Numerical Computation of the Electromagnetic Field inside a High Voltage Substation

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Abstract *- This paper presents a numerical implementation for the calculation of electromagnetic fields in high voltage substations. A study is conducted on the 110 kV high voltage substation Cluj-South. Reduced computing time, resources and the basic programming platform make this application a useful tool for electromagnetic field studies.*

Keywords – *High voltage, electromagnetic field, numerical application, Pascal.*

1. INTRODUCTION

The study of electromagnetic field distribution is vital when considering the design and placement of equipment and facilities inside high voltage substations, but also when considering human safety and environmental regulations.

Electromagnetic field distribution problems are solved using analytical or numerical methods depending on the complexity of the system's geometry. Analytical methods are used mostly for simple physical systems; their solving precision and general implementation make them the obvious choice in most cases. Numerical methods are tailored to solve specific problems, usually involving complex geometries, where the analytical approach would be very hard to apply.

The Finite Difference Method (FDM), the Finite Element Method (FEM), the Boundary Element Method (BEM) and the Charge Simulation Method (CSM) stand out as the most commonly used numerical methods. Combinations of these methods (FDM-CSM, FEM-CSM, BEM-CSM) are also often used, as can be noticed in [4], [3] and [10].

Computing the electromagnetic field distribution is done in two steps: first, the electric field distribution is computed using the CSM; this method requires the placement of fictitious charges outside of the studied area or inside the conductors (equipotential surfaces). To determine the charges, boundary conditions are applied on the contour points, then the electric field distribution can be calculated inside the studied region based on the superposition principle. Its effective computation on large model and open areas, make the CSM one of the most effective methods for calculating the electric field distribution in high voltage substations, as it can be observed in [9] and [8].

The second step represents the computation of the magnetic field distribution. In [1], the magnetic field distribution is calculated with a software module based on Biot-Savart's Law and the results showed a very good correspondence with the field measurement.

Computing the magnetic field distribution does not require a discretization step as in the case of the electric field; in this paper the magnetic field strength is computed by considering the current as being constant on the entire length of the conductor, and by applying the superposition principle, the magnetic field strength can be computed even for complex geometries [5] .

2. ALGORITHM

The algorithm used to compute the electromagnetic field in this paper is developed in Pascal, which is an open source programming platform, allowing users easy access to the algorithm's source code and programming language. The use of a programming platform rather than commercial software minimizes the costs, and by creating a tailored algorithm for a specific field problem, it reduces the resources and time needed for computing, especially when dealing with large models or complex geometries.

The algorithm presented in this paper is comprised of two modules: one for computing the electric field and another for the magnetic field. The use of software to compute electromagnetic field distribution was validated in [1] and [8].

2.1. Electric field computation algorithm

The module used to compute the electric field distribution is similar to the CSM; discrete charges are placed on the discretized substation conductors. Due to the imposed conditions, the values of the charges are determined so that the potential on the small conductor segments remains constant.

Using formula (1) from [2], the electric field distribution is computed taking into account all the discretized conductors:

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

where ρ_k is the electric charge density, L_k and L_{k-1} are the limits of the segment and r_k are the position vectors of the source segment and its image in relation to the computation point.

The module which computes the electric field distribution consists of a data input section, the main body of the algorithm and the output section. The input data can be collected manually, as was done in [7], or it can be read from a txt type file, the latter method requiring considerably less time and reducing the possibility of human error. In order to speed up the collecting data process, a macro, as developed in [6], can be used.

The conductor discretization procedure is performed in the main body of the electric module. The number of elements in which a conductor is divided dictates the precision of the results, but it also affects the computing time, which increases exponentially to the total number of elements.

The second step in determining the electric field distribution is the computation of the potential in each of the contour points. This is done by solving the system of equations (2) in which the given potential equals the charge value multiplied with a coefficient. These equations are solved using the Gauss elimination method.

$$\begin{bmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{bmatrix}\begin{bmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_n \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} \qquad (2)$$

where $[P]$ is the coefficient matrix, $[Q]$ is the matrix of unknown values of charges and $[V]$ is the matrix of given potential.

