Levels of Electric and Magnetic Fields inside 110/X kV Substations

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ABSTRACT

Power frequency electric and magnetic field levels which occur inside 110/x kV substations are analyzed in this paper in order to assess the exposure of workers to these fields. The analysis is based on results of electric field strength and magnetic flux density measurements inside 110/x kV substations in Serbia. The measurements were performed along the transport routes, near the HV/MV equipment and the power transformers, as well as inside and in the vicinity of the control buildings, with the purpose of estimating maximum field levels which can occur inside these substations. In order to estimate the exposure of workers to these fields, the obtained results were compared to the action levels prescribed by Directive 2013/35/EU. The first objective of the analysis performed is to reach general conclusions about field levels which can occur inside substations of the mentioned voltage level. The second objective is to check whether these levels comply with the action levels prescribed by Directive 2013/35/EU.

INTRODUCTION

The topic of non-ionizing radiation has become very important in Serbia over the last several years, thus initiating comprehensive research and testing regarding exposure of the general public and workers to power frequency electric and magnetic fields and mitigation techniques.

This paper presents an analysis of power frequency (50 Hz) electric and magnetic field levels inside 110/x kV substations. The analysis is based on results of electric field strength and magnetic flux density measurements inside substations of the aforementioned voltage level in Serbia, with the aim of assessing the exposure of workers to these fields. The measurements were carried out with the purpose of estimating maximum field levels which can occur inside these substations. The measurements were performed inside a large number of 110/x kV substations in Serbia, while results obtained inside two typical substations are presented in this paper.

In order to estimate the exposure of workers to these fields, the obtained results were compared to the action levels prescribed by Directive 2013/35/EU [1]. The first objective of the analysis performed is to reach general conclusions about the field levels which can occur inside the substations of the mentioned voltage level. The second objective is to check whether these levels comply with the action levels prescribed by Directive [1].

OVERVIEW OF DIRECTIVE 2013/35/EU

The issue of exposure of workers to non-ionizing radiation is addressed by Directive 2013/35/EU of the European Parliament and of the Council [1], which repealed Directive 2004/40/EC [2]. Directive [1] prescribes exposure limit values (ELVs) and action levels (ALs). ELVs represent “values established on the basis of biophysical and biological considerations, in particular on the basis of scientifically well-established short-term and acute direct effects, i.e. thermal effects and electrical stimulation of tissues”. ALs correspond to calculated or measured electric and magnetic field values at the workplace in the absence of the worker, and are established for the purpose of simplifying the process of demonstrating the compliance with relevant ELVs. The method of exposure assessment based on ALs is conservative. If field values obtained by measurements and calculations are below ALs, automatic compliance with ELVs is implied. ALs prescribed by Directive [1] are given in Table 1.

Table 1 – ALs for power frequency (50 Hz) electric field strength and magnetic flux density (rms)

Electric field strength		Magnetic flux density	
Low AL [kV/m]	High AL [kV/m]	Low AL [mT]	High AL [mT]
10	20	1	6

Directive [1] prescribes the minimum requirements, giving EU member states the option of maintaining or adopting more favorable provisions for the protection of workers, in particular by fixing lower values for the ALs or the ELVs for electromagnetic fields.

TESTING OF ELECTRIC AND MAGNETIC FIELDS INSIDE 110/X KV SUBSTATIONS

Measured Quantities

The testing was based on measurements of rms values of electric field strength and magnetic flux density. The intensity of these vector quantities was measured isotropically, by performing simultaneous measurements of all three spatial components of field vectors. The field frequency was also measured simultaneously with electric field strength and magnetic flux density, and it amounted to 50 Hz at all measurement points.

Measurement 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 [3]. These probes insure simultaneous measurements of all three spatial components of field vectors, based on which the instrument shows their resultant values.

The probe for electric field strength measurements is cube-shaped, with a 10 cm edge. During the measurements, this probe was placed on a wooden tripod and connected to the analyzer by a several-meters-long optical cable. In this way the influence of the operator on measurement results was avoided.

The probe for magnetic flux density measurements is sphere-shaped, with a cross-sectional area of 100 cm^2. During the measurements this probe was directly connected to the analyzer.

