Magnetic field in an apartment located above 10/0.4 kV substation: Levels and mitigation techniques

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Magnetic field in an apartment located above 10/0.4 kV substation: levels and mitigation techniques

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Abstract: The paper presents a real case of non-ionising radiation testing in an apartment located directly above a 10/0.4 kV substation in Serbia. In order to check the compliance with national regulations on protection of population from non-ionising radiation, it was necessary to perform measurements of magnetic flux density in the apartment. After the first measurements were performed, the distribution company implemented a mitigation technique by placing a passive conductive shield inside the substation in order to decrease magnetic field levels in the apartment. Measurements performed after the mitigation technique had been implemented have shown that the applied shield had an impact on magnetic field reduction to a certain extent. However, since the obtained shielding factor was not very high, the authors analysed another possible shielding solution which would provide higher shielding factor and consequently lower magnetic field levels in the apartment. Both shielding solutions and the results they provide are presented and analysed.

1 Introduction

The topic of non-ionising radiation has become very important in Serbia since the adoption of legislation on protection of population from non-ionising radiation in 2009 [1–3]. Studies performed since 2009 have shown that 10/0.4 and 20/0.4 kV substations located inside residential buildings represent very important sources of magnetic field, having in mind their large number and close proximity to residential areas [4].

This paper presents a real case of non-ionising radiation testing in an apartment located directly above a 10/0.4 kV substation. In order to check the compliance with national regulations on protection of population from non-ionising radiation, it was necessary to perform measurements of magnetic flux density in the apartment.

2 Serbian legislation on protection from non-ionising radiation

Protection of population from non-ionising 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 regulations. In this way, Serbia has fulfilled the requirements of the Recommendation 1999/519/EC [5].

The subject of the Regulation on Limits of Exposure to Non-Ionizing Radiation [2] are so-called ‘areas of increased sensitivity’, which include residential areas. Regulation [2] 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 field (50 Hz) in the areas of increased sensitivity.

Regulation [3] requires that higher attention is paid to so-called ‘sources of special interest’, which are defined as ‘sources of electromagnetic radiation that can be harmful to people’s health and are determined as stationary and mobile sources whose electromagnetic field in an area of increased sensitivity amounts to at least 10% of reference level prescribed for that frequency’. Owners of sources of special interest have the obligation of providing field measurements once every 4 years.

3 Magnetic field source

The source of magnetic field in the apartment in question, located on the first floor of a residential building, is a 10/0.4 kV substation no. Z-325, positioned directly below the apartment, on the ground floor. The substation consists of two separate rooms – the first one with 1000 kVA transformer and the second one with 0.4 and 10 kV switchboards.

4 First magnetic field testing

The first magnetic field testing was performed at the end of June of 2014 by Nikola Tesla Electrical Engineering Institute [6].

During the testing, the rms values of magnetic flux density were measured isotropically, using magnetic field analyser connected to the isotropic probe for magnetic field measurements [7, 8]. Electric field testing was not performed because it is theoretically known that in these cases electric field levels are negligible.

Since the magnetic field is proportional to the currents which flow through the conductors, the transformer load currents were measured in all three phases during the entire period of magnetic flux density measurements. Table 1 shows the minimum and maximum value of the load current during testing in each phase [$I_{\min}$ (A) and $I_{\max}$ (A)], as well as their percentages of the transformer rated current [$I_{\min}$ (%) and $I_{\max}$ (%)]. The transformer rated current amounts to $I_r = 1443.4$ A at the 0.4 kV voltage level. On the basis of the measured values of the currents, it can be concluded that the transformer load during the testing was from 15 to 25% of the rated load.

