RAD Conference Proceedings, vol. 8, pp. 83-88, 2024
ISSN 2466-4626 (online) | DOI: 10.21175/RadProc.2024.16
www.rad-proceedings.org

CALCULATIONS OF ELECTRIC AND MAGNETIC FIELDS AT THE LOCATION OF THE INTERSECTION OF TWO OVERHEAD POWER LINES

Maja Grbić*, **Stefan Obradović, Aleksandar Pavlović**

Nikola Tesla Institute of Electrical Engineering, University of Belgrade, Belgrade, Republic of Serbia

Abstract. *The paper is related to an important topic of the exposure of the general public to electric and magnetic fields in the vicinity of transmission overhead power lines. The analysis is carried out for the real situation where there is an intersection of the planned 110 kV double-circuit overhead power line with the existing 400 kV line. The analysis is based on the results of electric field strength and magnetic flux density calculations. The calculations are carried out using a software based on the Partial Element Equivalent Circuit numerical method. The results obtained by using this software were previously verified by comparing them with the results obtained with the model based on infinite straight-line conductors, for the case when there is only one power line. During the analysis of electric and magnetic field calculation results at the location of the intersection, the influence of different phase sequences on the 110 kV line is also analyzed. All the results obtained by calculations are compared with the reference levels prescribed by the legislation on protection of the general public from electromagnetic fields. The method presented in the paper can be used when it is necessary to analyze the levels of electric and magnetic fields at the location of the intersection of the overhead power line which is planned for the construction with an existing overhead line and to carry out an assessment of compliance of the field levels with the prescribed limits.*

Keywords: *electric field, electromagnetic field, magnetic field, magnetic flux density, non-ionizing radiation, overhead power line.*

1. INTRODUCTION

The paper is related to an important topic of the general public protection from non-ionizing radiation, i.e. low frequency electric and magnetic fields originating from overhead power lines. The topic related to the influence of electromagnetic fields originating from power facilities and lines as well as possible mitigation techniques was analyzed by several working groups [1-4]. The influence of overhead power lines on the environment from the standpoint of electromagnetic fields is a topic that requires detailed analysis. Due to their length and proximity to residential areas, overhead power lines are one of the most important sources of low frequency electromagnetic field in the environment. Knowing the levels of electric and magnetic fields in the vicinity of overhead power lines is of great importance for planning the construction of new power lines near residential areas as well as for the construction of residential buildings near existing power lines.

When planning the construction of a new overhead power line it is necessary to carry out the evaluation of its influence on the environment from the aspect of electromagnetic fields. The obtained results of electric field strength and magnetic flux density have to be in compliance with the reference levels prescribed by international [5-7] or national [8-10] legislation. The evaluations are based on electric field strength and magnetic flux density measurements for the situation before the implementation of the project and on calculations for the situation after the project realization. Calculations carried out for the situation after the project implementation have to take into account the influence of both the analyzed power line and the existing sources of electromagnetic fields along the power line route. Only in the case when the assessment carried out in the specified way shows that the electric and magnetic field levels will be within the prescribed limits, it is possible to proceed with the project implementation. Measurements are carried out in accordance with the relevant standards [11-14], while calculations can be based on various methods. Different methods for the calculations of electric field strength and magnetic flux density are presented in [14–26]. The model used for calculations has to be previously verified in order to obtain reliable results which will be used for the assessment of compliance with the reference levels prescribed by national or international legislation. The model can be verified by comparing the results with the results obtained by another software or by measurements. In this paper the method based on comparison of the results obtained by using two calculation models was applied. The measurement and calculation uncertainty [19] have to be taken into account in the conformity assessment.

The situation of the intersection of two transmission lines is analyzed in the paper. Since the new 110 kV line is intersecting with an existing 400 kV line it is necessary to determine the field levels at the location of intersection.

