ACTIVE AND PASSIVE SHIELD FOR AERIAL POWER LINES

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ABSTRACT

The work presents a procedure to optimise a mixed passive and active shielding. The shielding concerns a building in proximity of a high voltage overhead line. This condition often arises in the reality. For Italian legislation, if the building is located at a distance that does not guarantee the respect of the limits on the magnetic flux density, the use of such building is not authorised for stays longer than 4 hours per day. In the case of overhead lines, the line operator can install a shielding acting directly on the source at the cost of difficult and expensive modifications to the pylons. The most feasible solution is to perform a shielding of the building which is generally passive and very rarely active. The selection of one or the other type of shielding is generally linked to factors external to the purely technical ones. This paper presents an optimised design of a shielding based on the use of both technologies. The search of the optimal condition has been based on performance parameters not considering cost constraints. The work presents two study cases characterized by different distances of the building that has to be protected from the power line.

INTRODUCTION

The current legislation on protection from exposure to electromagnetic field (EMF) inside and outside the European Community is not homogeneous. In the EU the Council of the European Union published in 1999 a Recommendation (1999/519/EC, commonly known in the field jargon as “the Recommendation”) on the limitation of exposure of general public to EMF (from 0 Hz to 300 GHz). The Recommendation contains the reference levels for the strength of EMF at the various frequencies [1]. The limits in both the Recommendation and the related Directive are derived from the 1998 Guidelines for limiting exposure to time-varying EMF by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [2]. ICNIRP has published new guidelines for EMF at frequencies between 1 Hz and 100 kHz in 2010, but these have not yet led to changes in EU legislation [3]. Since the Recommendation is not legally binding, the EMF policy can vary among member states. However, it is possible to individuate three different groups of countries adopting similar approaches [4].
In the first group of member states, the Recommendation has been transposed in binding national legislations. This means that the *basic restrictions* and the *reference levels* provided by the ICNIRP Guidelines must be directly adopted as national reference limits. The member states of this group are Czech Republic, Estonia, Greece, Hungary, Luxembourg, Portugal and Romania. In the particular case of Germany and Slovakia, the reference levels of the Recommendation are applied without any reference to the basic restrictions.
In the second group of member states, the national limits based on the European Recommendation or ICNIRP Guidelines are not binding and the limits are less stringent or there is a lack of precise regulations. Member states in this group are Austria, Cyprus, Denmark, Finland, Ireland, Latvia, Malta, Netherlands and United Kingdom.
Only in some of these countries a precautionary policy has been adopted and it has been suggested to electricity companies which can voluntarily conform.
In the third group of member states, there are restrictions stricter than the ones directly provided by the Recommendation on the base of the precautionary principle that aims to protect people from possible long-term effects. Among these countries one can find: Belgium, France, Italy, Netherlands, Poland, Slovenia, Serbia, Sweden and Switzerland.
In the present paper, the attention is mainly devoted to Italy where the basic limits for magnetic flux density are identical to the reference levels in the Recommendation but an *attention value* of 10 μT is applied to the exposure for periods longer than 4 hours in homes, hospitals, playgrounds and schools built before 2003 and a *quality goal* of 3 μT is applied to the same category of constructions built after 2003. The same restrictions are imposed also for the construction of new power lines, primary or secondary substations close to residential areas.
In countries, like Italy, where magnetic induction limits are particularly low, it often happens that buildings located near to electrical sources require the installation of mitigation systems such as passive or active shields in order to be compliant with the legislative limits.
The solution to this problem can present many difficulties. The presence of openings such as doors and windows has to be taken into account and it may compromise the effectiveness of the shielding. Furthermore, the installation of the shielding solution is more complicated if it has not been carried out during the construction of the building and a retrofit operation is required. Another kind of problems, the one mainly addressed in the present work, occurs when the distance of the building from the power line is at the same order of magnitude of the distance between the different phase conductors. In these cases, the shielding effectiveness, in particular when considering conductive passive shiels, may be compromised.
The present work focuses on this issue presenting a

methodology for the optimal design of shielding systems coupling active loops and passive shields applied to buildings located in proximity of an overhead line. The methodology is applied to two particular case studies and the results are presented and discussed.

