MEASUREMENTS AND CALCULATIONS OF NON-IONIZING RADIATION LEVELS IN VICINITY OF 35 KV OVERHEAD POWER LINES

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ABSTRACT

The paper presents the testing results of power frequency non-ionizing radiation (electric field strength and magnetic flux density) in the vicinity of 35 kV overhead power lines, which are obtained by measurements and calculations. The measurements of electric field strength and magnetic flux density were performed in the vicinity of several 35 kV overhead power lines. The measurement locations along these lines were chosen on the basis of absence of any objects that could influence the non-ionizing radiation levels. The main goal of these measurements was to estimate the exposure of people to non-ionizing radiation, by comparing the obtained results with the reference levels prescribed by national and international legislation. In order to estimate the maximum non-ionizing radiation levels in the vicinity of power lines, the calculations of electric field strength and magnetic flux density were performed. The calculations were done by using the minimum heights of the conductors above ground and the maximum load currents, and therefore the obtained results are the highest possible. The conclusion about the compliance of the non-ionizing radiation levels with the prescribed reference levels is given on the basis of the results of both measurements and calculations.

The paper also emphasizes the significance of the approach to the problem of non-ionizing radiation in the vicinity of power lines which is based on combined measurement and calculation techniques, and describes the advantages of each technique.

INTRODUCTION

The paper presents the testing results of power frequency non-ionizing radiation in the vicinity of 35 kV overhead power lines (OHL) obtained by both measurements and calculations. For the testing purposes, the locations along the power line routes were chosen based on the absence of other objects which might affect the levels of non-ionizing radiation. The main goal of the measurements was to establish the realistic situation of exposure of people to non-ionizing radiation. In order to estimate the maximum non-ionizing radiation levels in the vicinity of power lines, the calculations of electric field strength and magnetic flux density were performed. The obtained highest possible levels of non-ionizing radiation were compared to reference levels prescribed by the Serbian [1-3] and international [4] legislation.

SERBIAN LEGISLATION ON PROTECTION FROM NON-IONIZING RADIATION

The protection of general public from non-ionizing radiation is legally regulated in the Republic of Serbia since 2009 by adoption of the Law on Protection from Non-Ionizing Radiation [1] and six guidelines. This way the Republic of Serbia has fulfilled the requirements of the Recommendation 1999/519/EC [4] establishing a framework for harmonized protection of population from non-ionizing radiation, which should adhere to all European Union countries in adopting local regulations.

The Guidance on Limits of Exposure to Non-Ionizing Radiation [2] established the exposure reference levels which are 2 kV/m for electric field strength and 40 μT for magnetic flux density. These reference levels refer to the power frequency field (50 Hz) and so called "areas of increased sensitivity". According to the Guidance [2], areas of increased sensitivity include "residential areas where people can stay 24 hours a day, schools, homes, preschools, maternity wards, hospitals, tourist facilities, children playgrounds, and areas of undeveloped parcels intended, according to the urban development plan, for specified purposes".

MEASUREMENTS OF ELECTRIC FIELD AND MAGNETIC FLUX DENSITY

Measured Quantities

During the testing of non-ionizing radiation levels the rms values of electric field strength and magnetic flux density were measured. The intensity of these vector quantities was measured isotropically, by performing simultaneous measurements of all three spatial components of field vectors. Simultaneously with the measurements of electric field strength and magnetic flux density, the field frequency was also measured.

Measuring Equipment

The measurements were performed by using an electromagnetic field analyzer connected to the isotropic probes for electric field strength and magnetic flux density measurements. These probes insure simultaneous measurements of all three spatial components of field vectors, based on which the instrument shows their resultant values. During the measurements of electric filed strength and magnetic flux density a measurement mode with a 5 Hz – 2 kHz filter was used.

Measurement Procedures

The measurements of electric field strength and magnetic flux density were conducted according to the measurement procedure described in [5-7]. On each overhead power line route one location without any other objects which might affect the levels of non-ionizing radiation was selected, with the purpose of determining the field distribution which originates exclusively from the tested power line. In order to determine the field distribution as accurately as possible, the measurements were conducted along the profiles approximately perpendicular to the power line axes (i.e. lateral profiles). The measurement profiles were placed on the locations where the heights of the phase conductors are at their lowest point. On these locations, where the heights of the phase conductors are the lowest, the values of both fields are the highest within the entire span.

