Computer modeling of electromagnetic field around the 22 kV high voltage overhead lines

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***Abstract*—This article deals with the impact of electromagnetic field close to conductors of high voltage poles. The results of this article are based on computer simulation an on-site measuring. The recommendations for persons close to high voltage poles and overhead lines were deduced according to obtained results.**

Keywords—electromagnetic field, ANSYS, measurement, overhead lines, simulation.

I. INTRODUCTION

Overhead lines are the important components of the electric power system. During the period of lifetime of overhead lines, they must fulfill many requirements, for example: the maximal transmitted power, the value of short-circuit currents, reliability, and space for their construction, maintenance programs and other requirements. During the power lines dimensioning (according to voltage level and the transmitted power) it is necessary to consider the level of exposure incurred by electric and magnetic fields (EMF) in the vicinity of power lines. The resulting EMFs are the side effect of the operation of all electrical devices.

At present, in Slovak Republic there is valid the Decree of Slovak Republic of Ministry of Health No. 534/2007 Coll. [3] and Government Ordinance of Slovak Republic No. 329/2006 Coll. [5]. The aim of these regulations is to reduce the possible risks of EMF exposure to the minimum achievable level. Assessing to exposure levels near electrical wires it is possible achieve in several ways. The most common procedures include measurement of the electric intensity and magnetic induction directly at the site of exposure. With the increasing of computational power of computer technology, it is possible to use advantages of numerical modeling. The interest of this method issues in its benefit during the design stage. By simulation of the power lines operation, it is possible to avoid the unnecessary increase in permissible exposure to EMF. It is also possible to get an idea on the operation of power lines during the extreme conditions, resulting from the short circuits and emergency conditions [4].

For this reason, it is necessary to deal with the EMF distribution and this article presents the way of investigation of the EMF distribution around the electric 22 kV high voltage overhead line and its exposure on persons or subjects using of computer simulation in ANSYS Workbench and verification using of measuring of electric intensity and magnetic induction on-site.

II. MEASURING OF PARAMETERS OF THE 22 KV DISTRIBUTION POWER LINES

The measurement was carried out in winter, during the most adverse climatic and operating conditions. Measuring of EMF around the poles was carried out in eastern Slovakia and the overhead lines were protected by digital protection relay with a record of transmitted power. By measuring on terminals there can be assigned to the measured data of electromagnetic fields of the particular currents and voltages that are causing them.

EMF measurement was carried out between the high voltage poles of the same type. Their designation was assigned as a pole 1 and pole 2. Geometrical parameters of the pole 1 and 2 were identical (Fig. 1), and were as follows:

- Pole type: Supporting concrete 10/6
- Span: 64 m
- Altitude of line L1, L2 and L3: 7,8 m (*a*)
- Console height: 7,5 m (*b*)
- Maximal power line sag: 7,2 m
- Distance of max. cable sag from pole 1: 22 m
- Distance between phase L1 and L3: 3 m (*c*)
- Distance between phase L2 and L3: 1,5 m (*d*)
- Conductor type: Al/Fe
- Conductor diameter: 110 mm²

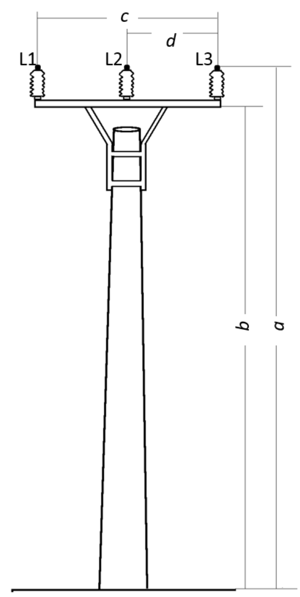


Fig. 1. Measured voltage characteristics from the output of the operational amplifier Geometrical parameters of concrete poles 1 and 2 (altitudes *a*, *b* and heights *c*, *d*).

A. Measuring tools

The measuring apparatus was used Gauss/Tesla meter 8030 shown in Fig. 2a. This tool combines the technology of measurement of magnetic induction with a user interface.

