Analysis of the possible solutions for the reduction of electric and magnetic fields near 400 kV overhead transmission lines

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Abstract

This paper focuses on the optimization of the design of high voltage transmission lines in order to reduce the negative impact of electric and magnetic fields. Within this paper the results of measurements of electric and magnetic fields near 400 kV transmission line were presented. Measurements were performed in the middle of the range between two towers, because at this point transmission lines are closest to the ground. In order to make better validation of the used calculation models of electric and magnetic fields, measurement of temperature, pressure, humidity and height of particular transmission lines in the middle range, were performed simultaneously. The values of current and voltage on the transmission line, at the time of measurement of the fields, are also given. Based on the measured values of electric and magnetic fields, validation of calculation was performed. This paper also contains a brief comparative analysis of regulations on non-ionizing radiation of power facilities that are in use in some European countries, as well as recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Calculation of electric and magnetic fields of different configurations of 400 kV transmission line, were performed in order to find optimal solution in terms of reducing the negative impact of electric and magnetic fields of high voltage transmission

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lines. Finally, on the basis of legislation and regulations on non-ionizing radiation and analysis of the electric and magnetic fields, authors suggest optimal configuration of analysed high voltage transmission line.
Keywords: overhead transmission lines, electric and magnetic fields, calculations, transmission line configurations.

1 Introduction

Overhead transmission lines are sources of strong electric and magnetic fields. Only a small number of people are exposed to these fields due to professional commitment. On the other hand, almost the entire general population is exposed to low levels of electromagnetic radiation in their homes and workplaces. Rising public concern regarding the impact of electric and magnetic fields has led to development of European guidelines and very rigorous standards in certain countries. All of these standards and regulations require limited exposure of staff and the general population to electromagnetic fields. Therefore, it becomes important to make measurements of electric and magnetic fields and compare them with critical values that are defined in standards and regulations. With the application of modern measuring equipment and calculation techniques it is possible to determine the values of the electric and magnetic fields as well as the ways to reduce them, which include structural interventions on overhead transmission lines and high voltage substations [1–7].

Even though the principals of the interaction of electromagnetic fields with materials were introduced long time ago in terms of the basic equations of magnetism, yet they can’t be safely applied to living organisms because they are very complex and there is variability of characteristics of biological tissue which makes analysis of the interaction even more complex. The mechanisms of interaction of electromagnetic radiation and organic matter are still insufficiently explored. Numerous mechanisms for electromagnetic interaction with living organisms have been discussed and analysed recently, but most of them are not scientifically confirmed or verified [8–9].

This paper presents the measured and calculated values of electric and magnetic fields in the vicinity of 400 kV high voltage overhead transmission line Sarajevo 10 – Sarajevo 20 for the purpose of defining optimal constructive solution to reduce electric and magnetic fields [10–11].

2 Legislative framework for electric and magnetic fields in EU countries and international recommendations

Considering that many countries don’t have defined standards in this matter, it is necessary to examine the situation in countries that have adopted the standards and regulations in this particular area. During this process it is important to consider the recommendations of the International Commission for Non-Ionizing Radiation Protection (ICNIRP) [1], as well as the European Parliament [2–3]. Some countries have adopted or intend to adopt an approach that standard values should be lower values than those prescribed by ICNIRP [4–7]. Table 1 gives the maximum allowable values of electromagnetic fields in some countries and values recommended by International and European organizations.

Table 1: Maximum allowable values of electric and magnetic fields in some countries and the values prescribed by international and European organizations.

Country/Organisation	Electric field (kV/m)		Magnetic field (μT)	
	Occupational exposure	General public exposure	Occupational exposure	General public exposure
ICNIRP[1]	10	5	1000	200
Directive 2004/40/EC	10	5	500	100
Italy	5	0.5[4]	100/10[2]/3[3]	0.2[4]
Slovenia	10	0.5	100	10
Croatia	5	2	100	40
Bulgaria	25	-	1200	-
Austria	10	5	500	100
Hungary	10/30[5]	5/10[5]	500/5000[5]	100/1000[5]

[1]ICNIRP Safety Guideline, 2010.
[2]Attention value at 10 μT for magnetic induction.
[3]Quality objective at 3 μT for magnetic induction.
[4]Three Italian regions, Veneto, Emilia-Romagna and Toscana, have set exposure limits for power lines at 0.2 μT for new installations near nurseries, schools, hospitals, houses and places where people spend more than four hours per day. Veneto also has a similar limit of 0.5 kV/ m.
[5]Environmental protection rules for short time.

