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Electric and Magnetic Field Distribution in Substations belonging to Transelectrica TSO

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***Abstract*--The paper emphasize the results of the first systematic electromagnetic field measurements performed in very high voltage substations belonging to the Romanian national power grid in order to face the requirements of the EU Directives regarding the human exposure to the electromagnetic fields. In the first part of the paper, the experimental field measurement results from a recently rehabilitated 400/220 kV substation belonging to the Romanian Transport and System Operator (TSO) Company are presented. The high intensity field zones are highlighted and the highest field value found is compared with the exposure limits given by the actual legislation. In the second part of the paper theoretical field computation methods are approached following two main reasons: to validate the experimental results and to proof their efficiency in evaluating the electromagnetic field values in the neighbourhood of the power devices from complex systems such as the substations. The final conclusions of the study performed and the actions proposed to be taken in practice finish the paper.**

***Index Terms*--Electromagnetic field, substations.**

I. Introduction

THE Romania's accession to the European Union in 2007 focused all efforts towards the harmonization with the European legislation and regulation. In the light of this attempt, the paper outlines the first systematic study that was performed in Romanian very high voltage substations in order to face the requirements of the European Directives regarding the human exposure to the risks arising from electromagnetic fields. One has to outline that since 2006 the corresponding EU Directives have been transposed into the Romanian legislation by two official governmental documents. The case study was carried out for one of the most recently rehabilitated 400/220 kV Romanian substation located in Rosiori, the Satu-Mare County [1], substation that interconnects the Romanian power system grid with the EU power grid via the Ukrainian Mukacevo substation. The experimental measurement values obtained were afterwards compared with the public and professional electromagnetic field exposure limits. Color maps of the electric and magnetic field distribution are presented in order to easily locate the high intensity field generating zones inside the substations.

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II. Exposure Limits to Electromagnetic Fields

The exposure limits to electromagnetic fields are quantified by two Directives. The most important one, the 2004/20/EC European Union Directive [2] refers to the minimal requirements on health and security of working personnel exposure to the electromagnetic fields. Since this Directive is an individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work, that Directive therefore applies to the exposure of workers to electromagnetic fields, without prejudice to more stringent and/or specific provisions contained in this Directive. The second Directive is the 1999/519/EC European Union Directive on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) [3].

Both above mentioned Directives have been transposed in the Romanian legislation by translation into two governmental documents [4], [5]. Following these documents, the exposure limits for the frequencies in the range 0 ÷ 1 MHz are presented in Table 1 (public exposure) and in Table 2 (professional exposure), where f is the frequency in the units indicated in the frequency range column.

TABLE I
PUBLIC EXPOSURE LIMITS

Frequency range	E (V/m)	H (A/m)
0 – 1 Hz		1.2x104
1 – 8 Hz	10,000	3.2x104
8 – 25 Hz	10,000	4000/f
0.025 – 0.8 kHz	250/f	4/f
0.8 – 3 kHz	250/f	5
3 – 150 kHz	87	5
0.15 – 1 MHz	87	0.73/f

TABLE II
PROFESSIONAL EXPOSURE LIMITS

Frequency range	E (V/m)	H (A/m)
0-1 Hz	-	1.63 x 105
1-8 Hz	20,000	1.63 x 105/f2
8-25 Hz	20,000	2 x 104/f
0.025-0.82 kHz	500/f	20/f
0.82-2.5 kHz	610	24.4
2.5-65 kHz	610	24.4
65-100 kHz	610	1600/f
0.1-1 MHz	610	1.6/f

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According to these tables, considering the 50 Hz power frequency, the public exposure to the electric field is limited to 5 kV/m while the professional exposure the limit is 10 kV/m.

Regarding the exposure to the magnetic field at 50 Hz power frequency, the public limit is 80 A/m while the professional limit is 400 A/m. These limits were particularly checked during the measurements performed in the Romanian substations.

III. Experimental Measurements

In order to perform the electric and magnetic field experimental measurements, grids covering the whole surface of the substations were set up. The field measurements have been performed going along the columns direction of these grids (meaning the direction perpendicular to the direction of the power lines entering the substation). The maximum distance between two adjacent measurement columns was 10 m while the distance between two adjacent test points on a measurement line was 3 m. The measurement lines have been selected such way that they passed in closed vicinity to the main power equipments.

Thus, for the 400/220 kV substation more than 3000 test points were considered. One has to outline that the measurements have been performed under substations normal working conditions and by monitoring the current flow in all bays.