The measurements in the apartment were performed at 107 points which are located in three bedrooms, bathroom and hall, since these rooms are closest to the substation (Figs. 1 and 2). More precisely, bedroom 3 is located above the room with the transformer, and bedroom 2 and the bathroom are located above the room with switchboards. In the rest of the apartment, the measured values of

Table 1 Transformer load currents during testing

Phase	I_{min}–I_{max}, A	I_{min}–I_{max}, %
A	223.3–336.4	15.5–23.3
B	228.9–367.2	15.9–25.4
C	241.0–339.9	16.7–23.6

Fig. 1 *Locations of measurement points 1–87*

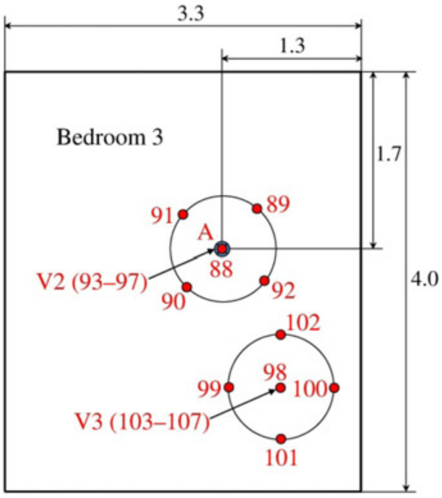


Fig. 2 *Locations of measurement points 88–107*

magnetic flux density were <0.3 μT, and therefore, these results are not presented.

The measurement points were placed along horizontal measurement profiles P1–P13 at the height of 1 m from the floor, as well as along vertical profiles (V1–V3), at heights of 0, 0.5, 1, 1.5 and 2 m, with the specified order. Five-point measurements were performed at two locations at the height of 0.2 m from the floor [8]. Point A (Fig. 2) is located at the height of 0.2 m from the floor. At this point, 100 measurements were performed with a time step of 5 s between them.

The results of the magnetic flux density measurements are shown in Figs. 3 and 4. In these figures, n signifies the ordinal number of a measurement point and B the measured value of magnetic flux density.

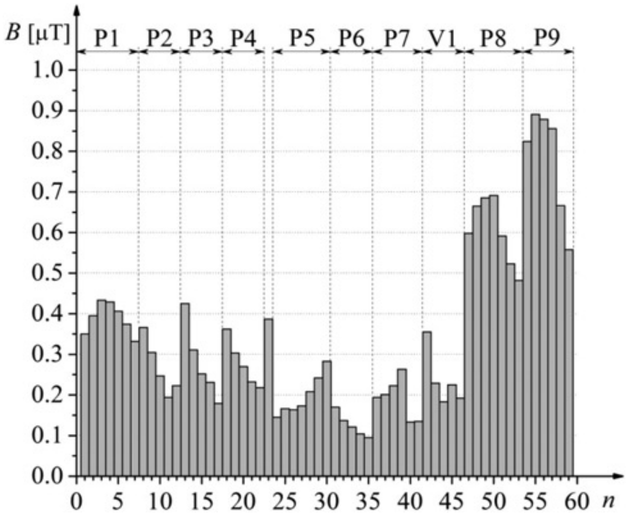


Fig. 3 *Results of first magnetic flux density measurements at measurement points 1–59*

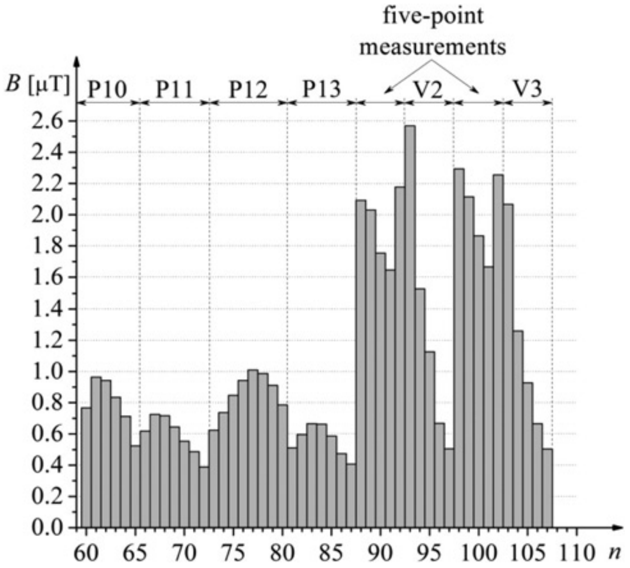


Fig. 4 *Results of first magnetic flux density measurements at measurement points 60–107*

The highest field values were measured in bedroom 3 located directly above the transformer. The highest value, which amounted to 2.57 μT, was measured at point no. 93, located at the floor level.

