ELIMINATION OF ELECTROMAGNETIC INTERFERENCE IN TRANSFORMER STATION

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ABSTRACT

The paper presents maximum values calculations of electric and magnetic fields intensity, emitted by TS 10(20)/0.4 kV, 3x1250 kVA, obtained in software package EFC-400 that allows the simulation in three-dimensional space. Calculations of effective values of the magnetic flow density (magnetic induction) and analysis of electromagnetic compatibility are obtained for height of 4.5 m above the ground surface, in the x-y plane, in parts of offices located above the substation, where the highest levels of the field intensity are expected, with a maximum current load at some equipment pieces. This load rarely appears in real operation, so the calculation results are on the side of safety. Substation is modeled without walls and other obstacles that significantly affects on the reduction of the electric field intensity. In this way, the results of the electric field intensity are largely on the side of safety, since an external wall of transformer stations damping down the same field on negligible values. These values can be verified by measuring on the substation location. The results are shown in diagrams that describes the 2D and 3D distribution of the magnetic flow density and electric field intensity, in the continuous distribution and using isolines. Recommendations for a new model of substation which realizes the reduction of electromagnetic interference are given.

1. INTRODUCTION

Electromagnetic compatibility (EMC) describes the ability of the selected electrical system to operate without difficulties in intensively electromagnetic environment and, at the same time, does not affect on the operation of other system components. The main source of all electromagnetic effects are the main fields (electric and magnetic) and the currents defined in the theory of electrodynamics. At lower frequencies the electric and magnetic field acting separately while at higher frequencies only propagating electromagnetic field is significant. The electric field is proportional to voltage, and therefore takes on greater values only in the presence of high voltage facilities. In most cases, electric field doesn't play an important role since, it significantly weakening or even completely vanishing by approaching on any obstacle. Magnetic field is proportional to current intensity. In many cases, current amounts can take high values, so the risk of electromagnetic influence is increased.This particularly refers to TN-C networks, since through the protective-neutral (PEN) line can flow currents which result in increased magnetic fields. An example of electromagnetic influence is flickering of image on the monitor, if a monitor is with a cathode tube. In some cases, the intensity of magnetic field of about 1.5 μT is enough, for which the current of 10 A, frequency 50 Hz, at a distance 1.3 m, is enough. All the mechanisms of electromagnetic effect can be described with a very simple model consisting of sources, the mechanism of influence, the media in which the influence occurs and the device over which the influence is happening. Inductive influence of the power facility to other infrastructure is appearing over inter-inductance between two or more current circuits. The current which is flowing through power circuit creates a magnetic field which is proportional to current intensity. This magnetic flow induces electromotive force in the nearby line, occurs appearing of the disturbance currents in a closed loop circle of other installations. This type of interference is the most common. The size of induced electromotive force is proportional to the current in the circle of power facility and inter-inductance between two circles. Inter-inductance between power facility and other installations is determined by the line geometry, as well as geometric space between two lines in air. Conductive influence of the power facility to another installation occurs when two different electric circuits have a common branch. In the commercial cable installations, conductive interference between power and other installations occurs when grounding systems of both networks are not well enough insulated to each other. It follows that this kind of feedback is the most dangerous during faults in grounded power network. In such situations the grounders of power facilities raises the potential of the ground in theirs nearby. Therefore, the nearby installations can be found on the raised potential which may occur adverse effects. Capacitive effect of power facility to another installation occurs through the capacity between two or more circuit circles. When considering the influence of the power facility on other infrastructure, all previously influences have to be taken into account as combined superponed influence. The most common cause of interferences, caused by electromagnetic interference, is caused by inductive influence.

2. LOW- FREQUENCY MAGNETIC AND ELECTRIC FIELDS

The main purpose of transformer station is transformation of voltage levels inside a transformer whose operation is based on the magnetic field. The same field is mostly closed in the transformer core. A part of the magnetic field is not closed in the core and leaves outside in the form of so-called. dissipating flows. It especially occurs in case of higher harmonics. Density of dissipating magnetic flows depends on the size of the current (load), but also it is depending on construction (armoring) of transformers and on the construction of the substation building itself. It is particularly important to underline that, outside of the transformer station, magnetic flow density decreases rapidly with distancing from the station. Thus, for example, although the immediate to walls of transformer station density of magnetic flow can reach high values, at a distance of several meters, that value is multiple reduced. In general, the magnetic field or the size of the magnetic flow density can be decomposed into three components that are orthogonal to each other in the space. Each of these components depends on time:

$$\vec{B}(t) = \vec{B}_x(t) + \vec{B}_y(t) + \vec{B}_z(t) \tag{1}$$

The largest number of magnetic fields, around the power facilities, are generated by basic harmonic, with dominant frequency of 50 Hz and have a negligible contribution of higher harmonics. Components are dependent on the time with sinus dependence:

$$\vec{B}(t) = \sqrt{2}B_x \sin(\omega t + \varphi_x)\vec{i} + t\sqrt{2}B_y \sin(\omega t + \varphi_y)\vec{j} + \sqrt{2}B_z \sin(\omega t + \varphi_z)\vec{k} \quad (2)$$