Gauss/Tesla meter 8030 is capable to measure the density of magnetic field quantified in unit gauss [G], tesla [T], ampere/meter [A/m] or oersted [Oe]. The device can measure static and time varying fields. The measuring frequency range of the alternating field is up to 50 kHz. An external 3D probe of type Z0A83-3208-10-T, with integrated Hall sensors, mediated the actual measurement. Hall sensors are placed on top of the external probe. The probe comprises of a sensor for the axes *x*, *y* and *z*. The integrated software evaluates and renders all axes separately. In addition to the three standard channels there is reserved also the vector sum feature for the vector measurement. This function serves the calculated amplitude value resulted from three different vectors and corresponding angles of the resulting vector. Regarding to vector sum it is possible to read out the total magnetic field, which impacts on one point. To prevent a malfunction of geometrical probe twisting towards to the measured object, the *x*-axis side is highlighted by an indication of the Hall element ***H*** by a notch and painting (Fig. 3). The probe is very susceptible to external noise fields. It is therefore necessary to calibrate the probe by a zero terminal before the measurement. The zeroing was performed also after every 50 measurements [2].

Measurement of electric intensity ***E*** was realized by a combined digital measuring instrument ME 3840B (Fig. 2b). Measuring with this device is possible in the frequency range from 5 Hz to 100 kHz. The device is not equipped with any external probe. The device has built-in sensors to measure the magnetic and electric alternating fields. As having only one Hall sensor, it is necessary to perform the measurement independently for the *x*, *y* and *z*-axes by manual rotating of the device in desired direction.

a) b)

Fig. 2. Gauss/Tesla meter 8030; b) ME 3840B.

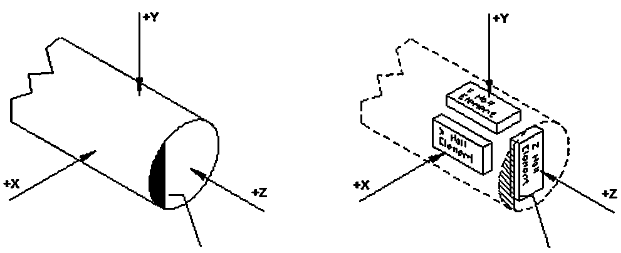


Fig. 3. 3-axis orientation of the probe with a marked indicator of Hall sensor in *x*-axis.

B. Auxiliary Measuring Tools

During the measuring, there were used also auxiliary measuring tools to determine the exact objectives:

- Distance meter served to precisely detect distance between two poles.
- Altimeter was placed under the wires and was able to read the altitudes of all conductors (overhead lines). By this step, it was also possible to accurate refine the geometrical design of the EMF modelling (for the following ANSYS simulations).
- Thermographic camera was used to highlight the effect of external environmental conditions, because the presented measurement was carried out at freezing temperatures.

Distance meter *Altimeter* *Thermographic camera*

Fig. 4. Auxiliary measuring tools.

III. MEASURING OF ELECTROMAGNETIC FIELD

The electromagnetic fields between the selected monitored power-lines were measured at altitude 1; 1.7 and 2 m from the ground. Measurement of EMF was realized along to middle conductor of phase L2, and the measuring step was chosen 2 m. There were carried out 99 measurements on the distance of 64 m between the poles 1 and 2. Measuring was also carried out at the point of 0 m that is on the pole 1. The results of the electric intensity ***E*** are shown in Fig. 6b, and the magnetic induction ***B*** in the Fig. 6c.

The measurement was carried out in addition to the longitudinal direction and to transverse (perpendicular) to the power lines. Magnetic induction ***B*** and electric intensity ***E*** were measured laterally to pole 1 and 2. According to theoretical assumptions, the measurements were carried out at the point of maximum line sag. It was assumed that the highest values of electric intensity and magnetic induction would be achieved close to phase conductors. The maximum deflection was obtained by measuring with altimeter. The transverse measurements were performed with the step of 1 m vertically to the conductor. Verification of the whole protection area for 22 kV power lines was realized by measurement up to 11 m in both sides from the middle of power line conductor of phase L2 (see Fig. 5).