SHIELDING MODELLING

The mitigation system proposal chosen in the present work is a mix of passive and active shielding systems. As discussed in [5] and [6], the coupling of passive and active shielding strategies can improve the global mitigation performances. The two shielding methods are briefly introduced and the design choices in terms of materials and layout are presented in the following.

Passive shield

The use of passive shielding for magnetic fields (MFs) mitigation is the most commonly adopted solution. For what concerns the choice of the shield material, there are several possible choices. However, in real applications, this choice is strongly limited by the material cost that is one of the most significant constraints. Another important issue is represented by the architectural constraints that force the design of the shielding solution. All these limitations have to be taken into account during the design and the optimisation procedure.

Many papers and technical reports address the issue of passive shielding and in some countries, such as Italy, the reduction of the magnetic field by means of passive shielding is currently a common standard practice for the protection of population or devices [7], [8]. In the last years, the automated and optimised design of passive screens has been developed and presented in some papers [9]. Regarding the shielding materials, it has been proven that the use of multilayer (ferromagnetic and conductive) screens allows excellent performances but they work optimally if they can be installed close to the sources [10], [11]. On the contrary, they are less efficient if the distance of the source is significant as in the case under exam in this work.

According to the above-mentioned reasons, a purely conductive passive shield made of aluminium has been considered in the optimization procedure.

Active shield

A solution for a strong mitigation of the extremely-low-frequency (ELF) magnetic field consists in the use of active shielding systems [12], [13]. This mitigation technique consists in the use of a single or a plurality of coils supplied by a set of alternating currents, controlled in magnitude and phase, that generates a magnetic field that is in opposition with the one generated by the source. This technique has shown to be useful for the reduction of the MF in wide areas close to overhead power lines [14], [15], for the mitigation of MV/LV substations [16] and also for some industrial applications [17].

Clearly, in the active shielding, the need for an external power supply increases the complexity of the system in comparison with other mitigation techniques. This aspect is also strictly related to the shape and the positioning of the loops that have to be much more precise in comparison with the passive shielding counterpart.

Furthermore, the active mitigation systems require a controller that has to be able to guarantee the optimal compensation also in presence of possible variations on the loading conditions of the MF source. A low-cost technical solution for the mitigation of power lines and substations based on an active shield has been presented by the Authors in [16].

SOURCE AND VICTIM CONFIGURATION

The configuration under analysis is shown in Fig. 1 and it consists of a building placed in parallel to a three-phase overhead power line. The characteristics and the dimensions of power line and building are reported in Tab.1 and Tab.2 respectively. The volume for which is required the MF mitigation is inside the building and is named *protected area.* The overhead power line assumes the typical catenary curve shape where the maximum height of the conductors (h_1) is equal to 15 m while the minimum height (h_2) is equal to 7 m. The axis of the line lies along the *x* axis. The distance of the centre of the building from the axis of the line is equal to 20 m in a first case study configuration and 30 m in a second one. In the first case study, the building is totally included within the distance of compliance of the power line related to the limit of 3 μT, while in the second case it is only partially inside. The distance of compliance is shown in Fig. 2.

Tab. 1. Characteristics of the overhead power line

Span (m)	Conductors' distance (m)	Rated current (A)	h_1 (m)	h_2 (m)
200	4	2000	15	7

Tab. 2 Dimensions of the building and the protected area

Dimension	Building	Protected area
along *x* (m)	16	16
along *y* (m)	10	9
along *z* (m)	6	5

OPTIMISATION PROCEDURE

The adopted optimisation procedure and its related coded algorithm have been here expressly developed in order to consider the simultaneous presence of a passive shield and two active loops. However, the same procedure can be also applied by considering only one of the shielding methods at a time.

