

PRACTICAL APPLICATION OF TECHNIQUE FOR REDUCING LEVELS OF MAGNETIC FIELD EMITTED BY 10/0.4 KV SUBSTATION

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ABSTRACT

The paper presents a real case of the implementation of the measures for reducing the levels of magnetic field emitted by a 10/0.4 kV substation.

The 10/0.4 kV substation is located in the basement of a primary school in Belgrade, Serbia. During the first non-ionizing radiation testing, the values of the magnetic flux density which exceed the reference level of 40 μ T, prescribed by the Serbian legislation, were measured in the classroom located above the substation. The cause of the high levels of the magnetic field is the fact that the busbars, which connected the transformer to LV switchboard, were attached to the ceiling of the substation and were located directly beneath the classroom floor. Since the busbars were a dominant source of the magnetic field, their replacement by cables that were placed at the floor level of the substation was performed. The applied technique led to the reduction of the magnetic flux density in the classroom below the prescribed reference level of 40 μ T.

The results of measurements before and after the application of the technique for reducing the magnetic field levels are presented and the efficiency of the applied measures is analyzed.

INTRODUCTION

The paper presents a case study of the 10/0.4 kV substation where the measures for reducing the magnetic field levels were implemented. This matter is very significant because it was the first case of the 10/0.4 kV substation in the Republic of Serbia where the mitigation techniques were applied.

The 10/0.4 kV substation is located in the basement of a primary school in Belgrade, Serbia. The first testing of non-ionizing radiation emitted from this substation was performed in the middle of April of 2011. On that occasion the values of magnetic flux density that exceeded the reference level of 40 μ T, prescribed by the Serbian legislation [1-3], were measured in the classroom located directly above the substation. The cause of the high magnetic field levels is the fact that the busbars that connected the transformer to the LV switchboard were attached to the ceiling of the substation, i.e. they were located directly below the floor of the classroom. In order to reduce the magnetic field levels, certain mitigation technique was applied and its efficiency was checked by repeating the measurements.

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 subject of the Guidance on Limits of Exposure to Non-Ionizing Radiation [2] are so called "areas of increased sensitivity" 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 intended, according to the urban development plan, for specified purposes". The Guidance [2] established the exposure reference levels which are 2 kV/m for electric field strength and 40 μ T for magnetic flux density. These reference levels refer to the power frequency field (50 Hz) and the areas of increased sensitivity.

FIRST TESTING OF MAGNETIC FLUX DENSITY

The first testing of non-ionizing radiation emitted from the aforementioned substation was performed in the middle of April of 2011.

Measurements were performed in the rooms on the first floor of the school that are located above the substation, in a large number of measurement points, because of the fact that the levels of magnetic field are the highest in the rooms that are the closest to the substation. In this paper, only the results obtained in the classroom located directly above the substation are presented, because in this room the highest values of magnetic flux density were measured.

During the testing, the rms values of magnetic flux density were measured together with the field frequency. Magnetic flux density was measured isotropically, using magnetic field analyzer connected to the isotropic probe for magnetic field measurements [5,6].

Electric field testing was not performed because it is theoretically known that in these cases electric field levels are negligible.

This 10/0.4 kV substation includes a 1000 kVA transformer, an HV switchboard (10 kV) and an LV switchboard (0.4 kV). 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. Measured values of transformer load currents are shown in Figure 1.

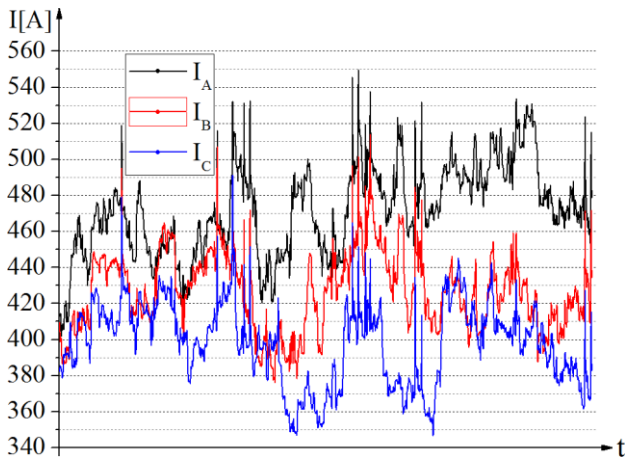


Figure 1 – Measured values of transformer load currents during magnetic flux density measurements

Table 1 shows the minimum and maximum value of the load current during testing in each phase, as well as their percentages of the transformer rated current. The transformer rated current, calculated according to its rated power of 1000 kVA, amounts to $I_n=1443.4$ A at the 0.4 kV voltage level. Based on the measured values of the currents it can be concluded that the transformer load during the testing was between 24% and 38% of the rated load.