Throughout the measurements of electric field strength and magnetic flux density, a measurement mode with a 5 Hz – 2 kHz filter was used.

Measurement Procedures

The measurements were conducted in accordance with the measurement procedure described in [4], at a large number of measurement points.

During measurements of magnetic flux density, load currents of the magnetic field sources were also monitored. Based on the ratio of maximum load currents and the currents at the time of measurements, as well as on the measured values of magnetic flux density, a conclusion was reached on compliance of maximum magnetic flux density levels, which would occur at the rated load, with action levels.

The measurements were performed along the transport routes, near the HV/MV equipment and the power transformers, as well as inside and close to the control buildings. At all the measuring points outdoors, the measurements were carried out at a height of 1.7 m above ground, as workers in these zones are usually in the standing position and dominant field sources (busbars, HV/MV equipment) are located above them. In the vicinity of metal-enclosed cabinets with MV equipment, the measurements were also carried out at the heights of 0.5 m, 1 m and 1.5 m.

RESULTS OF ELECTRIC AND MAGNETIC FIELD MEASUREMENTS

In this paper, measurements inside two 110/x kV substations in Serbia are presented.

110/10 kV Kraljevo 5 Substation

The measurements were performed at the measurement points shown in Figures 1 and 2 [5].

Figure 1 – Locations of measurement points 1–62

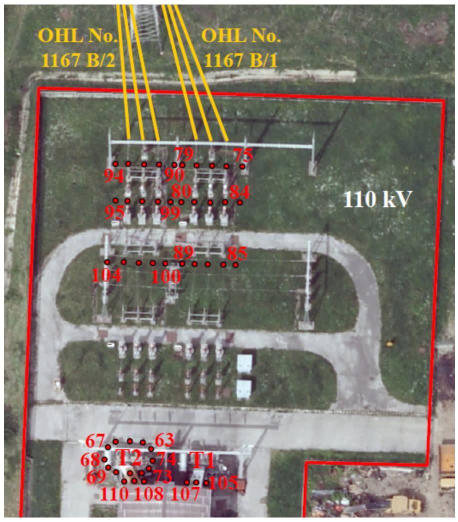

Figure 2 – Locations of measurement points 63–110

At measurement points 1–104, located outdoors, the measurements of electric field strength and magnetic flux density were performed at the 1.7 m height. At points 105–110, near 110/10 kV power transformers T1 and T2, only magnetic flux density measurements at the 1.7 m height were performed in the vicinity of 10 kV enclosed busbars. Measurement points 111–127 are located inside the control building. Points 111–126 are positioned near 10 kV metal-enclosed equipment, at the heights of 0.5 m, 1 m, 1.5 m and 1.7 m. Measurement point 127 is also positioned inside the control building at the 1 m height and represents the location where maximum magnetic flux density value of 0.35 μT was measured in the control room, where workers spend most of their time.

The load currents of the magnetic field sources during magnetic flux density measurements as well as the maximum load currents of these sources are shown in Table 2. The marks in Table 2 signify the following:

U [kV] – voltage level of magnetic field source,

I [A] – load current of magnetic field source during measurements,

I [%] – percentage of maximum load current, and

I_{max} [A] – maximum load current of magnetic field source.

In the case of power transformers, the transformer rated loads specified by the manufacturer are adopted as the maximum loads. In the case of overhead power lines (OHL), maximum current allowed within the period of 20 minutes is adopted as the maximum load.

Table 2 – Load currents of magnetic field sources

Magnetic field source	*U* [kV]	*I* [A]	*I* [%]	I_{max} [A]
OHL No. 1167 B/1	110	0	0	880
OHL No. 1167 B/2	110	92	10.5	880
Transformer T1	110	45	45.4	99.2
Transformer T2	110	47	47.4	99.2

The measurement results are shown in Figures 3–6, where *E* and *B* signify the measured values of electric field strength and magnetic flux density, respectively, and *n* signifies the ordinal number of measurement points.