Effective value of the magnetic flow density is expressed mathematically:

$$B_{ef} = \sqrt{\frac{1}{T}\int_0^T [B(t)]^2 dt} = \sqrt{B_x^2 + B_y^2 + B_z^2} \quad (3)$$

where is: t - time variable

T - period of time changing

Bx, By, BZ - effective values of time changing orthogonal components B

The intensity of the electric field is defined as the negative gradient of electric potential:

$$\vec{E}(\vec{r}) = -\nabla\Phi(\vec{r}) \quad (4)$$

where is:

$$\vec{\nabla} = \begin{pmatrix} \partial/\partial x \\ \partial/\partial y \\ \partial/\partial z \end{pmatrix} \quad (5)$$

Potential or potential difference, describes the work required for moving the test charge from point of reference with the potential (x, y, z) = 0, to the point with certain potential. In practice, the reference point is seting at infinity. A potential at a distance A against the source charge is then:

$$\Phi_A(\vec{r}) = \frac{W}{q} = \int_{\infty}^{A} \vec{E}(\vec{r})d\vec{s} \quad (6)$$

ie. shown with phasor of scalar potential Φ in the point r and with phasor of line charge density λ in a specific point r':

$$\dot{\Phi}(\vec{r}) - \int_l \frac{\dot{\lambda}(\vec{r}')dl}{4\pi|\vec{r} - \vec{r}'|} = 0 \quad (7)$$

For determining the function of line charge density a method of moments is using. Wires are divided into segments of finite size (length, arcs, parables). The preceding equations can be resolved in case of segment of line charge lying in origin, parallel to the x-axis:

$$\Phi_i(x_p, y_p, z_p, t) = \frac{Q_i}{4\pi\varepsilon_0} \ln \frac{(x_p) + \sqrt{x_p^2 + y_p^2 + z_p^2}}{(x_p - L_i) + \sqrt{(x_p - L_i)^2 + y_p^2 + z_p^2}} \tag{8}$$

The negative gradient of the potential gives the contribution of electric field intensity segment in the point P (x, y, z). Complete process of calculation is similar to the calculation of the magnetic field. Exception is determination of the line charge Qi. Unlike the currents by some segments, the charges are calculating by using surface voltage on the line. To do it, the line charge is puting in the center of each segment of the line. The amount of the same charge is determining by solving the above equation with certain potential U. In three-dimensional calculation the vector of electric field intensity is ellipticaly polarized in each point and the peak of the vector E describes an ellipse. Each of three components have a different size and phase shift:

$$E_x(t) = E_{x,max}\cos(\omega t + \varphi_x)$$

$$E_y(t) = E_{y,max}\cos(\omega t + \varphi_y) \tag{9}$$

$$E_z(t) = E_{z,max}\cos(\omega t + \varphi_z)$$

Absolute value of vector E is changing by law:

$$E(t) = \sqrt{E_{x,max}^2\cos(\omega t + \varphi_x)^2 + E_{y,max}^2\cos(\omega t + \varphi_y)^2 + E_{z,max}^2\cos(\omega t + \varphi_z)^2} \tag{10}$$

and effective value:

