Comparison of Electromagnetic Fields around Electric Power Lines

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***Abstract*—The generation of electromagnetic fields is conditioned by the time-varying movement of the electric charge. Electromagnetic field is emitted to the surrounding by devices that operate with electric current and voltage. The calculation of electromagnetic fields is important for assessing possible health risks in human interaction. The increasing trend in the use of electricity is also associated with an increase in transmitted power and hence a higher level of electromagnetic fields. With this in mind, understanding the levels of electromagnetic fields and their impact on the human body is still relevant. For this reason is in this paper mentioned comparison of electromagnetic fields around 400 kV power lines various power towers. Simulations were realized in multi-physic software ANSYS.**

Keywords—electromagnetic field, simulations, modeling, power lines, ANSYS

I. INTRODUCTION

The science of electromagnetism deals with the study of phenomena resulting from the force action of electric charges. This force action has two aspects: *electric* and *magnetic*. Since these two phenomena are inherently connected and their nature is common, we call them electromagnetism. Electromagnetism has taken an important position in the field of physics and engineering. Almost all modern society is built on its practical use. Today, electricity is the most widespread and purest form of energy used by man. We can say that civilization progress is conditioned by the extent to which the phenomena that originate in electromagnetism are utilized [1], [3].

Electric forces are also much more profound than just the use of electricity. The building materials of the world, such as atoms and molecules, are bound by coupling of electrical, magnetic and attracting origin. Finally yet importantly, electromagnetism has influenced our existence on a biological level. The human nervous system is based on the propagation of electrical signals in neurons, which represents our biological and mental activity. Man is basically a large electronic mechanism and therefore it is necessary to know the surrounding devices that generate an electric or magnetic field and can affect changes in the human body [1].

This work was supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences under the contract VEGA 1/0435/19 and VEGA 1/0372/18 and by the Slovak Research and Development Agency under the contract No. APVV-19-0576.

II. SOLUTION OF ELECTROMAGNETIC FIELD DISTRIBUTION AROUND 400 KV POWER LINES

The highest voltage level of the transmission system in Slovakia is 400 kV and it transmits the highest powers. For this reason, the electromagnetic field levels around these lines will be highest. It is therefore important to know the levels of these fields due to possible negative impacts on humans and the environment [7].

Magnetic field distribution was solved for 400 kV single-system power line in different arrangement. Magnetic and electric fields were compared depending on distance. ANSYS software, mechanical APDL environment, was used to calculate and model the magnetic induction distribution. In the calculation, the most unfavorable condition was considered: the lowest permissible height for 400 kV conductors above the ground, 8 m according to STN EN 50341-1 (33 3300): 12-2013 and the conductor load of 820 A per phase. This current is the average value of the summer and winter limit load of the used conductors. The simulation used a three-wire AlFe 450/52 bundled conductor with a diameter of 29.31 mm. Its individual strands are 40 cm apart [4], [5].

We assumed symmetrical load and phase shift of 120°. We assumed that all phase conductors have the same sag. We did not take into account the magnetization of the iron core of the strands themselves and the influence of grounding strands in magnetic fields. This has a negligible effect at distances where we determine magnetic fields. The simulation was solved as a 2D problem, and represents a perpendicular cross-section of the power line at the point with the lowest permissible conductor height. The problem was solved for one selected time, i.e. as a static problem. Surrounding (air), we considered as a homogeneous, linear environment [2].

A. Selection of conductors arrangement

There are several types of towers (poles) for single-system 400 kV power lines. This paper compares magnetic and electric fields for towers of the type: “mačka”, “guyed tower” and “octagonal tower” (in the conclusion there are also added data/results of another two types of towers: “donau” and “súdok”). The phase arrangement is identical for all three calculations. In Slovakia, mainly “guyed towers” are used, which replace “portal towers” and “mačka towers”. The

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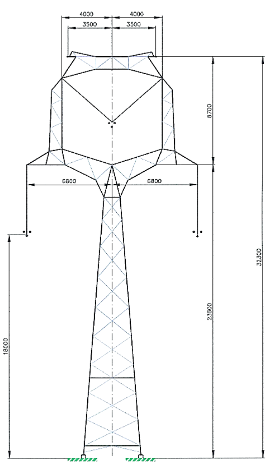
“octagonal towers” are used only rarely at 400 kV voltage level. From the figures and from the arrangement of the conductors, it is possible to assume different distribution of fields. In the arrangement of the conductors at the same height, it was assumed that the magnetic field will decrease more moderately, and the fields of the individual phases will be less suppressed than of the “mačka”-type tower and the octagonal tower. The second assumption is that for a guyed-type tower (“V” tower), all the conductors are at a minimum permitted height of 8 m, and for the other two towers there is only one phase at this height, the others are mounted higher [2].



