**ELECTROMAGNETIC ENVIRONMENT MANAGEMENT OF SUBSTATIONS**

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***Summary***

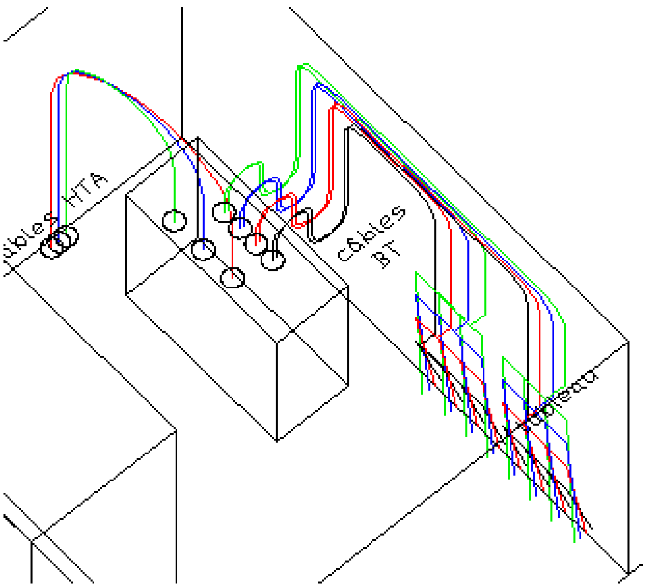
*In the vicinity of electricity distribution substations (HV/MV and MV/LV), the magnetic field levels found, no matter how weak, are likely to cause interference on computer screens. A knowledge of the magnetic environment of these installations, modelling tools and the development of "key in hand" solutions enable the best technical solution to the problems of locations close to substations to be established and their cost to be optimised.*

## 1. INTRODUCTION

The magnetic field at power frequency (60Hz or 50Hz) is transmitted by any device or installation which generates, transmits or consumes electricity. In the vicinity of electricity distribution installations, the magnetic field levels found, no matter how weak, are likely to cause interference on computer screens. The computer itself is not affected, but the interference is experienced in the form of oscillations of the image which may substantially reduce the ease and convenience of use for the operator.
Generic European electromagnetic compatibility standards establish emission and immunity levels of devices, the intention being to ensure a high level of interoperability between one device and another, and between devices and their environment. As far as the power frequency magnetic field is concerned, the generic standards do not establish a maximum emission level. On the other hand, a standardized immunity level is established as 1 A/m for screens, this value being mandatory for the industrial environment, but only a guide for the residential, commercial and light industry environment. The actual level of susceptibility of computer screens ranges from approximately 0.3 A/m to several A's/m. From the standardization point of view, the substation and screen are both in accordance with their respective standard, but their cohabitation frequently leads to screens perturbations.

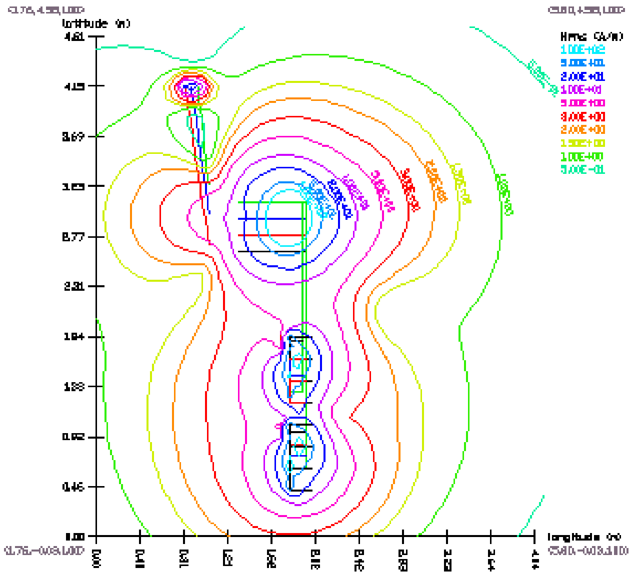
## 2. SUBSTATION ENVIRONMENT

Measurements and calculations in HV/MV and MV/LV substations, have made it possible to evaluate the contribution of the different elements of the substation when the magnetic field is emitted, as well as the global level which may be expected to exist in the environment of a substation. The results obtained enable it to be determined whether, in the case of interference, it is in fact the substation which is the magnetic source field (which is only the case within a radius of a few metres around the substation), and the components of the substation on which measures must be taken to reduce the magnetic field level at the screen location. In most cases the transformer is a relatively small field source compared with cables and busbars.