Measurements performed along measurement profiles chosen in accordance with the aforementioned conditions are representative because the obtained field distribution is approximate to theoretical distribution. The results obtained this way can be used for the estimation of the non-ionizing radiation levels on other spans, where, because of the presence of other objects or the inaccessibility of terrain, it is not convenient to perform measurements.

At each measurement profile many measurements were performed and the number of measurement points depended primarily on the terrain configuration. At all measurement points, measurements of electric field strength and magnetic flux density were performed at 1 m height above ground, simultaneously with the measurement of the field frequency. At all measurement points the field frequency of 50 Hz was measured.

MEASUREMENTS OF ELECTRIC FIELD

Measurements of rms values of electric field strength were performed in the way described in the previous section. The heights of the phase conductors above ground at locations of measurement profiles are shown in Table 1 for each tested power line. The measurements of the heights of phase conductors were performed by using laser telemeter.

Table 1 – Heights of phase conductors above ground for each tested power line

OHL numbers	Heights of phase conductors at locations of measurement profiles
319	11.7 m; 12.1 m; 14.6 m
320	7.5 m; 8.4 m; 10.7 m
350	10.7 m; 11.8 m; 13.1 m
346AB	OHL 346A: 11.4 m; 13.4 m; 15.7 m OHL 346B: 10.9 m; 13.4 m; 14.8 m
379 and 380	OHL 379: 8.4 m; 10.5 m; 12.9 m OHL 380: 8.5 m; 10.4 m; 12.9 m

The minimum permitted height of phase conductors of the 35 kV overhead power lines within populated areas in Serbia is 7 m.

Electric field measurement results

The results of the electric field measurements along lateral profiles are shown in Figures 1 and 2. The marks in Figures 1 and 2 have the following meaning:

x [m] – horizontal distance between the measurement point at the lateral profile and the power line axis;

E [V/m] – measured rms value of electric field strength;

h_i [m] – height of the phase conductor *i* (*i* = 1,2,3) at the location of measurement profile.

In Figures 1 and 2, next to the electric field distribution of each individual power line the heights of phase conductors are also shown because this parameter significantly influences the electric field levels.

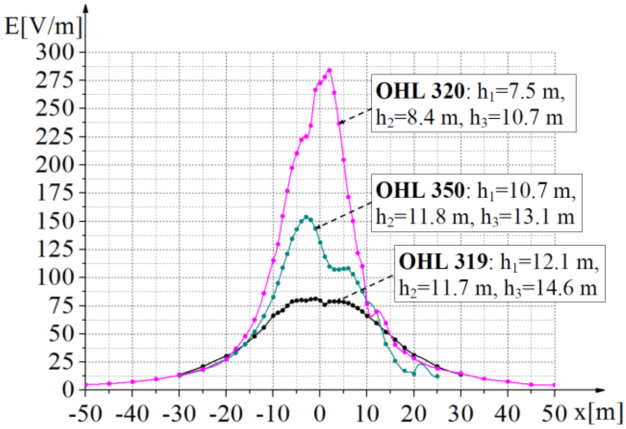

Figure 1 – Electric field distributions of single-circuit overhead power lines

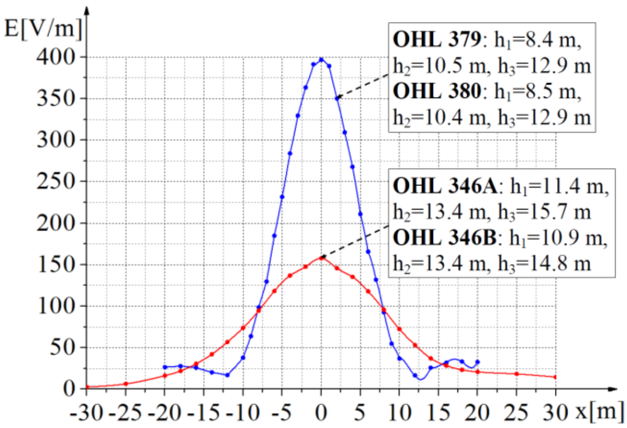

Figure 2 – Electric field distributions of double-circuit overhead power lines

The highest measured values of electric field strength for all tested power lines are shown in Table 2.

The marks in Table 2 have the following meaning:

E_{max} [V/m] – the highest measured value of electric field strength;

x_{max} [m] – the position of the measurement point where the highest value of electric field (E_{max}) was measured.