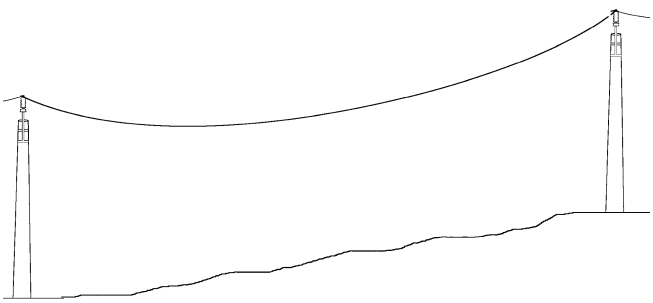
Fig. 5. Decomposition of measuring points between high voltage poles 1 and 2 for the height of 0.3 m.

In Fig. 5 there are shown the measured points along to span of poles 1 and 2, and at the place of maximal sag (22 m from the pole 1). Measuring was carried out from the pole 1 to pole 2. The phase L1 is on the left side of console.

A. Measuring Procedure and Conditions along to Phase L2

The temperature at the time of measurement (in January 2016) of electric intensity ***E*** and magnetic induction ***B*** was observed –4°C, humidity of 95 %. Measurement of electric intensity ***E*** was carried out at the time of 8:00 to 8:45. The calculated average RMS values of electric current were $I_{L1} = 81.06$ A, $I_{L2} = 82.62$ A, $I_{L3} = 83.47$ A and voltages $U_{12} = 22.8$ kV, $U_{23} = 23.01$ kV, $U_{31} = 22.96$ kV. The highest values of electric intensity ***E*** were observed at the point of maximum sag (deflection).

Measurement of magnetic induction ***B*** was carried out at the time of 8:50 to 9:50. The calculated average RMS electric current values were $I_{L1} = 87$ A, $I_{L2} = 89.3$ A, $I_{L3} = 88.66$ A and electric voltages $U_{12} = 22.84$ kV, $U_{23} = 22.9$ kV, $U_{31} = 22.88$ kV. During the measuring, there was not observed any significant local maxima.



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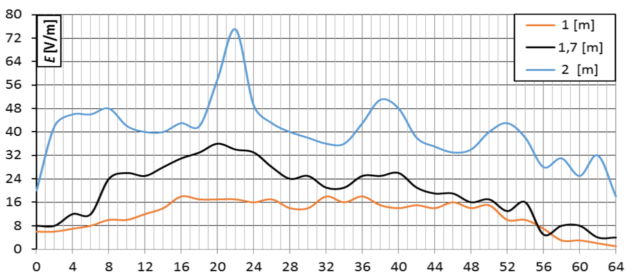

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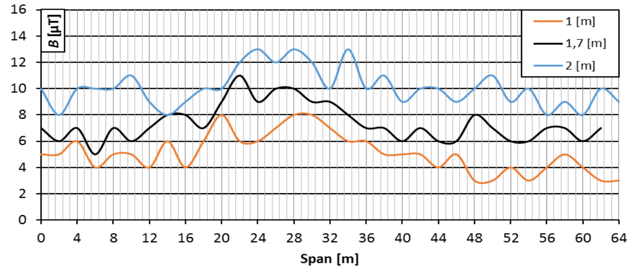

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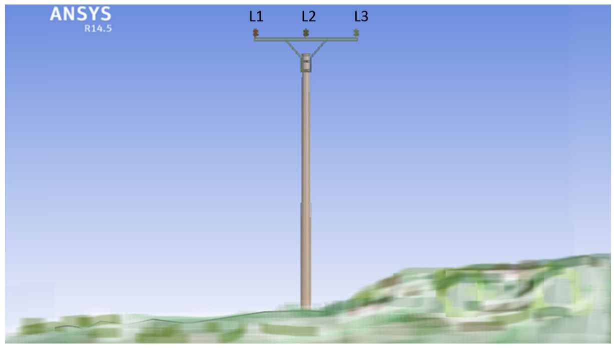
Fig. 6. a) Terrain visualization and dependence graphs of b) electric intensity ***E*** and c) magnetic induction ***B*** between the HV poles 1 and 2 measured at heights of 1; 1.7 and 2 m.

