HOW TO CONTAIN ELECTROMAGNETIC FIELDS IN MEDIUM VOLTAGE SUBSTATIONS: EXPERIENCE IN DESIGN AND OPERATIONS

Attilio Cipollone
Acea Distribuzione S.p.A.– Italy
attilio.cipollone@aceaspa.it

Emilio Zendri
Acea Distribuzione S.p.A.– Italy
emilio.zendri@aceaspa.it

Chiara Consani
Acea Distribuzione S.p.A.– Italy
chiara.consani@aceaspa.it

ABSTRACT

The subject addressed by this paper is the analysis carried out by Acea Distribuzione, DSO in Rome (Italy), about the magnetic induction field emitted by secondary MV stations of the electricity distribution network and the techniques identified in order to reduce, as much as possible, magnetic induction in living environment surrounding these cabins.

INTRODUCTION

Acea Distribuzione is the local Distribution System Operator (DSO) managing the service provided to the customers set in the area of Rome. The company owns and runs the electrical networks by which it provides distribution service: high voltage network (150 kV), medium voltage network (20 kV) and low voltage network (400 V). Seventy primary cabins provide energy to MV network and, in turn, about 13,000 secondary cabins supply energy to the LV network and to large end users.

The secondary cabins are often located inside buildings; that implies that cabins are close (or in contact) to apartments, shops, workshops or other rooms in which people stay for many hours a day (see Fig.1).
Each cabin produces a 50 Hz magnetic field in all the space inside and outside the cabin itself. Italian law prescribes that the effective values of the magnetic field must not exceed the upper limits showed in table n.1.

Layouts of secondary cabins

The set of cabins now working have been built over the last four decade, according to technology and design rules developed at the time.

Figure 1 – Typical secondary substations in urban areas

In the year 2001 the outline law was issued (by Italian Parliament) about protection of population from exposition to electric and magnetic fields, produced by both high frequency (antennas, etc.) and low frequency (power transmission and distribution networks) sources.

TABLE I

DPCM 29/08/2003		
Pos.	Currently working MV substation	New MV substation
	(μT)	(μT)
1)	≤10	≤ 3

Table I – Median values of the magnetic 50 Hz field over 24 h, under normal operating condition, in sensitive areas (nursery, houses,….places where people stay more than four hours a day)

Up to that time no special rules regarding magnetic field emission were adopted in designing secondary cabins. For example, in the past, low voltage busbar systems were used for connecting the power transformer to low voltage panel; such systems were often located just under the ceiling of the room, hence very close to the rooms located above the cabin (see Fig. 2).

Figure 2 – Low voltage busbar systems under the ceiling of the room

In most cabins the electrical equipment is placed close to the walls of the room. In many cases walls separates the cabin from other rooms in which people live or stay for many hours a day; more than four hours is significant as long term exposition according to the mentioned general law. If the power transformer or the LV panel, or both of them, are placed near the wall, the magnetic field on the

other side could exceed the allowable limit. In order to set up new technical rules to realize new cabins, and modify or refurbish the old ones when necessary, in full accordance with law, the company decided to pursue two goals:

a) investigating the cabins in service from the point of view of magnetic field emissions, both through specific magnetic field measurements inside and outside the room and by calculating thanks to a specific 3D software and by modelling cabin power circuits and relative stated operating conditions;

b) implementing new design rules for cabins aimed to minimize the magnetic field produced by currents in the space outside the cabins themselves, by acting on the layout, mainly on the dimensions and the shielding of the room.

CABIN FIELD EMISSIONS

The DSO has carried out several measurements of magnetic field produced by the cabins in real operative conditions, in different hours of the day (and then different power transformer current intensities), different seasons, different layouts and, above all, at different points in the space inside and outside the rooms, often selected with regard to the characteristics of the space around (apartments, shops, etc.). Values greater than the upper limit of 10 µT (related to working MV substations) in the space outside were measured only in very few cabins. For such cabins refurbishing works were devised in order to confine, as far as possible, magnetic field and then "clear" the space outside.
The type of work depends on the specific cabin; for example, if equipment (LV panel, power transformer) is near to the end of its technical life, it can be renovated and also the layout can be modified. Otherwise, different measures must be adopted, usually consisting in shielding solutions.