$$E = \sqrt{\frac{E_{x,max}^2 + E_{y,max}^2 + E_{z,max}^2}{2}} \tag{11}$$

3. MODELING AND CALCULATING OF MAGNETIC AND ELECTRIC FIELDS POWER STATION 10(20)/0,4 KV

Calculations of the magnetic and electric fields for TS 10(20)/0.4 kV, 3x1250 kVAm which is located in the basement part of the building, were done with software package EFC-400, which provides simulation and modeling in three-dimensional space. In substation TS 10(20)/0.4 kV transformation 10(20)/0.4 kV is performing on three separate power transformers 1250 kVA, of which, two are in operation, TR1 and TR3. Detailed informations about transformers and other equipment as well as disposition of facility are provided in the transformer station project. According to the given project a substation TS 10(20)/0.4 kV is modeled in the software package EFC-400. It is adopted maximum possible current load of transformers HV/MV. Transformers 10/0.4 kV, 1250 kVA, 4%, Dyn5 and belonging MV switchgear rated voltage 12 kV are modeled, with a current load of 75 A. LV cells rated voltage 0.4 kV are modeled as well, with a total load current of 1804 A, so the further calculation was on the side of safety. MV and LV switchgears are placed inside the facility building, as it is shown in the disposition of substation. Substation is modeled with ceiling height of 3.5 m. In addition, the model shown ceiling and groundfloor where there are office spaces with a longer stay of staff. From all quoted, the above gave the conclusion that the TS 10(20)/0.4 kV is modeled in EFC-400 for the worst case. The visual overview of the obtained results of magnetic flow density and intensity of the electric field is done in the computer program “Matlab“, using “Runal.B“ and “Runal.E“ programs, while subprograms “Crtajgraf.B“ and “Crtajgraf.E“ are used for opening , load and displaying the results of the calculation of the magnetic flow density and intensity of the electric field. Program EFC-400 counts electric field intensity and magnetic flow density according to the Germany norm DIN VDE 0848-1. The following figures show the distribution of electric field intensity (Figure 1) and the magnetic flow density (Figure 2), as well as the results of calculation in three-dimensional view (Figure 4) for the X-Y plane, at a height of 4.5 m and office spaces above the substation. Considering that the height of substation is 3.5 m, subject height of 4.5 m is the height of about 1 m inside the office spaces. Levels of electric field intensity are less than 65 V/m. According to the calculation of the magnetic field with the maximum load current, the area in which the value of magnetic flow density is above 100 µT includes mainly office spaces above the substation, where it can be expected impact on CRT monitors, but at the people as well, because they are above certain European Union recommendations and directives, as well as some legal regulations in neighboring countries. The analysis of the existing situation shows that the substation reconstruction is necessary to be done in order to reduce the level of magnetic fields, where the biggest problem are LV copper rails between the transformer and LV distribution box.

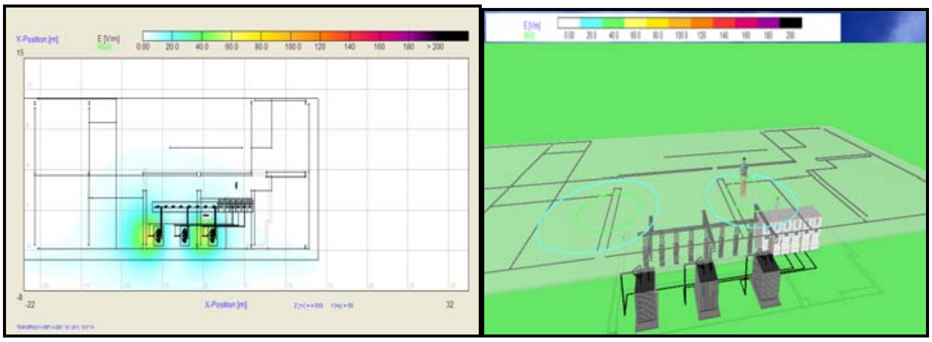

Figure 1. Distribution of electric field intensity in X-Y plane at height of 4.5m – continuous distribution

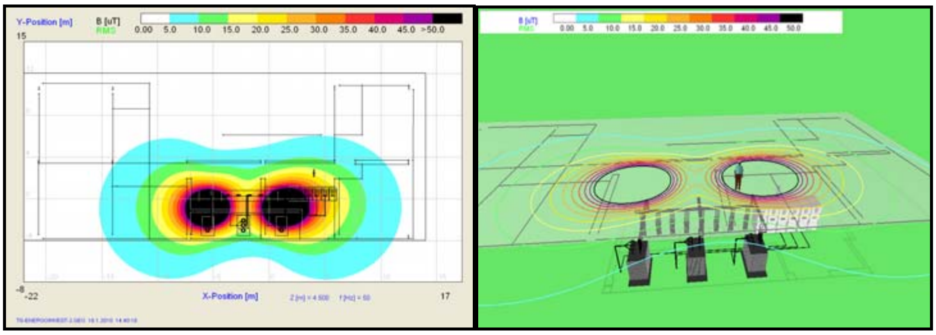

Figure 2. Distribution of magnetic flow density in X-Y plane at height of 4.5m – continuous distribution

