ZERO MAGNETIC EMISSION SUBSTATION

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ABSTRACT

In this paper, models and results obtained from the study of the shielding system of a MV/LV substation of the local distributor are presented. The analysis takes into account the different sources of a typical substation of the local distributor.
Mitigation of magnetic fields can be done in various ways, for instance, the optimal design of sources and the application of active or passive shielding systems.
The aim of this study is to design a shield able to keep the value of magnetic flux density below 3 μT at no more than 0.5 m from the internal perimeter of the substation.
In contrast to the traditional application, in this case, is not designed a shield for the whole substation. Differently, it is designed one shield for each individual component of the substation. This allows, in most cases, to save shielding material having cheaper solutions.
The magnetic field generated by each component is modelled through a proper electromagnetic model that is also used to design the shield. For all the components the best shielding performance are obtained by employing a conductive shield. Following the successful outcome of the simulations all the shields have been built and tested in the laboratory obtaining good agreement with the simulations related to the design..
Finally, the proposed solution is installed on a real ZZA<MV/LV substation of the local distributor (in Turin). This activity proved the validity of the shielding solution because the mitigation goal is obtained.

INTRODUCTION

About population protection from exposure to electromagnetic field the European situation is not homogeneous [1]. A first differentiation can be made between nations that have voluntary instruments, as guidelines, recommendations, and states that have mandatory instruments as laws or decrees. A second division is made on whether the nations consider as a reference the limits defined by guidelines ICNIRP [2] or not. Due to these limitations the shielding of secondary electrical substations, i.e. MV/ LV substation, for reducing the magnetic fields generated is often required and is provided by passive [3,4] or active techniques [5].
In Italy there is about one hundred thousand MV/LV substation of the local distributor realized with the same standards and components:

- an oil transformers MV/LV with maximum power of 630 kVA;
- three low voltage switchgear consisting each one of two compartments;
- a medium voltage switchgear consisting of three compartments;
- low voltage three phase power lines composed of two conductor for each phase and other one for the neutral .

The aims of this paper is to show the results obtain from the study of a customized shielding system able to keep the magnetic flux density values below 3 μT at no more than 0.5 m from the internal perimeter of the substation.
In this work we want to emphasize the importance of a correct design useful to the reduction of the dimension of the shielding system and therefore for the reduction of the cost of the shielding materials and of the installation.

MODELS OF THE DEVICES IN MV-LV SUBSTATION

In this analysis, at first, it is required to compute the distance of compliance (DOC), that is, the minimum distance from the source for having field levels lower than a given threshold [6]. For these application the threshold is the Italian "quality limit" equal to of 3 μT.
The MV/LV substations of the local distributor are different than the classic users substation because they include special equipment designed for this application and therefore can not be used the standard models of the components.
In order to calculate the DOC without the shielding system the model of each component has been implemented.

Integral model of the oil transformer

The model of the oil transformer has been split into two sub-models:

Models of LV terminals/conductors

LV terminals and conductors can be accurately described by straight current carrying wires. They are placed in the barycenter of the related conductors so that the Biot-Savart law can be integrated along them leading to a closed analytical expression of the magnetic field [7]. It is worth noting that MV conductors can be introduced in the model with the same approach because they are independent from the voltage value. However, they are often neglected because they are close to the transformer and their low level of current generates a negligible contribution to the overall magnetic field.

Models of Primary and secondary windings

Primary and secondary windings are introduced in the model as massive coil with rectangular cross section.

Therefore, each transformer column is composed by two of these windings as shown in Figure 1. The geometry of the windings is obtained from the actual geometrical data (DMV , DLV and Dax) and, equal and opposite ampere turns (N_1I_1, N_2I_2) are injected in the relative windings.
The magnetic field of each column is calculated as is computed as explained in [6].

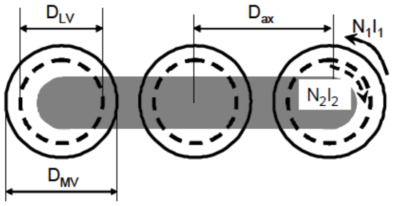

Figure 1 Characteristic geometric parameters for the evaluation of external magnetic fields

The metallic enclosure of an oil transformer is generally made of steel and it strongly affects the values of the magnetic field generated by the winding. In order to take into account this influence the shielding effect of the metallic enclosure is modeled by considering the magnetic properties of the material and by neglecting the possible eddy currents a shown in these references [8,9]. The influence of the metallic enclosure is then evaluated using a model for the computation of ferromagnetic shielding. The complete models of the oil transformer is show in Figure 2