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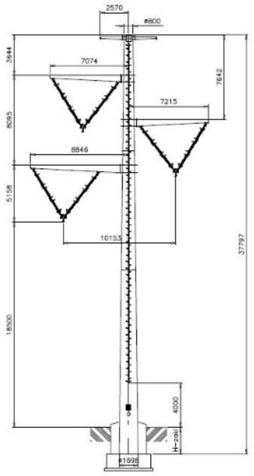

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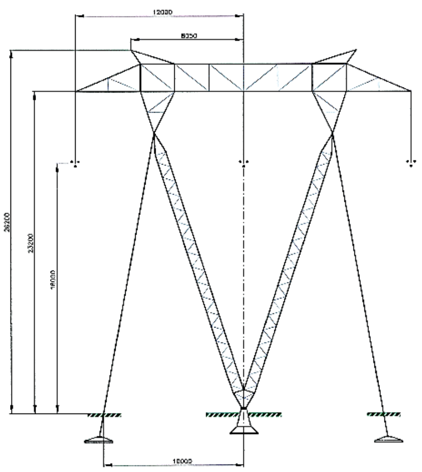

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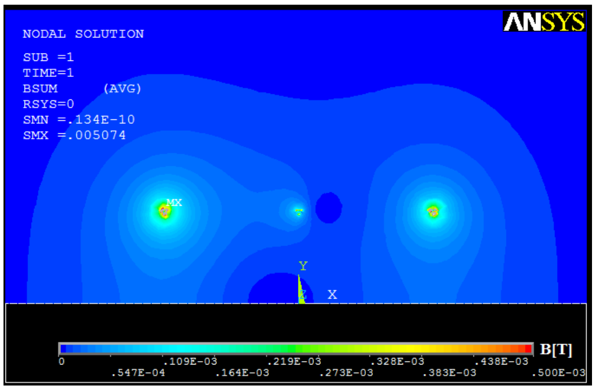
Fig. 1. Front-view at the towers used a) mačka b) octagonal c) guyed

Comparison of magnetic fields around 400 kV power lines

TABLE I. TABLE OF VOLTAGE AND CURRENT INPUT VALUES

t= 0.3·T	φ_0= 0°	φ_1= –120°	φ_2= +120°
U_m= 326.598 kV	u_1= 310.613 kV	u_2= –67.904 kV	u_3= –242.711 kV
I_m= 820A	i_1= 779.865 A	i_2= 170.486 A	i_3= –609.378 A

B. Graphical results for the arrangement of conductors on the tower at the same height



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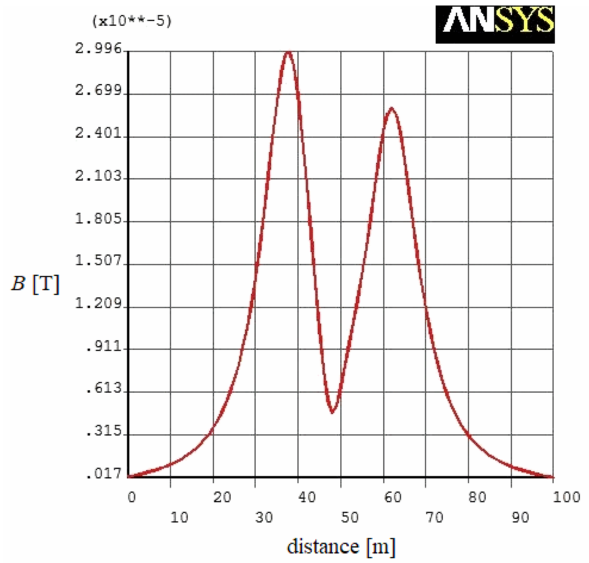