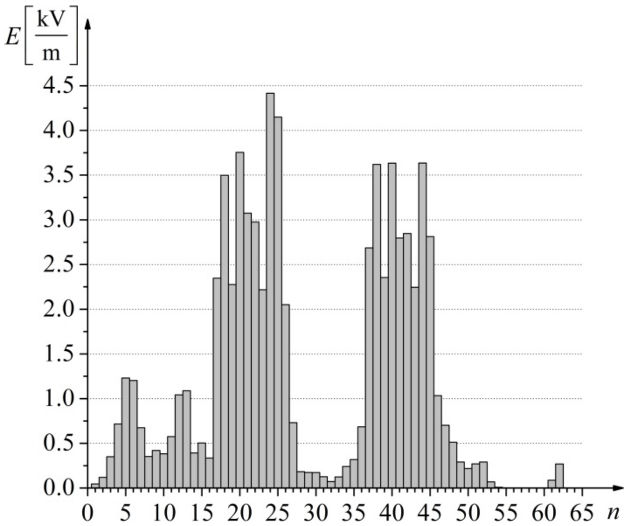

Figure 3 – Results of electric field strength measurements at measurement points 1–62

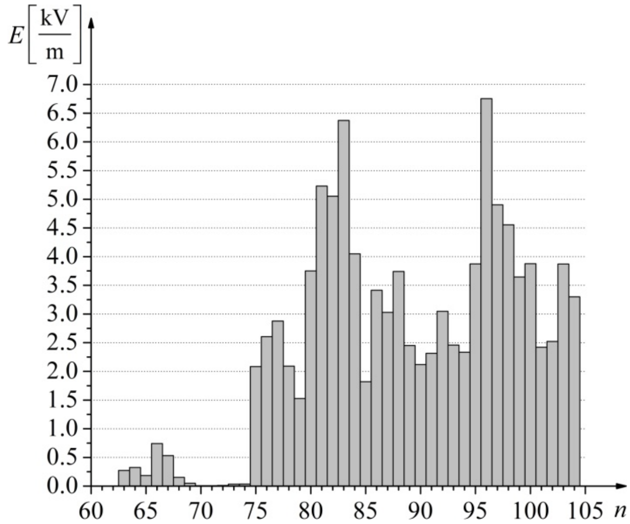

Figure 4 – Results of electric field strength measurements at measurement points 63–104

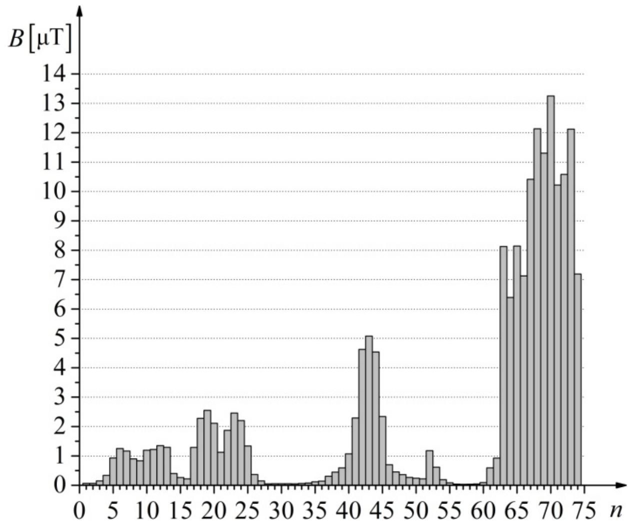

Figure 5 – Results of magnetic flux density measurements at measurement points 1–74

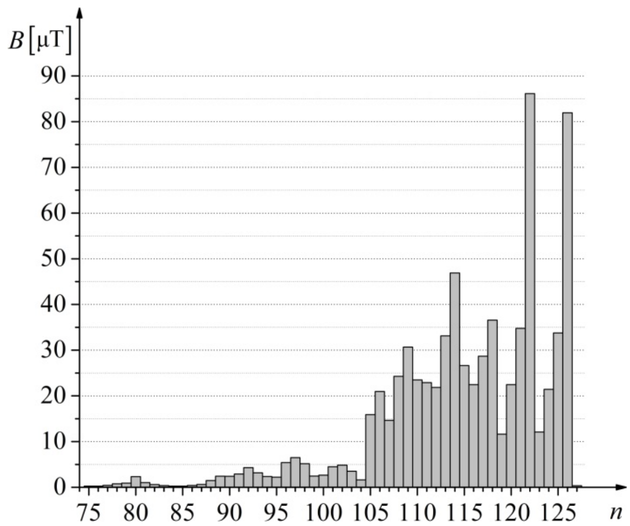

Figure 6 – Results of magnetic flux density measurements at measurement points 75–127