The field meter device was placed at 1.7 m height above the ground using a special shear leg device. In order to avoid the influence of the personnel presence during the data acquisition for the electric field measurements, a remote control device connected with the field meter via a 3m long fiber optic cable was used. For electric field measurements the field meter's measuring loop was set horizontally while for the magnetic field two orthogonal vertical measurement directions were considered [6], [7].

The experimental results of the magnetic and electric field measurements are given by color maps and 2D plots are built for the results along measurement lines.

Fig. 1 and Fig. 2 outline the magnetic and the electric field distributions in the 400/220 kV Rosiori substation. As it can be noticed in Fig. 1, the highest magnetic field value does not exceed 4 A/m and thus the human exposure to the magnetic field inside 400/220 kV substation is not at all dangerous with respect to the limits imposed by the applicable legislation. On the other hand, Fig. 1 outlines well the reactive power exchange between the shunt reactor and the Mukacevo power line.

Following the electric field map from Fig. 2, one can remark that there are large areas especially in the 400 kV side of the substation where the electric field intensity is higher than 10 kV/m, the professional exposure limit.

Fig. 3 outlines the actual zones where the 10 kV/m professional exposure limit is exceeded. The highest values have been found in the neighborhood of the line bays and bus-bars circuit breakers and disconnectors, where the electric field reaches values up to 23 kV/m. Also the electric field intensity exceeds the professional limit value on the access roads to the relay cabinets in the neighborhood of the bus-bar 1 and bus-bar 2. On the 220 kV side of the substation there are very few locations where the professional exposure limit is exceed but areas with field values between 5 kV/m and 10 kV/m are quite large.

Fig. 4 presents the electric field distribution in the 400 kV side of the substation along two measurement lines located in the vicinity of the line bays and bus-bar 1 circuit breakers and disconnectors [7]. One can notice that the 10 kV/m limit is reached in almost any test point located under the power line conductors, the maximum field value exceeding 20 kV/m. The high values of the electric field from these areas can be motivated by the fact that the circuit breakers and the disconnectors make the 400 kV potential to go down to 6.5 m above the ground.

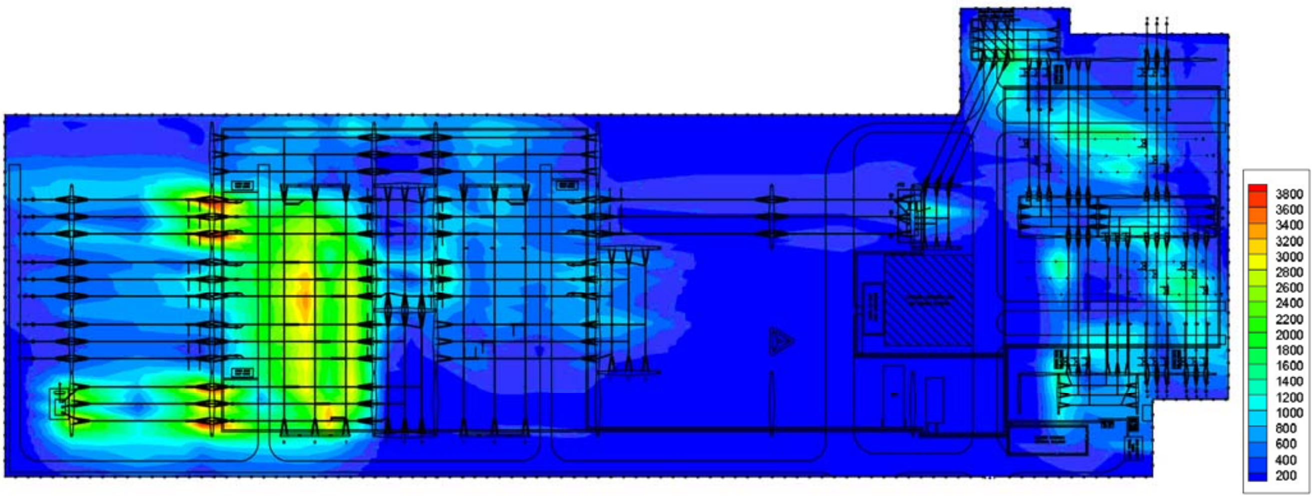


Fig. 1. Magnetic field distribution [mA/m] in the 400/220 kV Rosiori substation.