The electric field generated by each segment and its image is computed with regard to the line charge and phase. The total field is calculated using the superposition principle.

2.2. Magnetic field computation algorithm

The discretization process of the conductors, for the electric field, is no longer required for the magnetic field computation because the applied current is constant on the entire length of the conductor.

Computing the magnetic field H in a point P (fig.1) near a finite length conductor is done with equation (3):

$$\overline{H} = \frac{i}{4\pi d}\left(\frac{\overline{l}\cdot\overline{r_1}}{l\cdot r_1}-\frac{\overline{l}\cdot\overline{r_2}}{l\cdot r_2}\right) = \frac{i}{4\pi dl}\left(\frac{\overline{l}\cdot\overline{r_1}}{r_1}-\frac{\overline{l}\cdot\overline{r_2}}{r_2}\right) \qquad (3)$$

where the current has a constant value *i* on the entire length of the conductor, $\overline{r_1}$ and $\overline{r_2}$ are the distance vectors from the computation point to the ends of the segment, $\overline{l}$ is the length vector of the conductor's segment and *d* is the distance (perpendicular) from the computation point to the conductor segment.

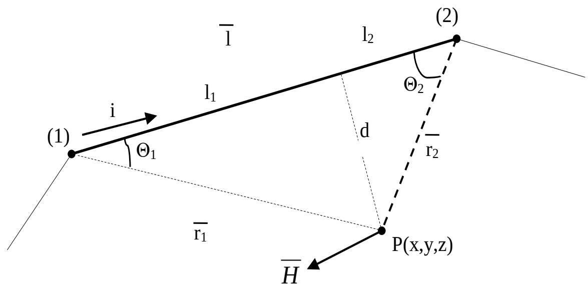

Fig.1 Finite segment of conductor with current *i* passing through it.

For more complex geometries, computing the magnetic field is done by applying the superposition principle on equation (3) with regard to the conductors' geometry and the phase angle between the currents which pass through them.

3. CAD MODEL

The field computation is conducted on a SolidWorks model which was created by the authors in [6] and which is presented in fig. 2. The model was built at a 1:1 scale using onsite measurements of the 110kV high voltage substation Cluj-South as well as equipment technical descriptions.

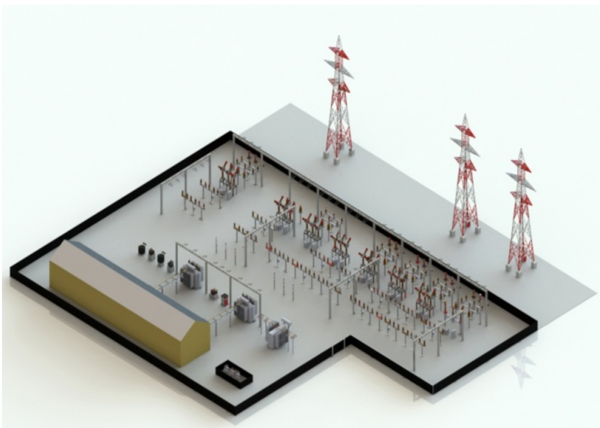

Fig.2 SolidWorks CAD model of the 110 kV Cluj-South substation.

The model in question consists of 12 cells and a total of 372 lines. With the aid of a macro, coordinates were extracted for the start and end of all the lines. Each of these lines is divided in 2 to 140 segments, with an overall total of 4870 segments.

For this study both power transformers are considered connected, the second bar and the transversal joint are disconnected. The placement and current values on each line can be observed in fig.3.