3 Measurements of the electric and magnetic field near high voltage overhead transmission line

Measurements of the electric and magnetic fields were performed near the section of high voltage 400 kV Sarajevo 10 – Sarajevo 20. The measurements were made at a height of 1 m above ground level, as recommended by [12]. The fields were measured at the middle of the range, between two adjacent transmission line towers. The reason for this lies in the fact that in these points the highest values of electric and magnetic fields are expected. At this part the high voltage overhead transmission lines is closest to the ground, and therefore expect the highest value of the fields [10].

Values of relative humidity, temperature, air pressure and height of the conductors were also measured and given in Table 2. These measurements were performed in order to determine the potential measurement errors and to obtain insight on possible deviations of the measured and calculated results. This deviation may be particularly emphasized in a measuring of the electric field strength [13].

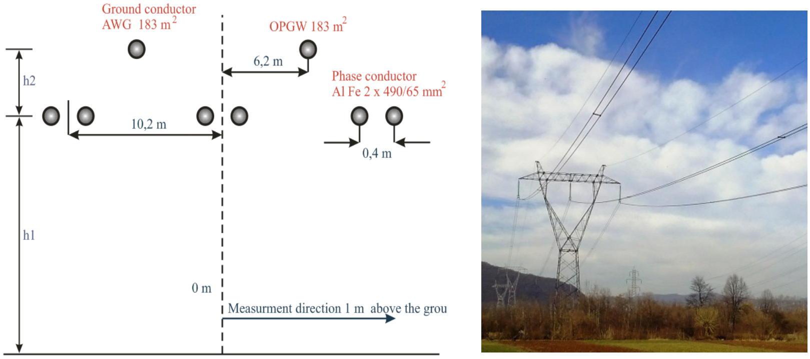


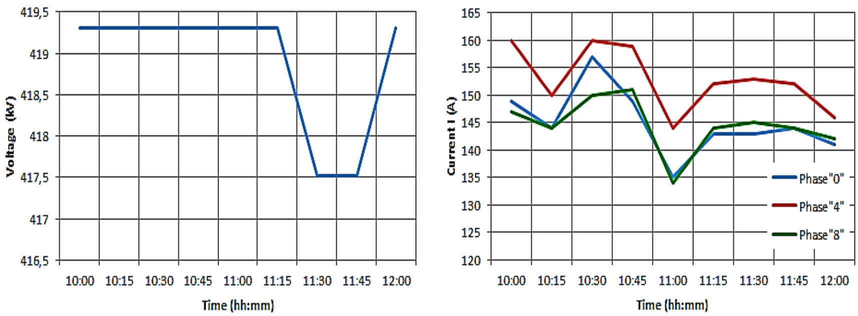
Figure 1: The considered 400 kV overhead transmission line.

Table 2: Environmental conditions during measurement [14].

ENVIRONMENTAL CONDITIONS DURING MEASUREMENT	
Temperature	8°C
Relative humidity	81%
Air pressure	1003 hPa
Vegetation	Bushes
Conductors high at the middle of the range	Phase conductor "0": 10.94 m Phase conductor "4": 10.99 m Phase conductor "8": 11.33 m Ground conductor: 17.27 m OPGW conductor: 17.53 m

Measurement of the electric field was performed at intervals of 5 m from the axis of the tower in one direction, because the field in such configuration of phase conductor is symmetrical, as it can be seen from Figure 1. Measurement of the magnetic field was performed at intervals of 1 m from the axis of the tower in same direction as electric field measurement. In order to preform measuring of the intensity of the electric field the instrument of manufacturer ETS LINDGREN, Model HI-3604 was used (1D sensor which operates on the principle of measuring displacement current on the basis of concentric plate). Measuring of the magnetic field was performed by instrument of manufacturers Narda, Model ELT-400 (3D sensor, isotopic coil 100 cm^2 was used).