*B. Measuring of **E** and **B** Laterally to Pole 1*



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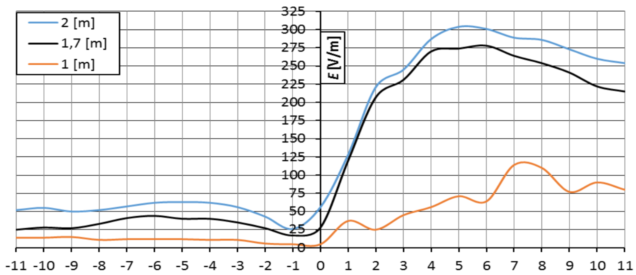

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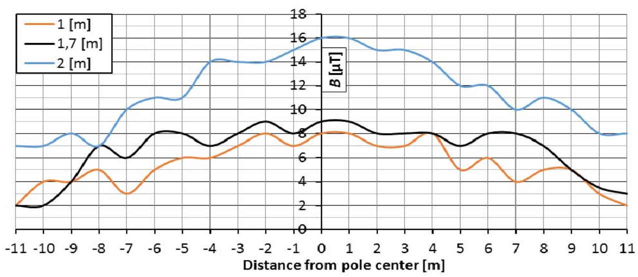

c)

Fig. 7. a) Terrain visualization and dependence graphs of b) electric intensity ***E*** and c) magnetic induction ***B*** laterally to pole "1" measured at heights of 1; 1.7 and 2 m

C. *Evaluation of Measurement*

From the measured data it can be concluded that the effect of rough terrain profile was expressed especially in the case of measuring of the electric field intensity (because of high voltage). The highest values of ***E*** and ***B*** were measured around (below) the phase conductor L3 (because of the shortest distance between the conductor and place of measuring – terrain inhomogeneity). The electromagnetic field in the space under the power lines as an open public space was evaluated according to decree 534/2007 (Requirements for sources of electromagnetic radiation and exposure limits on population to electromagnetic radiation in the environment) and the evaluated values were as follows:

- Electric field: the maximum level of the electric intensity ***E*** in the investigated section was 381 V/m, the action value is 5000 V/m.
- Magnetic field: Maximum level of magnetic induction ***B*** in the investigated section was 20 µT, the action value is 100 µT.

From the measured results arise that the mentioned area between poles 1 and 2 is in sufferance with the decree of 534/2007 and it is electromagnetically safe during the operational conditions (common load operation).

IV. Simulations of Electromagnetic Field Using ANSYS

The emphasis was placed on compliance with the geometrical distance between the conductors, ground and HV pole console, when creating a 3D model in ANSYS Workbench. To reduce the demands on computing power there were accepted particular simplifications in simulation model. One simplification was the neglecting of the bolts and fasteners.

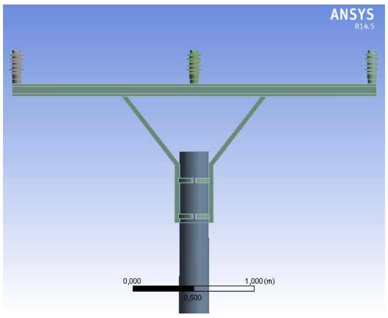

Fig. 8. Illustration of high voltage pole console model.

It was necessary to apply the symmetry of high voltage poles composition to shorten the calculation time. In addition, it was not considered the roughness of the terrain (it was considered planar ground surface) and the objects that could significantly affect the EMF distribution.