Instead LV connector constructed of copper rails between the transformer and LV box, which are mutually spaced and are not grouped in triplets, it is necessary to install LV cable connector. Cable connector is necessary to be performed with four cables per phase. Cables must be copper, surface 240 mm^2, as well as the type of PP-0 240 mm^2. Maximum load capacity of such cable is 480 A. Total load capacity of electric cable LV connection is $I_{uk} = 4 \cdot I_K = 4 \cdot 480A = 1920A$, 1920 A > 1804 A, so the subject cables satisfies. The same cables must be composed, ie. grouped in a triplets of different phases. This means that it is necessary for cables to be grouped into four groups with the cables of L1, L2 and L3 phases, and layed in triples and in which cables touching each other as it is shown at Figure 4.

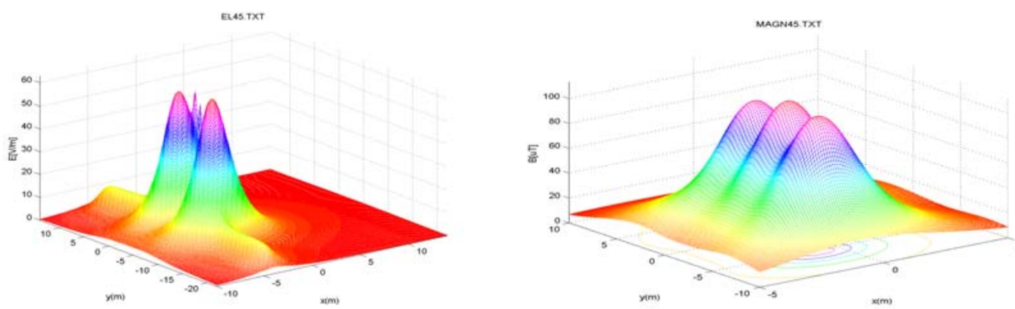

Figure 3. The results of electric field intensity and magnetic flow density in 3D view at heigh of 4.5m

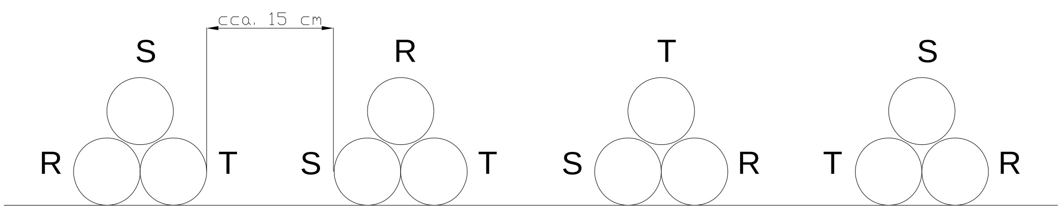

Figure 4. Laying of cables PP-0 240 mm^2

In this way there will be certain cancelation of electric and magnetic fields in the surroundings of cables themselves, as they are in antiphases and shifted to 120 degrees. Cables are necessary to be layed at the bottom of the room containing transformers and LV part of the substation. Crossing from the room where there are the transformers to the room with LV boxes need to be performed with the cables closing inlets. On all of the cable routes crossing points, from one fire sector to another, will predict closing with antifire mass, with fire-resistance which corresponds to the fire-resistance of partition walls. Also, it is necessary to uninstall the LV cells (boxes) and install new, modern boxes, much smaller. Smaller boxes have a smaller disipating inductance, and consequently much smaller levels of magnetic fields in the boxes surroundings that causes interference on equipment and possibly a danger to human health. This of course applies to the flats above the boxes. In this paper, the proposal with three LV boxes Jean Müller type NVT, ie with one LV box per transformer is given. Recommendation is installation of condenser batteries for reactive power compensating, and also filtering of a part of higher harmonics in the network. Free space for installation of surge arresters and capacitors (rated power max. 60% of fault) should be provided inside the housing of LV block. In this way, installation of capacitors, will filter the harmonics, compensate reactive power, and further reduce the current intensity in LV electric circuit which is also the largest source of magnetic field. Reconstructed substation was re-modeled in EFC-400 for the worst case. Three-dimensional and two-dimensional view of the electric field intensity distribution (Figure 6), magnetic flow density (Figure7), and the results of calculations in three-dimensional view (Figure 8). As it is previously mentioned, the electric fields are a problem in the substation , while the maximum value of the magnetic field appeares again above the transformer, but in this case their amount is 30 to 40 µT at maximum load current. Maximum values of magnetic induction at height of 4.5m, ie. at height 1m inside the office, in the present state of stations are about 125 µT, which gives reduced levels of magnetic fields of 3 - 4 times. These are extremely large values, not only in regard to the electromagnetic compatibility of devices that are located in offices above the substation, but also for the staff who exists and works in these offices. Measurements that were conducted by the Institute for the work protection from Sarajevo, under the number 497/08, from September 2008. have shown that, with the working current of 250 - 300 A, the maximum value of the magnetic flow density is around 13 to 15 µT in the rooms No. 012 /5 and 012/6, ie the value of the magnetic field in this case is around 14-16% of the maximum value at about the same points.