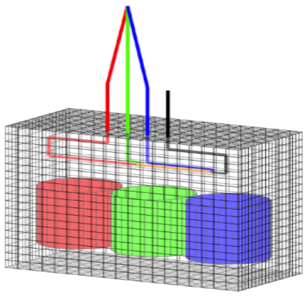

Figure 2 Transformer Model

Model of MV and LV switchgears

The approach used for MV and LV switchgears consists in building the geometry of the internal conductors, splitting them in several contiguous straight conductors, and applying the Biot-Savart law in order to calculate the magnetic flux density due to each segment [7].
An example of MV switchgear discretization is shown in Figure 3. The proposed model neglects the shielding effect of the metallic enclosure of the switchgear. A detailed analysis of the models is reported in [6].

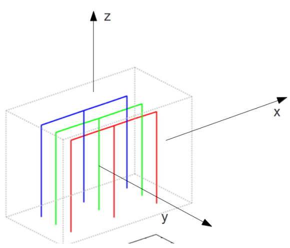

Figure 3 the 3D model of a three units MV switchgear

CALIBRATION OF THE SOURCES MODELS

Before showing the results of the study of shielding systems of each component is interesting to show the results obtained by the validation of computational models of the transformer that it is the hardest component to be modeled.
The magnetic field emission of a 630 kVA oil transformer 15kV/400V is investigated by means of measurements. Figure 4 shows the transformer under test with the LV terminals short-circuited by means of three massive conductors. The transformer is tested at its rated primary and secondary current.

Figure 4 Experimental investigation of the magnetic field emission of a 630 kVA oil transformer

The same configuration is analyzed with the proposed integral technique in order to verify its accuracy. In order to compare measurements and simulations, two inspection lines and one plane are considered as shown in Figure 5. They are both located at 1 m from the ground level and, particularly, Line 1 includes frontal and posterior points whereas line 2 is defined by some lateral points and the inspection planes is defined to compare the isolevel curves related to 3 μT and 10 μT (which are significant values in the Italian regulatory framework).

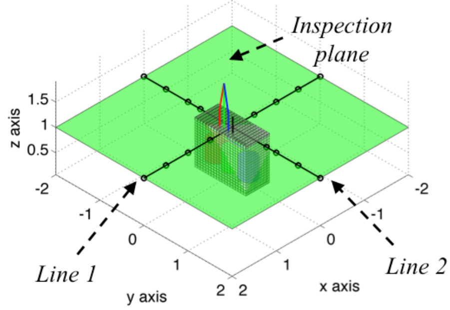

Figure 5 inspection lines and inspection plane.

Firstly, the model is calibrated identifying the relative permeability of the ferromagnetic material. The calibration is carried out by minimizing the error between simulation and measurement along the Line 1. Assuming a relative permeability (μ_r) equal to 550 a good result is obtained as shown in Figure 6. Moreover, the value of the identified permeability is in the correct order of magnitude for the commonly employed metallic material [10].

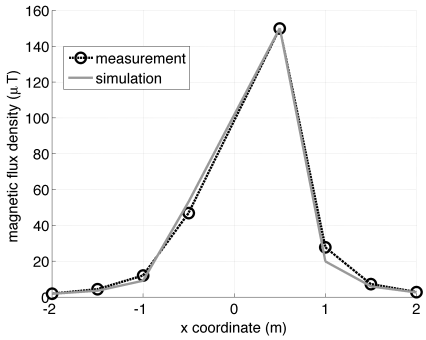

Figure 6 Measurement vs. simulation over the inspection line 1

The same value of μ_r is used for the other comparisons. In Figure 7 simulations and measurements along line 2 are shown. It is apparent that the model is still in good agreement with the measured values.

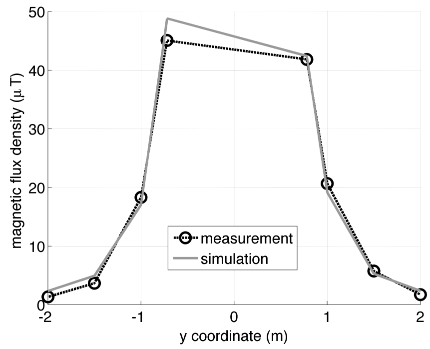

Figure 7 Measurement vs. simulation over the inspection line 2

Finally, in Figure 8 the isolevel curves related to 3 μT and 10 μT are shown. Thinner and wider lines correspond to simulations and measurements respectively.

