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Technical Possibilities for Implementing Measures to Reduce the Emitted Electromagnetic Field of a High-voltage Distribution Transformer

Miroslava Jámborová [1], Tibor Dzuro [1]*, Ervin Lumnitzer [1], Pavol Liptai [2]

[1] Technical University of Kosice, Faculty of Mechanical Engineering, Department of Process and Environmental Engineering, Park Komenskeho 5, 042 00, Kosice, Slovakia
[2] Technical University of Kosice, Faculty of Materials, Metallurgy and Recycling, Letna 9, 042 00, Kosice, Slovakia

Abstract: This paper deals with the measurement of electromagnetic field parameters near high voltage systems, characteristics of electric field, magnetic field and electromagnetic field, as well as the possibilities of implementing measures to reduce the emitted electromagnetic field. The paper describes the measurement of electromagnetic field parameters in the vicinity of high voltage systems, the analysis and synthesis of the measurement results in the external and internal environment of particular transformer stations is evaluated. The objects of interest in these measurements were brick transformer stations for transforming AC voltage from 22 kV to 400 V and 230 V at the operating frequency of 50 Hz. With regard to the influence of electromagnetic fields in the environment, individual measurements were assessed in accordance with selected criteria.

Keywords: *electromagnetic field, transformers, electric energy, magnetic field*

1. Introduction

The electromagnetic field is one of the forms of manifestation of matter and represents one another influencing electric field variables and magnetic field. Through it him the action is carried out between the electrically charged particles. The relation between electrical the magnetic field is that any change of one of the fields results in the formation of the other field. Electromagnetic field propagates in space by electromagnetic waves. Electromagnetic field as radiation is characterized by wavelength, frequency and the intensity of the magnetic and electric fields. It has a wave corpuscular character, thus reports both as a wave and as a particle.

The relation between frequency and wavelength is expressed by the following formula [1].

$$f = \frac{c}{\lambda} \tag{1}$$

where : c - speed of light, λ - wavelength.

The aim of the present article was to measure the values of electric field intensity and magnetic induction in ten transformer stations located near residential blocks in city district Kosice - Terasa. The paper deals with the measurement of electromagnetic field parameters in the vicinity of high-voltage systems, as well as with the characteristics of electric, magnetic and electro-magnetic fields. The aim of the post is measurement of parameters and analysis of results of individual measurements and evaluation of measurements, as well as recommended measures to improve the identified situation.

*** Corresponding author:** Miroslava Jámborová, ***E-mail:*** *miroslava.jamborova@tuke.sk*

2. Experimental Section

Measurement of electromagnetic field parameters

For measuring EMP as well as sound Class 1 measuring, instruments that meet the requirements of STN EN 50413: 2009 and requirements specified in Act No. 142/2000 Coll. on Metrology and on Amendments to Certain Acts, as amended [2, 3] are used. The objects of interest in these measurements were brick transformer stations for transforming AC voltage from 22 kV to 400 V and 230 V at the operating frequency of 50 Hz.

Ten transformer stations were evaluated and measured, all of which were located in residential areas of Kosice - Terasa. A view of one of these transformer stations (TS) is shown in Fig. 1. Photographic image of one bricked TS is shown in Fig. 2. The largest sources of electromagnetic fields at these stations are high voltage transformers. Furthermore, there are electrical elements of the substation such as cable distribution, protection and protection devices.

Figure 1: Satellite view of transformer station.

Figure 2: Brick transformer station on the street Vystavby - city district Kosice-zapad.

Measuring instruments

For measuring the electromagnetic field, a measuring chain consisting of [4] was used (Fig. 3).

– *Narda EFA 300 electromagnetic field analyser, PN 2245/30, serial number U-0020, frequency range from 5 Hz to 32 kHz,*

– *Probe for measuring the electric field component (electric field strength E), Narda BN 2245 / 90.31, serial number S-0018, measuring range from 1 V / m to 100 kV / m,*

– *Probe for measuring the magnetic field component (magnetic induction B), Narda BN 2245 / 90.10, serial number AO-0005, measuring range from 100 nT to 32 mT.*

Figure 3: Measuring chain of electromagnetic fields.

For this measurement chain, internal guideline no. IS - ÚOFP / EP / 01/12 (working procedure for measurement, objectification and evaluation of electromagnetic field variables in working and the environment and to determine uncertainty in the measurement process) was followed. The expanded measurement string uncertainty for both the E-probe and the B-probe was determined to be 29.1%.