When estimating the highest possible levels of magnetic flux density, it is necessary to take into account the highest possible load of the magnetic field source, i.e. the transformer rated current.

At point A, where the maximum magnetic field level was detected, 100 magnetic flux density measurements were performed. On the basis of the correlation of these results with the simultaneously measured currents in all three phases, as well as extrapolation, it is calculated that the maximum magnetic flux density value in this point, which would appear at the rated load of the transformer, amounts to 11.6 μT.

5 Application of technique for reducing magnetic field

In order to decrease the magnetic field levels in the apartment, a mitigation technique was applied by the distribution company. For that reason, two passive shields were placed inside the substation.

The first one was placed above the transformer (Fig. 5) and the second one above the 0.4 kV switchboard (Fig. 6). Each shield consists of two iron metal sheets, 2 and 4 mm thick, placed one above the other.

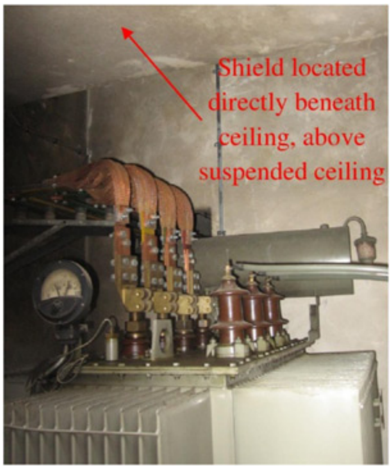


Fig. 5 *Shield located above the transformer*

Fig. 6 *Shield located above the 0.4 kV switchboard*

6 Second magnetic field testing

After the implementation of measures, the magnetic field testing was repeated at the beginning of March of 2016, in order to check their efficiency [9].

The measured values of transformer load currents in all three phases at the 0.4 kV voltage level are shown in Table 2. The transformer load during the testing was between 16 and 31% of the rated load.

Magnetic flux density measurements were made at 112 measurement points. The first 107 measurement points are located at the same positions as during the first measurement. The locations of points 108–112 are shown in Fig. 7.

The measurement results are shown in Figs. 8 and 9.

Table 2 Transformer load currents during testing

Phase	$I_{\min}$–$I_{\max}$, A	$I_{\min}$–$I_{\max}$, %
A	258.1–376.9	17.9–26.1
B	314.3–439.5	21.8–30.5
C	243.5–374.6	16.9–26.0

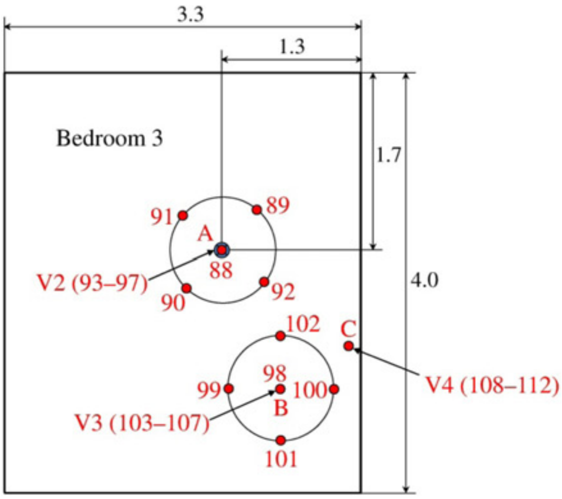


Fig. 7 *Locations of measurement points 108–112*

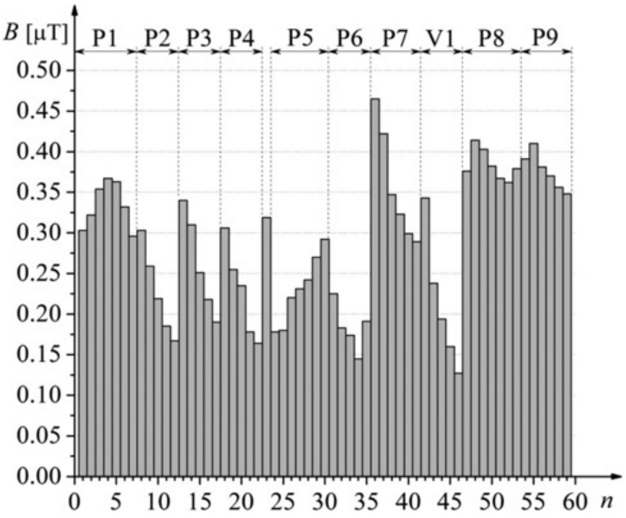


Fig. 8 *Results of second magnetic flux density measurements at measurement points 1–59*