2. SERBIAN AND INTERNATIONAL LEGISLATION ON PROTECTION FROM NON-IONIZING RADIATION

Recommendation 1999/519/EC [6] establishes a framework for harmonized protection of the general public from non-ionizing radiation to which all the European Union countries should adhere in adopting

*E-mail of the corresponding author: maja@ieent.org

local regulations. The reference levels of exposure of the general public to power frequency (50 Hz) electric and magnetic fields, prescribed by [6], are set to 5 kV/m and 100 μT, respectively. These reference levels are equal to those given by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in the ICNIRP guidelines from 1998 [5]. In the ICNIRP guidelines from 2010 [7] the reference levels for power frequency (50 Hz) electric and magnetic fields are 5 kV/m and 200 μT.

The Republic of Serbia fulfilled the requirements of [6] in 2009 by adopting the Law on Protection from Non-Ionizing Radiation [8] and six rulebooks. The subject of the Rulebook on Limits of Exposure to Non-Ionizing Radiation [9] are the so-called "increased sensitivity areas" which 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 of land intended, according to the urban development plan, for the specified purposes, in accordance with recommendations of the World Health Organization". Rulebook [9] established the reference levels, which are 2 kV/m for electric field strength and 40 μT for magnetic flux density. These reference levels refer to RMS values of the power frequency (50 Hz) field in the increased sensitivity areas. The comparative review of reference levels for power frequency electric field strength and magnetic flux density prescribed by international and Serbian legislation is given in Table 1.

Table 1. Comparative review of reference levels for power frequency (50 Hz) electric field strength and magnetic flux density prescribed by international and Serbian legislation

	ICNIRP 1998 [5]	Recommendation 1999/519/EC [6]	ICNIRP 2010 [7]	Rulebook [9]
Electric field strength	5 kV/m	5 kV/m	5 kV/m	2 kV/m
Magnetic flux density	100 μT	100 μT	200 μT	40 μT

According to the Rulebook on Sources of Non-Ionizing Radiation of Special Interest, Types of Sources, Methods and Frequentness of their Testing [10], before the construction of a new electromagnetic field source or the reconstruction of an existing one, it is necessary to carry out an evaluation study in order to confirm that electromagnetic field levels will not exceed the prescribed reference levels after the realization of the project. This study is obligatory when planning the construction or reconstruction of 110 kV, 220 kV and 400 kV transmission overhead power lines. In order to proceed with the project implementation, the study has to demonstrate that the field levels after the project realization will be within the prescribed limits.

3. Analyzed situation of 110 kV and 400 kV overhead power lines intersection

The situation of an intersection of 110 kV double-circuit and 400 kV single-circuit overhead power line is analyzed. The situation is presented in Figure 1. Profiles P1 and P2 which are perpendicular to the axes of the 110 kV and 400 kV lines are also shown in Figure 1. The angle between the axes of these two power lines is 20°.

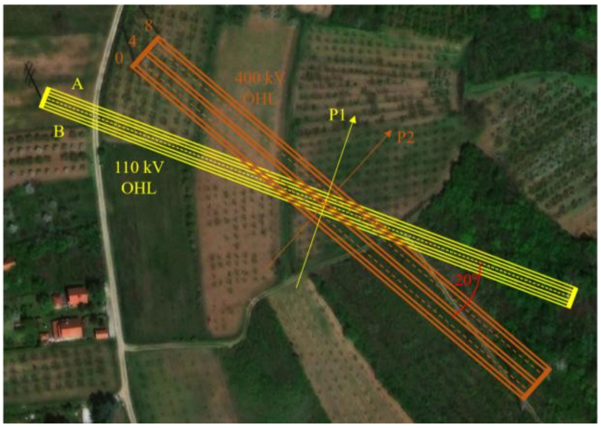

Figure 1. Intersection of the 110 kV and 400 kV overhead lines

The 110 kV overhead power line is a line whose construction is planned and it will intersect with the existing 400 kV line. For that reason, it is necessary to analyze the levels of electric and magnetic fields at the location of their intersection in order to confirm that the field levels will be within the prescribed limits after the construction of the 110 kV line. Since the 110 kV line is planned for construction, the analysis has to be based on field calculations. The calculations have to be carried out using appropriate software tools, which are previously verified, in order to obtain reliable results which will be used for the assessment of compliance with the prescribed reference levels. The towers of the 110 kV and 400 kV overhead power lines on the analyzed span are presented in Figures 2 and 3.

