Examination of electric and magnetic fields around high voltage equipment

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Abstract – In the whole territory of the European Union, both public and occupational exposures are controlled by the Council of the EU, itself. These are strict and clear limits based on the latest researches of World Health Organisation and International Agency for Research on Cancer. International Commission on Non-Ionizing Radiation Protection is also an important body to declare exposure limits which vary on the frequency.

In Hungary, latest guidelines of EU Council became a national law. As a result of that, the inspection of occupational exposures of both electric and magnetic field became obligatory. A complete risk analysis has to be performed by accredited bodies to examine, calculate, simulate and measure the potential sources of risks; experts from medical field also must be involved to these researches.

This paper introduces the practical results of a 3D simulation with finite element method regarding to both electric and magnetic exposures in the surroundings of a high voltage equipment. All the results were validated by on-site measurements, as well. With this technique, E and B field distributions can not only be analyzed, but visualized easily, as well.

1. Introduction
The modelled arrangement is located in the centre of Budapest, where the feeder 220 kV link of a complete district with highly populated areas approaches the substation in the surrounding of an elementary school.

Unfortunately, level of extra-low frequency electric and magnetic fields is a matter of confuse not only regarding to occupational, but public exposures, as well [1]. In this specific case, workers of the elementary school and parents of attending students were especially worried about the possible harmful health effects of the power line in the vicinity of the backyard of the building. Based on the national law by EU Council’s recommendations [2], [3], for 50 Hz frequency, currently, the limits of exposures are the following in Hungary: electric field: 5 kV/m for public and 10 kV/m for occupational exposure, magnetic flux density: 200 µT for public and 1000 µT for occupational exposure [4], [5].

2. Simulations
As the magnitude of exposures was estimated by numerical calculations, a detailed 3D model has been generated because of the complexity of the geometry. Figure 1 shows the CAD model with the mesh generated for the finite element calculations. Complexity of our numerical model is limited because of the applied software. However, from earlier 3D field models for transmission lines it was found, that applying only one phase conductor results in an error that is connecting to the higher safety. COMSOL MultiPhysics finite element software was used to perform the simulations.
2.1. Electric field

As a grounded metal fence ran around the buildings, highest electric field around the facility occurs between the nearest phase conductor (as shown in the pictures) and the fence, itself. Electric potential distribution is characterized by the RMS value of the phase-to-ground voltage and the grounded fence, as it is shown in Figure 2.

From electric potential distribution and geometry, critical electric field distribution can be derived. Using nowadays’ advanced computational resources, this distribution can be visualized even in three dimensional figures (Figure 3). In this case, when the aim of the research is not only the determination the exact values of electric and magnetic field strengths, but to inform the affected personnel about them, this is an especially powerful tool of explanation.
As the main aim of this research was to analyze the risks, besides the visual representation of electric and magnetic fields, their exact values must also be determined. For this, 2D planes were cut at the critical segments (Figure 4).

![2D representation of electric field results](image)

**Figure 4:** 2D representation of electric field results

Than electric field can be visualized at the height of 1.8 meters from the fence towards the buildings. It can be determined from the results that even maximal value is much below the public limit (0.47 kV/m compared to 5 kV/m, less than 10%), which means that the whole territory of the elementary school is safe.

![Electric field versus distance](image)

**Figure 5:** electric field versus distance

### 2.2. Magnetic field

Analysis of magnetic flux density was performed in the same geometry as electric field. Both real-time and worst-case scenarios were simulated: in the first case, actual power of the interconnection during the on-site measurements was acquired from the SCADA system of the Hungarian TSO. This current has been set during the first part of the simulation to make data from measurement and calculation comparable to each other. Contrary to electric field strength, magnetic flux density increases with power or current. To gather worst-case results, simulation has been repeated for the current belonging to the nominal power of the transmission line; results for the first case are shown in Figure 6.

![2D representation of magnetic flux density results](image)

**Figure 6:** 2D representation of magnetic flux density results
As it can be seen from the colour map, even maximal values of magnetic flux density (0.40 µT) were below 0.5% of the limit. However, in this case, the current was about 30% of the maximal ampacity; it can be stated that even during worst-case conditions, no risk occurs from the aspect of magnetic field, either.

![Figure 7: magnetic flux density versus distance](image)

3. **Validation**

Several on-site measurements have been performed to prove the results of the simulations. Both electric and magnetic fields were analysed by the accredited instruments of the High Voltage Laboratory of Budapest University of Technology and Economics.

![Figure 8: on-site electric field measurement along the power line for validation](image)

An EMDEX-II High Field meter was used to gather data for further processing on PC. For the measurement itself, a grid has been prepared on the map. At each point of the grid, both electric field and magnetic flux density values were recorded. In pre-defined directions, these values were continuously logged and saved. From the numerous simulation and on-site measurement results, a comparison could be achieved between the two datasets.

Average accuracy for both cases was above 90%, which is an excellent result for validation. Figure 9 shows an example for on-site measurement results along the fence of the school. In this section, average electric field strength was 91.45 V/m, while the maximal value was 470 V/m. In the same section, average magnetic flux density was 164 nT; the maximal value was 395 nT.
4. Summary

In Hungary, strict limits are defined for both public and occupational exposures by law. However, all employers are instructed to analyze and assess risks related to non-ionizing radiations, in some cases, public exposures are in the focus of the interest.

As an educational facility with an accredited laboratory for exposure measurements, Budapest University of Technology and Economics is actively involved in the clarification of – often excessive – worries about the magnitude of strength and the health effects of extra-low frequency electric and magnetic fields [6], [7], [8].

However, the operators of high voltage and high current equipment are forced to keep the exposure values below their limits in all circumstances [9], [10], [11], [12], in special cases [13], [14], [15], upon request, some measurements and calculations are necessary for clarification, to prove design values.

In this case, neither public, nor occupational values were exceeded. The maximal electric field strength remained below 10% of the limit (470 V/m). Regarding to magnetic flux density, exposure was even less than 0.5% of the acceptable value (135 nT).

As this study introduces, even in such extreme arrangement, when an elementary school is located just in the surroundings of a high voltage power line corridor, no worries are necessary regarding to the health effects of E and H fields. Besides these results, some further recommendations were made (e.g. improve the grounding of the fence or take special care of the vegetation height to always keep the prescribed safety distances).

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