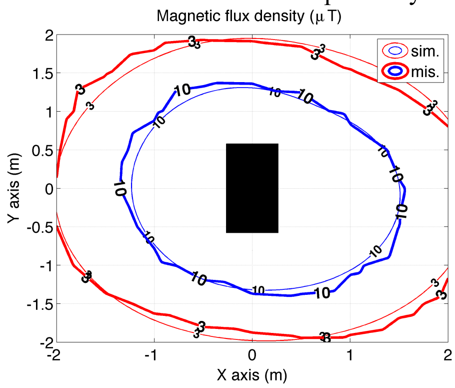

Figure 8 Results for the inspection plane: isolevel curves at 3 μT and 10 μT

The comparisons highlighted a good agreement between simulations and measurements allowing the use of this model for the design of the transformer shield.

THE SHIELDING SYSTEM

For each component listed before the design of the shield was carried out using a conductive material.

The simulations have been carried out using the models of the component described before. Moreover, the conductive shielding systems are designed using the PEEC method [11, 12]. For the sake of shortness in this paper only the results obtained for the shielding system of the MV/LV transformer and for the entire substation shielding system are reported.

Shielding system of the transformer

In the classical layout of a MV/LV substation of the local distributor the transformer is placed on a corner of the substation and so the shielding system have been designed in order to protect by magnetic fields generated on both external walls close to the corner. The values of the magnetic flux density have been calculated on the two different planes shown in Figure 9 (a) (x-z plane) and in Figure 9 (b) (y-z plane).

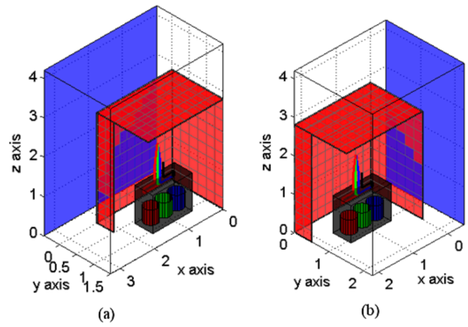

Figure 9 Layout of the shielding system (in red) with the computation planes (in blue): (a) x-z plane, (b) y-z plane

At first, the computation of the magnetic field generates by the transformer, without the shielding system, was performed. The results are presented in Figure 10 (a) for the x-z plane and in Figure 10 (b) for the plane y-z.

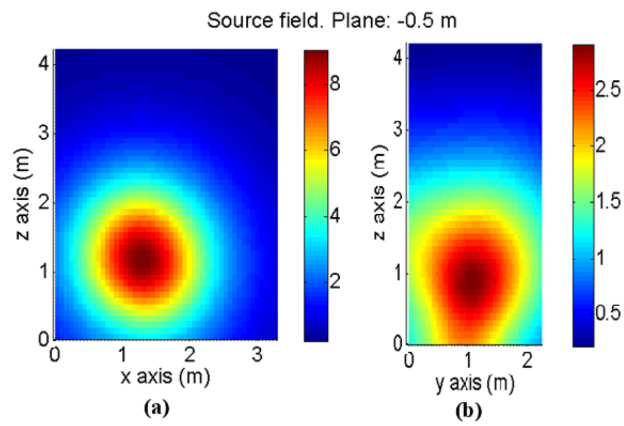

Figure 10 Field colored map in μT of the computed values of magnetic induction generated by the transformer on the x-z plane (a) and on the y-z plane (b)

With the shielding system the values of magnetic flux density is reduced as shown in Figure 11 (a) for the x-z plane and (b) for the plane y-z.

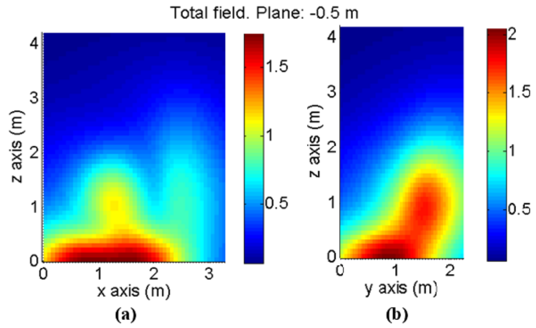

Figure 11 Field colored map in µT of the computed values of magnetic induction generated by the transformer on the x-z plane (a) and on the y-z plane (b) after the positioning of the shielding system

Shielding system of the entire substation

After the design of the shielding system for each components of the MV/LV substation, the simulation of the entire substation has been carried out. In Figure 12 it is shown the model of the entire substation with the shielding system of each component.