Table 1 – Transformer load currents during testing

Phase	Range of load currents during testing	Percentage values of transformer rated current
A	402.0 A – 549.6 A	27.9% – 38.1%
B	376.3 A – 513.7 A	26.1% – 35.6%
C	346.7 A – 491.2 A	24.0% – 34.0%

The measurements of the magnetic flux density were performed at 108 measurement points in the preschool children's classroom, because this room is located directly above the substation. The locations of measurement points in the classroom are shown in Figure 2.

In order to determine the magnetic field distribution, the measurement points were placed along horizontal measurement profiles P1–P8 at the 1 m height. Five-point measurements were performed in two places at the 0.2 m height [6]. In order to check the field uniformity, the measurements of the magnetic flux density at different heights were performed at the points V1–V5.

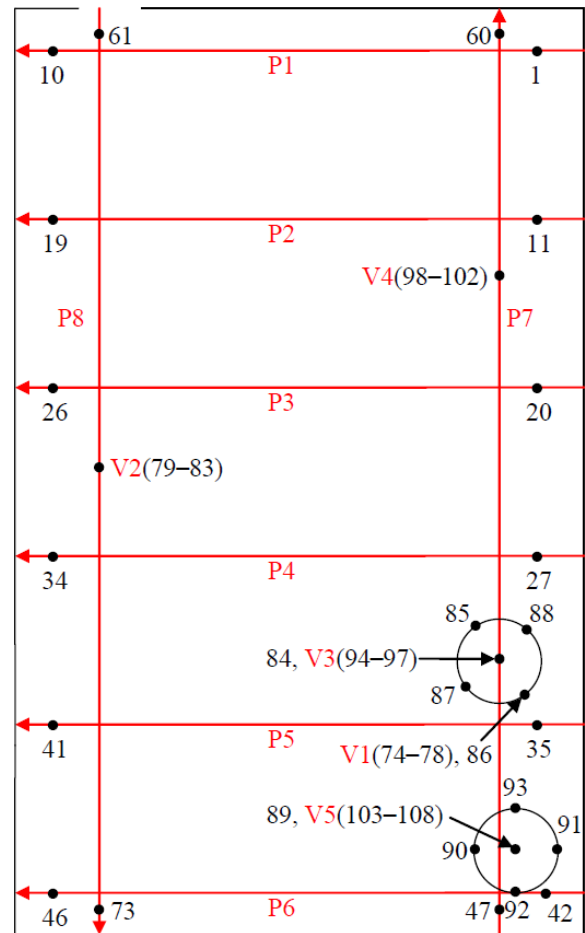


Figure 2 – Locations of measurement points

The results of the magnetic flux density measurements are shown in Figures 3 and 4. In these figures n signifies the ordinal number of measurement point and B [μ T] the measured value of magnetic flux density. At all measurement points the field frequency of 50 Hz was measured.

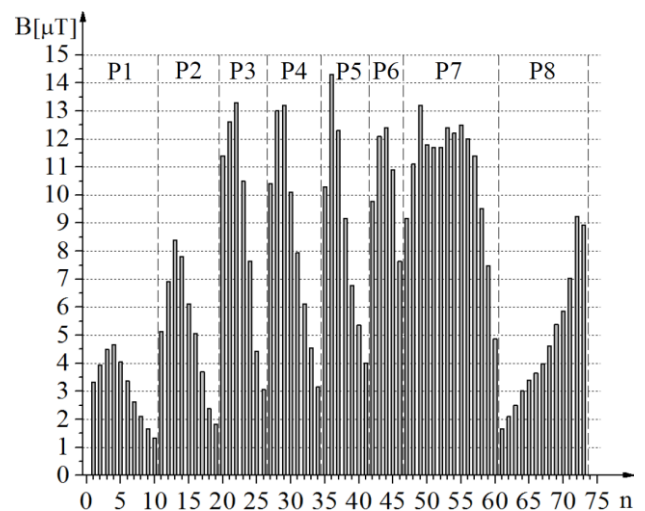


Figure 3 – Results of magnetic flux density measurements along horizontal measurement profiles

