Study of the Electric Field Generated by the High Voltage Substations

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Abstract: - The paper outlines the results of a study regarding the electromagnetic field generated by a 400 kV high voltage (HV) substation belonging to the Romanian national Power Grid Company Transelectrica SA. In the first part of the paper, a semi-analytical computation module dedicated to the electric field computation inside substations is presented. Comparison of the computation results with the experimental measurements performed in the substation is outlined. Scenarios to reduce the field value inside substation in order to fulfill the requirements of the actual legislation regarding the occupational exposure to power frequency electromagnetic fields are proposed. The final conclusions of the study performed end the paper.

Key-Words: - Electromagnetic field, computation, HV Substations, Human Exposure, Limits

1 Introduction

The study outlined in this paper was carried out for one of the most recently rehabilitated 400 kV substation belonging to the Romanian Power Grid Company Transelectrica S.A. The substation, named "Rosiori", interconnects the Romanian power grid with the EU power grid via the Mukacevo substation from Ukraine. It is well known [1] that for high voltage substations the electric field generated by the power equipment exceeds very much the human exposure limits. Therefore, the actual study focuses only on the electric field distribution inside substations.

The study performed consists in two main parts. The first part emphasizes the electric field distribution inside substation obtained using a semi-analytical field computation module developed by the authors. Comparison with the experimental measurements are presented and discussed in order to analyse the accuracy of the field computation algorithm developed and also to validate the experimental measurements data.

The high intensity field zones are highlighted and discussed with respect to the actual legislation. The exposure limits to electromagnetic fields are quantified by two EU documents. The most important one, the 2004/20/EC EU 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 document is the 1999/519/EC EU Council Recommendation on the limitation of exposure of the general public to electromagnetic fields [3]. Both above mentioned documents have been transposed in the Romanian legislation by direct translation into two governmental documents [4], [5]. Following these documents, considering the 50 Hz power frequency, the public exposure to the electric field is limited to 5 kV/m while the occupational exposure the limit is 10 kV/m. These limits were particularly checked during the analysis performed.

In the second part of the paper possible scenarios to reduce the electric field intensity inside substations are proposed.

The final conclusions about the study performed end the paper.

2 Electric Field Computation inside Substations

The computation of the electric field values inside a substation is a difficult task due to the complexity of the power devices geometrical structure and of the conductor's arrangements. Therefore, in order to determine the field distribution inside a substation, full 3D computation algorithms must be developed. For this purpose, the authors propose a semi-

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analytical field computation algorithm written in Mathematica programming environment [6].

The main idea for the electric field computation is to model the whole structure of the substation by straight finite length conductor segments. Curved conductor lines of various shapes are therefore segmented with set of straight line segments in xyz coordinate system that contribute to the resultant field in points of the space. Thus, any segment of the final equivalent geometrical structure of the substation will play a part to the electric field strength global computation formula.

The computation algorithm developed is based on a semi-analytical computation method and consists in two main steps:

In the fist step the thin conductors charge density distributions are numerically evaluated such that every conductor segment to be maintained at the given constant potential;

In the second step the total electric field strength is determined by adding the contribution of each conductor segment of the substation based on the following general vector formula [7]:

$$\underline{E} = \frac{e^{j\frac{2m\pi}{3}}}{4\pi\varepsilon} \sum_{k=1}^{n} \rho_k \int_{L_{k-1}}^{L_k} \left(\frac{\overline{r_{1k}}}{r_{1k}^3} - \frac{\overline{r_{2k}}}{r_{2k}^3} \right) dl \qquad (1)$$

In formula (1) ✕$_k$ is the electric charge density assumed to be constant on a small piece of the conductor segment, located between the segment limits L_{k-1} and L_k, while r_k are the position vectors from the source segment and its image with respect to earth respectively to the computation point. The complex exponential in (1) assures the conductor's phase.

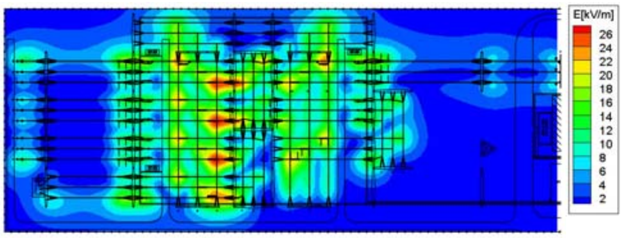
3 Computation Results. Comparison with the Experimental Measurements.

The developed electric field computation algorithm was used to determine the electric field strength distribution in the 400 kV Rosiori substation. In order to achieve the data for the graphical representation, 41,151 computation nodes were used and a total computation time of 8 hours was necessary. The computation results are compared with the experimental measurements performed in the substation.