The passive shield and the loops are placed on different planes as shown in the scheme sketched in Fig. 3. Fig. 3

also shows the geometrical parameters used in the optimisation procedure. The bottom edge of the L-shaped passive shield is maintained fixed in the space as well as its size along the *x* direction and its thickness (fixed at 3 mm) while the extensions along the *y* and *z* axes (i.e. the variables Δy and Δz) are the two optimization variables.

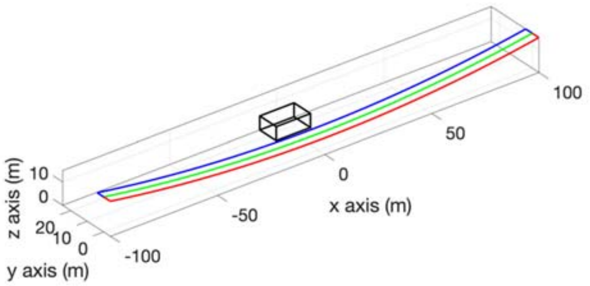

Fig. 1 Configuration of building and power line.

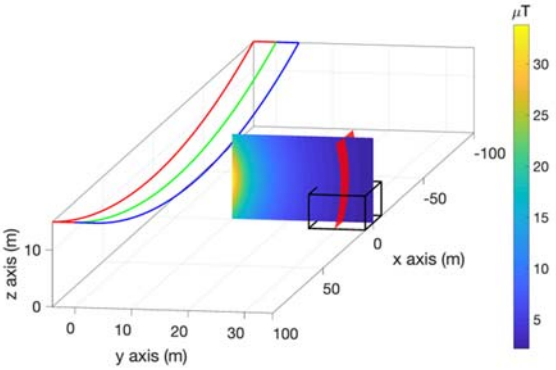

Fig. 2 Distance of compliance at *x=0* in the plane *y-z*. The red surface represents all the points at 3 μT.

For what concerns the two active loops, only their distance from the building is fixed while their shape and the position in the respective plane is free to change. Shape and position are controlled by using the cartesian coordinates of two opposite vertexes.

The adopted constraints are chosen in a way to represent limits that can be found in real applications. For example, in the case of the active loops, the maximum dimensions are chosen considering that brackets fixed to the building will support the loops. According to this, the maximum extension of the loops has been chosen considering a maximum practical length of the supporting brackets equal to 1 m (i.e. none of the loop edges can exceed a limit distance of one meter from the building walls).

In presence of the active loops, together with the geometrical properties, the optimisation process sets the magnitude and the phase of the currents flowing into each loop.

The goal of the optimisation is the minimization of the average value of magnetic flux density evaluated on a grid of points inside the inspection volume (i.e. the protected area). The choice of this evaluation criterion has been deeply treated in [11].

The optimisation is carried out by means of the use of two optimisation algorithms.

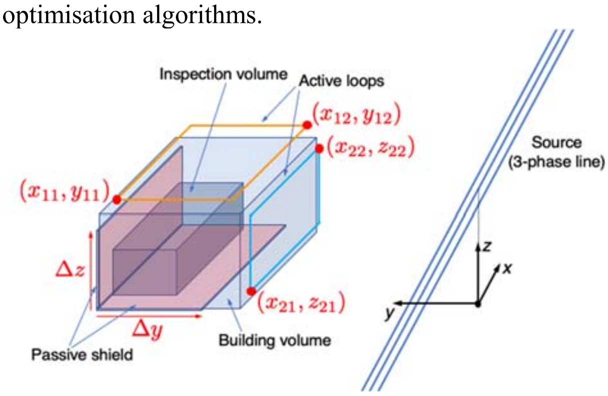

Fig. 3 Scheme of the case study. In red are indicated the geometrical optimization variables.

In the first instance, the optimal configuration is searched by using a genetic algorithm (GA) encoded by using a binary representation on which each variable is represented on 16 bits. This algorithm starts with a randomly selected initial population of 20 individuals. A refinement of the solution is then searched by using a pattern search algorithm that moves from the best-fitting individual resulted from the GA run.