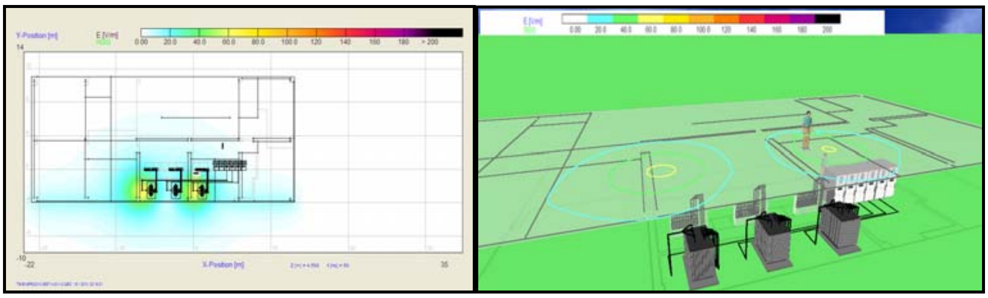

Figure 6. Distribution of electric field intensity in X-Y plane at height of 4.5m – reconstructed substation

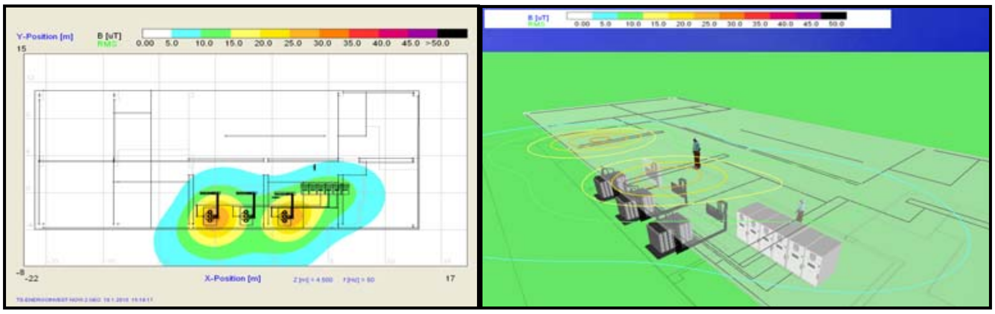

Figure 7. Distribution of magnetiv field density in X-Y plane at height of 4.5m – reconstructed substation

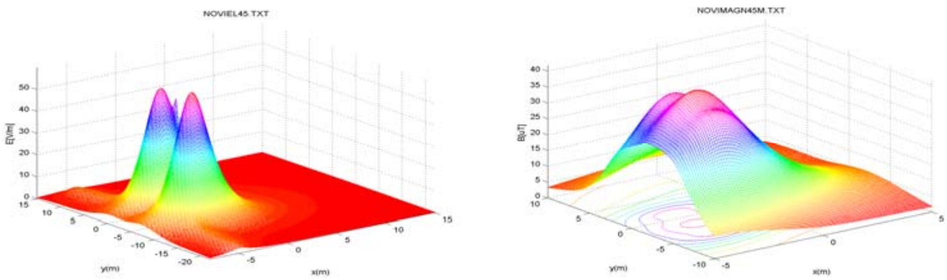

Figure 8. The results of electric field intensity and magnetic flow density in 3D view at heigh of 4.5m