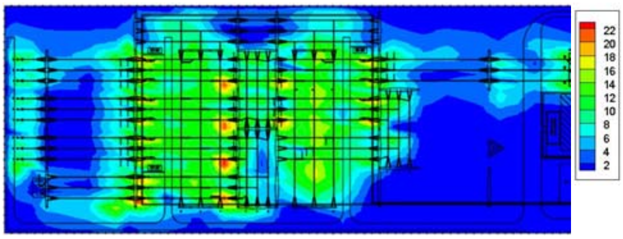
One has to outline that in order to perform the experimental measurements about 1800 data acquisition points were considered in a grid covering the whole surface of the 400 kV substation. The field measurements have been performed going along the columns direction of these grids (meaning the direction 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. The field meter device was mounted on a special shear leg device [8]. 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.

All the results are considered for 1.7 m height above the soil. This height was considered based on the known health effects of the power frequency electromagnetic field on humans [2]. Therefore, the human head was considered as the most exposed part of the human body to the electromagnetic field.

The computation and the experimental results are presented in Figure 1. Figure 2 emphasizes the areas where the electric field strength exceeds the 10 kV/m, the occupational exposure limit.



(a) computation results [kV/m]



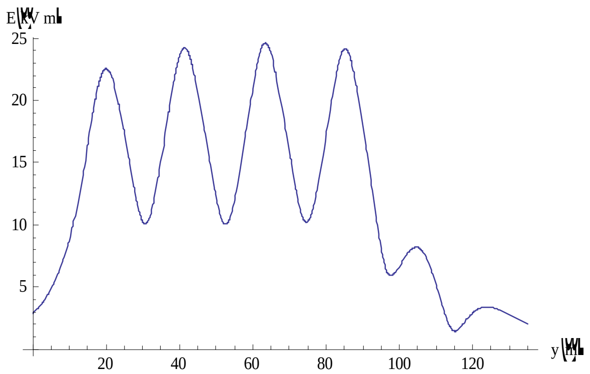
(b) experimental measurement results [kV/m]

Fig. 1. The electric field strength distribution in the 400 kV part of the Rosiori substation

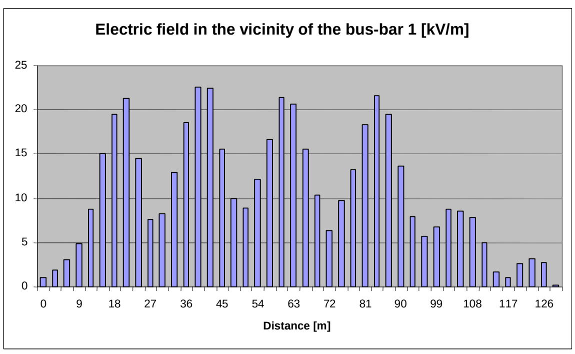
As it can be noticed from Figure 1, there is much similarity between the computed and measured electric field distribution inside the substation. The highest field value computed is 26.6 kV/m while the highest field value measured was 22.7 kV/m. There is 15% deviation between these data results. This deviation can be explained first of all by the fact that the computed and measured maximum values are not located in the same point. On have to outline that for the computation results there are used 23 times more points than the number of measurements points so the computation grid is much finer than de measurement grid. In order to prove this idea, a measurement line in the vicinity of the Bus-bar 1 was selected to more accurately compare the computed and the measured data. The corresponding shapes of the computed and measured electric field distribution along this line are presented in Figure 2. One can notice the very good agreement between the two shapes. The maximum computed field value is in this case 24.1 kV/m while the maximum measured field value is 22.7 kV/m, which means a deviation of only 6%. This deviation is very suitable for the purpose of this kind of study.

Looking to the exposure limits, Figure 3 outline the areas where the 10 kV/m limit goes over. One can notice that there are large areas inside substation where the occupational exposure limit is exceeded.

The highest field values were found in the neighbourhood of the line bays and bus-bars circuit breakers and disconnectors, where the 400 kV potential goes down to about 6.5 m above the soil.



(a) computation results



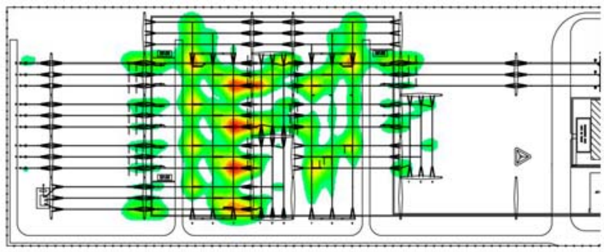
(b) experimental measurement results

Fig. 2. The computed electric field strength values along Bus-Bar 1, on a measurement line

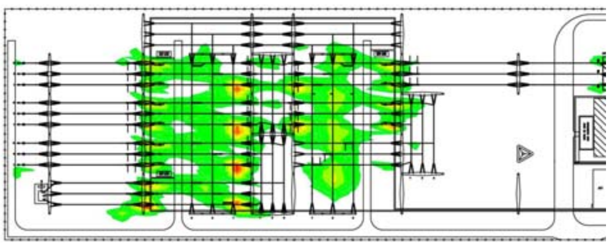
4 Scenario to Reduce the Electric Field inside Substations

As it can be noticed from Figure 3, the occupational exposure limit is exceeded on the relay cabinet access roads. This is an important aspect that motivates the analysis of scenarios to reduce the field value inside high voltage substations.