Measurement procedure

In all measurement cases, the minimum distance between the probe tip and the body of the measuring technician, as well as any reflecting object, is 1 m when measuring below 300 MHz. The distance of the person carrying out the measurement from the measuring probe must be large, so that the effect of their proximity is less than 3 %. The electric field strength of non-homogeneous fields (e.g. around devices and earthed structures in substations) shall be measured at a horizontal distance of more than 0,5 m from grounded constructions [5, 6]. The measurements were performed in the frequency range from 30 Hz to 2 kHz. During the measurement, the RMS mode was set for effective values. All measurements inside the object were made at a distance of 2 m from the high-voltage transformer at a height of 1.5 m, which approximately corresponds to the height of the geometric centre of the head and torso of an average adult standing person. Measuring points in the outdoor environment were carried out at a distance of 1 m from the transformer metal door in the direction of the 1,5 m residential blocks above ground level. An illustration of one external measuring point is shown in Fig. 4.

Figure 4: Measuring point at the object.

3. Results and Discussion

The measurement results are presented in tabular form. The results of the measurement of the electric field intensity E and the magnetic induction B inside the ten transformer station objects are shown in Tab. 1. During the measurements inside the TS objects, atmospheric conditions were also recorded and were in the range of:

- *air temperature – t = 4 ÷ 5 °C,*
- *atmospheric pressure – p = 996 ÷ 1002 hPa,*
- *relative humidity – 70 ÷ 78 %.*

The results of measurement of the electric field intensity E and the magnetic induction B in the external environment are shown in Tab. 2. Atmospheric conditions, were in the range of:

- *air temperature – t = 10 ÷ 12 °C,*
- *atmospheric pressure – p = 998 ÷ 1006 hPa,*
- *relative humidity – 58 ÷ 65 %.*

Table 1: Results of electric field intensity and magnetic induction measurement inside TS objects.

No.	Place of measurement (Internal environment)	Measured value of electric field intensity (E) [V/m]	Measured value of magnetic induction (B) [μT]
1	TS 403 Obrody	33,62	13,17
2	TS 409 Sokolovská	35,41	15,10
3	TS 411 Pokroku	34,35	8,05
4	TS 415 Obrody	37,15	9,98
5	TS 419 Čapajevova	31,36	11,49
6	TS 421 Kysucká	39,80	6,21
7	TS 422 Vystavby	39,83	16,70
8	TS 423 Ľudová	37,73	10,11
9	TS 424 Slobody	33,32	10,01
10	TS 430 Hronská	34,46	12,04

Table 2: Results of electric field intensity and magnetic induction measurement in outdoor environment.

No.	Place of measurement (External environment)	Measured value of electric field intensity (E) [V/m]	Measured value of magnetic induction (B) [μT]
1	TS 403 Obrody	0,788	695,7
2	TS 409 Sokolovská	0,723	682,8
3	TS 411 Pokroku	0,742	601,8
4	TS 415 Obrody	0,878	732,6
5	TS 419 Čapajevova	1,250	609,8
6	TS 421 Kysucká	0,859	653,3
7	TS 422 Vystavby	0,888	600,8
8	TS 423 Ľudová	0,941	700,2
9	TS 424 Slobody	0,784	681,6
10	TS 430 Hronská	0,849	699,1

Analysis of results and evaluation

Measurement results of magnetic induction values Bef and Eef plus uncertainty and comparison with action values for impact on employee are given in Tab. 3. Measurement results of magnetic induction values B_{ef} and E_{ef} plus uncertainty and comparison with action values for impact on population are given in Tab. 4.

Based on the results of measurements of electric field intensity and magnetic induction evaluated for the frequency of 50 Hz, at the places where the employees of the East Slovak power plants are moving and thus inside the transformer station objects, pursuant to the Regulation of the

Table 3: Comparison of assessed values (EC) with legislation for impact on employees.

Identification of transformer station	Measured values of electric field intensity	Eef values plus expanded uncertainty	Measured values of magnetic induction	Bef values plus expanded uncertainty	Action value for electric field strength	Action value for magnetic induction
	E_{ef} [V.m^{-1}]	E_C [V.m^{-1}]	B_{ef} [μT]	B_C [μT]	E_R [V.m^{-1}]	B_R [μT]
TS 403 Obrody	33,62	43,40	13,17	17,00	10 000	500
TS 409 Sokolovská	35,41	45,71	15,10	19,49		
TS 411 Pokroku	34,35	44,34	8,05	10,39		
TS 415 Obrody	37,15	47,96	9,98	12,88		
TS 419 Čapajevova	31,36	40,48	11,49	14,83		
TS 421 Kysucká	39,80	51,38	6,21	8,01		
TS 422 Vystavby	39,83	51,42	16,70	21,56		
TS 423 Ľudová	37,73	48,70	10,11	13,05		
TS 424 Slobody	33,32	43,01	10,01	12,92		
TS 430 Hronská	34,46	43,40	12,04	17,00		

Table 4: Comparison of assessed values (EC) with legislation for impact on the population.