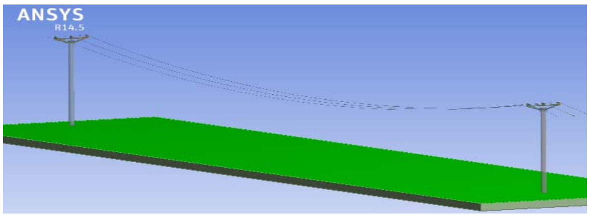

Fig. 9. Illustration of modeled poles and power lines.

The models of HV poles consist of conductors, i.e. the source of electromagnetic field, HV poles, insulators and ground. Each material is of particular physical properties, especially relative permeability μ_r and electrical conductivity σ, so it was necessary to assign them to particular geometrical volumes [1], [6]:

- Air: $\mu_r = 1{,}000006$, $\sigma = 8 \cdot 10^{-13}$ S·m^{-1};
- Ground: $\mu_r = 1{,}08$; $\sigma = 10$ S·m^{-1};
- Metal: $\mu_r = 89$, $\sigma = 3.6\ 10^6$ S·m^{-1};
- Insulator: $\mu_r = 1$, $\sigma = 2 \cdot 10^{-23}$ S·m^{-1}.

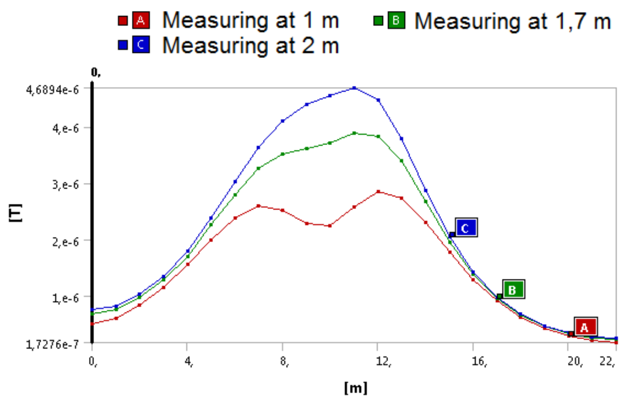

Fig. 10. Graph of magnetic induction ***B*** at the point of maximum deflection during the operation load.

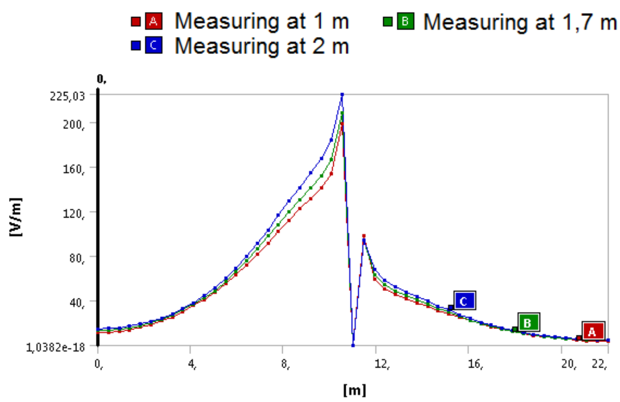

Fig. 11. Graph of electric intensity ***E*** at the point of maximum deflection point during the operation load.

A. Simulation Evaluation

From the simulation results one can see that the area near the 22 kV power lines is electromagnetically safe according to decree of 534/2007. Maximal values from simulations:

- Electric field: the maximum level of the electric intensity $\boldsymbol{E}$ in the simulated section was 225 V/m, the action value is 5000 V/m.
- Magnetic field: Maximum level of magnetic induction $\boldsymbol{B}$ in the measuring section was 4,7 μT, the action value is 100 μT.

The calculated results from simulation (with particular geometrical simplification) correspond to measured data and they compose the accurate tool for evaluating electromagnetic field distribution during operation.

V. Conclusion

This paper presents the results of measurements and simulation of electromagnetic field distribution near high voltage overhead lines. Measurement and simulation confirmed that the environment around that protection zone of overhead 22 kV lines during the operation load is suitable for free movement of people. The measured values were not exceeded the permitted EMF exposure according to Decree 534/2007 (Requirements for sources of electromagnetic radiation and exposure limits on population to electromagnetic radiation in the environment) [3], [5].

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