The highest value of electric field strength is measured at point 96 and amounts to 6.75 kV/m. This value is measured close to 110 kV equipment, where workers spend little time.
The highest value of magnetic flux density is measured at point 122 and amounts to 86.15 μT. This value is measured at the 1.7 m height, just below 10 kV busbars of the transformer T2. The load of this transformer during the measurements was about 47.4% of its rated load.

110/35 kV Očaga Substation

The measurements were performed at the measurement points shown in Figures 7 and 8 [6]. In Figure 8, electric field strength and magnetic flux density measurement points are separated where maximum values of these fields are in fact spatially separated. In these instances, measurement points are marked with E and B followed by appropriate ordinal numbers.

Figure 7 – Locations of measurement points 1–76

Figure 8 – Locations of measurement points 77–119

At points 1–118, located outdoors, the measurements are performed at the 1.7 m height.

Point 119, positioned at the 1 m height, represents the location where maximum magnetic flux density value of 0.26 μT was measured inside the control building.
The load currents of the magnetic field sources and their maximum load currents are shown in Table 3.

Table 3 – Load currents of magnetic field sources

Magnetic field source	U [kV]	I [A]	I [%]	I_{max} [A]
OHL No. 120/1	110	30	4.6	650
OHL No. 120/2	110	100	15.4	650
Transformer T1	110	65	33.3	195
Transformer T2	110	65	33.3	195

The measurement results are shown in Figures 9–12.

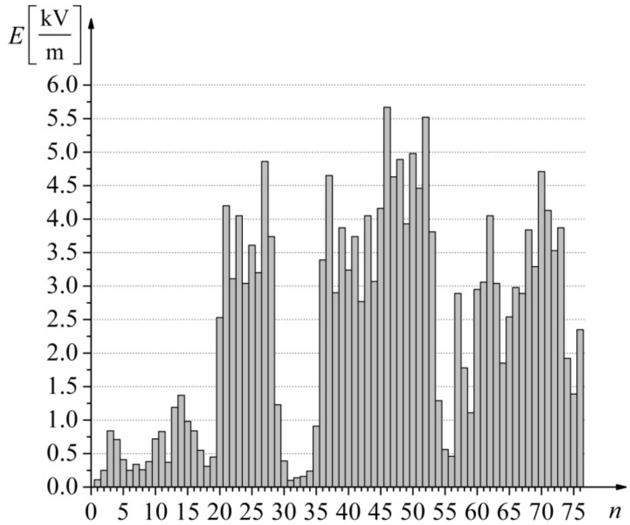

Figure 9 – Results of electric field strength measurements at measurement points 1–76

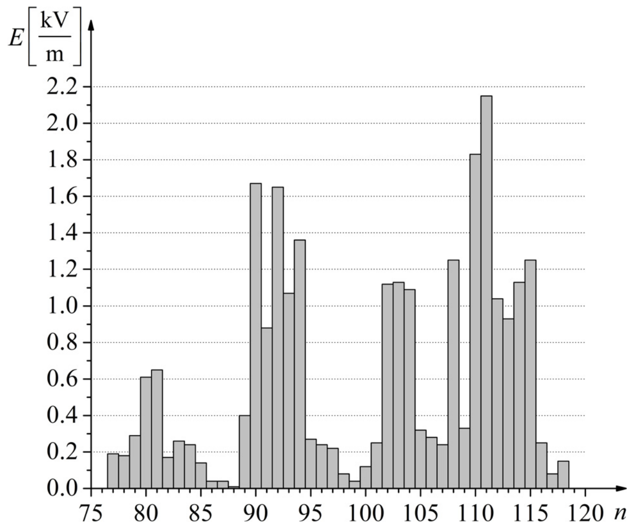

Figure 10 – Results of electric field strength measurements at measurement points 77–118