Identification of transformer station	Measured values of electric field intensity	Eef values plus expanded uncertainty	Measured values of magnetic induction	Bef values plus expanded uncertainty	Action value for electric field strength	Action value for magnetic induction
	E_{ef} [V.m^{-1}]	E_C [V.m^{-1}]	B_{ef} [μT]	B_C [μT]	E_R [V.m^{-1}]	B_R [μT]
TS 403 Obrody	0,78	1,02	0,69	0,89	5 000	100
TS 409 Sokolovská	0,72	0,93	0,68	0,88		
TS 411 Pokroku	0,74	0,96	0,60	0,77		
TS 415 Obrody	0,87	1,13	0,73	0,94		
TS 419 Čapajevova	1,25	1,61	0,61	0,79		
TS 421 Kysucká	0,85	1,11	0,65	0,84		
TS 422 Vystavby	0,88	1,15	0,60	0,77		
TS 423 Ľudová	0,94	1,22	0,70	0,90		
TS 424 Slobody	0,78	1,01	0,68	0,88		
TS 430 Hronská	0,84	1,10	0,69	0,89		

Government of the Slovak Republic no. 329/2006 Coll. on minimum health and safety requirements for the protection of workers before the risks related to the exposure to the electromagnetic field, we can state that in all of the transformer substations assessed, the EC field strength values assessed did not exceed the ER field intensity values and the BC field strength induced values did not exceed the BR magnetic induction action values [7]. Based on the results of measurements of electric field intensity and magnetic induction evaluated for the frequency of 50 Hz, in places where mostly residents of dwellings move and thus in front of objects of transformer stations in the external environment it can be stated, pursuant to Decree of the Ministry of Health of the Slovak Republic No. 534/2007 Coll. on details of requirements for sources of electromagnetic radiation and for occupational exposure limits to electromagnetic radiation in the environment, that in all of the transformer stations assessed, the effective values of the electric field intensity EC did not exceed the action values of the electric field intensity ER and also the assessed effective values of the magnetic induction BC did not exceed the action values of the magnetic induction BR [8].

Recommended measures for improving the state

We used SchetchUp 2019 environment for creation of the transformer station model with internal elements of electric transmission and transformation systems. In this 3D program, a detailed drawing of the transformer station, which is an exact copy of the TS located in our assessed areas, was modelled. A 3D view of the external structure of the transformer station object is shown in Fig 5. 3D views of the interior of the building with the relevant technological elements of electrical equipment are shown in Fig. 6 and Fig. 7.

Figure 5: Visualization of transformer station using SchetchUp 2019 software.

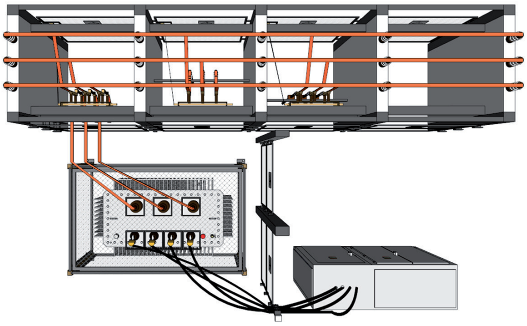

Figure 6: Visualization of the interior of the object - floor plan.

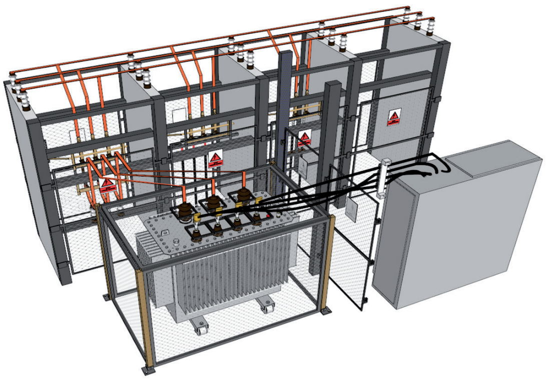

Figure 7: Side view visualization.

Design solution and proposal of shielding materials

An optimal measure that would reduce the emissions of electromagnetic fields inside the transformer station, where the employees of the East Slovakian Power Plant are located, would be possible with the Faraday Cage, which is shown in Fig. 8, Fig. 9, and Fig. 10.

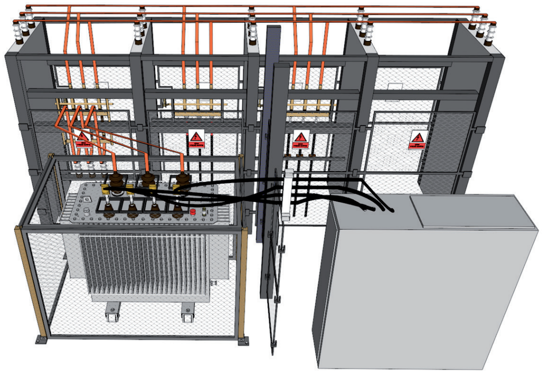

Figure 8: Visualization of Faraday cage using SchetchUp 2019.

