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Uncertainty of measurements of electric field strength and magnetic flux density in the vicinity of overhead power lines

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Abstract **– Measurements of electromagnetic fields in the vicinity of overhead power lines are carried out in order to assess the exposure of the general public to these fields and to check whether the field levels are within the prescribed limits. Since the measurement results are compared with the prescribed reference levels, the measurement uncertainty should be evaluated and taken into account in the conformity assessment. The paper analyzes the most relevant uncertainty components related to measurements of electric and magnetic fields near overhead power lines. The uncertainty components related to the calibration of the measuring system, proximity of the operator and positioning of the measuring probe are analyzed and evaluated for the real example of measurements near an overhead power line. In order to provide the validity of the measurement results the measurements are carried out with two measuring systems and they are also compared with the calculation results.**

I. INTRODUCTION

The topic of the paper is related to the assessment of electric and magnetic fields in the vicinity of transmission overhead power lines [1-6]. The results of electric and magnetic field measurements are significant for the assessment of exposure of the general public living in the vicinity of the power lines. In the case when the assessment of exposure of the general public is based on measurements, the measurement uncertainty has to be taken into account when giving the conclusion about the compliance of the field levels with the reference levels prescribed by national or international legislation [7-9]. The evaluation of the uncertainty of electric and magnetic field measurement results is particularly important when the obtained results of the electric and/or magnetic field are close to the prescribed reference level [10]. Since the measurement results are used for the evaluation of human exposure, it is crucial to ensure the validity of the obtained results. Ensuring the validity of testing results is a direct requirement of the standard [11]. According to [11], there are several ways to ensure the validity of the results, which, among others, include: the use of alternative instruments that are calibrated so as to give traceable results, functional verification of the measuring and test equipment, the use of reference standards, intermediate checks of the measuring equipment, repeating the testing by using same or different methods, interlaboratory comparisons, etc. In this paper, the measurement results are compared with the results obtained by calculations in order to provide their validity. Comparing the results of measurements and calculations is a way of ensuring the validity of the results, based on the repetition of testing using different methods, in accordance with [11]. This way of ensuring the validity of the results is particularly suitable if it is not possible to perform measurements using two instruments in order to compare the results, or if the two instruments show results between which there is a significant deviation. The comparison of the results can be carried out on site during each electric and magnetic field testing, which ensures continuous monitoring of the validity of the results, as well as checking of the measuring equipment in the period between two calibrations or two intermediate checks. The comparison of measurement and calculation results can also be carried out within interlaboratory comparisons [4], during which laboratories, in addition to measurements, can carry out electric and magnetic field calculations as well. If, as a part of an interlaboratory comparison, several laboratories conduct testing based on measurements, the calculation can be used as a method for determining the assigned value of the quantity that is the subject of the testing, i.e. value that is declared true value and which the results obtained by measurement are compared with. In any case, it is necessary to add an expanded uncertainty to the results obtained by measurements and calculations.

II. METHODS

A. *Measurements*

The measurements were performed by using an electromagnetic field analyzer and isotropic probes for electric field strength and magnetic flux density measurements [12]. This system enables simultaneous measurements of all three spatial components of field vectors, based on which the instrument shows the resultant values of the field vectors.

Procedures for measurements of electric field strength and magnetic flux density in the vicinity of overhead power lines are given in [13-16].

The heights of the power line conductors at the location of the lateral profile where the measurements are carried out were measured with a laser rangefinder [1].

During the electric field strength and magnetic flux density measurements, the data on values of power line voltages and currents was provided by the electric power transmission company that owns the power line. The data is significant for the comparison of measured values with the values obtained by calculations.

B. Calculations

The calculations of electric field strength and magnetic flux density were based on a two-dimensional analysis using the method described in [1-3, 6]. Electric field strength calculations were based on the method of image charges, while magnetic flux density calculations were based on the Biot-Savart law. The overhead power line was simulated by a set of infinitely long, straight-line phase conductors. The conductors were parallel to each other and to the ground surface.