OPTIMISATION RESULTS

Case 1

In the first case study, the building is considered placed at a distance of 20 m from the overhead power line axis. In this case the magnetic flux density inside the building is over the limit of 3 μT at all points (Fig. 4). In particular, in the area close to the power line, the magnetic flux density is slightly over 11 μT.

A first optimisation design considering the presence of the only active loops has been carried out and the resulting performances can be seen in Fig. 5. The magnetic flux density results significantly reduced inside the inspection volume and a higher level of about 6-7 μT is reached uniquely at the borders of the volume. These results are improved if also the presence of the passive shield is considered as shown in Fig. 6. However, it is not possible to avoid points at the borders of the inspection volume for which the goal of 3 μT is not exceeded. The parameters resulted from the two optimisations are reported in Tab. 3.

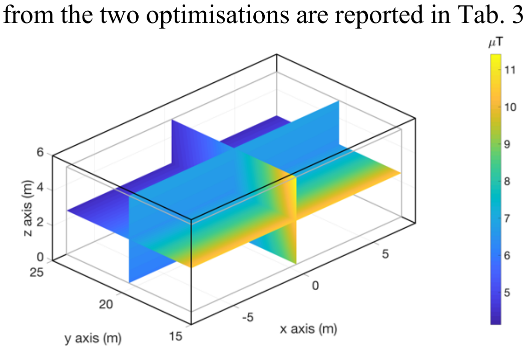

Fig. 4 Colourmap of the magnetic flux density inside the protected area without shielding (case study 1).

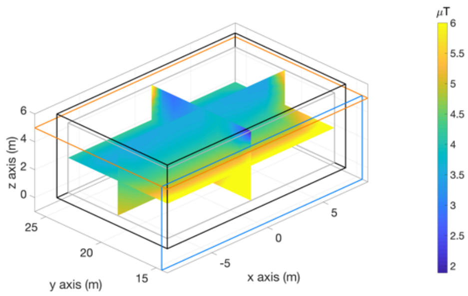

Fig. 5 Colourmap of the magnetic flux density inside the protected area with only active loops (case study 1).

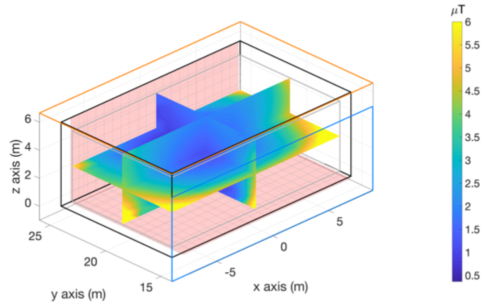

Fig. 6 Colourmap of the magnetic flux density inside the protected area with active loops and passive shield (case study 1).

Tab. 3. Optimised shielding parameters of the case study 1

Parameters	**Only active loops**	**Active loops and passive shield**
x_{11} (m)	-8.96	-8.98
x_{12} (m)	8.86	8.99
y_{11} (m)	14.13	14.14
y_{12} (m)	26.00	25.97
z_{11} (m) = z_{12} (m)	5.73	6.97
x_{21} (m)	-8.95	-8.74
x_{22} (m)	8.96	8.58
z_{21} (m)	-1.00	-0.96
z_{22} (m)	5.01	5.13
I_1 (A)	37.30	75.39
ϕ_1 (rad)	0.01	0.00
I_2 (A)	79.9	62.9
ϕ_2 (rad)	5.46	5.43
Δz (m)		7.58
Δy (m)		5.73

Case 2

In the second case study the building is located at 30 m from the overhead power line axis. As shown in Fig. 8, the magnetic flux density inside the inspection volume exceeds the limit of 3 μT at the borders closer to the power line. Also in this configuration, a first optimisation design considering only the active loops has been carried out and the obtained performances can be observed in Fig. 9. As can be seen, the compliance with the limit of 3 μT is already reached practically in the whole inspection volume by using the only active loops. As shown Fig. 10, this performance is even improved if also the presence of the passive shield is considered. In this case the passive shield helps to have a higher reduction of the magnetic field in the area close to the passive shield itself.