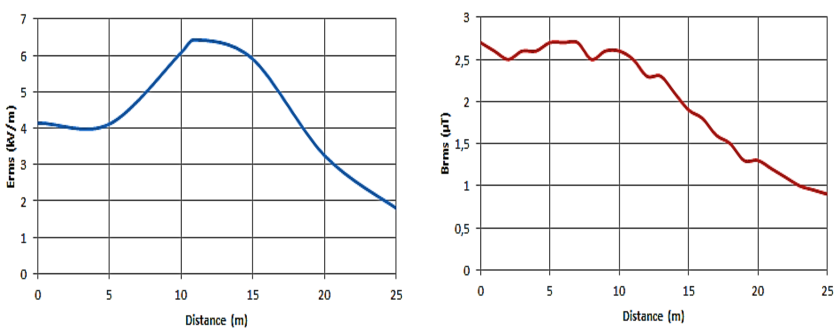
As it is well known, electric field is produced by charges which are correlated to the overhead transmission line voltage, while source of the magnetic field is current that flows through overhead transmission line conductors. In order to calculate the field in the vicinity of high voltage overhead transmission lines it is necessary that the exact value of voltage and current of all phase conductors is known. The measured values of line voltage and phase conductor current at intervals of 15 minutes, on a transmission line during the measurement of the electric and magnetic field near given sections are shown in Figure 2.



a) b)

Figure 2: Measured values at intervals of 15 minutes a) line voltage and b) phase currents of transmission line Sarajevo 10 – Sarajevo 20 [14].

The measurement results of electric and magnetic fields are given in the Figure 3.

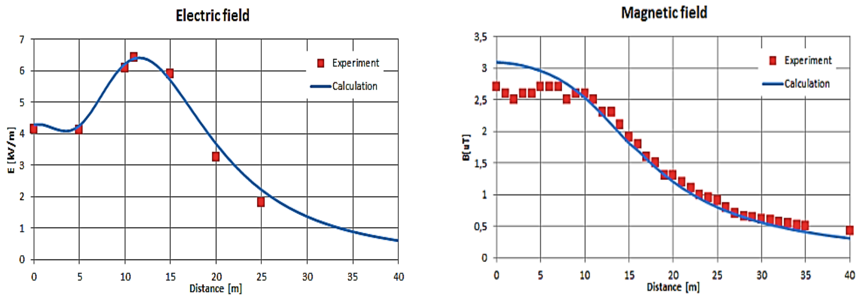


a) b)

Figure 3: Measured value of the a) electric field and b) magnetic field [14].

4 Measures for reduction of electric and magnetic fields in vicinity of overhead transmission lines

The measurement of voltage and current were used as input data for calculation of the electric and magnetic fields, while measurement results of electric and magnetic fields were used to verify the calculation model of the electric and magnetic fields (given in [11] and [15]) produced by overhead transmission lines. Figures 4a and 4b show excellent matching of measured and calculated values of electric and magnetic fields, respectively.



a) b)

Figure 4: Comparison of measurement results with the calculated results a) electric field and b) magnetic field.

Based on the results shown in Figures 4a and 4b the verification of the used models was successfully done and it can be concluded that this method of calculation is valid for the evaluation of measures for lowering the value of ELF electric and magnetic fields near high voltage overhead transmission lines. From the measured and calculated values of the electric field shown in Figure 4a, it can be concluded that the values of the electric field (at the maximum permissible voltage, Figure 2a exceed allowed threshold of some national standards, given in Table 1. Therefore it is necessary to analyse measures to lower electric fields near transmission lines. From the Figure 4b it is obvious that the values of the magnetic field are far below the recommended values of the International Commission on Non-Ionizing Radiation Protection (ICNIRP), and the main reason for this is the small value of the current at the time of measurement (Figure 2b). The calculations which aims to analyse the reduction of ELF electric and magnetic fields will be performed for continuous nominal voltage (line voltage 400 kV) and nominal current on transmission line (1920 A), in which case it can be expected that with certain configurations of lines, the calculated values of the magnetic field exceed the limits defined in some national standards.