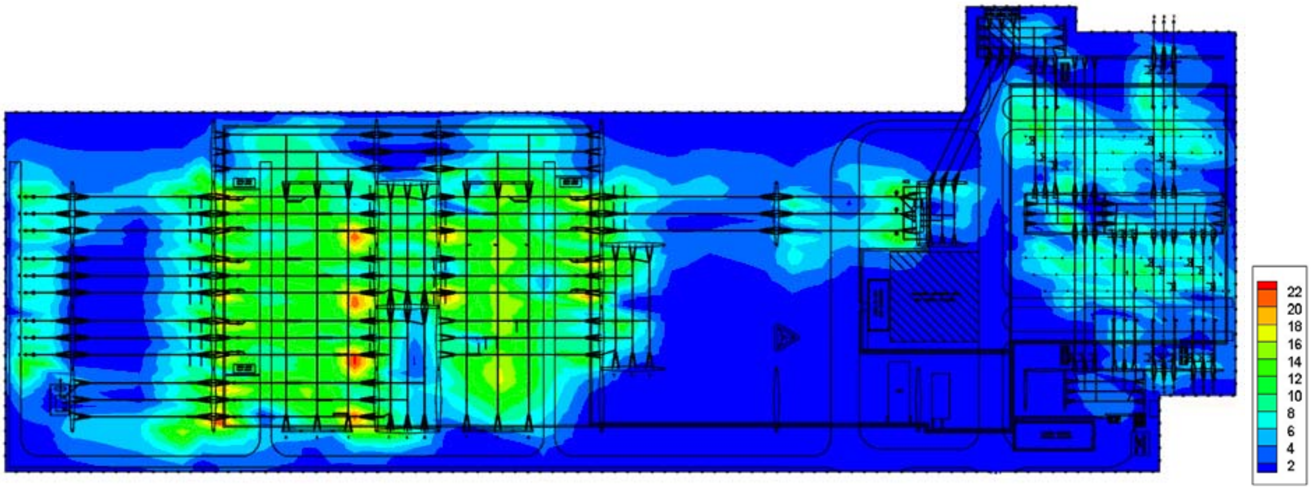


Fig. 2. Electric field distribution [kV/m] in the 400/220 kV Rosiori substation.

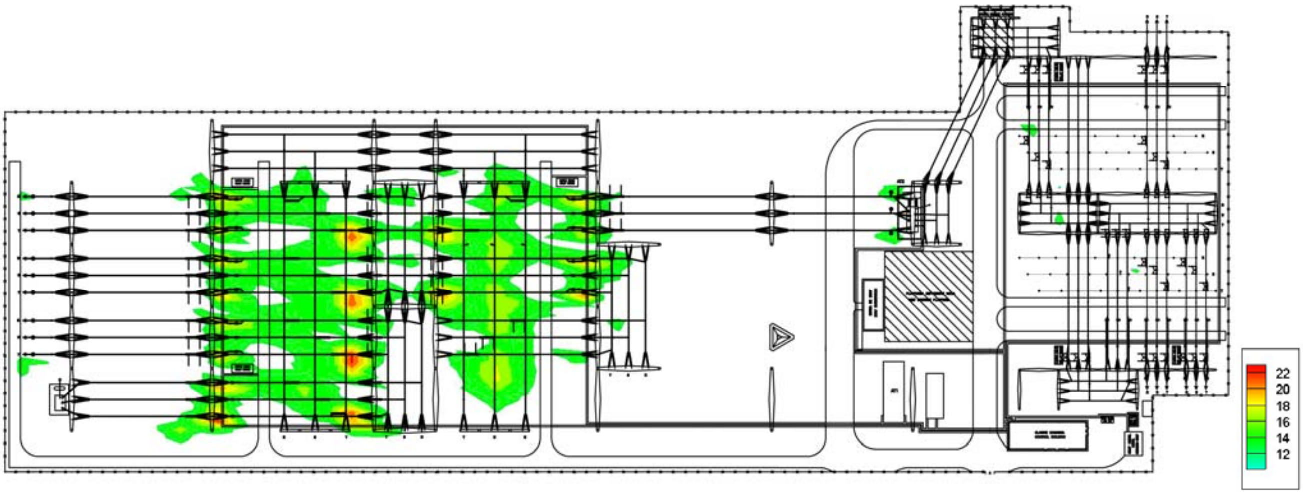


Fig. 3. Electric field map with values higher than 10 kV/m in the 400/220 kV Rosiori substation.