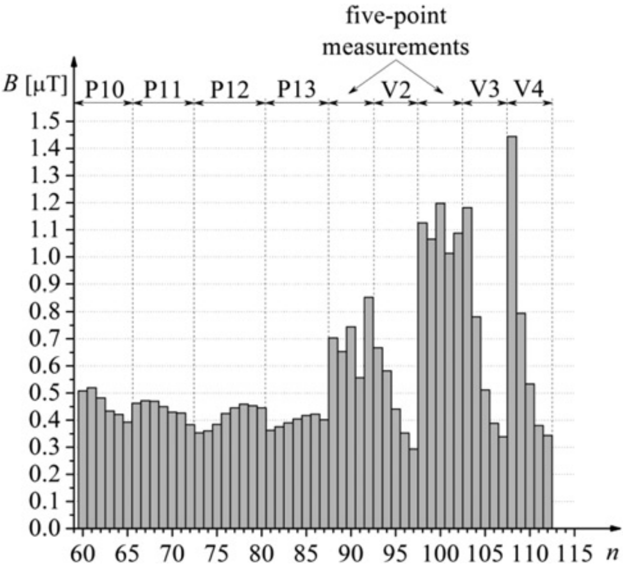


Fig. 9 *Results of second magnetic flux density measurements at measurement points 60–112*

The highest value of magnetic flux density was measured at measurement point no. 108, located at the floor level, and amounts to 1.44 μT.

At locations A, B and C (Fig. 7), where high magnetic field levels were detected, magnetic flux density measurements were performed during several minutes at heights of 0.2 and 1 m. At each point, 50 magnetic flux density measurements were performed with a time step of 5 s. These values are extrapolated in order to estimate the highest magnetic flux density values which would appear at these locations. The highest magnetic flux density values obtained by extrapolation at the height of 0.2 m at locations A, B and C amount to 3.41, 5.69 and 6.71 μT, respectively. The highest magnetic flux density values at the height of 1 m at the same locations amount to 1.43, 2.33 and 2.03 μT, respectively.

7 Comparison of results obtained before and after mitigation

The comparison between the results of magnetic flux density obtained before and after mitigation is shown in Table 3. The marks $B_{\max 1}$ and $B_{\max 2}$ represent maximum values of magnetic flux density obtained by extrapolation for the transformer rated load before and after mitigation, respectively. The shielding factor (SF) represents the ratio between magnetic flux density values before and after mitigation, i.e. $\text{SF} = B_{\max 1}/B_{\max 2}$.

The highest value of the shielding factor appears at location A at a 1 m height and amounts to 3.6.

The maximum value of magnetic flux density during the first testing appears at location A at a 0.2 m height and amounts to 11.60 μT at the maximum load. During the second testing, due to the presence of the shield, the maximum appears at location C at the 0.2 m height and amounts to 6.71 μT at the maximum load. Therefore, the ratio between the maximum magnetic flux density values obtained during the first and the second testing is ∼1.7. Finally, it can be concluded that the applied shield had an impact on magnetic field reduction to a certain extent.

Table 3 Comparison between magnetic flux density results obtained before and after mitigation

Location	h, m	$B_{\max 1}$, μT	$B_{\max 2}$, μT	SF
A	0.2	11.60	3.41	3.4
	1	5.15	1.43	3.6
B	0.2	9.96	5.69	1.75
	1	4.39	2.33	1.88
C	0.2	—	6.71	—
	1	—	2.03	—

8 Mitigation technique proposed by the authors

Since the obtained shielding factor was not very high, the authors analysed another possible solution which would provide higher shielding factor and consequently lower magnetic field levels in the apartment. This solution was analysed by means of 3D simulations using suitable numerical methods [10–12] and consists of passive shields made of pure conductive material.