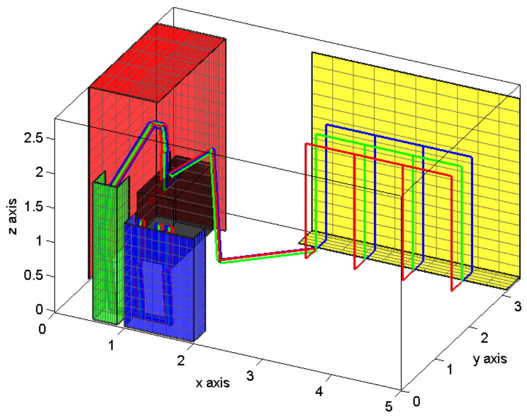

Figure 12 Layout of the substation, with the shielding system, used for the simulations

The results obtained on a plane x-y (with z equal to 1 m) without and with shielding system are reported respectively in Figure 13 and in Figure 14.

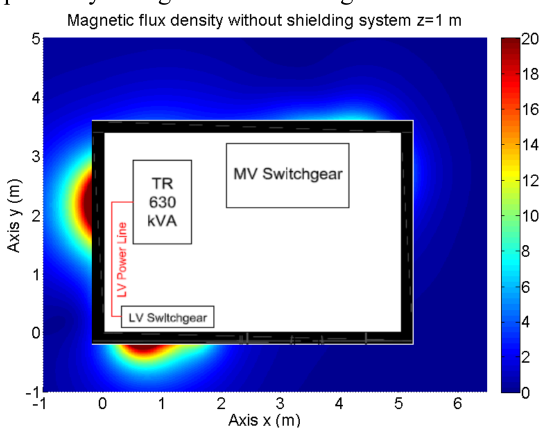

Figure 13 Magnetic flux density in µT calculate on a plane x-y with z equal to 1 without the shielding system

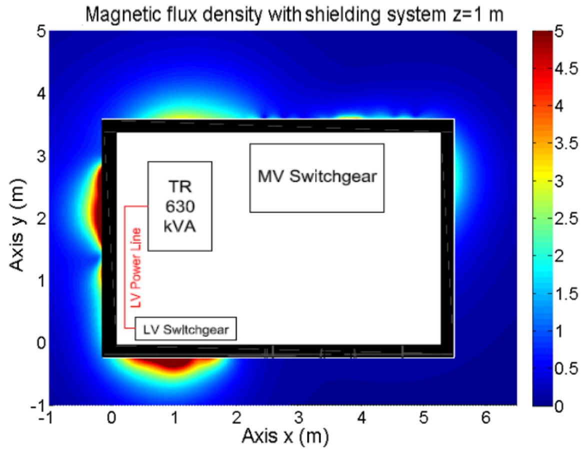

Figure 14 Magnetic Induction in µT calculate on a plane x-y with z equal to 1 with the shielding system

From the analysis of these results it is evident the efficiency of the designed shielding system but an experimental validation of the shielding performance has been provided.

REAL TEST OF THE SHIELDING SYSTEM

After the installation of the devices the MV/LV substation has been inserted in medium voltage ring and commissioning. The test of the shield has been carried out making the measurements of the values of the magnetic flux density all around the MV/LV substation. According to Figure 15 the measurements are referred to an x-y inspection plane located at z = 1 m. The measurement points are located on three closed paths obtained by offsetting the substation perimeter. The three offsets are 0.3 m, 0.5 m and 1 m. Along each path the point-to-point distance is 0.5 m.
The current of the MV ring and of the low voltage output of the transformer have been measured and saved in order to refer each measure of the magnetic flux density respectively at the rated current of the MV ring and of the transformer. The layout of the measurement point is shown in Figure 15. In the same figure five points are highlighted in red color to show where the goal (magnetic field lower than 3 µT) is not reached.
The critical points are in correspondence of the LV power lines and of the LV switchgears. After a careful analysis it was determined the reason of the difference from the computed and measured values. A measurement campaign highlighted an unbalance of the LV conductors. Particularly, the loading factor of one phase was 20% lower than the other two. As a direct consequence, the neutral conductor carries a current that influences the magnetic field distribution. After the identification of the problem, some simulations were carried out to identify the optimal transposition of the unbalanced conductors.