This paper presents different methods for the reduction of ELF electric and magnetic fields based on the change in the line configuration and increase of the height of the towers. Increasing the height of the transmission lines certainly leads to a reduction of electric and magnetic fields within the corridor of overhead transmission line, but the most significant reduction for considered horizontal configuration of lines given in Figure 1 can be seen in the area of outer phase conductors and decreases in the wider area of the corridor lines. Since the reduction is required in the wider area of the corridor, this solution is not the most suitable for high voltage transmission lines. The objects for which reduction of electromagnetic field is performed are not located in narrow area corridor. Figures 5a and 5b give the results of calculation of electric and magnetic fields of the transmission line for the line configuration shown in Figure 1, with varying height the of the lines for 1, 2, 3 and 4 m, respectively.

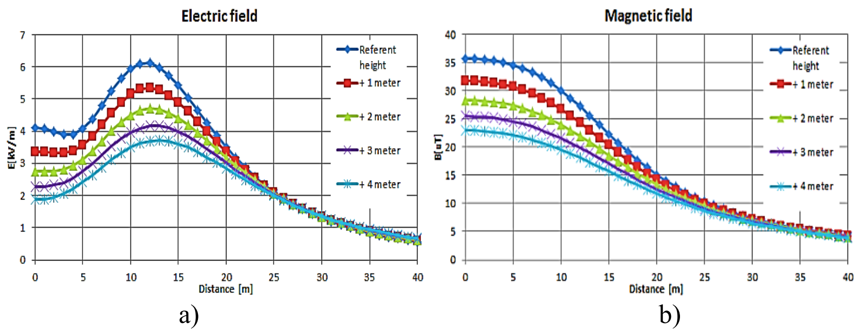


Figure 5: Calculated values of a) electric field and b) magnetic field in dependence of the transmission line height.

Significant reduction of electric and magnetic fields in the wider area of the corridor is possible to achieve by selecting the appropriate configuration of conductors of the transmission line. Calculations were performed for several configurations, starting from the existing situation with horizontal configuration (curve 1), through a vertical configuration (curve 2) to the "delta" configuration (curve 3) "reverse delta" configuration (curve 4) and "split-phase" configuration (curve 5), as it is shown on Figure 6. During the calculation, the heights of the lowest phase conductors and interphase distances are kept the same for all configurations.

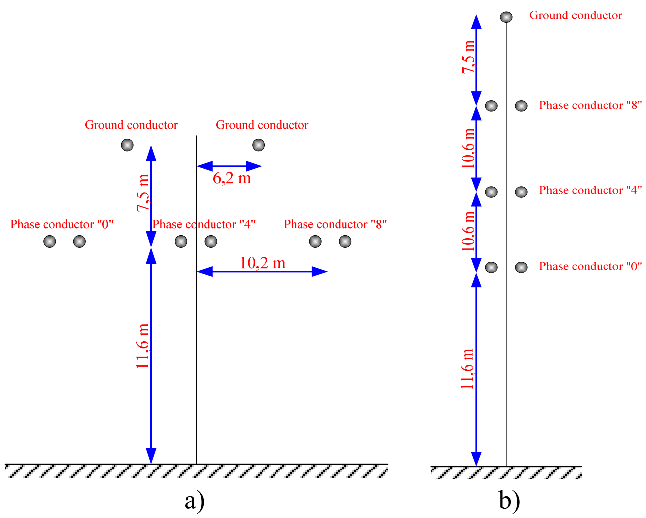


Figure 1: Analysed configurations of the overhead transmission lines a) horizontal configuration; b) vertical configuration; c) "delta" configuration; d) "reverse delta" configuration; e) "split-phase" configuration.