The scenario proposed in this paper is what would happen if all the substation power equipments would be elevated with 2 meters. A comparison between the actual situation and the results for the scenario proposed are presented in Figures 4 and 5, by using the computation algorithm developed.

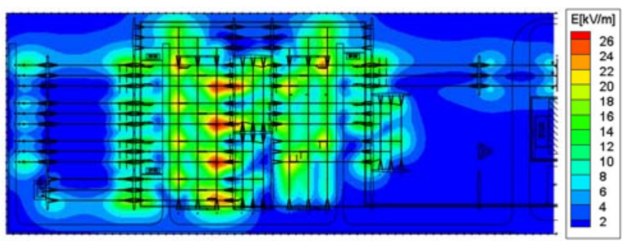


(a) computation results

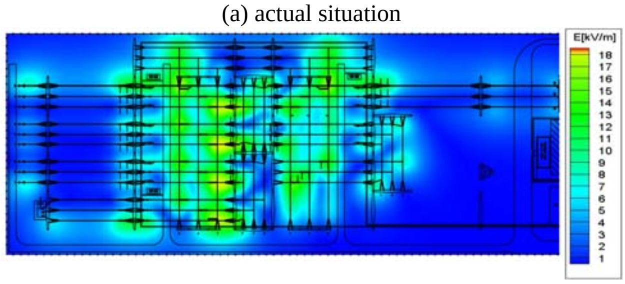


(b) experimental measurement results

Fig. 3. The areas where the electric field strength distribution exceeds the 10 kV/m occupational exposure limit

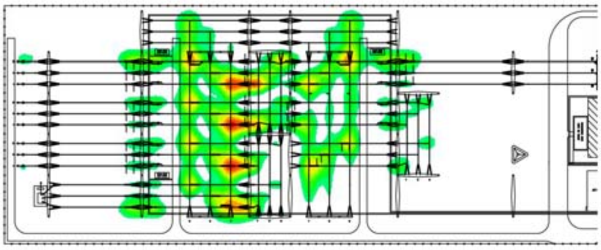


(a) actual situation

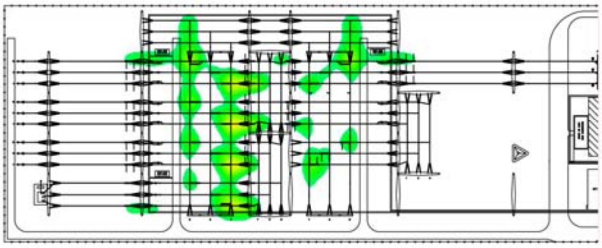


(b) elevation with 2 meters

Fig. 4. Comparison between the actual field distribution and the case of 2 meters elevation of all power equipments



(a) actual situation



(b) elevation with 2 meters

Fig. 5. Areas with field values higher than 10 kV/m

As it can be noticed from Figure 4 and Figure 5, there is a significant reduction of the areas where the field values exceeds the 10 kV/m occupational exposure limit. On the other hand, comparing the maximum field values computed in both cases, one notices a decrease from 26.6 kV/m to 18.9 kV/m.

5 Conclusions

The paper outlines a study regarding the power frequency electric field strength generated by a 400 kV substation.

The main conclusion of the paper is that using fundamental field computation formulas one can accurately evaluate the field strength distribution produced by high voltage power devices from substation. In order to validate the semi-analytical computation algorithm developed, the results were compared with the measured values collected over the whole area of the substation. The good agreement between the two field distributions outline the effectiveness of the computation method proposed and validates as well the measurement method used in practice.

The second important conclusion of the paper is that the occupational exposure limit to the electric field is significantly exceeded in large areas of a 400 kV substation. This situation is motivated mainly by the fact that the circuit breakers and disconnectors force the high voltage to come down to about 6.5 m above the soil. Using the computation algorithm developed, a scenario considering the power devices elevation with 2 meters was proposed. The results emphasize that the field values decrease significantly using this method.

The third important conclusion is that the field computation tool developed is of much help in the design of new substations. Using the software module, different scenarios of power devices arrangements may be analysed in order to reduce as much as possible the field strength and especially on the access roads inside substations.

Moreover, the computation module developed makes possible the analysis of the electromagnetic interferences produced by the high voltage substation to the neighbouring utilities such as gas or water pipe networks.

Acknowledgment

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