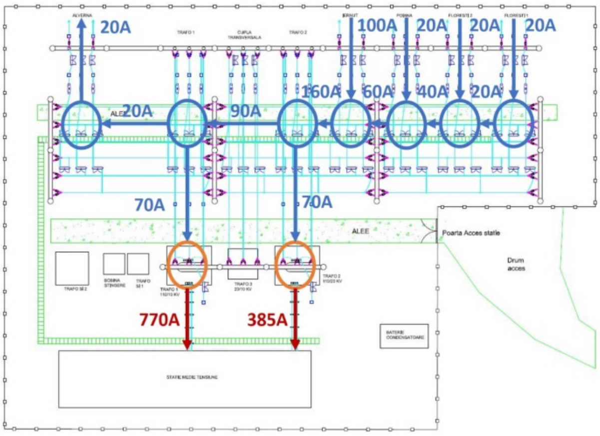

Fig.3 Directions and values of the currents.

4. RESULTS

An analysis of the results from computing the electromagnetic field strength with the algorithm presented in this paper showed good correspondence with results from literature. Fig. 4 shows the results obtained at 1.8m above ground level with the algorithm presented in the paper, the computing time for this case taking 1 hour and 50 minutes.

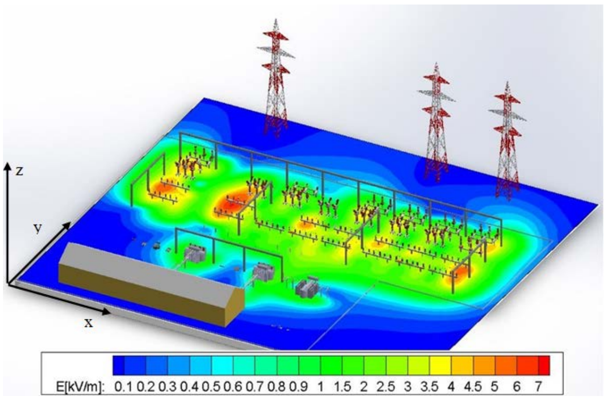

Fig.4 Electric field distribution at 1.8m above ground level.

Fig.5 shows cross-sections at a distance of x = 10, 47.5 and 83.5m in reference to the left outer fence. The electric field distribution around the breakers of the Alverna cell can be seen in the first section from the left; the second section slices through the bars and conductors towards the command building. In the last section the electric field is represented around the 6 longitudinal bars and around one conductor which descends from the high voltage tower.

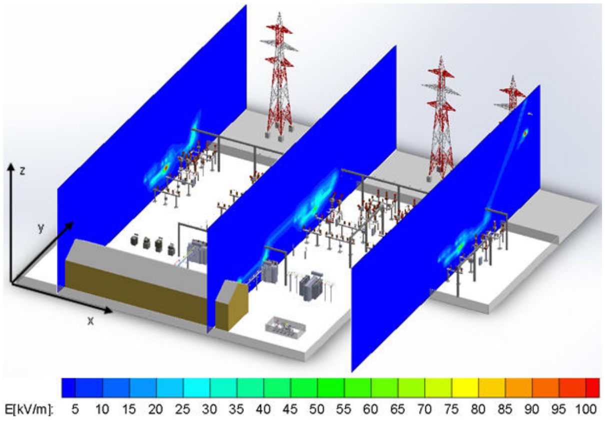

Fig.5 Electric field distribution at cross-section x = 10, 47.5 and 83.5m.

Fig.6 shows a section at y = 48m through the two breakers rows where the highest electric field values were computed at 30kV/m.

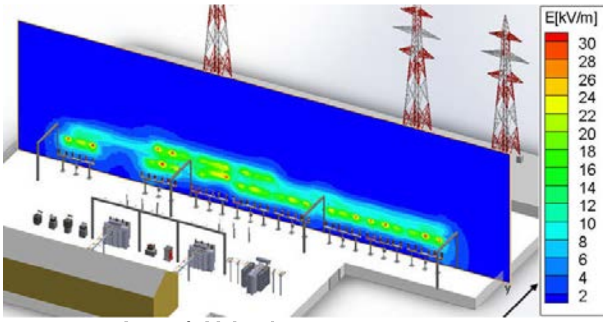

Fig.6 Electric field distribution at cross-section y = 48m.