III. RESULTS AND DISCUSSION

A. Electric field strength and magnetic flux density measurements and calculations

In the following text, an example of electric field and magnetic flux density testing in the vicinity of the 220 kV overhead line is given and a comparison of the results obtained by measurements and calculations was made. This example shows how the results of measurements and calculations can be used not only for internal control of the validity of the results but also for conducting interlaboratory comparisons.

Electric and magnetic field testing was conducted in the vicinity of 220 kV overhead power line no. 228, on the span between towers no. 32 and 33. The towers on the analyzed span are shown in Fig. 1 and the location where the testing is performed is shown in Figs. 2 and 3. In Fig. 3, the points where the electric and magnetic fields were measured are marked with E_1 and B_1, respectively.

Fig. 1. The towers on the analyzed span of the 220 kV overhead power line.

Fig. 2. The location where the testing was conducted.

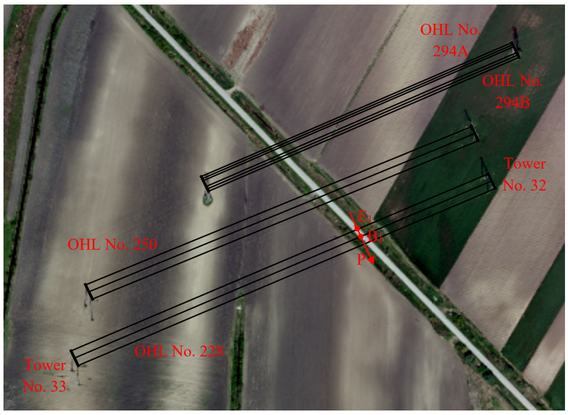

Fig. 3. The location where the testing was conducted and the position of the measurement points.

The testing was conducted at a height of 1 m above the ground. For conducting the testing, a location was chosen where the terrain could be considered flat and where there were no objects that could cause electric field perturbation.

Fig. 4 shows the geometry of the overhead line at the location of the lateral profile P.

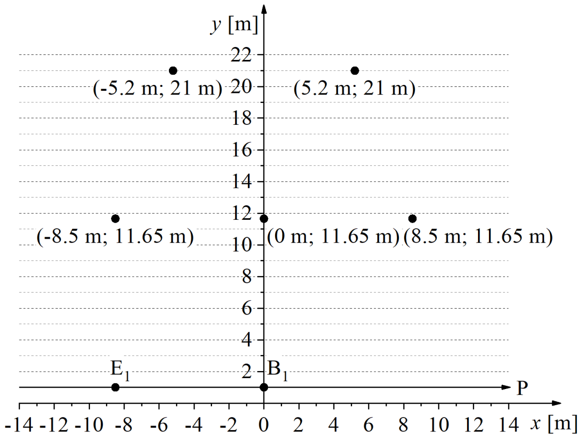

Fig. 4. Geometry of the overhead line with the position of measurement points E_1 and B_1 (observed from tower no. 33 towards tower no. 32).

Measurement point E1 is located below the phase conductor corresponding to phase 8, at a distance of 8.5 m from the line axis (x = -8.5 m). The measurement point B_1 is located in the power line axis (x = 0 m), i.e. below the middle phase conductor (phase 4). It was decided that the measurement points should be located below the mentioned phase conductors, in order to additionally reduce the error originating from their positioning along the lateral profile. The measurement point B_1 is located at the place where the highest value of magnetic flux density occurs along the lateral profile, while the measurement point E_1 is located near the place where the highest value of the electric field strength occurs along the lateral profile.

Two measuring systems, marked as measuring system 1 and measuring system 2, were used to measure the electric field strength and magnetic flux density.

Measurements of magnetic flux density performed at point B_1 by using the mentioned two measuring systems were performed simultaneously in order to ensure that the measurements were carried out under the same conditions, i.e. at the same overhead line load current. This way, the deviation of the measurement results due to a change in the overhead power line load current is eliminated.

Measurements of the electric field strength performed at point E_1 by using the mentioned two measuring systems were carried out separately in order to avoid the occurrence of electric field perturbation due to the proximity of the second measuring system.