*3D modelling of cables of an MV/LV substation*

The calculations were carried out using ANAPOST software, 3D software for calculating the magnetic field transmitted by stations and lines. It enables all the conductors of the substation to be described and the field level to be predicted at a given location. In studying modifications of the substation components or rearranging the cables, it was possible, by a fast calculation, to evaluate the influence of a change in geometry on the radiated magnetic field levels.



*Map of the magnetic field 1 m above the ground*

As illustrated in the map above, the 50 Hz magnetic field decreases rapidly with distance. The field emitted by the MV/LV substations in the EDF network is generally lower than 1A/m beyond a few metres in distance from the substation, for a mean load of the substation.

## 3. REDUCTION OF THE PERTURBATIONS

The solution of removal, where possible, is the most effective and the least expensive. If this solution cannot be implemented for reasons of space, or if it is inadequate, other measures may be taken.

### 3.1 Rearrangement of the source

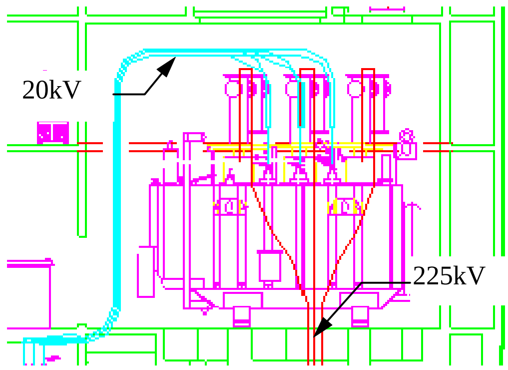
If modifications must be carried out in a substation, it is on the secondary winding of the transformer that action must generally be taken, as a priority: the movement or rearrangement of the cables is often relatively easy and gives wholly satisfactory results.

As an example, the ANAPOST software was used to optimize the 50Hz electromagnetic environment of a HV/MV building substation under construction. The use of this tool enabled:

- the 50Hz magnetic field to be evaluated in the vicinity of the substation,
- the most emitting magnetic field sources to be identified (conductor sections in particular),
- different geometric configurations of the conductors to be compared, in order to determine the least emitting.

The substation was initially modelled according to the normal rules of design, which did not take particular account of the reduction in the magnetic field in its vicinity.

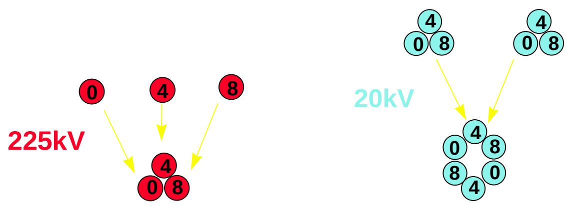
The calculations carried out on this configuration showed that the 50Hz magnetic field in the vicinity of the substation attained a level of several A/m. Moreover, we were able to demonstrate that the rise of the 225kV cables toward the transformer cell, as well as the 20kV cable section between the transformer and disconnecting switch, were the main sources.




*View of the side of the HV/MV transformer*

In order to minimise the magnetic field close to the substation we tested other arrangements for these two cable sections, with the ANAPOST software, by comparing them with the initial configuration. The main modifications made were:

- grouping of the 225kV rising toward the transformer in the shape of a trefoil,
- symmetrical, hexagonal phase grouping of the 20kV cables at the transformer output,
- different routing of the 20kV cables between the transformer and the circuit breaker.




*Rearrangement of the cable profiles*

The configuration considered indicated an arrangement of the 225kV and 20kV cables which enabled the 50Hz magnetic field to be reduced in the vicinity of the substation by a factor of between 2 and 3.

### 3.2 Shielding : the principle

When the substation does not permit any rearrangement of its equipment, there is another solution which involves protecting the computer screens with electromagnetic screens or shields. Among these solutions the following will be distinguished :

- The case of shields arranged around the sources of interference. In order to be effective, shielding must surround as much of the source as possible, which may result in structures of large dimensions at a high cost of construction.

- The case of external shielding surrounding the sensitive element of the computer screens, the electron gun. In this case the shielding is small in size, but this solution may be disadvantageous from the aesthetic point of view, or when there is a large number of computers to be protected (computer room).