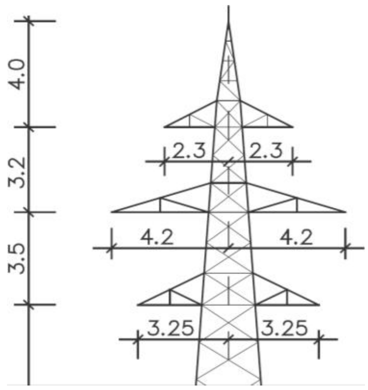

Figure 2. The 110 kV overhead power line tower

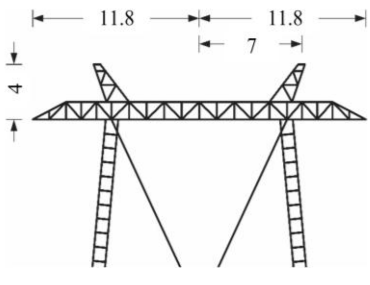

Figure 3. The 400 kV overhead power line tower

4. Calculations of electric field strength and magnetic flux density

4.1 Calculation methods

The calculations of electric field strength and magnetic flux density are based on two different models. In both cases, the overhead power lines are simulated by a set of straight-line conductors, which are parallel to each other and to the ground surface.

The first model (Model 1) is based on a two-dimensional analysis using the method described in [14, 15]. Electric field strength calculations are based on the method of image charges, while magnetic flux density calculations are based on Biot-Savart law. The power lines are simulated by a set of infinitely long, straight-line conductors. The software based on this model is previously verified by comparing the results with the results given in [14]. This model can be used when it is necessary to calculate electric and magnetic fields in the vicinity of one overhead power line or several overhead power lines with parallel routes. However, the model cannot be used for modelling complex geometries and power line intersections. For that reason, it is necessary to use more complex models for the analysis of electric and magnetic fields at the location of the power lines intersection.

The second model (Model 2) is based on the Partial Element Equivalent Circuit (PEEC) numerical method which is described in detail in [27, 28]. In this case, the power line conductors have a finite length of 1000 m. The calculations were carried out using commercial software [27, 28]. The software is based on the PEEC full-wave numerical model, which is suitable for a wide range of applications. The benefits of this calculation method include the ability to model complex conductor geometries, such as those found in intersections of overhead power lines.

The calculations are performed for the power line geometries presented in Figures 4 and 5 and for the data specified in Table 2. The data given in Table 2 include types/materials, cross sections (S) and radii (r) of phase conductors and ground wires, as well as maximum permitted load currents of the power lines during the winter period (I_{max}) prescribed by [29]. The current I_{max} is the maximum power line load during normal operating conditions. The calculations are carried out for values of the power line rated voltage (U_r), i.e. 110 kV and 400 kV.