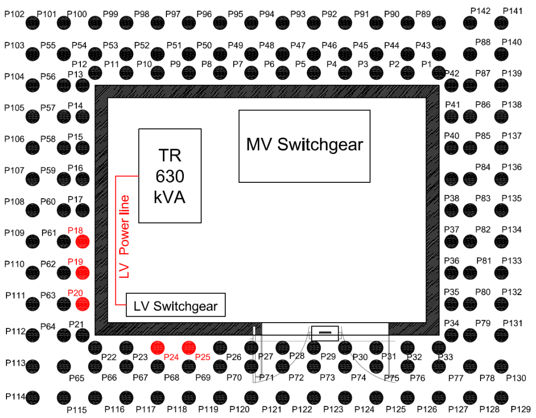

Figure 15 Layout of the measuring points with highlighted in red the points were the goal is not reached

In this paper we present the magnetic field distribution along a significant inspection line for the original unbalanced configuration and for an optimized configuration under unbalanced condition as shown in Figure 16.

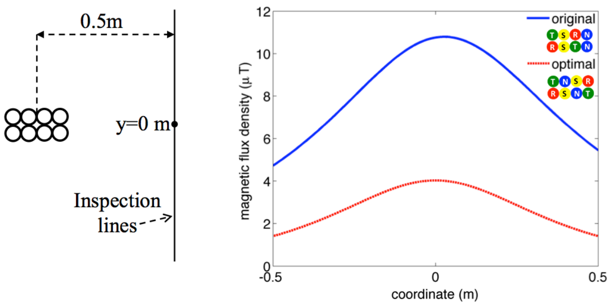

Figure 16 Classical and optimized configuration of a power line with current unbalance of 20%

This result shows that the optimal configuration is obtained when the barycenter of each phases are as close as possible. From the results presented in Figure 16 it is clear the influence of the unbalance in relation to the configuration of the line. Finally, since the optimal transposition was not sufficient, the shield of the LV switchgears was endowed of the small appendices to the lower and upper parts.

The improvements presented above have been implemented inside the substation and the measurements were again performed in all the points represented in Figure 15. These last tests verified the effectiveness of the solution because the magnetic flux density was below 3 μT at all the inspection points.

CONCLUSION

In this paper a customized shielding techniques for MV/LV substation of the local distributor is presented. The paper demonstrates that by using a shield for each component it is possible to obtain challenging results. In this paper the Distance Of Compliance is reduced at no more than 0.5 m from the internal perimeter of the substation.

The shielding system described above allows to reach the goal with a total cost of material between half to one third of the cost of a traditional shielding system. Moreover, the installation is also less expensive and faster (about 4 hours). In this case, since the paper deals with a standard substation, the proposed solution can be used to shield the majority of MV/LV substation of the local distributor using the same design. However, this principle can be applied to whatever substation layout provided that a proper design is carried out.

REFERENCES

[1] S. Kandel, ELF policies worldwide – protection of general public, in: WHO Workshop, 2007 June.

[2] ICNIRP, Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz–100 kHz), Health Phys. 99 (6) (2010) 818–836.

[3] H. San Segundo, V. Roig, Reduction of low voltage power cables electromag- netic field emission in MV/LV substations, Electr. Power Syst. Res. 78 (2008) 1080–1088.

[4] D. Bavastro, A. Canova, L. Giaccone, M. Manca, Numerical and experimental development of multilayer magnetic shields, Electric Power Syst. Res. 116, (2014) 374–380.

[5] J. C. del-Pino-López, L. Giaccone, A. Canova, P. Cruz-Romero, Design of active loops for magnetic field mitigation in MV/LV substation surroundings, Electric Power Syst. Res. 119, (2015) 337–344.

[6] Bavastro D., Canova A., Giaccone L., Manca .M (2013), Integral and analytical models for evaluating the distance of compliance, Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/jnm

[7] A.Canova, et al., 2005, Description of Power Lines by Equivalent Source System. COMPEL, p. vol. 24, pp. 893-905.

[8] L. Giaccone, D. Ragusa, M. Khan, O. Manca, Fast magnetic field modeling for shielding systems, IEEE Trans. Magnet. 49 (7) (2013) 4128–4131.

[9] L. Giaccone, C. Ragusa, Fast analysis of ferromagnetic shields by means of fixed point iterative technique, Phys. B: Phys. Condens. Matter 435 (2014) 96–99.

[10] Mitigation techniques of power frequency magnetic fields originated from electric power systems, Tech. Rep. Working group C4.204, CIGRE' (2009).

[11] F.Freschi, M.Repetto, A general framework for mixed structured/unstructured PEEC modelling, ACES J. 23 (3) (2008) 200–206.

[12] A. Canova, D. Bavastro, F. Freschi, L. Giaccone, M. Repetto, Magnetic shielding solutions for the junction zone of high voltage underground power lines, Electr. Power Syst. Res. 89 (2012) 109–115.