In the two previous solutions, the principle of reducing the magnetic field is the same: it is necessary to reduce the coupling between the source of interference and the target (computer screen). In order to quantify the impact of a shielding on the coupling, an efficiency S is defined by:

$$S = \frac{Induction\_without\_shielding}{Induction\_with\_shielding}$$

The shielding efficiency varies according to the materials used. The following are therefore distinguished :

- attenuating shielding consisting of conducting, impermeable materials;
- deflecting shielding, consisting of permeable, conducting materials.

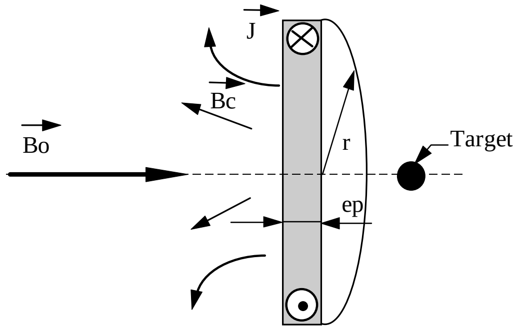
*The attenuating shielding*

These consist mostly of aluminium, and less commonly of copper, the latter being more expensive for a similar efficiency. The principle of these shielding is based on Lentz and Ohm's laws. The low frequency magnetic field induces Foucault (eddy) currents in the conducting shielding, which create an opposing field *Bc* to the source field *Bo*.

The distribution of the induced currents differs according to the orientation of the source field. For a magnetic field directed along the perpendicular of an aluminium plate of radius *r* and thickness *ep*, the efficiency of the shielding is proportional to the induced current density *J* [2].

$$|J| = \frac{2\pi f \sigma B_o r}{2}$$

where $f$ is the frequency of *Bo* (50 Hz) and $\sigma$ is the conductivity of the material.

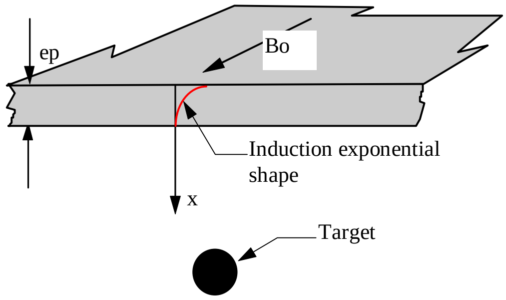



*Normal induction with an attenuating shielding*

The current density is highest around the periphery of the plate, and the opposing field *Bc* is not uniform.

*Property no. 1 :* In a normal field the efficiency S of a conducting plate is proportional to its thickness, its radius and its conductivity. On the other hand, S decreases with the square of the distance separating the target and the shielding.

If the magnetic field is tangent to a conducting plate, the efficiency of the shielding depends on the skin thickness $\delta$, but also on the dimensions of the plate (turn around the plate).




*Induction tangential to an attenuating shielding*

Assuming a semi-unfinished plate (plate finished according to the thickness), the modulus of the magnetic field according to the thickness of the plate may be written thus:

$$B = B_o \exp\left(-\frac{x}{\delta}\right) \text{ where } \delta = \frac{1}{\sqrt{\pi f \sigma \mu}}$$

where $\mu$ is the permeability of the material and $B_o$ is the induction without shielding. The second property of attenuating shielding may be deduced from this equation.

*Property no. 2 :* In a tangent field, the lower the skin thickness $\delta$ in front of thickness *ep*, the greater the efficiency of an attenuating shielding. For aluminium the skin thickness is approximately 11 mm.

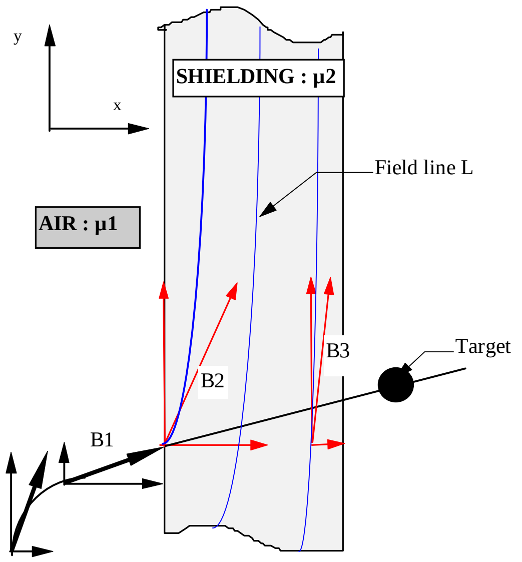
*The deflecting shielding*

The deflecting shielding consist of high permeability materials, and their principle consists in driving the low frequency magnetic field in the direction of "easy magnetisation", i.e. in the direction of high permeability.

