VERIFICATION OF MAGNETIC FIELD PREDICTION OF A 3D COMPUTER MODEL ON MV/LV SUBSTATION

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ABSTRACT

A 3D computer model has been developed for predicting magnetic fields in order to comply with legislation concerning safety and environment issues. The developed software, named "EMF-CS", allows the user to predict and simulate magnetic fields generated by electrical MV/LV substations whose magnetic field emission has to be evaluated inside the plant as well as in surrounding areas. The model allows the positioning of different electrical components, such as MV cells, bus bars and cables, LV cables and switches, and the whole plant can be shown with 2D/3D views. Once the model has been created, the software automatically makes a test of the electrical scheme, checking the agreement among data/equipment involved. The outcome can be represented numerically (charts) or graphically (profiles or isolines) and can be exported as a spreadsheet, ASCII or graphical format. The model has been applied to an Italian standard MV/LV substation supplied by a synthetic circuit in order to simulate a rated and stable power condition. Comparison between measurements and predictions outside the substation shows a good agreement. A significant overestimation is shown only near MV cells probably due to the metallic enclosure which shields the magnetic fields generated by MV circuits.

INTRODUCTION

Italian legislation about human exposure to electromagnetic fields is based on the Law No. 36/2001 "*Framework law on protection against exposures to electric, magnetic, and electromagnetic fields*" and the 08/07/2003 Decree "*Establishment of exposure limits, attention values, and quality goals to protect the population against power frequency (50 Hz) electric and magnetic fields generated by power lines*".

The Law No. 36/2001 establishes that the State must define the parameters for the creation of safety-zones (right-of-way) along power lines and assimilable plants like substation; within these safety zones no dwellings, schools, hospitals or other buildings where people spend a period longer than four hours a day are allowed.

The 2003 Decree establishes that in order to determine the right-of-way, reference shall be made to the quality goal of 3 μT for magnetic field, and to the electric current load under normal operating conditions of the line or the assimilable plant. The quality goal, to be applied on new buildings nearby existing electric plants and vice versa, was introduced by the Law No. 36/2001 with the purpose of progressively minimising exposures to electric and magnetic fields generated by 50-Hz power lines.

Within this framework the realization of new substations requires the calculation of the right-of-way meant as the volume within which the magnetic field is greater than 3 μT. Especially for substations realized inside buildings, where there may be safeguarded neighbouring places such as apartments or offices, the calculation of the right-of-way plays an important role in order to obtain the necessary authorizations by the competent authorities.

In this context, in order to answer to requests for evaluation of electromagnetic fields in compliance with both the requirements of environmental legislation applicable outside the substation, and the requirements laid down by the legislation on the protection of health and safety at work, applicable inside plants (Directive 2004/40/EC), a 3D software, named *EMF-CS*, for the prediction of the magnetic fields associated with substations has been developed.

The software *EMF-CS* has been developed in order to satisfy those requirements by using, as will be seen, an accurate forecasting model with a relatively simple and intuitive interface.

BIOT-SAVART LAW

The model is based on the 3D solution of the Biot-Savart law for each current $\boldsymbol{I}$ summing magnetic field vectors generated by each conductor as stated by the superposition principle.

$$\overrightarrow{d\boldsymbol{B}} = \frac{\mu_0 \boldsymbol{I}\overrightarrow{d\boldsymbol{L}} \times \overrightarrow{\boldsymbol{l}_r}}{4\pi r^2}$$

Where (see **Figure 1**):

$\overrightarrow{d\boldsymbol{L}}$ = infinitesimal length of conductor carrying electric current $\boldsymbol{I}$;

$\overrightarrow{\boldsymbol{l}_r}$ = unit vector to specify the direction of the vector distance r from the current to the field point.

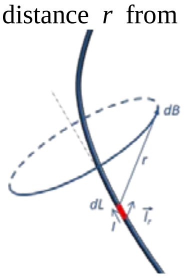

Figure 1 – Relationship between the magnetic field contribution and its source current element.

SOFTWARE DESCRIPTION

The software *EMF-CS* provides an approach similar to that of construction in bricks. The elementary "blocks", each of which represents a "category" of electrical components, are connected one to the other in an appropriate way. Three basic bricks have been identified for electrical MV/LV substations: the transformer brick, the MV switchgear, the LV switchgear and finally the electrical connections between different bricks.
The model of the substation is built by placing the various electrical components on the layout (see **Figure 2**).