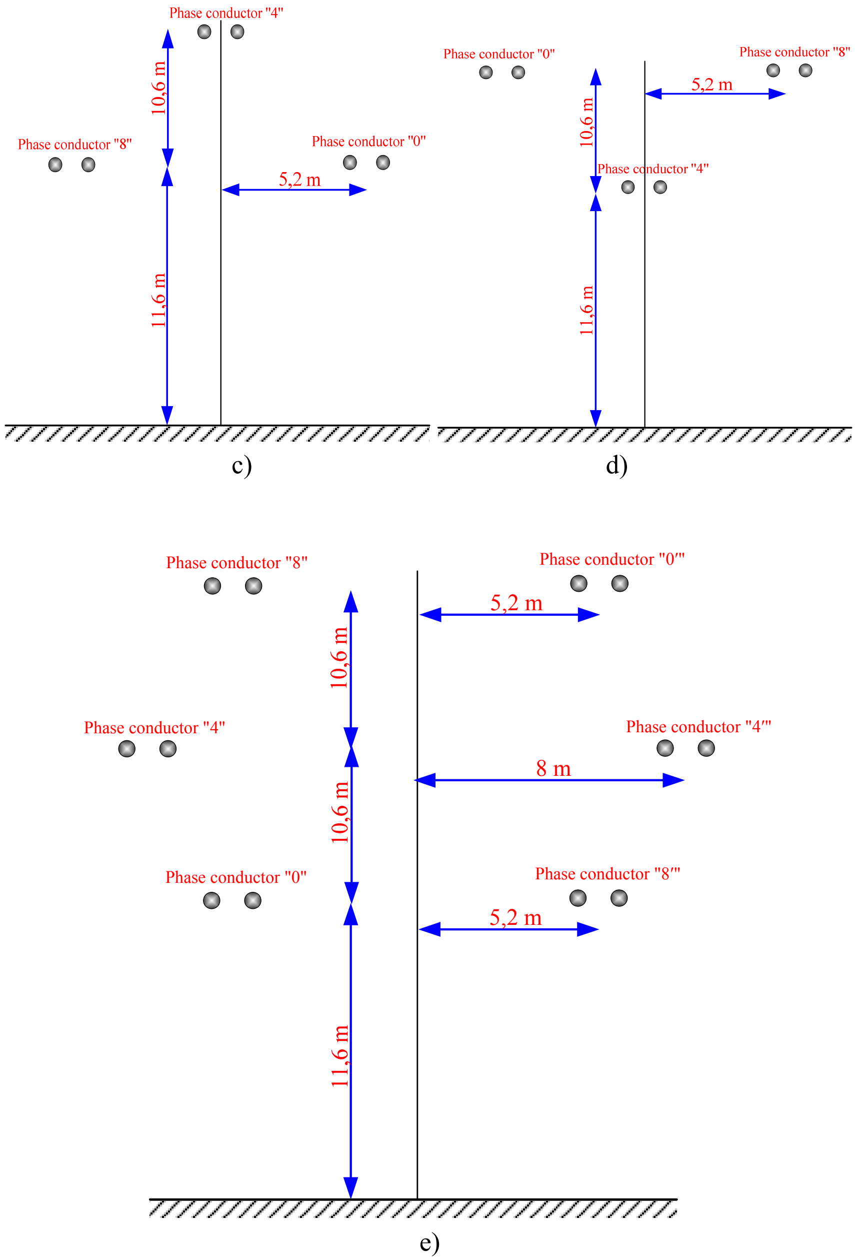


Figure 1: Continued.

From Figure 7 a significant decrease in magnetic field can be observed, in both narrow and wider area of the corridor.