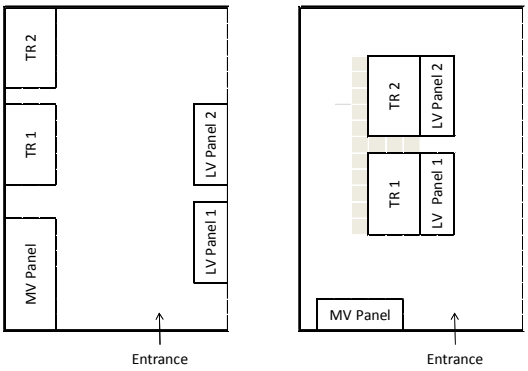

Figure 3 – Layout of both the traditional and optimized Cabin (case with two transformers)

Field emission modelling

The DSO has used a specific calculus software [1] to model the magnetic induction field produced by the currents into conductors and transformer windings. The software allows the planner in making predictions about the values of magnetic field produced in each point of the space, both inside and outside the cabin. The software is based on the application of the well-known Biot-Savart law, which states that the elementary contribution of the current **i** flowing into the conductor of infinitesimal length $\mathbf{d\vec{l}}$, located at point $\vec{\mathbf{r}}'$, to the magnetic field at point $\vec{\mathbf{r}}$, is given by:

$$d\vec{B} = \frac{\mu i}{4\pi} \frac{d\vec{l} \times (\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3}$$

The value of the magnetic field $\vec{B}$ at a specific point $\vec{\mathbf{r}}$ is obtained by adding all the elementary contributions coming from all the conductors in secondary cabin (three-phase system, plus neutral conductor on LV side).

Furthermore, the software makes it possible to simulate the effects of shields made of conducting materials (typically aluminium) or magnetic material, or compound materials.

The software contains a collection of typical standard arrangements considering different layouts of equipment and conductors (or insulated cables) connecting power transformer to LV panel and MV switchgear to power transformer. The planner can thus investigate the field produced by standard cabins or he can even "picture" special layouts, connections, shielding arrangements, etc.

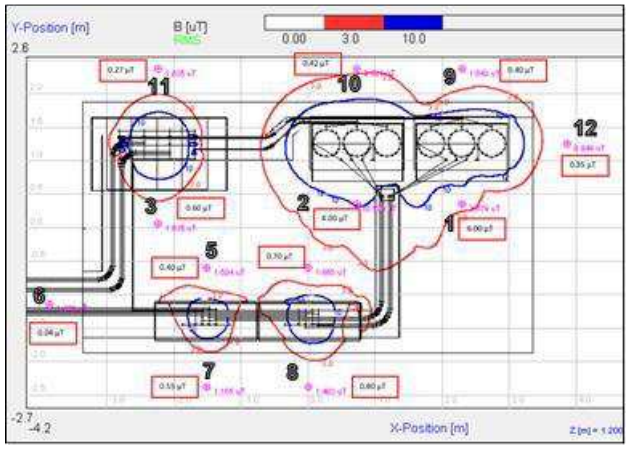

Figure 4 – Simulation of magnetic fields in the traditional configuration (actual operation load)

Once the cabin under investigation has been represented from the geometrical point of view, it is necessary to defines the current intensities in each conductors: MV cables, power transformer, LV cables, etc.

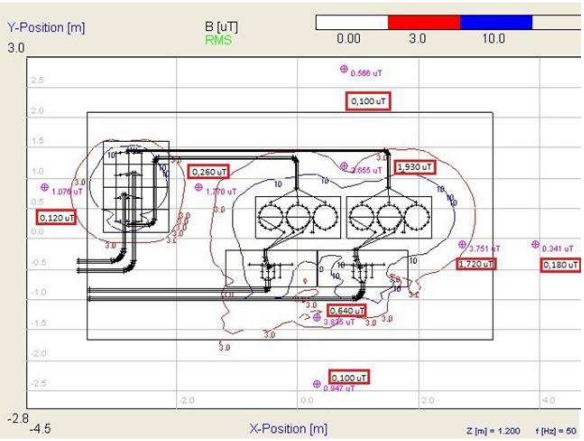

Figure 5 – Simulation of magnetic fields in the optimized configuration (actual operation load)

In particular, different operative conditions of the networks has been considered. Two conditions are mainly interesting:

(a) normal conditions;
(b) full load condition.

PROBLEMS AND SOLUTIONS

By using the software described above, in the case of new plants, it becomes easier to find the equipment arrangement that minimizes the magnetic field emissions outside of the cabins and evaluate the effectiveness of any shield on the walls or ceiling or near single equipment.
Figure 3 shows the layout of a Secondary Cabin with traditional arrangement (left) and with the optimized one in order to reduce electromagnetic fields (right).
Figures 4 and 5 show the corresponding results concerning magnetic induction.
Figures above show 10 and 3 μT isolines as resulting from the calculation (actual measured values in rectangles).