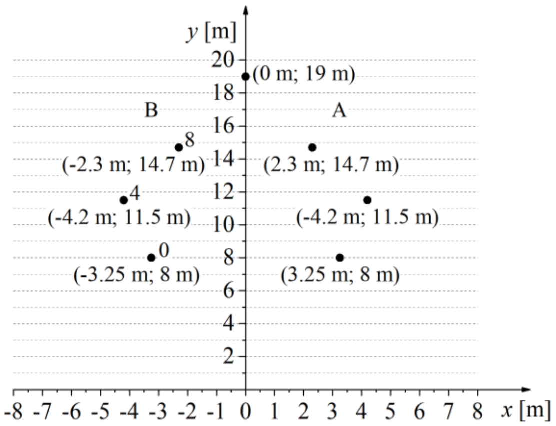

Figure 4. The 110 kV overhead line conductor disposition

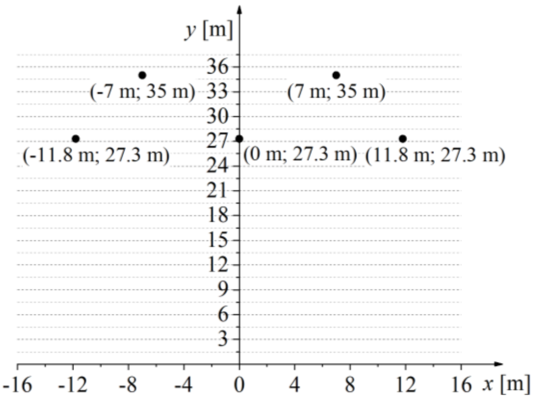

Figure 5. The 400 kV overhead line conductor disposition

Table 2. Main technical data referring to analyzed power lines

U_r [kV]	Phase conductors	Ground wires	I_{max} [A]
110	ACSR 240/40, r = 10.4 mm	Steel, S = 35 mm², r = 3.75 mm	880
400	ACSR 2 × 490/65, r = 15.3 mm	Steel, S = 50 mm², r = 4.5 mm	2740

4.2 Comparison of the calculation results obtained by two different methods

In order to confirm the validity of the obtained results the initial calculations are carried out using both methods. These calculations are performed for the situation when there is only one power line. The results of electric field strength (E) and magnetic flux density (B) calculations for the case when there is only the 110 kV double-circuit line are presented in Figures 6 and 7. The calculations are performed for the untransposed phase sequence 048-048 of the 110 kV line, where 0, 4 and 8 represent the marks of the phases. The calculation results for the case when only the influence of the 400 kV line is taken into account are given in Figures 8 and 9. Marks 1 and 2 in Figures 6-9 refer to the models used for calculations. The results presented in these figures are the RMS values of the field along the lateral profile (profile perpendicular to the power line axis) positioned at 1 m height above the ground.

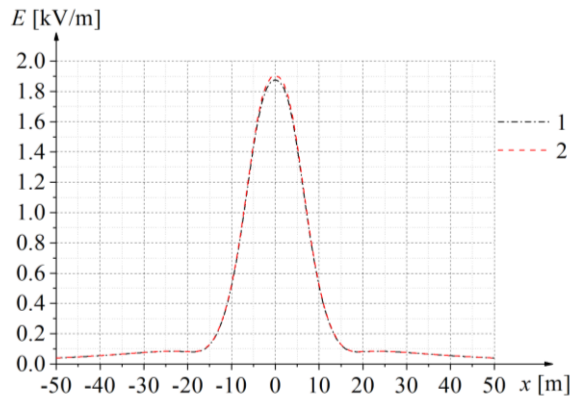

Figure 6. Results of electric field strength calculations for the 110 kV overhead power line

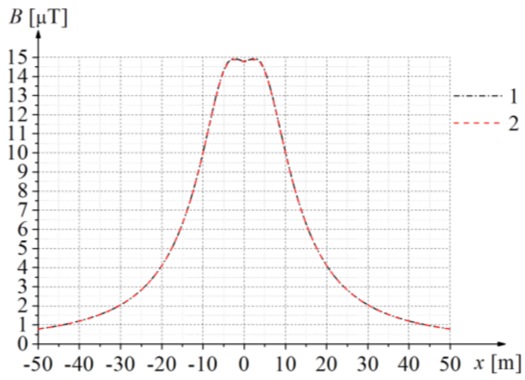

Figure 7. Results of magnetic flux density calculations for the 110 kV overhead power line