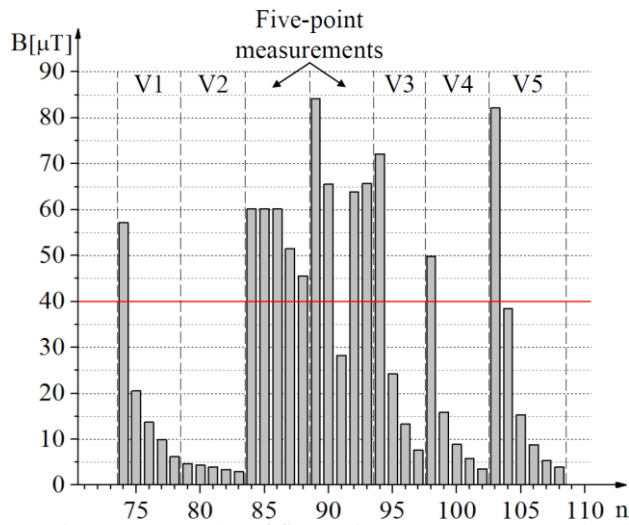


Figure 4 – Results of five-point measurements and measurements at different heights

From the results shown in Figures 3 and 4 it can be observed that the measured values of magnetic flux density at several different measurement points significantly exceeded the prescribed reference level of 40 μT [2]. The highest value of magnetic flux density, which amounted to 84.10 μT , was measured at the measurement point no. 89, located at the height of 0.2 m measured from the room floor.

The rms values of magnetic flux density obtained by measurements depend on the relative position of each measurement point in relation to the non-ionizing radiation source, as well as on the source load at the moment of each individual measurement. It is necessary to analyze all the measured values of magnetic flux density according to the source load currents obtained at the very same time when the specific values of magnetic flux density are measured.

When estimating the highest possible levels of magnetic flux density it is necessary to take into account the highest possible load of the non-ionizing radiation source. The relevant data that describes the maximum designed working mode of the substation is the rated power of the transformer. The transformer rated power of 1000 kVA determines the rated current of 1443.4 A at the 0.4 kV voltage level. The estimation of the highest possible levels of magnetic flux density based on transformer rated current is on the safety side.

Having in mind that high levels of magnetic flux density were measured at the transformer load of 24% to 38% of its rated power, the results were extrapolated and it is estimated that the level of magnetic flux density could exceed the value of 100 μT in the large part of the classroom during the period of the maximum load of the transformer.

The unfavorable particular situation of exposure should also be taken into account, because the children of the age of 6 spend a great deal of time playing and lying on the floor of the classroom, which leads to direct exposure

of the central nervous system, which is most sensitive to low-frequency non-ionizing radiation.

For the abovementioned reasons, the urgent implementation of measures for reducing the magnetic field levels was proposed, as well as the testing of the efficiency of these measures by repeating the measurements.

APPLICATION OF TECHNIQUE FOR REDUCING MAGNETIC FIELD

The 0.4 kV busbars situated near the ceiling of the substation, i.e. directly under the classroom floor, were identified as the main source of magnetic field. For that reason the busbars which connect the transformer to the LV switchboard were removed (Figure 5) and replaced with cables (Figure 6) which were placed on the floor of the substation.



Figure 5 – Removal of 0.4 kV busbars



Figure 6 – Cable connections between transformer and LV switchboard

The applied technique was based on the increase of distance between the radiation source and protected area. The entire process was finished quickly and efficiently, just several days after the high levels of magnetic flux density were measured.

SECOND TESTING OF MAGNETIC FLUX DENSITY

After the implementation of measures, the magnetic field testing was repeated at the end of April of 2011, just 10 days after the first testing.

The transformer load currents were measured in all three phases at the 0.4 kV voltage level, during the entire process of magnetic flux density measurement. The measured values of load currents are shown in Figure 7.