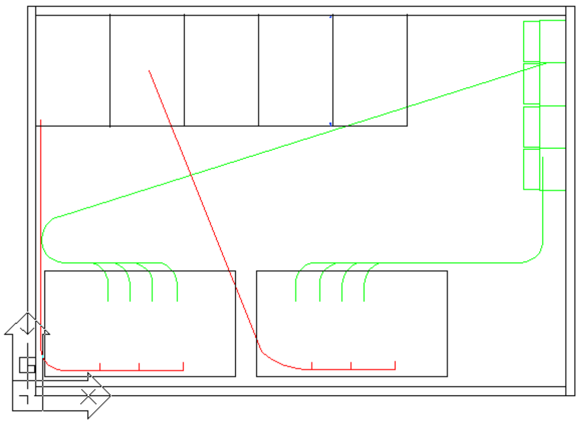

Figure 2 – Layout of a LV/MV substation.

The layout, in .dxf format, can be imported into the model in order to make the positioning of each component easier. The user can put different components on the layout choosing the right module from existing elements. Alternatively the user can build new elements by himself. Special functions and "pop up" menus help to combine, align, delete, rotate, position precisely inserted components.
Selecting one of the 3D view it is possible to see the dimensions of the components used, their status and internal circuits (see **Figure 3**).

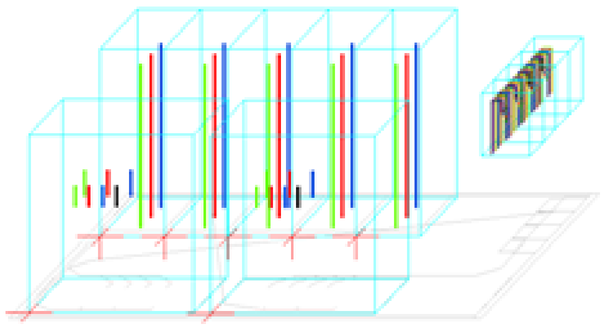

Figure 3 – Three-dimensional view of the dimensions and the electrical circuits of the components used.

The next step is the definition of connections by selecting the corresponding icon and cable type to be simulated. The software allows to draw the cables from the transformer to the respective LV and MV switchgear. Then it can be drawn paths of low voltage cables that go from the LV switchgears to their connections and medium voltage cables that enter to the substation and exit from it (see **Figure 4**). The software creates the multi-wire circuit model of the substation by selecting the main menu item. The operation is completely automatic: controls are planned and error messages or warning are displayed. The user can transpose, in any order, the phases of the electrical connections. At this stage currents in the various system circuits according to Kirchhoff's law are calculated.

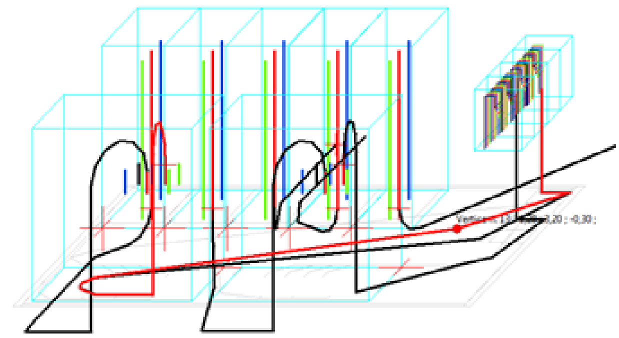

Figure 4 – 3D interface view with all the electrical connections.

Magnetic field calculation results can be displayed in numeric form (table of magnetic field at each calculation point) or graphic as magnetic field profile or isolevel curves in defined plane surfaces (see **Figure 5**).
Calculation results can be saved in *x*, *y*, *z*, *B* format for further processing and isolevel curves can be exported in .dxf format.

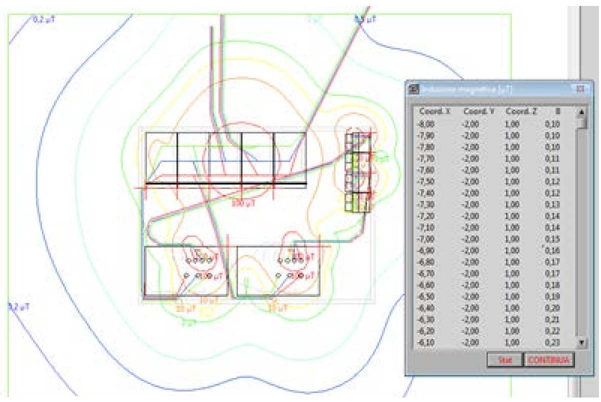

Figure 5 – Displaying calculation results in numerical form (table of the magnetic field values) and graphics (isolevel curves).

SOFTWARE VALIDATION

The software *EMF-CS* has been applied to an Italian standard MV/LV substation supplied by a synthetic circuit in order to simulate a rated and stable power condition.
The main features of the substation are (see **Figure 6**):

- three-phase transformer 15/0.4 kV 630 kVA;
- four low voltage switchgears;
- medium voltage air insulated switchgears.