Table 2 – Highest measured values of electric field strength

OHL numbers	E_{max} [V/m]	x_{max} [m]
319	81.25	-1
320	284	2
350	153.89	-3
346AB	157.70	0
379 and 380	396.78	0

The measurement results of electric field strength did not exceed the prescribed reference level of 2 kV/m. These values refer only to the heights of the phase conductors measured during the electric field testing. Taking into account the highest measured values of electric field strength (E_{max}) and the heights of phase conductors during measurements, it can be estimated that the electric field values will not exceed the prescribed reference level of 2 kV/m, even in the case when phase conductors are at their lowest point, i.e. when the phase conductor sag is at maximum. The lowest possible height of phase conductors is considered to be the minimum permitted height, which amounts to 7 m in populated areas.

MEASUREMENTS OF MAGNETIC FLUX DENSITY

Measurements of rms values of magnetic flux density were performed along the same lateral profiles as the electric field measurements.

Measured values of magnetic flux density are proportional to the power line load currents during measurements. When estimating the highest possible levels of magnetic flux density it is necessary to take into account the ratio of the highest possible load currents of the power line and the load currents during each magnetic flux density measurement. According to the obtained data, the load currents of the tested power lines were practically constant during the magnetic flux density measurements. The measurements of the load currents of 35 kV overhead power lines were performed in only one phase, so the asymmetry between the currents in different phases during the measurements is not known. The load currents during the measurements are shown in Table 3. The information about the cross section of the phase conductors and their maximum load is also shown in Table 3.

The marks in Table 3 have the following meaning:

S [mm^2] – cross section of the phase conductors;

I [A] – power line load current during magnetic flux density measurements;

I_r [A] – power line rated current;

I_w [A] – maximum permitted load current of the power line during winter period;

I_s [A] – maximum permitted load current of the power line during summer period.

Table 3 – Load currents of power lines during measurements and maximum permitted load currents

OHL numbers	S [mm^2]	I [A]	I_r [A]	I_w [A]	I_s [A]
319	95	85	290	550	376
320	70	53	235	447	305
350	70	50	235	447	305
346AB	70	346A: 66 346B: 0	235	447	305
379 and 380	70	379: 96 380: 67	235	447	305

Magnetic flux density measurement results

The results of measurements of magnetic flux density, B [μT], along lateral profiles are shown in Figures 3 and 4. In these figures, next to the magnetic flux density distribution of each individual power line the heights of phase conductors and load currents during measurements are also shown, because these parameters significantly influence the magnetic flux density levels.

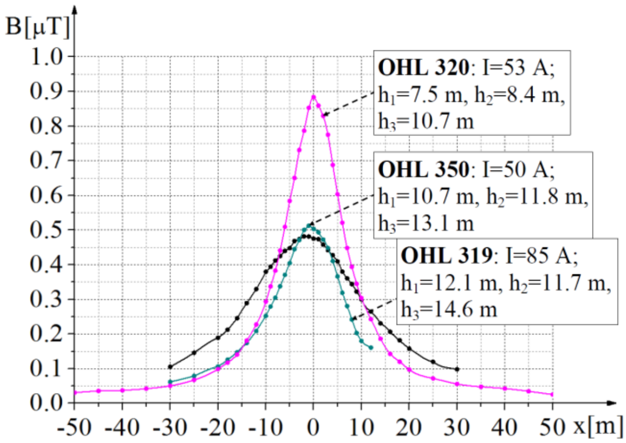

Figure 3 – Magnetic flux density distributions of single-circuit overhead power lines

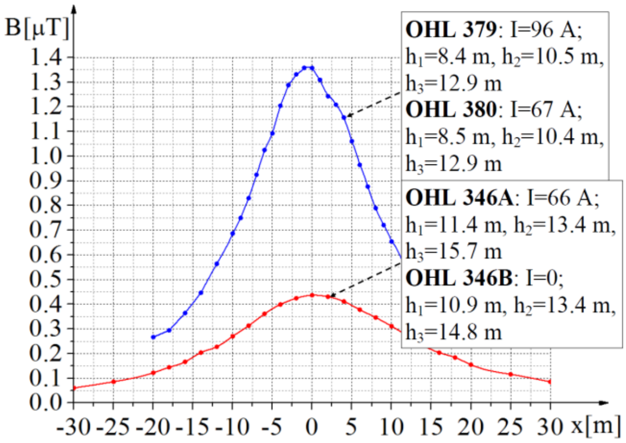

Figure 4 – Magnetic flux density distributions of double-circuit overhead power lines

The highest measured values of magnetic flux density for all tested power lines are shown in Table 4.
The marks in Table 4 have the following meaning:
B_{max} [μT] – the highest measured value of magnetic flux density;
x_{max} [m] – the position of the measurement point where the highest value of magnetic flux density (B_{max}) was measured.