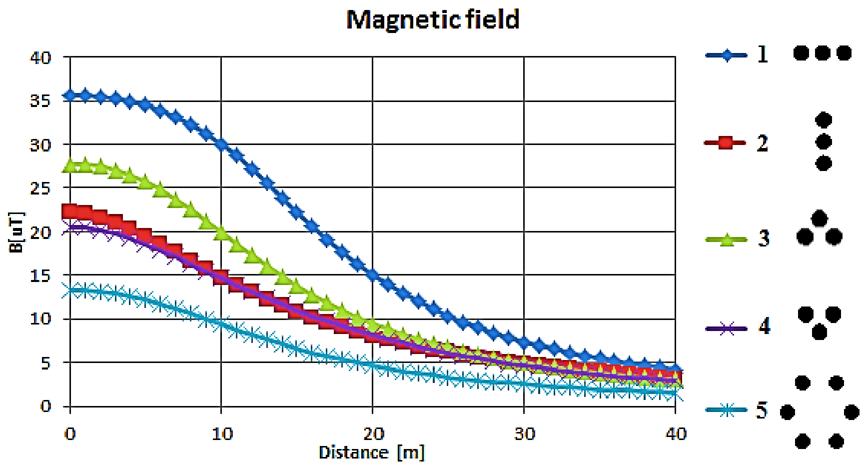


Figure 2: Calculation results of magnetic fields for various configurations of the conductors.

After calculating of magnetic fields, calculation of electric field for the same transmission line configuration was preformed, and the results are given in Figure 8. All proposed configurations (curve 1, 2, 3 and 4), according to the calculation results also lead to a reduction in the value of electric fields near high voltage transmission line.

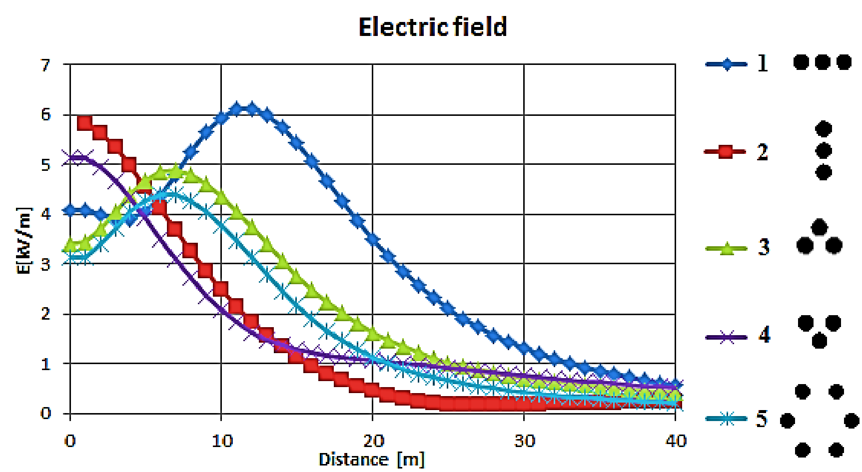


Figure 3: Calculation results of electric fields for various configurations of the conductors.

In addition to the above configurations, it is possible to perform the so-called "split-phase" (curve 5), or division of the phase conductor to more conductors, which can significantly reduce the magnetic field. "Low Resistance" configuration forms two systems of conductors, one with the phases configuration from top to bottom 8, 4, 0 (vertical layout) and the second with the phases configuration from top to bottom 0, 4, 8. The total value of the current through each phase is divided to all its conductors. This configuration gives the best results in terms of magnetic field and very good results regarding electric field, as shown on Figures 7 and 8 (curve 5). Transmission line configuration "split- phase" has certain negative aspects, such as the high cost, in comparison to the others transmission line configurations. This is due to fact that this configuration requires twice as many conductors, as well as insulator strings necessary for connection with the transmission line tower, and also more of other equipment is needed for this configuration. Also, transmission line towers for configuration "split-phase" are more complex for production and therefore much more expensive compared to towers of other configurations. However, when the reduction of electric and magnetic fields is necessary in a limited number of ranges, this solution has many advantages.

5 Conclusion

Results of measurements and calculations for the 400 kV overhead transmission line in Bosnia and Herzegovina were presented in this paper. Also, the paper presents the calculations of electric and magnetic fields for different heights and configuration of the high voltage transmission lines, in order to find optimal solutions in terms of reduction of electric and magnetic fields. From the presented results it is clear that increasing the conductor's height has a significant impact on reduction of both electric and magnetic fields within a narrow corridor of the high voltage transmission line, but the fields in wider corridor are only slightly reduced. Similar conclusions can be drawn for most of the analysed configurations of high voltage transmission line.