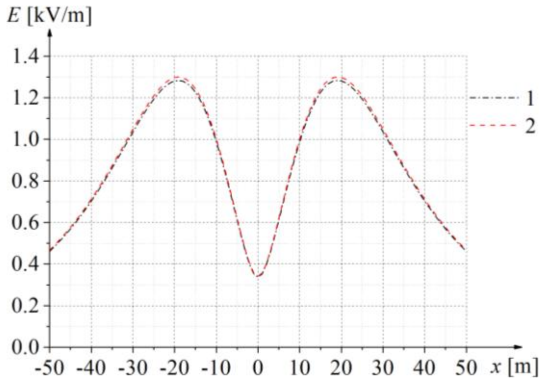

Figure 8. Results of electric field strength calculations for the 400 kV overhead power line

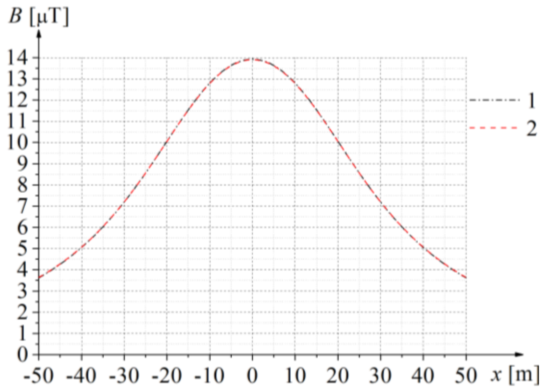

Figure 9. Results of magnetic flux density calculations for the 400 kV overhead power line

The highest values of electric field strength and magnetic flux density obtained for 110 kV and 400 kV power lines by using both methods are given in Table 3.

Table 3. The highest values of electric field strength and magnetic flux density obtained for the 110 kV and 400 kV power lines by using both methods

Power line	E_{max} [kV/m]		B_{max} [μT]	
	Model 1	Model 2	Model 1	Model 2
110 kV	1.88	1.90	14.93	14.89
400 kV	1.28	1.30	13.92	13.91

From the results presented in Figures 6-9 and in Table 3 it can be concluded that there is an agreement between the results obtained by the applied methods. The relative deviation between the results of electric field strength obtained by the two models is lower than 2.3% in all calculation points and for both power lines. The relative deviation between the results of magnetic flux density is lower than 0.90% in all calculation points.

4.3 Calculations of electric and magnetic fields at the location of 400 kV and 110 kV overhead power lines intersection

Based on the presented results, it can be concluded that there is an agreement between the results obtained by the two models. Since the model is verified, the calculations at the location of the power line intersection can be carried out. These calculations are performed by using Model 2. In order to obtain the highest values of electric and magnetic fields, calculations are performed assuming minimum phase conductor heights above ground, which occurs at the phase conductor temperature of +80°C. The power line geometries for this case are shown in Figures 4 and 5.

The phase sequence of the 400 kV line is shown in Figure 1. However, the phase sequence of the planned 110 kV double-circuit line was not determined, so it is necessary to analyze the different phase sequences shown in Figure 10 in order to obtain the highest levels of electric and magnetic fields.

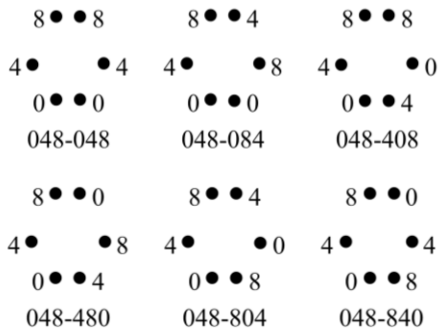

Figure 10. The 110 kV overhead power line phase sequences

For each analyzed phase sequence the highest values of electric field strength and magnetic flux density which occur in the area of power line intersection are determined. These values are presented in Table 4. The highest values of electric and magnetic fields are obtained for the untransposed phase sequence (048-048) of the 110 kV line phase conductors. The calculation results for this case are shown in Figures 11 and 12.