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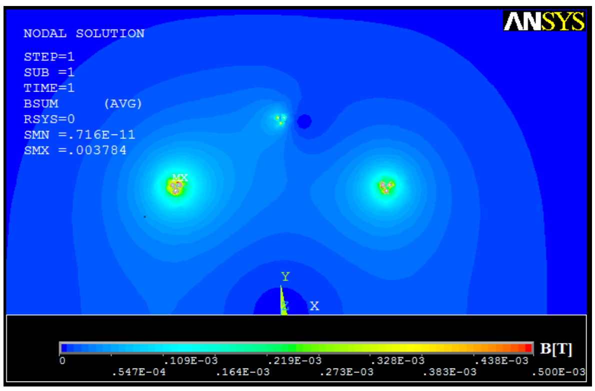
Fig. 2. a) Graphical interpretation of magnetic induction distribution, b) Dependence of magnetic induction on distance (arrangement of conductors on the tower at the same height)

C. Graphical results for the arrangement of conductors on the “mačka”-type tower



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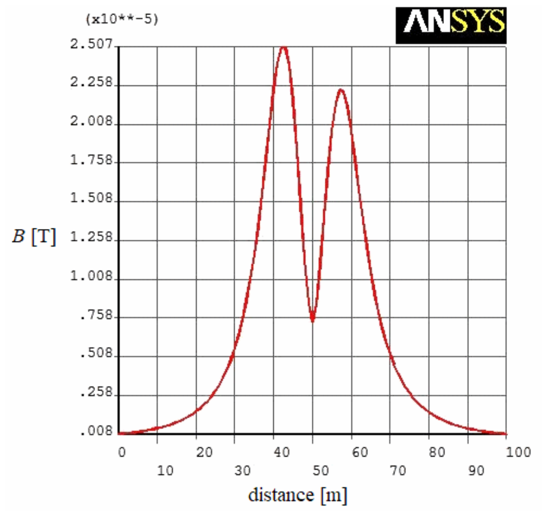
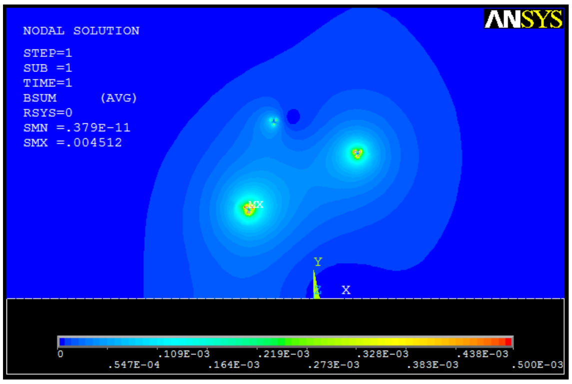


b)

Fig. 3. a) Graphical interpretation of magnetic induction distribution, b) Dependence of magnetic induction on distance (arrangement of conductors on the "mačka"-type tower)

D. Graphical results for the arrangement of conductors on the "octagonal"-type tower



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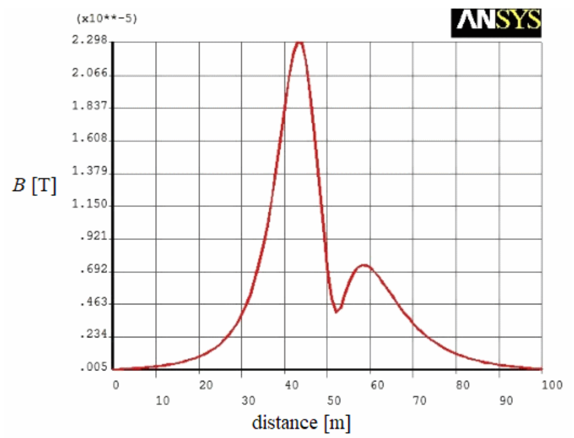

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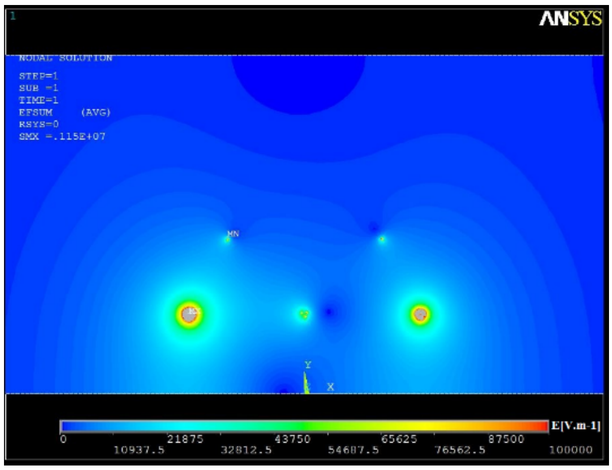
Fig. 4. a) Graphical interpretation of magnetic induction distribution, b) Dependence of magnetic induction on distance (arrangement of conductors on the "octagonal"-type tower)