In the vicinity of overhead line no. 228, which is the subject of the testing, there are 220 kV overhead lines no. 250 and no. 294AB. Considering the distances between these lines and line no. 228, as well as the fact that at the time of measurements, the closest line no. 250 was out of service, it was concluded that the influence of the mentioned lines on the measurement results at measurement points E_1 and B_1 is negligible, i.e. that the results obtained at these measurement points originate exclusively from overhead line no. 228.

Data on voltages and currents of overhead line no. 228 at the time of measurements were obtained from the authorized department of the owner of the overhead line and are shown in Tables 1 and 2.

Table 1. Power line voltages at the time of measurements carried out using measuring systems 1 and 2.

Measuring system	U_0 [kV]	U_4 [kV]	U_8 [kV]
1	130.20	129.83	129.62
2	130.39	130.04	129.74

Table 2. Power line currents at the time of measurements carried out using measuring systems 1 and 2.

Measuring system	I_0 [A]	I_4 [A]	I_8 [A]
1 and 2	850.87	851.28	847.64

Based on the results shown in Table 1 it can be concluded that the power line voltage was very stable in the period of interest, which eliminated the possibility of deviation of electric field strength measurement results obtained by measuring systems 1 and 2 due to the change of the overhead power line voltage. By calculating the electric field strength, in both cases, i.e. for both sets of voltage values from Table 1, the value of 1.95 kV/m was obtained.

Table 3 shows the results of electric field strength and magnetic flux density measurements and calculations.

Table 3. Results of electric field strength and magnetic flux density measurements and calculations.

	E [kV/m]	B [μT]
Calculation	1.95	14.85
Measuring system 1	1.89	14.98
Measuring system 2	1.82	15.23

In order to compare the results obtained by measurements and calculations and to ensure the validity of the results, it is necessary to calculate the uncertainty of measurements and calculations.

B. Evaluation of the expanded uncertainty of electric field strength and magnetic flux density measurement results

During the calibration of both measuring systems, it was determined that the measurement error is within the range of ±3% when measuring the electric field, as well as when measuring magnetic flux density [17]. When measuring the electric field strength, the distance between the operator and the measuring probe was 10 m, thus it is considered that the measurement uncertainty component which originates from the presence of the operator is negligible in accordance with [5, 16]. It can also be assumed that the errors originating from the positioning of the measuring probes along all three axes are negligible, taking into account the way in which the positioning was performed. Before the testing, the height of the measuring probe was checked and it was confirmed that it was 1 m in all cases. The measurement points were located directly under the phase conductors, and their positions were checked by measuring with a laser rangefinder and a measuring tape. For the abovementioned reasons, it was adopted that the expanded uncertainty of the measurement results in all cases amounts to ±3%.

Table 4 presents the results of electric field strength and magnetic flux density measurements with their expanded uncertainties (U_{Em} and U_{Bm}).

Table 4. Measurement results with their expanded uncertainties.

	$E \pm U_{E_m}$	$B \pm U_{B_m}$
Measuring system 1	1.89 kV/m ± 3% (1.83–1.95 kV/m)	14.98 μT ± 3% (14.53–15.43 μT)
Measuring system 2	1.82 kV/m ± 3% (1.77–1.87 kV/m)	15.23 μT ± 3% (14.77–15.69 μT)

C. Evaluation of the expanded uncertainty of the electric field strength and magnetic flux density calculation results

The evaluation of uncertainty of electric and magnetic field calculation results was carried out in the way described in [1, 2]. The dominant components of electric field strength calculation uncertainty are the components that come from the uncertainty of phase conductor height measurement [1] and the uncertainty of voltage measurement [2].

The component originating from the uncertainty of measuring the phase conductor heights was calculated in the way described in [1]. It was adopted that the height measurement error is ±0.4 m. The calculation showed that the true value of the electric field strength is 1.951 kV/m. When the height measurement error of ±0.4 m is taken into account in the calculation, the results of the electric field strength calculation are in the range from 1.837 kV/m to 2.074 kV/m, i.e. in the range from 1.951 kV/m - 5.845% to 1.951 kV/m + 6.335%.