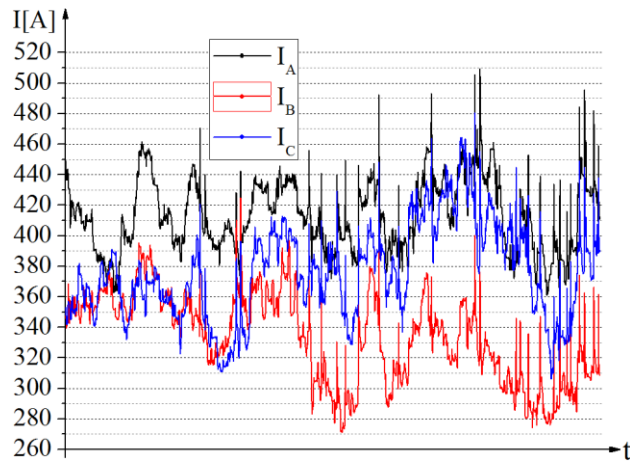


Figure 7 – Measured values of transformer load currents during second testing

In Table 2, minimum and maximum values of currents in each phase are shown, as well as their percentages of the transformer rated current, which at the voltage level of 0.4 kV amounts to $I_n=1443.4$ A. Conclusion can be made that the transformer load during the testing was between 18% and 36% of the rated load.

Table 2 – Transformer load currents during second testing

Phase	Range of load currents during second testing	Percentage values of transformer rated current
A	361.0 A – 509.3 A	25.0% – 35.3%
B	271.3 A – 425.0 A	18.8% – 29.4%
C	306.2 A – 480.4 A	21.2% – 33.3%

Magnetic flux density measurements within the classroom were made at 155 measurement points. The measurement points were distributed along 8 horizontal measurement profiles (P1–P8) set at 1 m height, 9 vertical profiles (V1–V9), while five-point measurements were performed at 5 locations at 0.2 m height. The locations of measurement points are shown in Figure 8.

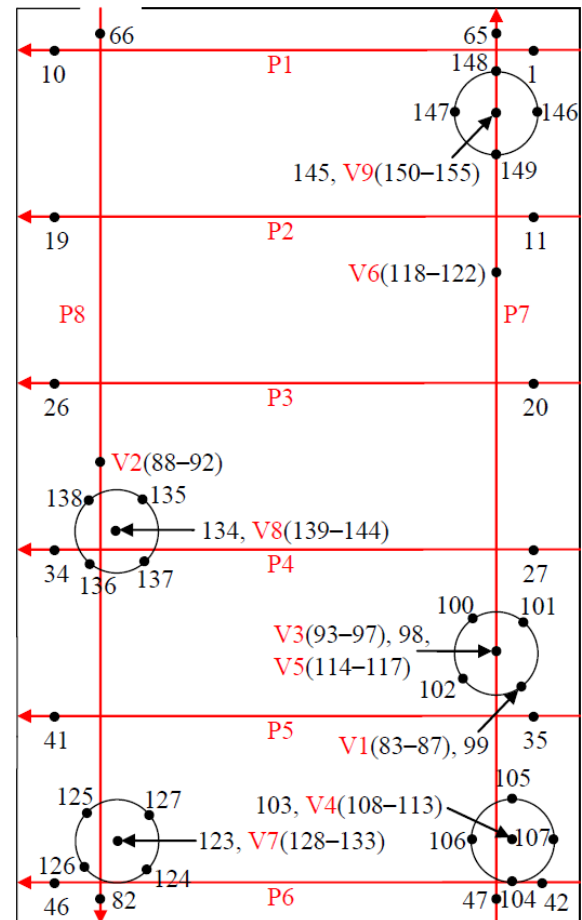


Figure 8 – Locations of measurement points in classroom during second testing

The results of magnetic flux density measurements are shown in Figures 9 and 10. It can be concluded that measured values did not exceed the prescribed reference level of 40 μ T at any of the measurement points.