Comparison of electric fields around 400 kV power lines

The magnetic field is one of the two components of the electromagnetic field, so it is necessary in the next step to determine also the distribution of the electric field. Electric field simulations were performed in ANSYS Mechanical APDL. We also assumed the lowest possible height of 400 kV conductors according to STN EN 50341-1 (33 3300): 12-2013, which is 8 m above the ground. The electric fields were simulated for a 400 kV power line voltage. Phase shift between phases was +/– 120°. The influence of earthing conductors was also considered in the simulation of electric fields. Other conditions for the arrangement of conductors, i.e. time and environment, were assumed identical to those given for the calculation of magnetic fields. The modeling procedure and simulation steps are comparable to the procedure performed for magnetic fields. We determined separately the distribution of the electric field for each conductor arrangement. The source of the electric field in the simulations is the phase voltages on each conductor. The amplitude of the phase voltage was calculated from the line-to-line voltage and assuming a sinusoidal waveform of the voltage and phase shift, we determined the individual voltages for the selected time $t = 0.3 \cdot T$. The electric field is more influenced than the magnetic field, so this simulation was simplified compared to real fields (this may cause some deviations in values). In simulations, we assumed air as a homogeneous, isotropic environment with constant permittivity. Compared to magnetic permeability, the permittivity and hence the electrical properties of the environment and their interaction with the electric field are more influenced by humidity (air composition) [6].

A. Graphical results for the arrangement of conductors on the tower at the same height



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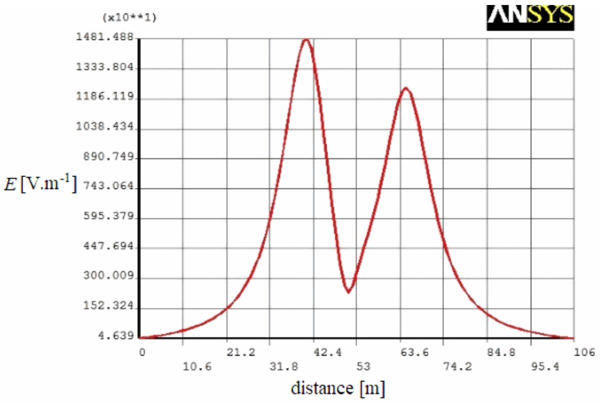

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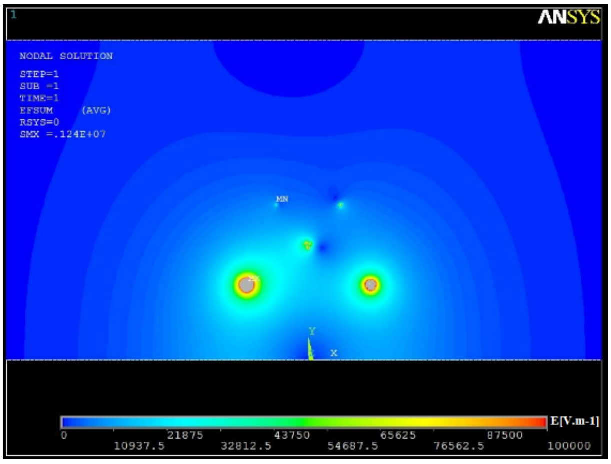
Fig. 5. a) Graphical interpretation of electric field intensity distribution, b) Dependence of electric field intensity E on distance (arrangement of conductors on the tower at the same height)

B. Graphical results for the arrangement of conductors on the "mačka"-type tower



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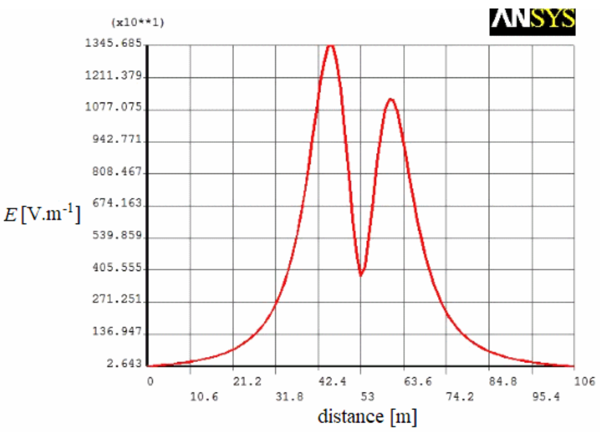