The materials currently used for deflecting shielding are Iron Nickel (FeNi) and Iron Silicon (FeSi). FeNi has a high relative isotropic permeability ($\mu r$ = 100000), provided that it is not saturated. Its deflecting capacity is greater than low field FeSi, but it is still expensive and difficult to work: its magnetic properties deteriorate under any mechanical action.

FeSi saturates less quickly than FeNi, but it has a relatively lower permeability ($\mu r$=~ 20000). Moreover, its magnetic properties are anisotropic, in other words it will not act in the same way on the three components of the impinging field. However, it is less expensive than FeNi, because it is widely used in electrical engineering (motors and transformers).

To summarise the parameters governing the principle of deflecting shielding, let us take the case of a semi-unfinished plate impinged by a magnetic field of any incidence.



*Deflecting shielding in a magnetic field*

It is assumed that there is no current circulating in the shielding (zero conductivity). Under these assumptions, the shielding may be studied in static and the conditions of flow of the fields at the interfaces may be written.

- Continuity of the perpendicular component of the induction

$$B1x = B2x$$

- Discontinuity of the tangential component

$$B1y = \frac{\mu 1}{\mu 2} * B2y \quad \text{where} \quad \mu 1 << \mu 2$$

On the basis of these laws of flow we can establish the first two properties of the deflecting shielding:

- *Property no. 1:* Upstream, the perpendicular induction (*Bx*) will be strengthen and the tangential component will be attenuated.
- *Property no.* 2: When the air/shielding interface is crossed, the induction is re-orientated parallel with the surface of the shielding. When the shielding/air interface is crossed, the induction is re-orientated perpendicular to the surface of the shielding.

*Note :* a perpendicular field *(B=Bx, By=Bz=0)* is a particular case because it will have no difficulty in crossing the shielding (zero conductivity assumed).

For a inhomogeneous source field, the field lines inside the shielding are not parallel straight lines. It is then shown [2] that the field is larger on the concave than on the convex side of an induction line *L*. This property is expressed by a re-orientation of the field in parallel with the surfaces of the shielding.

*Property no. 3 :* Depending on the thickness of the shielding, the perpendicular component (*Bx)* will be highly attenuated, whilst the tangential component *(By)* will remain more or less constant.

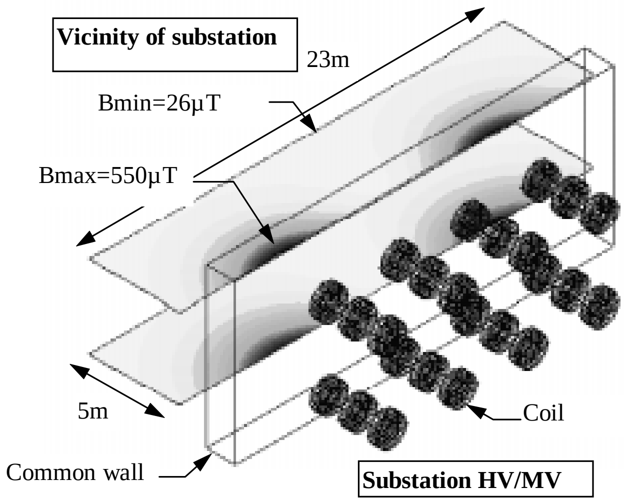
In conclusion, a deflecting shielding orientates the incident magnetic field in parallel with the plate. The perpendicular component of the induction downstream from the shielding (target side) is attenuated, whilst the tangential component remains more or less constant, but is driven according to the profile of the plate.

*Note:* The ferromagnetic materials used for the shielding have a non-zero conductivity and high permeability. Consequently they combine the properties of the deflecting and attenuating shielding, but behave predominantly as deflecting shielding.