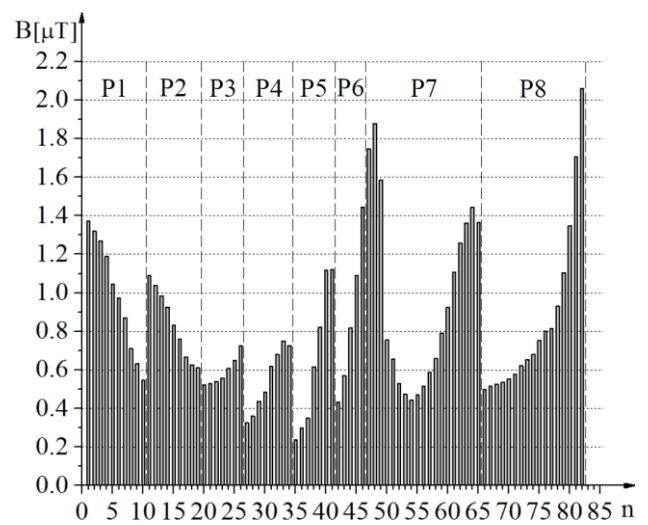


Figure 9 – Results of magnetic flux density measurements along horizontal measurement profiles obtained during second testing

The highest value of magnetic flux density was measured at the measurement point no. 123, which is located at a height of 0.2 m measured from the room floor and amounts to 7.03 μT . The reason why the magnetic flux density levels at the measurement point no. 123 and surrounding points (124–128) are higher compared to the levels in the rest of the classroom is the fact that below that location the cables are connected to the transformer, and consequently, their distance to the classroom floor is smaller.

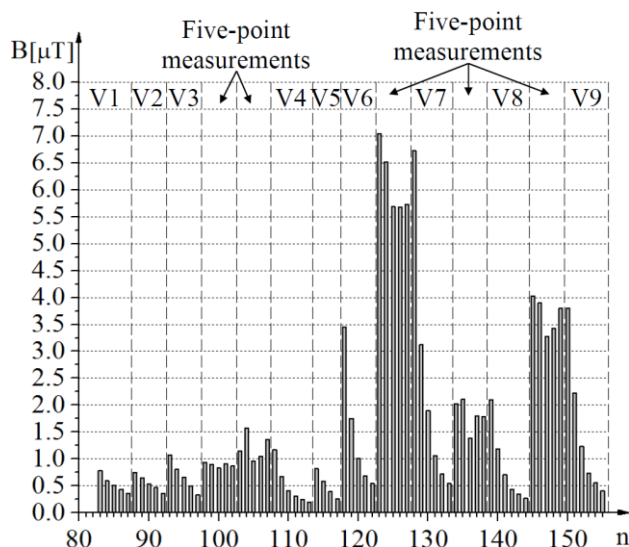


Figure 10 – Results of five-point measurements and measurements at different heights during second testing

Having in mind that the values of magnetic flux density were measured at the transformer load of 18% to 36% of its rated load, it is estimated that the level of magnetic flux density would not exceed the prescribed reference level of 40 μT at the maximum designed load of the substation.

CONCLUSION

The 0.4 kV busbars, which were attached to the ceiling of the substation, were removed and replaced with cables, which proved to be a very efficient technique for reducing the level of magnetic field in the classroom located directly above the substation. Cables which connect the transformer to the LV switchboard were placed on the floor of the substation, which resulted with

the increase of distance between the main source of magnetic field and the protected area. In that way the level of magnetic field in the classroom was significantly reduced. Since the transformer load currents during both the first and the second testing had similar values, the levels of magnetic flux density during the first and the second testing could be compared directly in order to obtain the approximate assessment of the efficiency of the applied measures. In this way it can be concluded that the values of magnetic flux density after the applied measures were several times lower compared to the values obtained during the first testing.

It is very important to emphasize that the 10/0.4 kV substations with the 0.4 kV busbars located immediately next to the ceiling or outer wall of a substation represent the most unfavorable configuration from the aspect of exposure to non-ionizing radiation, if there is an area of increased sensitivity on the other side of the ceiling or wall. Therefore, these configurations should be avoided when building new substations within houses, schools and other facilities which represent the areas of increased sensitivity.

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] IEC 61786:1998: "Measurement of Low-Frequency Magnetic and Electric Fields with Regard to Exposure of Human Beings";
- [6] IEC 62110:2009 "Electric and Magnetic Field Levels Generated by AC Power Systems – Measurement Procedures with Regard to Public Exposure".