Fig.7 shows the magnetic induction distribution at 1.8m above ground level with the algorithm presented in the paper, the computing time for this case taking 40 minutes.

The highest value in this case, approx. 11 μT, is located under the medium voltage conductors from Trafo 1 through which a current of 770A passes.

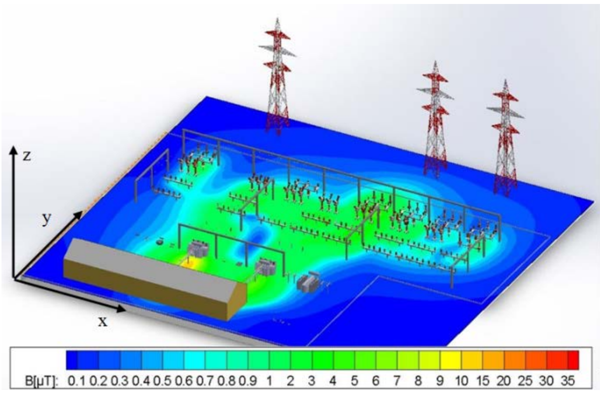

Fig.7 Magnetic induction distribution at 1.8 m above ground level.

The magnetic induction distributions in vertical sections parallel to the station's left outer limit are presented in fig.8 at x = 20, 47 and 80 m. The highest value, 172μT, is located around the conductors which connect Trafo 2 to the command building.

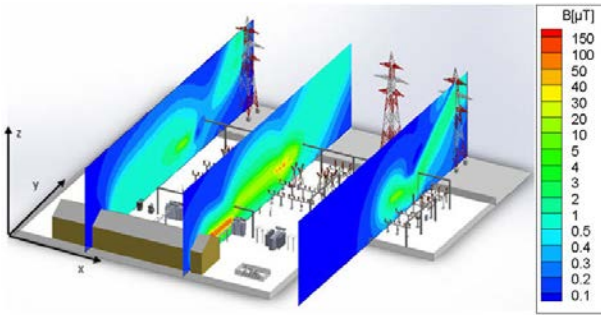

Fig.8 Magnetic induction distribution in parallel sections at x=20, 47 and 80m.

Fig.9 represents the magnetic induction distribution in cross-section at y = 47 m between the breakers. The values for the magnetic induction in this case average around 10 µT. Peak values of 40 µT are located around medium voltage conductors.

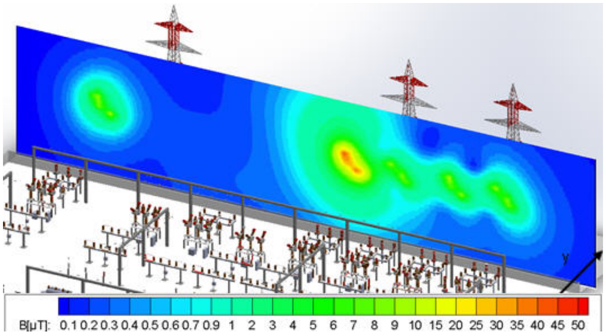

Fig.9 Cross-section between the disconnectors at y = 47m.

5. CONCLUSIONS

This paper presented an algorithm for the study of the electromagnetic field distribution inside the 110 kV high voltage substation Cluj-South. The algorithm consists of two modules, one for the computation of the electric field and another for the magnetic field. The total computing time sums up to 2 hours and 30 minutes. The electromagnetic field study was performed at 1.8m above ground level. The electric field peak value at this height is 5kV/m near the bar breakers. For the magnetic field, the peak value at 1.8m level was 11µT, located under the medium voltage conductors.

Cross-section through areas of interest showed that the electric field's highest values, 30kV/m, are located around the breakers, while magnetic induction peak values are located around the medium voltage conductors near Trafo 2.

The results showed good correspondence with literature.

Due to its easy and fast data implementation, reduced computing time and resources, this algorithm is a useful tool when conducting studies on the electromagnetic field in high voltage substations.

6. AKNOLEDGMENT

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