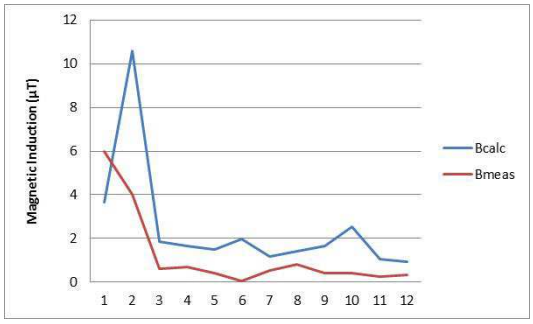

Figure 6 – Comparison between the actual measured values and those calculated (equipment in traditional configuration, refer to Fig. 4)

Figure 6 shows the comparison between the actual measured values and those calculated.

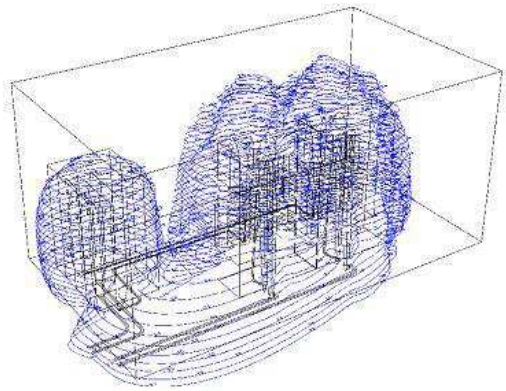

Figure 7 – Spatial trend 10 μT isolines (equipment in the optimized configuration and actual operation load)

Figure 7 shows the spatial trend 10 microtesla isolines for the cabin with equipment in the optimized configuration and loaded under normal operating conditions.

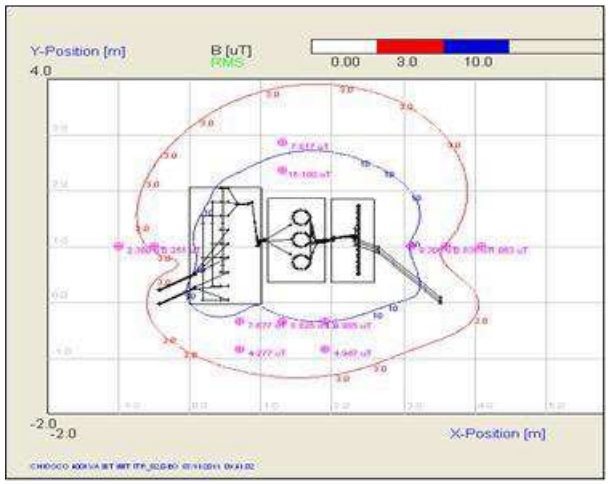

Figure 8 – Trend isolines (10 and 3 μT) in the absence of a shield in a Secondary Substation

Figures 8 and 9 show the trend isolines (10 and 3 μT) in the absence of a shield and with shield (aluminium foil, thickness 5 mm, see Fig. 10) placed on the walls, ceiling and on the doors.

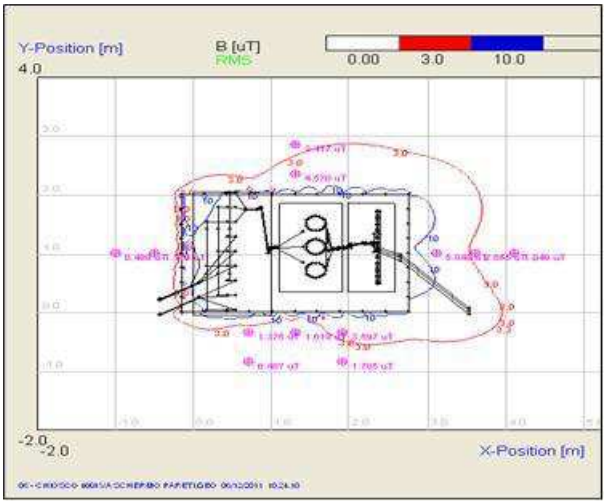

Figure 9 – Trend isolines (10 and 3 µT) with a shield (aluminum foil, thickness 5 mm, on the walls, ceiling and on the doors), comparison with the Fig. 8

The analysis about the secondary substations in operation investigated the effects of the optimization deriving from the different arrangements of the output cables from LV transformer bushing (which is one of the main sources of electromagnetic field, see Fig. 11) to the LV panel.

Figure 10 – Type of shield used in Fig. 9 and secondary substation

The effectiveness of the local aluminum box shields and/or ferromagnetic material has also been investigated.

Figure 11 – LV cables, connecting the power transformer to the LV power panel in optimized configuration (n. 3 multipolar cables (RST + N) per phase)

Figure 12 shows two different types of shields developed: the first interesting only LV transformer bushings (aluminum plate, 3 mm thickness); the other interesting LV and MV transformer bushings (aluminum plates, 2 mm thickness, interposed with a steel plate 1 mm thickness).