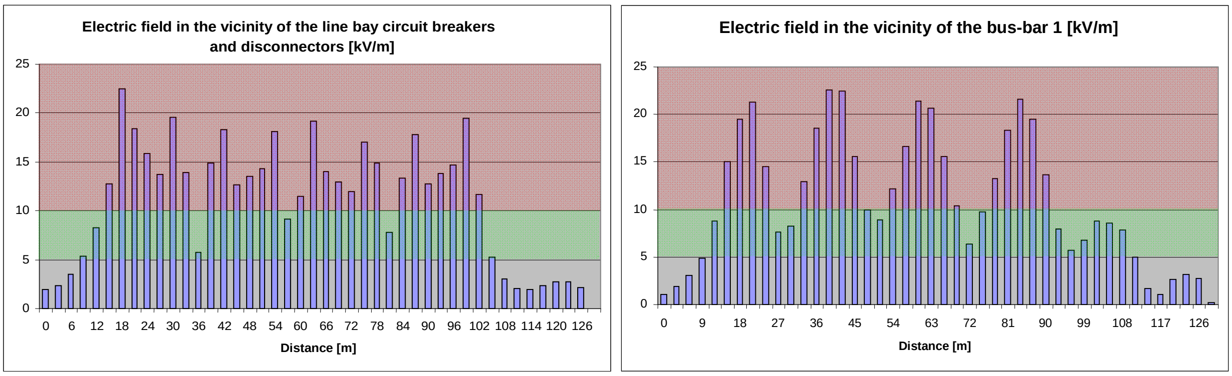


Fig. 4. Electric field distribution along two measurement lines in the 400 kV side of the Rosiori substation.

IV. Theoretical Computation

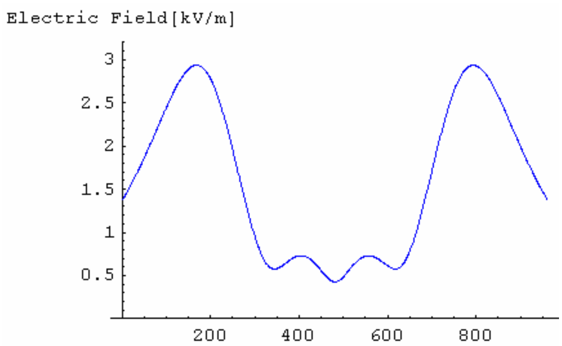
The computation of the electric and magnetic field values inside a substation is a difficult task due to the complexity of the power devices geometry and of the conductor's arrangements. Therefore, regarding the exposure to the electric and magnetic fields, the main aim of the theoretical computation developed in this paper is to evaluate with an assured degree of accuracy the electric and magnetic field values in a certain zone of the substation by taking into account the most representative field sources.

There are two main ways to approach the electric and magnetic field computation: by analytical formulae and by 3D field numerical modeling. In this paper, examples using the analytical electromagnetic field formulae are emphasized.

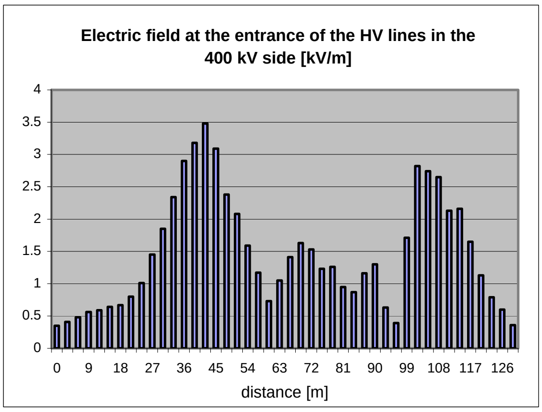
The first example refers to the electric field computation in the area of the power lines entering the 400 kV side of the substation. In this area the electric field values can be evaluated by direct implementation of the following analytical formula and by applying the superposition principle as well [8]:

$$\overline{E} = V_0 \sum_{k=1}^{3} e^{j\frac{2k\pi}{3}} \frac{\left(\frac{\overline{r_{2k}}}{r_{2k}^2} - \frac{\overline{r_{1k}}}{r_{1k}^2} \right)}{\ln \frac{2h_k}{r_{0k}}} \tag{1}$$

As it can be noticed from Fig. 5 there is a good agreement between the theoretical and the experimental results. The shapes and the values of the two outcomes are in good agreement, the maximum absolute error of up to 0.5 kV/m (about 15 %) being an acceptable value with respect to the computation objectives.



(a) analytical computation.



(b) experimental result.

Fig. 5. Electric field distribution in the area of the HV lines entering in the 400 kV substation.

The second example refers to the magnetic field computation along the Bus-bar 1 taking into account the reactive current flowing through the Mukacevo line to the power shunt reactor (see Fig. 1), in accordance with the schematic representation given in Fig. 6. The magnetic field is evaluated considering the following analytical formula [8]:

$$\overline{H} = \frac{I}{2\pi} \sum_{k=1}^{3} e^{j\frac{2k\pi}{3}} \frac{\overline{r_{1k}}}{r_k^2} \tag{2}$$

Looking at the magnetic field distribution along the Bus-bar 1 outlined in Fig. 7 one can notice the good agreement between the analytical and the experimental results. The shapes and the values of the two outcomes are in good agreement, the maximum absolute error of up to 0.5 A/m (about 15 %) being also an acceptable value with respect to the computation objectives.

