - 100 kHz)," Health Physics, vol. 99(6), pp. 818- 836, June 2010.

[15] Del-Pino-López,J.C.;Cruz-Romero,P,L.;Martíne Roman ,J. Magnetic field shielding optimization in underground power cable duct banks. Electr. Power Syst. Res. 2014, 114, 21–27 ,doi.org/10.1016/j.epsr.2014.04.001

[16] Souza, D.S.C.; Caetano, C.E.F.; De Paula, H.; Lopes, I.J.S.; Boaventura, W.D.C.; Paulino, J.O.S.; Evo, M.T.A. "Experimental Investigation of Magnetic Field Shielding Techniques and Resulting Current Derating of Underground Power Cables". IEEE Trans. Ind. Appl. 2018, 54, 1146–1154,doi.org/10.1109/TIA.2017.2785762

[17] Ahmed Hasan Mohammad, Ghanim Thiab Hasan, Kamil Jadu Ali "Numerical analysis of the photovoltaic system inspection with active cooling" International Journal of Electrical and Computer Engineering (IJECE) Vol. 11, No. 4, August 2021, pp. 2779~2789.doi: 10.11591/ijece.v11i4.

[18] Kuznetsov B.I., Nikitina T.B., Kolomiets V.V., Bovdui I.V., Voloshko A.V., Vinichenko E.V. "Synthes of robust active shielding systems of magnetic field generated by group of high-voltage power lines". Electrical engineering & electromechanics, 2018, no.5, pp. 34-38, doi: 10.20998/2074-272X.2018.5.06.

[19] Voloshko, A.V.; Bovdyj, I.V.; Nikitina, T.B.; Vinichenko, E.V.; Kuznetsov, B.I.; Kobilyanskiy, B.B. Synthesis of Active Screening System of Magnetic Field of High Voltage Power Lines of Different Design Taking Into Account Spatial and Temporal Distribution of Magnetic Field. Electr. Eng. Electromec. 2017, 0, 29–33, doi.org/10.20998/2074-272X.2017.2.04.

[20] Kuznetsov, B.; Voloshko, A.; Bovdui, I.; Vinichenko, E.; Kobilyanskiy, B. High Voltage Power Line Magnetic Field Reduction by Active Shielding Means with Single Compensating Coil. In Proceedings of the 2017 International Conference on Modern Electrical and Energy Systems (MEES), Kremenchuk, Ukraine, 15–17 November 2017; pp. 196–199. Doe:10.1109/MEES.2017.8248887.

[21] Canova A., del-Pino-Lopez J.C., Giaccone L., Manca M. Active Shielding System for ELF Magnetic Fields. IEEE Transactions on Magnetics, 2015, vol.51, no.3, pp. 1-4, doi: 10.1109/tmag.2014.2354515.

[22] Kuznetsov B.I., Nikitina T.B., Voloshko A.V., Bovdyj I.V., Vinichenko E.V., Kobilyanskiy B.B. Experimental research of magnetic field sensors spatial arrangement influence on efficiency of closed loop of active screening system of magnetic field of power line. Electrical engineering & electromechanics, 2017, no.1, pp. 16-20, doi: 10.20998/2074-272X.2017.1.03.

[23] Chystiakov P., Chornyi O., Zhautikov B., Sivyakova G. Remote control of electromechanical systems based on computer simulators. 2017 International Conference on Modern Electrical and Energy Systems (MEES), Nov. 2017, doi: 10.1109/mees.2017.8248934.

[24] Chystiakov P., Chornyi O., Zhautikov B., Sivyakova G. Remote control of electromechanical systems based on computer simulators. 2017 International Conference on Modern Electrical and Energy Systems (MEES), Nov. 2017, doi: 10.1109/mees.2017.8248934.

[25] Kamil Jadu Ali, Ghanim Thiab Hasan, Mahmood Ali Ahmed. "Investigate and Analyze the Electromagnetic Field Levels Inside an Electric Power Substation". Tikrit Journal of Engineering Sciences, Vol.24.No 3.2017, PP (10-14), doi.org/10.25130/tjes.24.3.02.

BIOGRAPHIES OF AUTHORS

Ghanim Thiab Hasan He is an associate professor at the department of electrical engineering, Al-Sherqat engineering college, Tikrit University, Iraq, where he has been a faculty member since 2006. He graduated with a first-class honours B.Eng. degree in electrical and Electronic Engineering from Belgrade Universityy, Serbia, in 1984, and M.Sc. in Electrical Engineering fromBelgrade University, Serbia in 1986. His research interests are in the area of electrical and electronic engineering. He can be contacted at email: ganimdiab@yahoo.com

Ali Hlal Mutlaq He is a lecturer at the department of electrical and electronic engineering, Al-Kitab University, Iraq, where he has been a faculty member since 2005. From 2015-2018. He graduated with a first-class honours B.Eng. degree in Electronic Engineering from Belgrade Universityy, Serbia, in 1982, and M.Sc. in Electrical Engineering fromBelgrade University, Serbia in 1984. His research interests are primarily in the area of wireless communications and networks as well as in the area of electrical engineering. He can be contacted at email: ali.h.mutlaq@uoalkitab.edu.iq

Kamil Jadu Ali He is an associate professor at the department of electrical engineering, Al-Sherqat engineering college, Tikrit University, Iraq, where he has been a faculty member since 2006. He graduated with a first-class honours B.Eng. degree in Electrical and Electronic Engineering from Belgrade Universityy, Serbia, in 1984, and M.Sc. in Electrical Engineering fromBelgrade University, Serbia in 1986. His research interests are primarily in the area of electrical and electronic engineering. He can be contacted at email: kamil.ali78@tu.edu.iq.