From all mentioned above can be estimated that the value of the magnetic field above the reconstructed substation in the office area, at substation load of 250 - 300 A will be about 15% of the maximum value of magnetic flow density at maximum current load:

$$B_{max} = 0.15 \cdot 35\ \mu T = 5.25\ \mu T \tag{12}$$

It can be expected that, in the same work conditions, reconstructed transformer station will give about 4 times lower values of magnetic fields, which in work state at 250 - 300 A gives the maximum magnetic flow density in the order size of 5 μT. Magnetic field penetrates through most substances in our environment and only obstacles of magneticly conducting substances (for example iron) can prevent or reduce its penetration. The penetration and expansion of the electric field is very easy to prevent by using of conducting obstacles. This is known as a Faraday cage. Magnetic field may not be so easily reduced or on the simple and cheap way can be prevented his penetration. Thinking about the floor covering with metal material in the form of steel meshes and plates will not give the desired result, which can be seen in Figure 9. It is visable that the levels of magnetic fields are the same as in the case when the basis does not a exist. Therefore is not recommended additional cost of floor covering in the rooms above the substation because the classical background in the form of metal meshes and plates does not give the desired results. Covering of the floor in the offices above the transformer station can be done with materials which have extremely high permeability. Today, there are market-available products for covering the walls of rooms where there are huge levels of magnetic fields. These products are extremely expensive and specific price is about 1500 EUR/m^2. The parameters of such materials have extremely large relative permeability, in the order of μ_r= 7000 and magnetic flow density at which there is saturation in the amount of 2 T. These are extremely expensive materials, and surface required for covering is about 70 m^2 minimum and therefore the cost of covering would be approximately 105 000 EUR. That cost is extremely high and payable is only for extremely valuable and expensive equipment such as electronic microscopes etc. In these situations, particularly when there is no expensive equipment, and all the international recommendations for human health are respected, it is not necessary additional covering of the rooms walls and floors. The values of magnetic fields at the maximum load have values about level of 30 µT in the points exactly above the transformer station, so the additional cost of this type is not recommended.

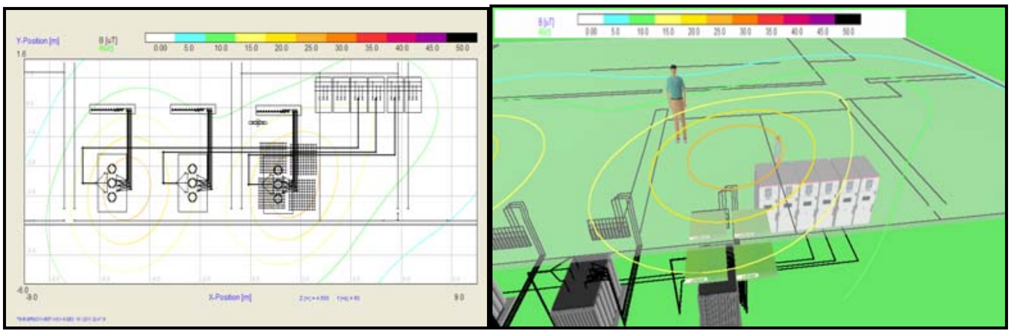

Figure 9. Magnetic fields at height of 4.5m with metal plates installed above transformer T3

4. CONCLUSION

Magnetic flow density even on greater distances from the transformer and other equipment has a value above 100 µT, which is greatly above the value of 40 µT as it is prescribed by the directives and recommendations of the European Union for a people staying. Values above 40 µT occurs almost on a larger part of the floor in the upper rooms. It is necessary to note that the calculations of the magnetic field were performed with the maximum load current of 1804 A and with two transformers in the work. It is therefore necessary to perform the reconstruction of substations. First of all it is necessary to dismount the copper rails with which the low voltage from the transformer leads to LV cells. The same rails are the largest source of unfavorable magnetic fields. It is necessary to replace them with cable connection according to the technical description of the project. From the calculation results of reconstructed substation it is visable that the values of magnetic flow density, after the reconstruction, already in the immediate vicinity of the transformers are less than the prescribed values for the professional exposure. For longer distances, that values are falling down to the lower values. At a distance about 1m from the transformers magnetic flow density values fall in value below 20 µT, which is much lower than the value of 100 µT, the amount recommended for peoples health. Since, the much wider area than described is fenced and clearly marked by substation building, additional protection measures are not necessary. Also, the calculation is done with maximum values of current load of transformer stations that are in the real work very rarely occurs. Therefore, the calculations are on the side of safety, and expected electric and magnetic fields intensities in the normal work are less than the limited values prescribed by standards and directives relating to electromagnetic compatibility and recommendations for the longer stay of people.The values in real work will therefore be even lower which will be verified by measuring. Regarding of the influence to the devices, most devices in the room belongs to the upper class in accordance with international standard IEC 61000-4-8. This however does not refer to monitors with cathode tubes, which in some cases may show a reduced immunity to magnetic flow density up to 5 μT. This is the case with a very small values of magnetic fields that still impact on the equipment, and their removal would be extremely expensive. Therefore, the recommendation is using of LCD monitors in the offices located above transformer TR3, observed substation.

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