The component originating from the uncertainty of the voltage measurement is calculated in the way described in [2], for the case when the voltage measurement is performed with 0.2 accuracy class measuring transformers. When the voltage measurement error of ±0.2% is taken into account in the calculation, the results of the electric field strength calculation are in the range from 1.945 kV/m to 1.957 kV/m, i.e. in the range from 1.951 kV/m - 0.299% to 1.951 kV/m + 0.300%.

If a rectangular probability distribution is adopted for both uncertainty components, the uncertainty budget of the electric field strength calculation results given in Table 5 is obtained.

When calculating the expanded uncertainty, a coverage factor of 2 was adopted which corresponds to the level of confidence of 95.45% according to [10].

When the expanded uncertainty given in Table 5 is taken into account, the calculation result is in the range from 1.82 kV/m to 2.09 kV/m, i.e. in the range from 1.951 kV/m - 6.76% to 1.951 kV/m + 7.32%.

Table 5. Uncertainty budget of electric field strength calculation results obtained by the method given in [1, 2].

Uncertainty component	Expanded uncertainty [%]	Distribution	Divisor	Standard uncertainty [%]
Phase conductor heights	-5.85–6.34	Rectangular	1.73	-3.37–3.66
Voltage	±0.3	Rectangular	1.73	±0.17
	Combined uncertainty:			-3.38–3.66
	Coverage factor:			2
	Expanded uncertainty:			-6.76–7.32

The dominant components of magnetic flux density calculation uncertainty are the components that come from the uncertainty of phase conductor heights measurement and the uncertainty of current measurement.

The component originating from the uncertainty of phase conductor heights measurement was calculated in the way described in [1]. The calculation showed that the true value of the magnetic flux density is 14.845 µT. When the height measurement error of ±0.4 m is taken into account in the calculation, the results of the magnetic flux density calculation are in the range from 14.093 µT to 15.653 µT, i.e. in the range from 14.845 µT - 5.064% to 14.845 µT + 5.444%.

The component originating from the uncertainty of the current measurement is calculated in the way described in [2] applied to magnetic flux density, for the case when the current measurement is performed with 0.2 accuracy class measuring transformers. When the current measurement error of ±0.2% is taken into account in the calculation, the results of the magnetic flux density calculation are in the range from 14.815 µT to 14.875 µT, i.e. in the range from 14.845 µT - 0.200% to 14.845 µT + 0.200%.

The uncertainty budget of the magnetic flux density calculation results is given in Table 6.

When the expanded uncertainty of the calculation results given in Table 6 is taken into account, the calculation result is in the range from 13.98 µT to 15.78 µT, i.e. in the range from 14.845 µT - 5.86% to 14.845 µT + 6.30%.

Table 6. Uncertainty budget of magnetic flux density calculation results obtained by the method given in [1, 2].

Uncertainty component	Expanded uncertainty [%]	Distribution	Divisor	Standard uncertainty [%]
Phase conductor heights	-5.06–5.44	Rectangular	1.73	-2.92–3.14
Current	±0.2	Rectangular	1.73	±0.12
	Combined uncertainty:			-2.93–3.15
	Coverage factor:			2
	Expanded uncertainty:			-5.86–6.30

D. Comparative review of the measurement and calculation results of electric field strength and magnetic flux density

Fig. 5 shows a comparative review of the ranges of electric field strength and magnetic flux density results obtained by measurements and calculations, with their expanded uncertainties taken into account.

Based on the obtained results, it can be concluded that there is an overlap of the ranges of the electric field strength results obtained by calculation and measurements using measuring systems 1 and 2. The same conclusion applies to the values of magnetic flux density.

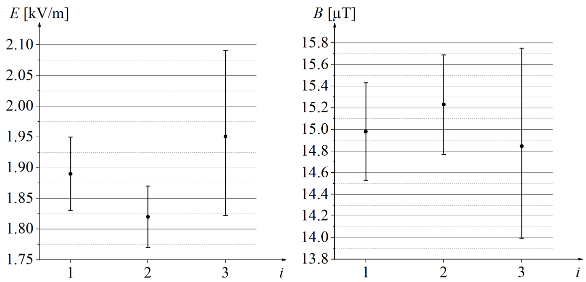

Fig. 5. The ranges of the electric field strength and magnetic flux density results obtained by measurements and calculations (1, 2 – measuring systems 1 and 2, 3 – calculations).