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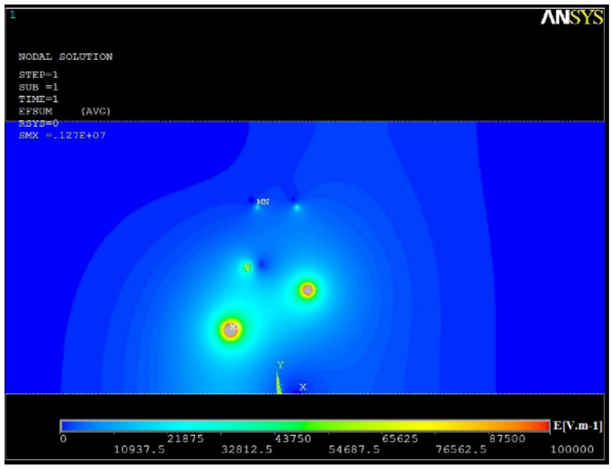
Fig. 6. a) Graphical interpretation of electric field intensity distribution, b) Dependence of electric field intensity E on distance (arrangement of conductors on the "mačka"-type tower)

C. Graphical results for the arrangement of conductors on the "octagonal"-type tower



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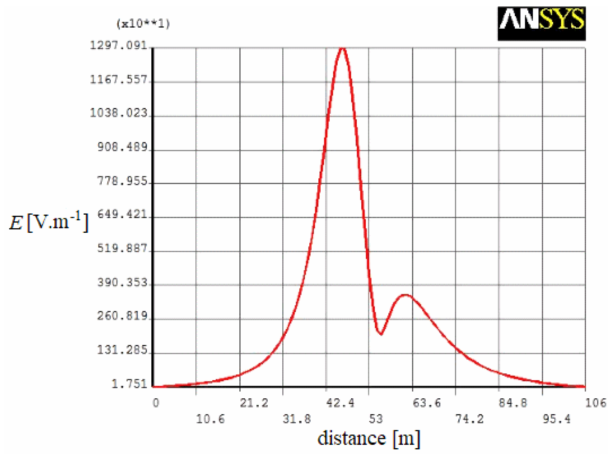

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Fig. 7. a) Graphical interpretation of electric field intensity distribution, b) Dependence of electric field intensity E on distance (arrangement of conductors on the "octagonal"-type tower)

TABLE II. TABLE OF DISTANCES WITH PERMISSIBLE VALUES OF ELECTRIC FIELD INTENSITY E

	Permissible level of electric field intensity ***E*** for continuous exposure at specific distance [m]:	
Conductors arrangement	***From the left***	***From the right***
conductors at the same height	23	21
"mačka"-type tower	17	16
"octagonal"-type tower	15	0

The distances at which the permissible values are reached are given in Table 2. Electric field intensities below 5 kV·m^{-1} were also occurred directly below the conductors, where the fields of the individual phases are suppressed. This simulation was solved as static at time of $t = 0.3 \cdot T$. The distribution of electric and magnetic fields changes periodically over time and the boundaries of the field with permissible value thus shift slightly over time.

III. COMPARISON OF SIMULATION RESULTS

TABLE III. COMPARISON OF MAXIMUM *E* AND *B* VALUES FOR SIMULATIONS MENTIONED IN THIS PAPER

Maximum values of electric field intensity ***E*** and magnetic induction ***B*** obtained in the simulations					
Arrangement	Guyed	Mačka	Octagonal	Súdok	Donau
El. field int. ***E*** [V.m^{-1}]	14815	13457	12971	10908	10736
Magn. ind. ***B*** [T]	$3.0{\cdot}10^{-5}$	$2.51{\cdot}10^{-5}$	$2.29{\cdot}10^{-5}$	$2.84{\cdot}10^{-5}$	$3.13{\cdot}10^{-5}$
Location of the value	Under the outer left conductor	Under the outer left conductor	Under the outer left conductor	Under the outer right conductor	Under the lower left conductors