Table 4. The highest values of electric and magnetic fields obtained for different phase sequences of the 110 kV line

Phase sequence	*E* [kV/m]	*B* [μT]
048-048	2.22	26.58
048-084	2.17	26.01
048-408	1.69	23.52
048-480	1.60	26.58
048-804	1.50	24.32
048-840	1.45	26.48

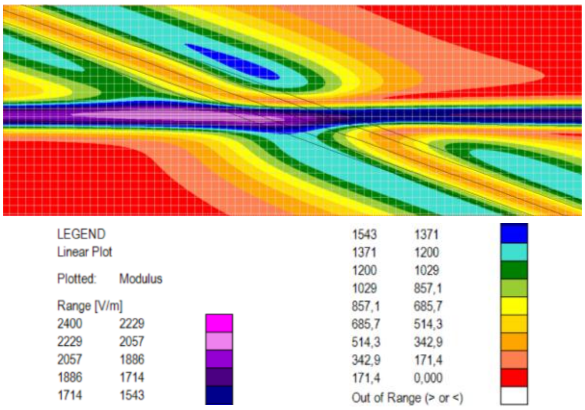

Figure 11. Results of electric field strength calculations at the intersection of the 110 kV and 400 kV overhead power lines

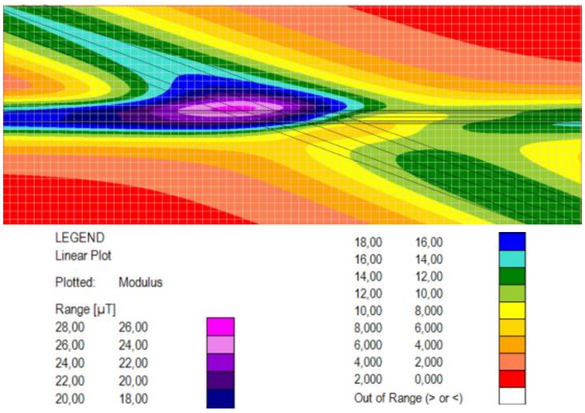

Figure 12. Results of magnetic flux density calculations at the intersection of the 110 kV and 400 kV overhead power lines

The results presented in Figures 11 and 12 are the RMS values of electric field strength and magnetic flux density at 1 m height above the ground. As expected, the maximum field levels are obtained near the intersection of the power lines.

The results of electric field strength and magnetic flux density obtained by calculations along lateral profiles P1 and P2, shown in Figure 1, are presented in Figures 13 and 14. These calculations are performed for the 048-048 phase sequence since in this case the highest values of electric and magnetic fields were obtained.

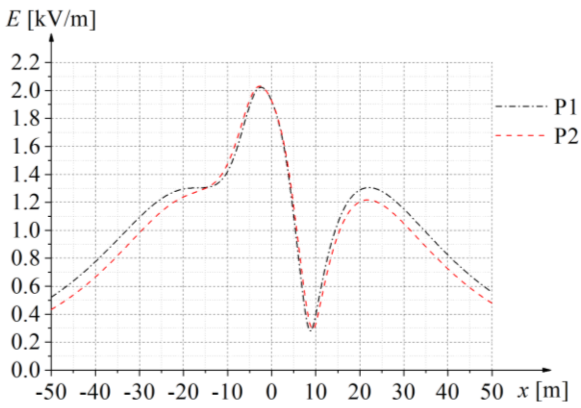

Figure 13. Results of electric field strength calculations along profiles P1 and P2

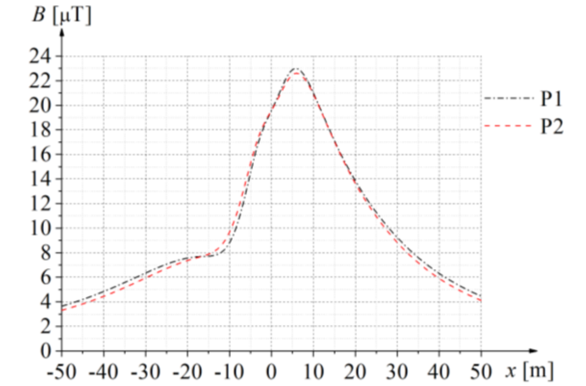

Figure 14. Results of magnetic flux density calculations along profiles P1 and P2

The highest values of electric field strength and magnetic flux density shown in Figures 13 and 14 are slightly lower compared to the values given in Table 4 since the highest field values given in Table 4 represent the highest values in the entire intersection area.