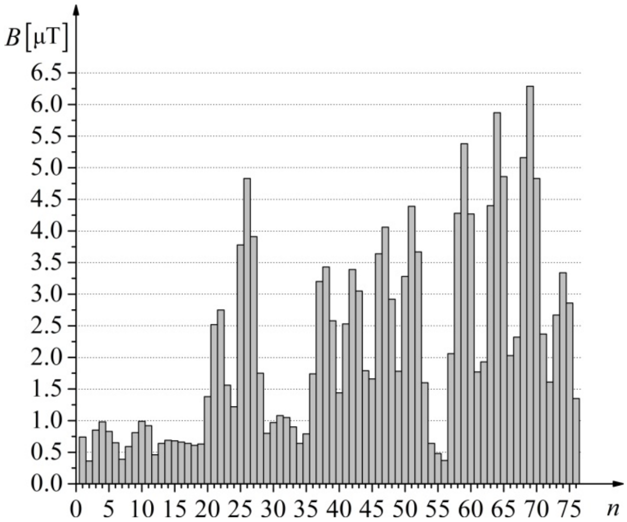

Figure 11 – Results of magnetic flux density measurements at measurement points 1–76

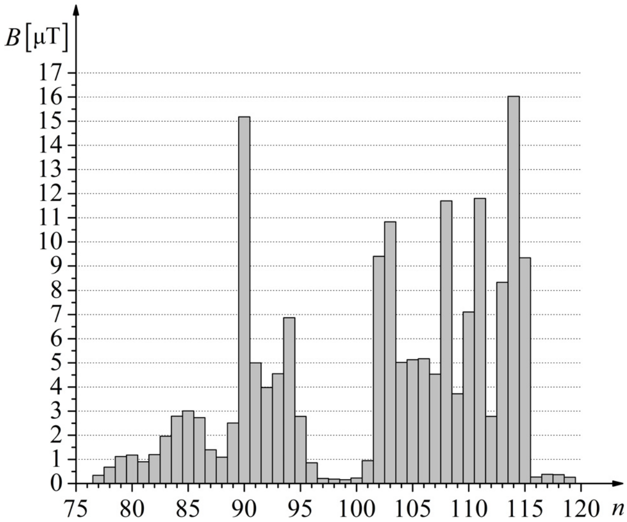

Figure 12 – Results of magnetic flux density measurements at measurement points 77–119

The highest value of electric field strength is measured at point 46 and amounts to 5.67 kV/m. This value is measured at the height of 1.7 m, close to 110 kV equipment, where workers spend little time.
The highest value of magnetic flux density is measured at point 114 and amounts to 16.03 μT. This value is measured at the height of 1.7 m, near the 35 kV equipment and busbars, at the transformer load of 33.3% of its rated load.

CONCLUSION

On the basis of results of detailed measurements conducted inside two 110/x kV substations, a general conclusion about the levels which can occur inside these substations can be made. It can be concluded that in both cases measured values of electric field strength are lower than the low AL of 10 kV/m. Measured values of magnetic flux density, as well as the maximum values of magnetic flux density, which would appear at the rated load, are significantly lower than the low AL of 1 mT.

REFERENCES

[1] Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC, Official Journal of the European Union, 29 June 2013.

[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) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC), Official Journal of the European Union, 24 May 2004.

[3] EN 61786-1:2014: "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".

[4] EN 50499:2008: "Procedure for the assessment of the exposure of workers to electromagnetic fields".

[5] Nikola Tesla Electrical Engineering Institute, report No. 315407-L: "Testing of exposure of workers to non-ionizing radiation – Measurements of low frequency electric field strength and magnetic flux density inside 110/10 kV Kraljevo 5 Substation", 28 December 2015 (in Serbian).

[6] Nikola Tesla Electrical Engineering Institute, report No. 315307-L: "Testing of exposure of workers to non-ionizing radiation – Measurements of low frequency electric field strength and magnetic flux density inside 110/35 kV Očaga Substation", 28 December 2015 (in Serbian).