8.1 Model for magnetic flux density calculations

Calculations of magnetic flux density in the apartment are based on 3D simulations of the main magnetic field source, i.e. the 0.4 kV busbars, which are modelled by a set of straight-line segments. The model is verified by comparing calculation and measurement results. In order to be concise, these results are not presented.

8.2 Shielding solution

The shape of the shielding system and its position are shown in Fig. 10. The thickness of the shield is 3 mm, and its conductivity is 35 MS/m.

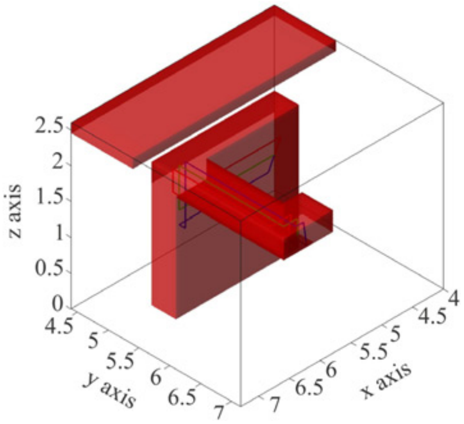


Fig. 10 *Shape and position of the shielding system*

8.3 Calculation results after shielding

In order to estimate the magnetic flux density levels after the shielding, calculations are performed for the rated load, i.e. for the current of 1443.4 A at 0.4 kV voltage level of the transformer in each phase. The calculation results for the heights of 0.2 and 1 m are shown in Fig. 11.

The levels of magnetic flux density at the 0.2 m height are reduced <3.5 μT at the rated load. At the height of 1 m, magnetic flux density level is <1.5 μT.

Fig. 12 shows the values of the shielding factor at the 0.2 and 1 m heights. The highest values of the shielding factor are slightly >5 at the 0.2 m height and 4.5 at the 1 m height.

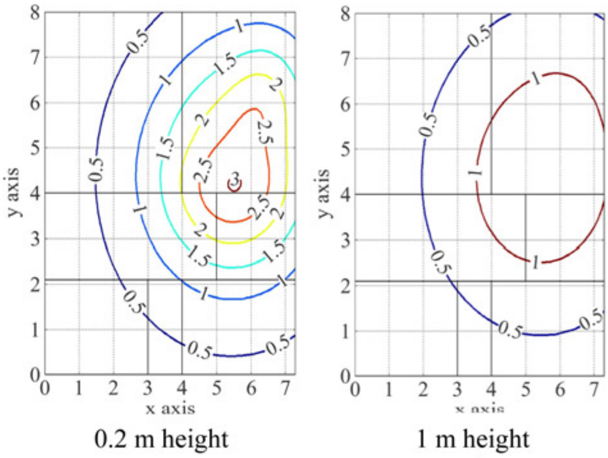
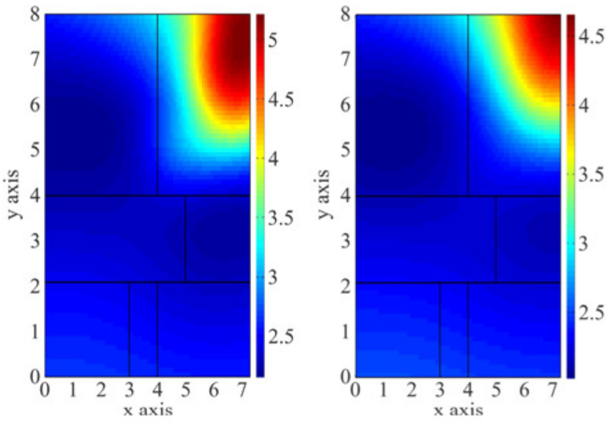


Fig. 11 *Calculation results obtained after shielding for rated load*



0.2 m height

a

1 m height

b

Fig. 12 *Shielding factor*

9 Conclusion

On the basis of the presented results, it can be concluded that the shielding solution applied by the distribution company had an impact on magnetic field levels reduction in the apartment to a certain extent. However, the values of magnetic flux density obtained by extrapolation for the rated load exceeded 4 µT at the 0.2 m height and consequently the substation remained a source of special interest. Therefore, the authors proposed another solution which would provide magnetic flux density levels in the apartment <4 µT even in the case of maximum load of the substation.

10 References

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