Based on the presented results, it can be concluded that in this way the validity of the measurement and calculation results is ensured.

IV. CONCLUSION

The paper presents an evaluation of the uncertainty of electric and magnetic field measurement results in the vicinity of an overhead power line. The evaluation of uncertainty of electric field strength and magnetic flux density measurement results is very important when it is necessary to compare the measurement results with the prescribed reference level in order to provide the conclusion regarding the exposure of people to electromagnetic fields. In these cases, the conclusion has to take into account the measurement uncertainty. The most relevant components of measurement uncertainty come from measuring system calibration and the positioning of the measuring probe, and in the case of the electric field from the presence of the operator. The obtained results are verified on a real case of a 220 kV transmission overhead power line. For the selected example, the results obtained by electric and magnetic field measurements are compared with the calculation results and in this way, the validity of the results is verified.

REFERENCES

[1] M. Grbić, J. Mikulović, D. Salamon, "Influence of measurement uncertainty of overhead power line conductor heights on electric and magnetic field calculation results", Int. J. Electr. Power Energy Syst., vol. 98, 2018, pp. 167–175.

[2] M. Grbić, D. Salamon, J. Mikulović, "Analysis of influence of measuring voltage transformer ratio error on single-circuit overhead power line electric field calculation results", Electr. Power Syst. Res., vol. 166, 2019, pp. 232–240.

[3] M. Grbić, A. Pavlović, "Determining the zone of influence of transmission overhead power lines from the aspect of non-ionizing radiation", Proc. of the 6th RAD Conference, 2018, vol. 3, pp. 52–57.

[4] M. Grbić, A. Pavlović, B. Vulević, "Interlaboratory comparison of measuring and calculation results of electric field strength near 35 kV overhead power line", Proc. of the 2nd RAD Conference, 2014, pp. 255–258.

[5] M. Grbić, A. Pavlović, "Quantification of the operator proximity effect on the measurement results of electric field strength in the vicinity of overhead power lines", Proc. of the 6th RAD Conference, 2018, pp. 58–62.

[6] Electric Power Research Institute (EPRI), "Electric and magnetic fields" in EPRI AC Transmission Line Reference Book – 200 kV and Above, 3rd edition, EPRI, Palo Alto, CA, USA, 2005, pp. 7.1-7.118.

[7] International Commission on Non‐Ionizing Radiation Protection (ICNIRP), "ICNIRP guidelines for limiting exposure to time‐varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", Health Phys., vol. 74, no. 4, 1998, pp. 494–522.

[8] 1999/519/EC, "Council recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)", OJ L, July 30, 1999.

[9] International Commission on Non‐Ionizing Radiation Protection (ICNIRP), "ICNIRP guidelines for limiting exposure to time‐varying electric and magnetic fields (1 Hz – 100 kHz)", Health Phys., vol. 99, no. 6, 2010, pp. 818–836.

[10] Joint Committee for Guides in Metrology, "Evaluation of measurement data – Guide to the expression of uncertainty in measurement", JCGM 100:2008, September 2008.

[11] ISO/IEC 17025:2017, "General requirements for the competence of testing and calibration laboratories".

[12] EN 61786:2014, "Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 1: Requirements for measuring instruments".

[13] IEC 61786:2014, "Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings – Part 2: Basic standard for measurements".

[14] EN 50413:2019, "Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)".

[15] EN 62110:2009, "Electric and magnetic field levels generated by AC power systems – Measurement procedures with regard to public exposure".

[16] Technical guide for measurement of low frequency electric and magnetic fields near overhead power lines, WG C4.203, CIGRE, April 2009.

[17] M. Grbić, D. Naumović-Vuković, A. Pavlović, "Calibration of Magnetic Field Analyzer", Proc. of 21st IMEKO World Congress, 2015, pp. 663–666.