The resulting parameters from the optimisation are reported in Tab. 4.

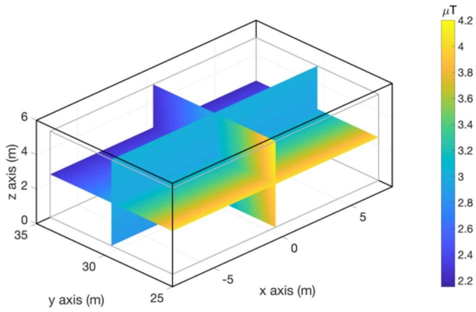

Fig. 8 Colourmap of the magnetic flux density inside the protected area without shielding (case study 2).

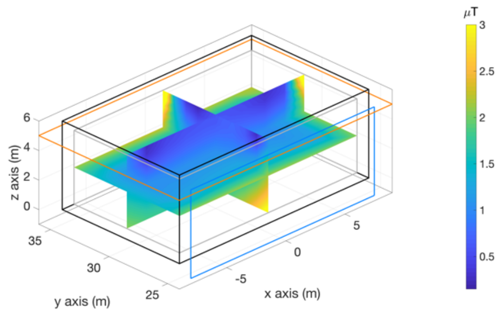

Fig. 9 Colourmap of the magnetic flux density inside the protected area with only active loops (case study 2).

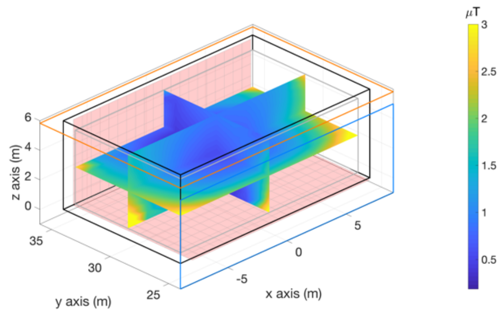

Fig. 10 Colourmap of the magnetic flux density inside the protected area with active loops and passive shield (case study 2).

CONCLUSIONS

This paper has shown an optimised design procedure for a MF shielding system based on a passive conductive shield and two active loops. In particular this procedure has been applied to the case of a building exposed to the magnetic field produced by a near overhead power line that represents a standard configuration that is often encountered in the reality.

The results of the paper have shown that the contemporary presence of both mitigation solutions can represent a valid shielding method especially when the building that has to be protected is located in proximity of the source. In this case the use of active loops can provide a strong mitigation of the magnetic field in the volume surrounded by the loops. The addition of a passive shield can contribute to improve the mitigation in the regions of the volume that are close to the shield itself. This demonstrated that the use of active loops together with the more standard passive shields can represent a valid option especially in presence of possible openings as windows or doors that can make the use of the screens unfeasible.

Future work will aim to investigate the possibility to use a combination of passive shields and active loop also on the same planes by developing a dedicated optimization procedure for the design.

Tab. 4. Optimised shielding parameters of the case study 2

Parameters	Only active loops	Active loops and passive shield
x_{11} (m)	-9.00	-8.90
x_{12} (m)	8.99	9.00
y_{11} (m)	24.23	24.55
y_{12} (m)	35.85	35.72
z_{11} (m) = z_{12} (m)	6.92	7.00
x_{21} (m)	-7.11	-8.83
x_{22} (m)	7.01	8.70
z_{21} (m)	-0.54	-0.94
z_{22} (m)	6.32	5.18
I_1 (A)	42.2	37.7
ϕ_1 (rad)	5.49	0.00
I_2 (A)	5.6	15.9
ϕ_2 (rad)	5.79	4.69
Δz (m)		9.82
Δy (m)		5.19

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