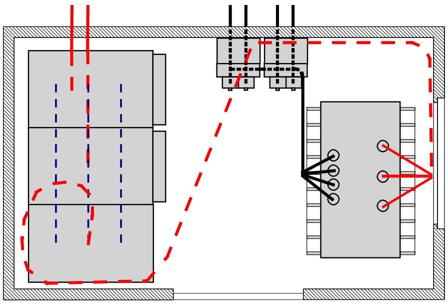

Figure 6 – Layout of the substation.

The substation was modeled with *EMF-CS* as shown in **Figure 7**.

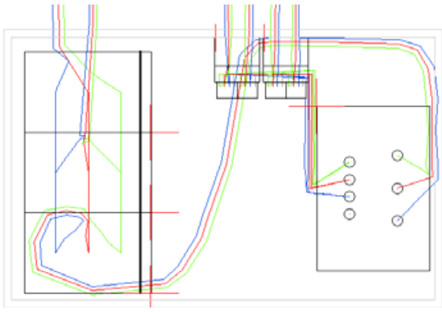

Figure 7 – Plan view of the substation as modeled by *EMF-CS*.

Magnetic field measurements were performed at 10 cm from the wall on the points of a grid (50 cm x 50 cm) drawn on each side of the substation by Emdex II (Enertech Consultants).
In the following figures (see **Figure 8**, **Figure 9**, **Figure 10**, **Figure 11** and **Figure 12**) comparison between measured and calculated field are shown. Comparison between measurements and predictions outside the substation shows a good agreement. A significant deviation is shown only near MV cells (see **Figure 9**).

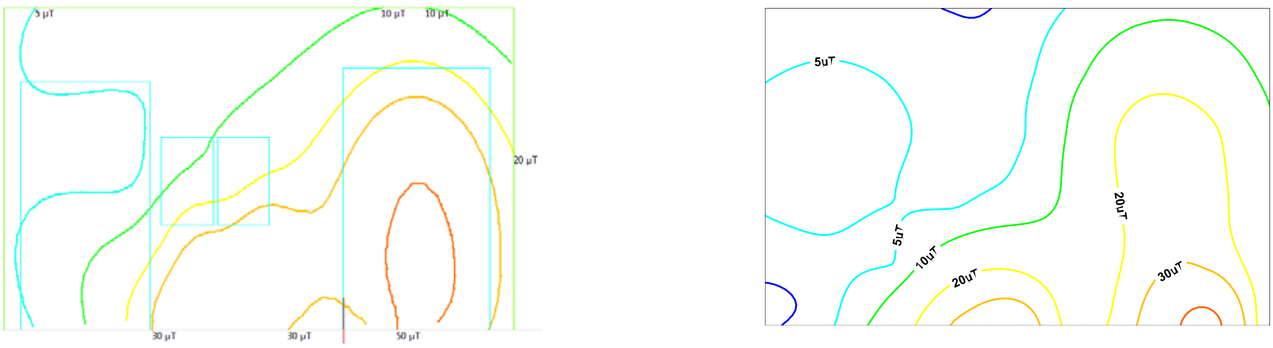

Figure 8 – Comparison of the magnetic field distribution on LV switchgear side. Left: calculations, right: measurements.

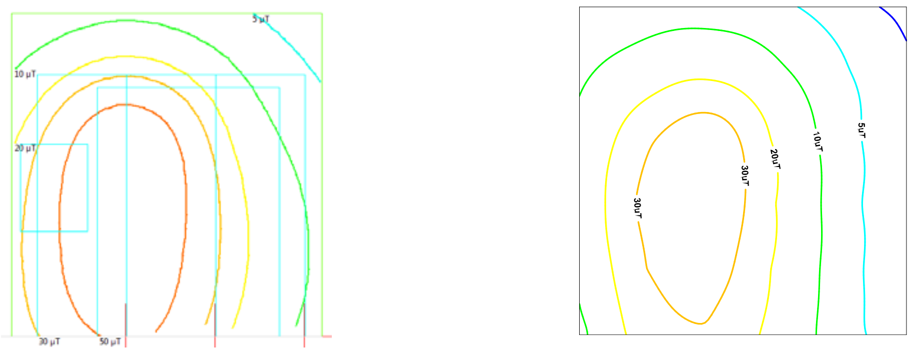

Figure 9– Comparison of the magnetic field distribution on MV switchgear side. Left: calculations, right: measurements.