From the presented results it can be concluded that the obtained results are lower than the reference levels of 5 kV/m and 100 μT prescribed by [5, 6].

5. Conclusion

In this paper the calculation results obtained at the location of 110 kV and 400 kV overhead power lines intersection are presented. The model used for calculations is previously verified by comparison with the model based on infinitely long straight-line phase conductors. In order to obtain the maximum values of electric and magnetic fields, the calculations are carried out for different phase sequences of the 110 kV double-circuit power line. It is shown that all the obtained results are lower than the reference levels of 5 kV/m and 100 μT, prescribed by the ICNIRP 1998 Guidelines and Recommendation 1999/519/EC. The approach presented in the paper can be used when it is necessary to calculate the values of electric and magnetic fields in the vicinity of new overhead power lines at the locations of the intersection with existing overhead power lines in order to demonstrate that the field levels after the construction of the new power line will be within the prescribed limits.

Acknowledgments: *This work was supported in part by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia under the Contract on the Realization and Financing of the Scientific Work of Reseach Organizations in 2024 (contract No. 451-03-66/2024-03).*

References

1. *Technical guide for measurement of low frequency electric and magnetic fields near overhead power lines*, CIGRE Working Group C4.203, 2009.
2. *Mitigation techniques of power frequency magnetic fields originated from electric power systems*, CIGRE Working Group C4.204, 2009.
3. *Characterisation of ELF magnetic fields*, CIGRE Working Group C4.205, 2007.