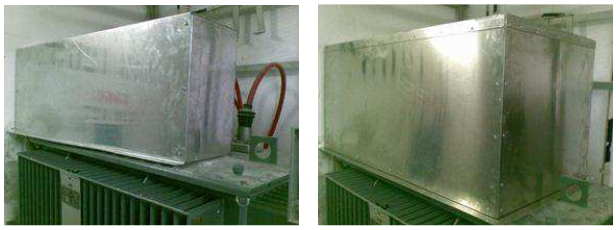

Figure 12 – Aluminum shields for LV and for (MV + LV) bushings on the transformer

Figure 13 shows a shield made of ferromagnetic material (two sheets of aluminium (thickness 2 mm and 1 mm) with an interposed plate of Magnitech (ferromagnetic material, thickness 0.4 mm).

LV cables leaving from the transformer to the LV panel were inserted into tubes made of the same ferromagnetic material.

Table II shows the measurement of magnetic induction field carried out in the Secondary Substation whose layout is shown in Fig. 14 according to the various configurations set out (see Fig. 11, 12 and 13).

Figure 13 – Ferromagnetic shield for LV bushing and ferromagnetic tubes for LV cables connecting transformer and LV panel

The analysis points out, as easy and effective solution to reduce the values of the field, the installation of local shield in aluminum on the LV transformer bushing.

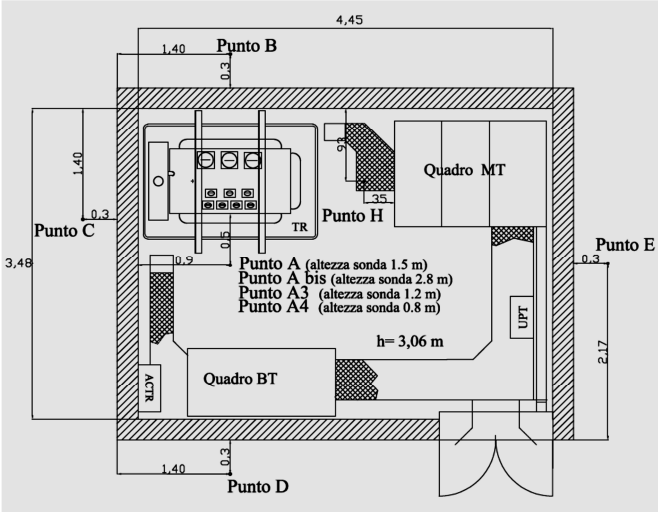

Figure 14 – Layout of the cabin submitted to measurement with the points investigated (see Table II for the values and comparison)

The optimization of the configuration of the phases described above will reduce the field in the space close to the LV path cables.

TABLE II

Measurements of magnetic induction field (μT)					
Measuring point (height)	LV cables in the initial set-up	LV cables in the optimized set-up	Aluminium Shield on LV TR bushings	Aluminium Shield on (LV +MV) TR bushings	Ferromagnetic Shield on LV TR bushings
A - 1,5 m	43	43	22	25,4	23,9
A_{bis}, - 2,8 m	87	5,65	2,06	2,49	3,68
B - 1,1 m	3,94	3,34	1,69	1,5	1,32
C - 1,1 m	3,4	2,8	2,28	2,03	1,66
D - 1,1 m	4,3	5,7	4,2	4,02	4,2
E - 1,1 m	0,45	0,5	0,46	0,38	0,5
NB: Transformer MV/LV: 630 kVA; 8,4/0,23 kV; I_{LV}(average value): 400 A					

CONCLUSION

When you need to design a new secondary substation placed into buildings of civilian housing is possible, by using the calculation model developed, evaluate the magnetic induction field and minimize the values in sensitive areas with appropriate equipment positioning.

The main sources of the field are the transformer LV bushings and LV cables typically coming out the local cabin.

They should be placed far from sensitive areas as much as possible.

In case you do not get values respectful of the law, or in case of interventions in currently working secondary substations, specific expedients, such as arrangement of the phases of the cables coming from the transformer or a specific shield for each of the field sources, may be used.

Shield boxes of conductive material (aluminum) of a thickness max 5 mm are lightweight, inexpensive and effective to break down the values both in the proximity of the source and outside.

Shields made of ferromagnetic material are more expensive and suitable to break down the values of the magnetic field near the sources.
For both types, it is also necessary to design appropriate geometries (location, shape, size).

Only if all these devices and arrangements are still not sufficient to reduce emissions, it becomes necessary to shield the walls and the ceiling of the cabins.

For currently working secondary substations, however, the analyses described and the measurement campaigns carried out suggest that, not many cases, outside the cabins, can manifest critical situations under load levels normally found in transformers.

For new substations, as it is necessary to perform assessments with equipment working at full load, critical situations could be manifested and they can be treated as described above.

REFERENCES

[1] Software Narda EFC - 400LF