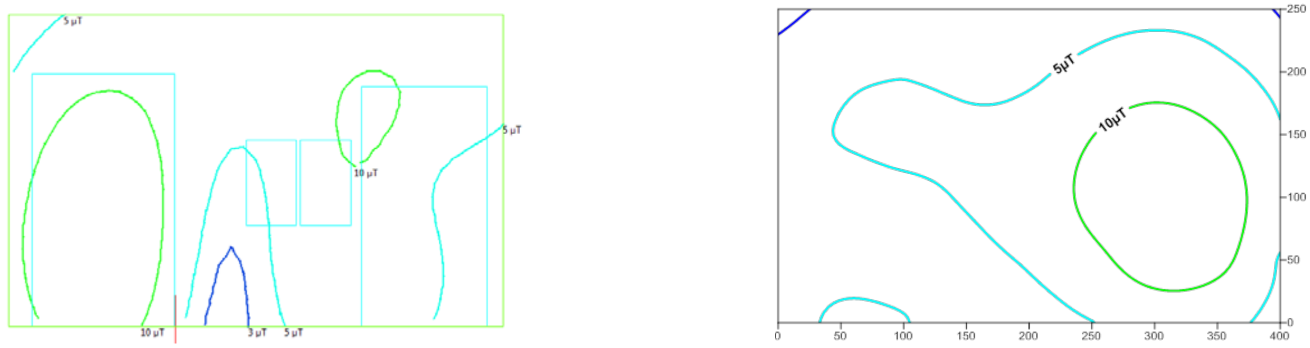

Figure 10 – Comparison of the magnetic field distribution on input door side. Left: calculations, right: measurements.

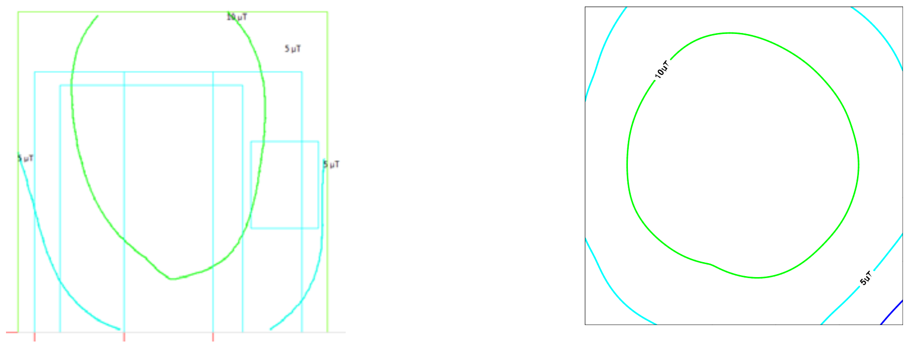

Figure 11 – Comparison of the magnetic field distribution on transformer side. Left: calculations, right: measurements.

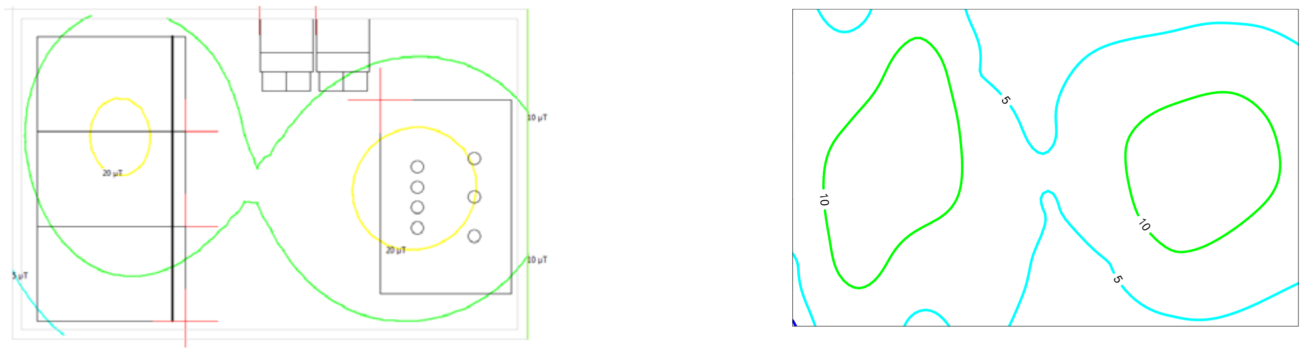

Figure 12 – Comparison of the magnetic field distribution on the substation roof. Left: calculations, right: measurements.

CONCLUSIONS

Main features of the software *EMF-CS* were outlined. The software is relatively simple and straightforward, especially for users who already have some experience with the interface of software engineering design.

Comparison between calculations and measurements indicates that the software overestimates the magnetic field in correspondence to some of the MV/LV substation sides. The major differences with reference to the maximum magnetic field value, were found on the roof and on the MV switchgear side.

In particular on the MV switchgear side, the magnetic field provided by the calculation code is almost twice that the one produced by the circuits of actual substation.

This gap, to be further investigated, is most likely due to the mitigation effect (mainly ferromagnetic and partially conductive) of the iron enclosures.

Finally, although developed for assessing the environmental aspects relating to magnetic fields, *EMF-CS* can also be used for the evaluation of exposure of workers to magnetic field inside substations.