The best constructive solution, without considering its economical aspect, is so-called "split-phase" configuration. From the results, it is noticeable that with this configuration significant reductions of the magnetic field in the narrower and wider corridor of high voltage transmission line, as well as a significant reduction of the electric field in the narrow corridor are achieved.

The price of construction of the transmission line configuration "split-phase" is very high compared with other configurations, so that such a solution is reasonable to use only for the sections where reduction of electric and magnetic fields is required due to population (densely populated areas). For the sections where these requirements do not need to be fulfilled (uninhabited and inaccessible areas) one of the cheaper configurations of overhead transmission lines can be used.

References

[1] ICNIRP Safety Guideline, *Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic fields (1Hz-100KHz)*, Health Physics Society, 99(6): 818-836, 2010.

[2] *Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)*, Official Journal of the European Union L 159 of 30 April 2004.

[3] *Directive 2008/46/EC of the European Parliament and of the Council of 23 April 2008 amending Directive 2004/40/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)*, Official Journal of the European Union L 114/88 of 16 April 2008.

[4] S. Čaršimamović, *Current ELF EMF exposure legislation & practice in the see region*, International Colloquium Power Frequency Electromagnetic Fields ELF EMF, Sarajevo 2009.

[5] M. Klarić, *EMF Calculations and measurements in the vicinity of power system facilities according to Croatian legislative*, International Colloquium Power Frequency Electromagnetic Fields ELF EMF, Sarajevo 2009.

[6] M. Rebilini, P. Paterno, A. Guarneri, S. Barnaba & S. Madonna, *Italian legislative framework on EMF: Quality objectives and respect width. Study of mutual influence of parallel overhead lines in dimension of respect width,* International Colloquium Power Frequency Electromagnetic Fields ELF EMF, Sarajevo 2009.

[7] B. Cestnik, K. Grabner & N. Ljubijankić, *Electromagnetic field calculation and measurement of electric power facilities according to Slovenian legislation*, International Colloquium Power Frequency Electromagnetic Fields ELF EMF, Sarajevo 2009.

[8] V. Šinik, *Biological effects of electromagnetic fields, standards, recommendations and problems in measurements of electromagnetic fields*, INFOTEH-JAHORINA Vol. 10, Ref. E-VI-3, pp. 855-859, March 2011.

[9] D. Poljak, *Human exposure to non-ionizing radiation*, Kigen, Zagreb 2006.

[10] A. Mujezinović, A. Čaršimamović & I. Turković, *Electric field calculation around the overhead transmission lines using finite element method*, 11th Conference Bosnia-Herzegovina committee of CIGRE, Neum, September 2013.

[11] M. Kokoruš, S. Delić & M. Muratović, *Analysis of magnetic field around the overhead transmission lines and possible solutions to mitigate their impact*, 11th Conference Bosnia-Herzegovina committee of CIGRE, Neum, September, 2013.

[12] CIGRE WG C4.203, *Technical Guide for Measurement of Low Frequency Electric and Magnetic Fields near Overhead Power Lines*, August 2008.

[13] S. Čarsimamović, Z. Bajramović, M. Raščić, M. Veledar, E. Aganović & A. Čaršimamović, *Experimental Results of ELF Electric and Magnetic Fields of Electric Power Systems in Bosnia and Herzegovina*, IEEE EUROCON - International Conference on Computer as a Tool, 27-29 April 2011.

[14] Measurement of electric and magnetic fields, Faculty of Electrical Engineering, Report dated 23.02.2013, Sarajevo 2013.

[15] N. Kovač, D. Poljak, S. Kraljević & B. Jajac, *Computation of maximal electric field value generated by a power substation*, WIT Transaction on Modelling and Simulation, Vol. 42, pp. 165-174, 2006 WIT Press, www.witpress.com, ISSN 1743-355X.