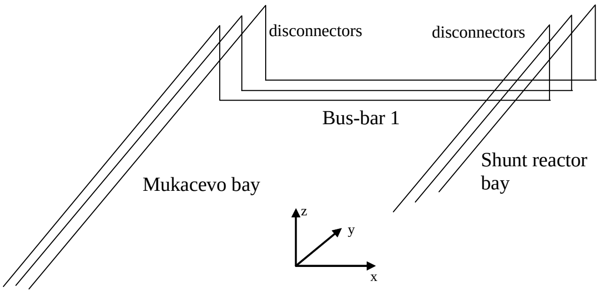
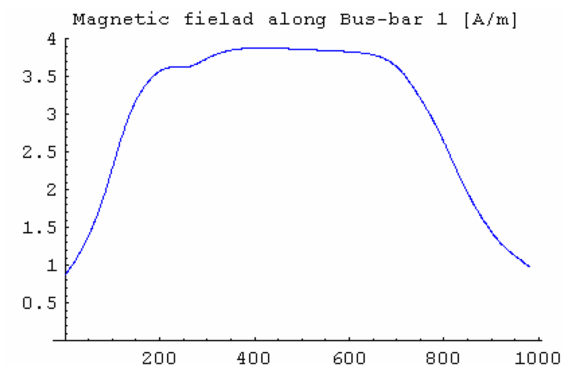
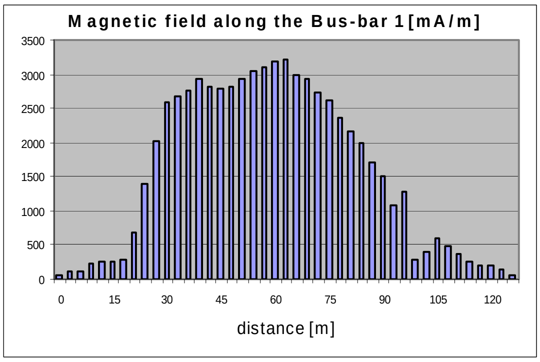


Fig. 6. The reactive current circuit flowing between the Mukacevo line and the Rosiori shunt reactor bay.



(a) analytical computation.



(b) experimental result.

Fig. 7. Magnetic field distribution along the Bus-bar 1 of the 400 kV Rosiori substation.

Therefore, one can remark that using the fundamental field computation formulae the electric and magnetic field values in the vicinity of the main power devices can be evaluated fast and with acceptable accuracy as regards the exposure to the electric and magnetic field theoretical computation purposes.

V. Final Conclusions

The results presented in the paper outline that the professional human exposure limit to the electric field is significantly exceeded in certain areas of a 400/220 kV substation. This situation is motivated mainly by the fact that the circuit breakers and disconnectors force the high voltage to come down to 6.5 m above the ground. The usage of flexible bus-bars instead of the rigid ones is another important reason for the high electric field intensity values found in the 400 kV side of the studied substation.

Another important conclusion of the study is that at the substation's fences the public exposure limits are not exceeded in any point.

Following the study performed, the authors strongly recommends the evaluation of the electric and magnetic field values in the vicinity of the main power devices early from the substations design stage. The computation examples presented in the paper outline the fact that the electric and magnetic field values can be evaluated fast and accurately enough using analytical computation formulae. Of course, in order to get a better accuracy of the theoretical results, more complex computational solutions must be developed in the future.

The measurement and the computation methods outlined in the paper were used for the very first time in very high voltage substations belonging to the Transelectrica TSO Company. They can be also successfully applied in other exploitation installations and in other Companies that own high voltage substations, in accordance with the in force legislation.

The authors consider that the conclusions regarding the electromagnetic field distribution inside a substation and emphasized in the paper are very useful for the working personnel from such substations as well. As the first measures taken to diminish the exposure risks in exploitation would be the limiting the access time and labeling the high intensity electromagnetic field areas.

VI. References

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VII. Biographies

Gheorghe Visan was born in Craiova, Romania, on April 21, 1964. He received the M.Sc. degree in electrical engineering from University of Craiova, Romania, in 1988. Today he is the Head of the Investment Projects Management Division from Romanian Power Grid Company Transelectrica SA. His main research interest is related to power electric networks and electromagnetic compatibility.

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