4. *Responsible management of electric and magnetic fields*, CIGRE Working Group C3.19, 2020.
5. 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, pp. 494–522, 1998.
6. European Union. (Jul. 12, 1999). *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.
Retrieved from:
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999H0519
Retrieved on: Apr. 24, 2025.
7. 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, pp. 818–836, 2010.
8. Влада Републике Србије. (15. мај 2009.). Закон о заштити од нејонизујућих зрачења, Службени гласник Републике Србије бр. 36/09. (Government of the Republic of Serbia. (May 15, 2009). Law on Protection from Non-Ionizing Radiation, Official Gazette of Republic of Serbia No. 36/09)
Retrieved from:
https://www.ekologija.gov.rs/dokumenta/zastita-od-nejonizujucih-zracenja/zakoni
Retrieved on: Apr. 24, 2025
9. Влада Републике Србије. (16. децембар 2009.). *Правилник о границама излагања нејонизујућим зрачењима*, Службени гласник Републике Србије бр. 104/09. (Government of the Republic of Serbia. (Dec. 16, 2009). *Rulebook on Limits of Exposure to Non-Ionizing Radiation*, Official Gazette of Republic of Serbia No. 104/09)
Retrieved from:
https://www.ekologija.gov.rs/dokumenta/zastita-od-nejonizujucih-zracenja/pravilnici
Retrieved on: Apr. 24, 2025
10. Влада Републике Србије. (16. децембар 2009.). *Правилник о изворима нејонизујућих зрачења од посебног интереса, врстама извора, начину и периоду њиховог испитивања*, Службени гласник Републике Србије бр. 104/09 (Government of the Republic of Serbia. (Dec. 16, 2009). *Rulebook on Sources of Non-Ionizing Radiation of Special Interest, Types of Sources, Methods and Frequentness of Their Testing*, Official Gazette of Republic of Serbia No. 104/09)
Retrieved from:
https://www.ekologija.gov.rs/dokumenta/zastita-od-nejonizujucih-zracenja/pravilnici
Retrieved on: Apr. 24, 2025
11. *Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)*, EN 50413, 2019.
12. *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*, IEC 61786, 2013.
13. *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*, IEC 61786, 2014.
14. *Electric and magnetic field levels generated by AC power systems – Measurement procedures with regard to public exposure*, EN 62110, 2009.
15. Electric Power Research Institute (EPRI), "Electric and magnetic fields", in *EPRI AC Transmission Line Reference Book – 200 kV and Above*, Third Edition, Palo Alto, CA, USA, EPRI, 2005, pp. 7.1–7.118.
16. *Power lines: Demonstrating compliance with EMF public exposure guidelines: A voluntary code of practice*. Government of the UK, Department of Energy & Climate Change, London, UK, 2012.
Retrieved from:
https://assets.publishing.service.gov.uk/media/5a796799ed915d07d35b5397/1256-code-practice-emf-public-exp-guidelines.pdf
Retrieved on: Apr. 24, 2025
17. M. Grbić, A. Pavlović, "Measurements and calculations of non-ionizing radiation levels in the vicinity of 35 kV overhead power lines", *The 23rd International Conference and Exhibition on Electricity Distribution – CIRED Conf. Proc*, Lyon, France, 2015.
18. M. Grbić, A. Pavlović: "Determining the zone of influence of transmission overhead power lines from the aspect of non-ionizing radiation", *The 6th International Conference on Radiation and Applications in Various Fields of Research*, *RAD Conf. Proc*, vol. 3, Ohrid, Macedonia, 2018, pp. 52–57.
https://doi.org/10.21175/RadProc.2018.11
19. 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, pp. 167–175, 2018.
https://doi.org/10.1016/j.ijepes.2017.11.038
20. 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, pp. 232–240, 2019.
https://doi.org/10.1016/j.epsr.2018.10.001
21. G. Lucca, "Magnetic field produced by power lines with complex geometry" *Eur. T. Electr. Power*., vol. 21, no. 1, pp. 52-58, 2011.
https://doi.org/10.1002/etep.411
22. A. Z. El Dein, "Calculation of the electric field around the tower of the overhead transmission lines" *IEEE T. Power. Deliver.*, vol. 29, no. 2, pp. 899-907, 2014.
https://doi.org/10.1109/TPWRD.2013.2273500
23. A. Z. El Dein, "Parameters affecting the charge distribution along overhead transmission lines' conductors and their resulting electric field", *Electric Power Syst. Res.*, vol. 108, pp. 198-210, 2014.
https://doi.org/10.1016/j.epsr.2013.11.011
24. E. Turajlić, A. Mujezinović, A. Alihodžić, "A novel method based on PSO algorithm and ANN for magnetic flux density estimation near overhead transmission lines", *J. Electr. Eng.*, vol. 74, pp. 399-410, 2024.
https://doi.org/10.2478/jee-2024-0048
25. A. Alihodžić, A. Mujezinović, E. Turajlić, "Artificial neural network-based method for overhead lines magnetic flux density estimation", *J. Electr. Eng.*, vol. 75, pp. 181-191, 2024.
https://doi.org/10.2478/jee-2024-0022
26. E. Turajlić, A. Alihodžić, A. Mujezinović, "Artificial neural network models for estimation of electric field intensity and magnetic flux density in the proximity of overhead transmission line", *Radiat. Prot. Dosimetry*, vol. 199, pp. 107-115, 2023.
https://doi.org/ 10.1093/rpd/ncac229
27. XGSLab User's Guide, Release 9.4.1 – 03/20, SINT Ingegneria Srl, 2020.
28. XGSLab Tutorial XGSA_FD, Release 9.4.1 – 03/20, SINT Ingegneria Srl, 2020.
29. ЈП „Електромрежа Србије", *Дозвољене струје фазних проводника на далеководима ЈП ЕМС-а, Техничко упутство ТУ-ДВ-04, верзија 2*, ЈП ЕМС, Београд, Србија, 2011. (Public Enterprise Elektromreža Srbije, *Permitted currents of phase conductors of power lines owned by the Public Enterprise Elektromreža Srbije, Technical Guidance TU-DV-04, ver. 2*, PE EMS, Belgrade, Serbia, 2011.)