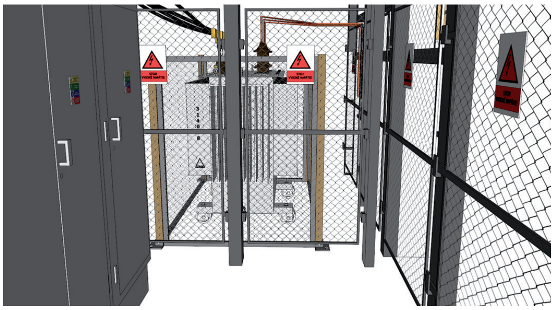

Figure 9: Visualization of Faraday cage using SchetchUp 2019.

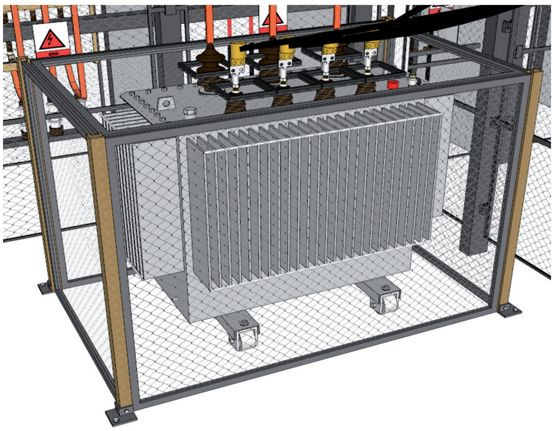

Figure 10: Visualization of Faraday cage using SchetchUp 2019.

For this particular case, we propose a cage that would have a length x width x height of 1150 x 1850 x 1300 cm. The dimensions of the designed Faraday cage, as well as the cage, are shown in Fig. 11.

Faraday's cage is used in practice for protection of electrical equipment. Such a cage is a completely closed cage made of electrically conductive material, for our case we suggest:

– *wire mesh,*
– *a fabric which is interwoven with an electrically conductive (ferromagnetic) material in the form of thin fibres.*

This solution has the effect of reducing the emission of electromagnetic fields into the environment as well as the opposite effect, i.e. the transformer is protected against external influences of electromagnetism as other sources or lightning.

The supporting structure of this cage is designed of wood, the surface of which will be treated by, for example:

– *a coat of paint with ferrite powder mixed with synthetic dye,*
– *or treated with ferromagnetic foil.*

The whole construction will consist of 5 parts, which will fit together by means of wooden grooves and pins (Fig. 12 and Fig 13), commonly used in the wood industry for joining parts. This design solution is designed for quick dismantling of the structure, thus ensuring quick operator access to the transformer in case of maintenance or repairs.

Figure 11: A view of the grooves of the wooden load-bearing structure.

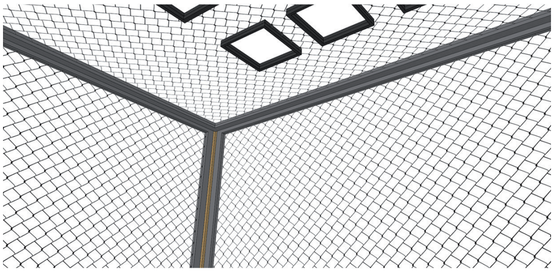

Figure 12: Detail view of side parts mounted in grooves.

4. Conclusion

On the basis of measurements of electromagnetic field parameters in transformer station objects, it was found that the action values described in Government Regulation no. 329/2006 Coll. and directive of the Ministry of Health of the Slovak Republic no. 534/2007 Coll. were not exceeded in any of our substations, and residents moving near these transformer stations are exposed to electromagnetic radiation only to a minimum extent. VSE staff is exposed to this electromagnetic radiation, whether short- or long-term, particularly when carrying out regular inspections of such equipment; or for repairs and maintenance. Of course, the effects of electromagnetic fields impact is manifested differently for each person, and set action values are converted to a single number.

In this case, is an action value for 50 Hz for an electric field intensity (E) of 10 000 V / m and for magnetic induction (B) 500 μT. Measured values with added expanded uncertainty are about 200 times lower than the action value for E and about 30 times lower than the action value for B. The aim was to compare these measurements with action values in the relevant legislation of the Slovak Republic, and to evaluate the exposure of employees and inhabitants to electromagnetic fields. Another aim was to propose a design that would reduce the electromagnetic radiation of these sources. This measure is designed as a cubic Faraday cage made of electrically conductive material.

Acknowledgments

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