TABLE IV. COMPARISON OF ELECTRIC FIELD INTENSITY AT SELECTED DISTANCES

Comparison of electric field intensity ***E*** at the distance from the outer conductors					
Distance [m]	Electric field intensity values [V·m^{-1}]				
	Guyed	Mačka	Octagonal	Donau	Súdok
5	8547.4	7975	3546.8	6346.4	5571.3
10	4311.7	4030.6	2820.1	2275.7	1994
20	1200.2	1124.4	1154.7	100.21	96.202
30	372.25	370.75	436.4	159.91	148,4
40	53.925	102.63	145.51	104.76	108.06
The second part of the table represents the left side of the surroundings					
–5	10493	9540.6	9094.9	6440.3	5207
–10	5274.1	4696.2	4204.3	3394.2	2329.8
–20	1446.8	1250.8	970.05	1026.4	356.72
–30	445.17	402.91	287.9	395.13	22.353
–40	64.328	91.964	80.735	164.02	47.098

TABLE V. COMPARISON OF MAGNETIC INDUCTION AT SELECTED DISTANCES

Comparison of magnetic induction ***B*** at the distance from the outer conductors					
Distance [m]	Magnetic induction values [T]				
	Guyed	Mačka	Octagonal	Donau	Súdok
5	$1.80{\cdot}10^{-5}$	$1.78{\cdot}10^{-5}$	$7.35{\cdot}10^{-6}$	$1.57{\cdot}10^{-5}$	$1.51{\cdot}10^{-5}$
10	$9.05{\cdot}10^{-6}$	$8.70{\cdot}10^{-6}$	$5.67{\cdot}10^{-6}$	$4.73{\cdot}10^{-6}$	$6.90{\cdot}10^{-6}$
20	$2.44{\cdot}10^{-6}$	$2.22{\cdot}10^{-6}$	$2.18{\cdot}10^{-6}$	$9.80{\cdot}10^{-7}$	$1.16{\cdot}10^{-6}$
30	$7.10{\cdot}10^{-7}$	$6.65{\cdot}10^{-7}$	$7.54{\cdot}10^{-7}$	$9.75{\cdot}10^{-7}$	$7.15{\cdot}10^{-8}$
40	$9.92{\cdot}10^{-8}$	$1.71{\cdot}10^{-7}$	$2.31{\cdot}10^{-7}$	$5.47{\cdot}10^{-7}$	$1.08{\cdot}10^{-7}$
The second part of the table represents the left side of the surroundings					
–5	$2.13{\cdot}10^{-5}$	$1.58{\cdot}10^{-5}$	$1.61{\cdot}10^{-5}$	$1.52{\cdot}10^{-5}$	$1.43{\cdot}10^{-5}$
–10	$1.07{\cdot}10^{-5}$	$7.98{\cdot}10^{-6}$	$7.37{\cdot}10^{-6}$	$7.81{\cdot}10^{-6}$	$4.91{\cdot}10^{-6}$
–20	$2.82{\cdot}10^{-6}$	$2.14{\cdot}10^{-6}$	$1.62{\cdot}10^{-6}$	$2.19{\cdot}10^{-6}$	$2.79{\cdot}10^{-7}$
–30	$8.18{\cdot}10^{-7}$	$6.57{\cdot}10^{-7}$	$4.49{\cdot}10^{-7}$	$7.86{\cdot}10^{-7}$	$5.25{\cdot}10^{-7}$
–40	$1.14{\cdot}10^{-7}$	$1.71{\cdot}10^{-7}$	$1.18{\cdot}10^{-7}$	$3.12{\cdot}10^{-7}$	$3.55{\cdot}10^{-7}$

In the tables Tab. 3 and Tab. 4 there are compared simulation values for both single- and dual-system power lines. Table 3 shows the maximum values of electric field intensity and magnetic induction that were occurred during the simulations. It can be appreciated that the maxima are located below the outer conductor with the highest instantaneous voltage for the electric field intensity *E*, and the highest current for magnetic induction *B*. The position of these maxima will periodically change from one outer conductor to the other along with varying current and voltage. The frequency of this change will be 50 Hz. In the "Donau"-type arrangement, the maximum is located below and between the conductors of the system where the highest instantaneous voltage *U* and current *I* values are on the lower conductors. Electric fields had reached a higher level under single-system lines The magnetic induction values were comparable for both single and dual-system lines and differ only slightly from $2.29{\cdot}10^{-5}$ T for the "octagonal"-type tower arrangement to $3.13{\cdot}10^{-5}$ T for "Donau"-type tower. The locations of the occurrence of maximums are approximately the same for *E* and *B*, since the simulations for these quantities were run separately for magnetic induction and then for electric field intensity. With respect to separate simulation, it was not necessary to consider the phase shift between current and voltage.