Table 4 – Highest measured values of magnetic flux density

OHL numbers	B_{max} [μT]	x_{max} [m]
319	0.482	-2
320	0.884	0
350	0.513	-1
346AB	0.437	0
379 and 380	1.357	-1, 0

The measured values of magnetic flux density are far below the prescribed reference level of 40 μT. These values should be put in proportion with the power line load, in order to estimate the highest possible levels of magnetic flux density and compare them to the prescribed reference level. The assessment of the highest possible value of magnetic flux density (B'_{max}) is based on the linear dependence of the highest measured value of magnetic flux density (B_{max}) on the power line load currents during the measurements. The estimated highest possible values of magnetic flux density of the tested power lines are shown in Table 5.
In Table 5, I [%] signifies the percentage value of the load current during magnetic flux density measurements in relation to the maximum load current of the power line during winter period, I_w.

Table 5 – Estimated highest values of magnetic flux density

OHL numbers	B_{max} [μT]	I [A]	I_w [A]	I [%]	B'_{max} [μT]
319	0.482	85	550	15.5	3.1
320	0.884	53	447	11.9	7.5
350	0.513	50	447	11.2	4.6
346AB	0.437	346A: 66 346B: 0	447	14.8; 0	5.9
379 and 380	1.357	379: 96 380: 67	447	21.5; 15	7.4

Besides the maximum load of the power line, the assessment of the highest possible levels of magnetic flux density should also include the decrease of the heights of phase conductors. It can be estimated that the levels of magnetic flux density cannot exceed the prescribed reference level of 40 μT, even in the case of the highest possible load of the power line and maximum sag of the phase conductors.

CALCULATIONS OF ELECTRIC FIELD AND MAGNETIC FLUX DENSITY

In order to estimate the highest possible values of electric field strength and magnetic flux density more accurately, and take into account the lowest possible heights of the phase conductors, the field calculations were performed.
The calculations are based on a two-dimensional simplified analysis using the image theorem. The overhead power line is simulated by a set of infinitely long, straight-line phase conductors and ground wires. The conductors are parallel to each other and to the ground surface. The detailed description of the calculation method is given in [7,8].
Typical towers used for single-circuit and double-circuit 35 kV overhead power lines in Serbia are shown in Figure 5. The aforementioned power lines are also constructed using these towers, at certain locations with insignificant modifications. Therefore, the calculations were performed for one single-circuit and one double-cuircuit power line with the towers shown in Figure 5. In order to obtain the highest possible values of electric field and magnetic flux density it is adopted that the lowest phase conductor of each power line is located at minimum permitted height of 7 m. When calculating the field distribution of double-circuit power line the most unfavorable arrangement of phase conductors (048-048) is adopted. The exact geometry (in meters) used for the calculations is shown in Figure 6.

Figure 5 – Typical towers used for single-circuit and double-circuit 35 kV overhead power lines in Serbia

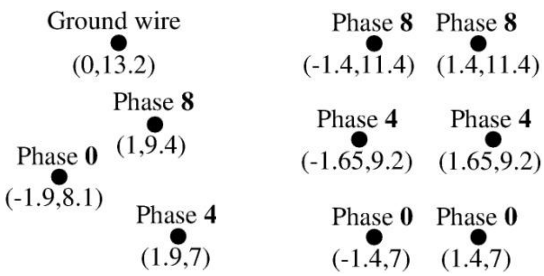

Figure 6 – Geometry of single-circuit and double-circuit 35 kV overhead power line used for field calculations

Calculation results

The calculations of electric field strength and magnetic flux density were conducted at 1 m height above ground. Calculations of electric field strength were performed for the rated voltage of 35 kV and the geometry of power lines shown in Figure 6. The calculation results for single-circuit and double-circuit power lines are shown in Figure 7.