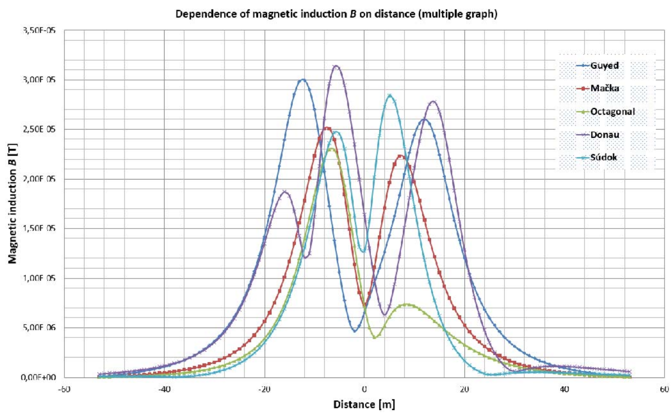

Fig. 8. Magnetic induction *B* characteristics for all mentioned towers

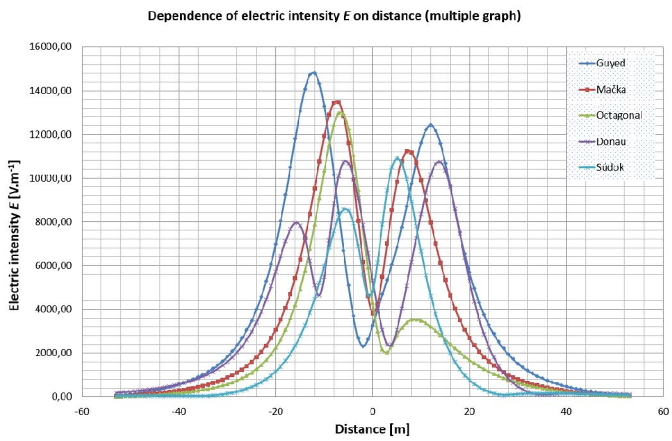

Fig. 9. Electric field intensity *E* characteristics for all mentioned towers

The values of *B* and *E* at selected distances from the outer conductors and 1.7 m above the ground are given in Tab. 3,

Tab. 4 and Tab. 5. It can be seen that in addition to the different magnitude of the maximum values, the rate of their decrease varies depending on the distance.

Fig. 8 and Fig. 9 show the diagrams of the electric field intensity E and the magnetic induction B for all simulations performed.

IV. CONCLUSION

From the results of the simulations, it is apparent that from the point of view of the assessment of the effects of electric fields, it is suitable to use an octagonal-type tower, followed by a mačka-type tower and finally a guyed-type tower. The advantage of the octagonal tower is that only one lowest conductor is located 8 m above the ground. From the mentioned three conductor arrangements compared, this type is therefore best suited for the electromagnetic field criterion. With this tower, there are visibly lower electric intensity values compared to the other two towers on the side where only one conductor is located. From this simulation, we can conclude that it is more important to verify the value of electric fields to assess the effect of electromagnetic fields.

The distribution of the electric field was solved for 400 kV, which represents the common voltage level for these power lines. The magnetic field was solved for the permissible current value for the conductors, which, however, does not occur commonly in operation. The protection zone for 400 kV is 25 m from the edge conductor. However, when the line is loaded with current 820 A, magnetic field levels that exceed the continuous exposure limits were not achieved (according to the Decree of the Ministry of Health of the Slovak Republic no. 534/2007 Coll. (for residents) and government regulation 209/2016 Coll. (for employees), that set exposure limit values and exposure action values for electromagnetic fields). According to the simulation, the electric field intensity in the protection zone exceeds the required value. These fields have no negative effects in the short term. The effects of EM fields in the long term, at 50 Hz, are not yet fully understood, so actual prevention is important. When loading lines with higher currents than considered, and after evaluating the results of the simulations, long-term occurrence of persons in the vicinity of and under lines is not recommended. There are relatively high levels of electric and magnetic fields in these places, which, according to some sources, have an adverse effect on human health, even if they do not exceed the allowable value mentioned in Decree 534/2007 Coll [3].

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