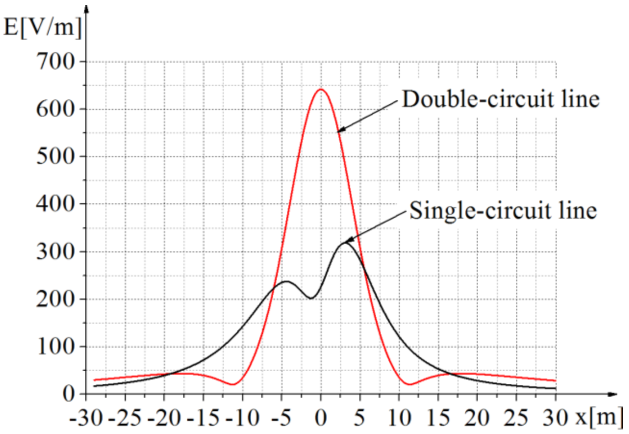

Figure 7 – Results of electric field strength calculations

Calculations of magnetic flux density were performed for the geometry of power lines shown in Figure 6 and the maximum permitted load current of the power lines during winter period of 550 A. The calculation results are shown in Figure 8.

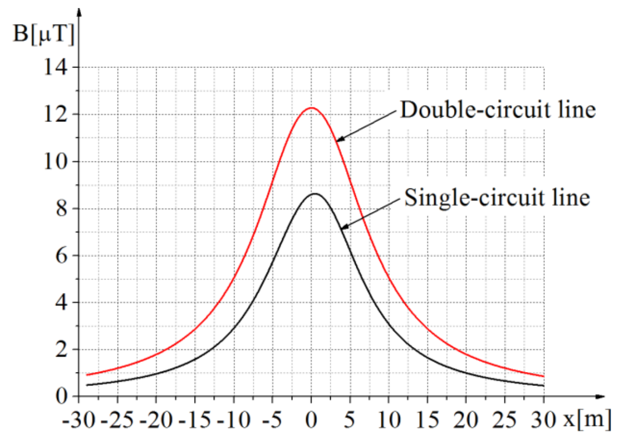

Figure 8 – Results of magnetic flux density calculations

The highest values of electric field strength and magnetic flux density obtained by calculations are shown in Table 6.

Table 6 – Highest values of electric field strength and magnetic flux density obtained by calculations

OHL type	E_{max} [V/m]	B_{max} [μT]
Single-circuit	318.9	8.6
Double-circuit	642.2	12.3

The highest field values are significantly below the reference levels of 2 kV/m and 40 μT prescribed by the Serbian legislation, and consequently also below the reference levels of 5 kV/m and 100 μT prescribed by [4].

CONCLUSION

The analysis of the levels of non-ionizing radiation in the vicinity of 35 kV overhead power lines was performed using combination of measurement and calculation techniques. Results obtained by measurements reflect the real situation, and provide the field distribution that existed in the conditions at the time of measurements. If it is necessary to assess the highest possible field levels it is suitable to use calculations. Approach to the problem of non-ionizing radiation in the vicinity of overhead power lines which is based on results obtained by both measurements and calculations gives the most reliable results because it takes advantage of both methods.

The main goal of the performed analysis was to check for the compliance of non-ionizing radiation levels in the vicinity of 35 kV overhead power lines with the prescribed reference levels. The higest field values obtained at 1 m height for the maximum load of the power lines and maximum sag of the phase conductors were still significantly below the reference levels of 2 kV/m and 40 μT. In this way the compliance with the Serbian and international legislation was proven.

REFERENCES

[1] Law on Protection from Non-Ionizing Radiation, Official Gazzete of Republic of Serbia No. 36/09 from 15.05.2009 (in Serbian);

[2] Guidance on Limits of Exposure to Non-Ionizing Radiation, Official Gazzete of Republic of Serbia No. 104/09 from 16.12.2009 (in Serbian);

[3] Guidance on Sources of Non-Ionizing Radiation of Special Interest, Types of Sources, Methods and Frequentness of their Testing, Official Gazzete of Republic of Serbia No. 104/09 from 16.12.2009 (in Serbian);

[4] 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 199, 30.7.1999;

[5] ANSI/IEEE Standard 644:1994, "Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines";

[6] CIGRE Working Group C4.203: "Technical guide for measurement of Low Frequency Electric and Magnetic Fields near Overhead Power Lines", April 2009;

[7] IEC 62110:2009 "Electric and Magnetic Field Levels Generated by AC Power Systems – Measurement Procedures with Regard to Public Exposure";

[8] EPRI AC Transmission Line Reference Book - - 200 kV and Above, Third Edition, December 2005.