### 3.3 Application example for a source shielding

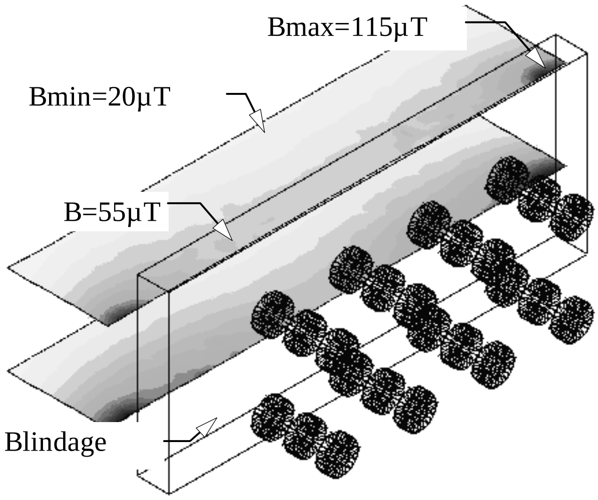
To illustrate the impact of a shielding on a power frequency magnetic field, we modelled an HV/MV substation with Flux3D, software for calculating electromagnetic fields by finite elements method [3].

The substation have height MV outputs with a reactance limiting the short-circuit currents in each phase. These reactances are coiled in the air and emit a high magnetic field into their environment. The following figure shows a map of the fields generated by the reactances without shielding.



*Map of the induction without shielding.*

An deflecting shielding was applied to the common wall, which consisted of four cross layers of anisotropic Iron Silicon, each 0.35 mm thick, to obtain an isotropic shielding. To model the Foucault currents in the shielding we used the shell formulation developed by [4].




*Map of the induction with shielding*

The shielding of Iron Silicon enabled the induction to be reduced by a factor of 10 in the best of the cases. However, the field is strengthen at the edges (B=115µT) and at a distance of 5 m from the shielding the level remained almost identical. This example shows the limits of this technical shielding :

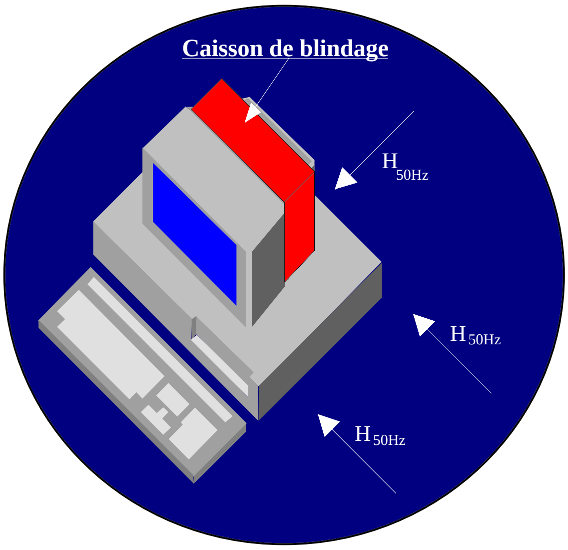
- to reduce the induction at 5 m (due mainly to the turn around field) it would be desirable to increase the length of the plates, but with a limit on the thermal and cost aspects;
- to reduce the induction close the shielding, where the impinging field is perpendicular to the plates, it would be desirable to combine an *attenuating shielding* with the FeSi (property no. 1).

### 3.4 Shielding on the target

Where the number of computers is not too high, and where aesthetics are not a limiting factor in the protection specification, a shielding may be installed around the computer screen.

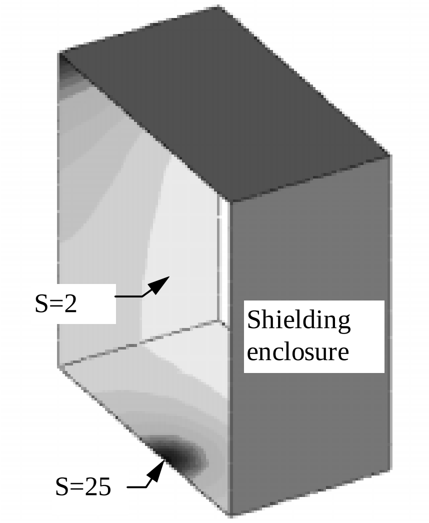
The most efficient method consists in covering the 5 faces of the computer screen with a deflecting shielding, but this solution is expensive because of the qualities of the material (in most cases Iron Nickel) and the difficulties in design (Thermal processing of the shielding after bending the sheets). Moreover, the shielding enclosures currently on the market are cumbersome, expensive and over strengthen in relation to the magnetic fields currently measured in the MV/LV substations.

We then developed a shielding enclosure better adapted to the electromagnetic environment of the MV/LV substations, more aesthetics for the user and less expensive, apart from the quantity of material used and apart from the simplicity of design. The enclosure are of Iron Nickel and are adjusted to the rear section of the computer screen: the orientation of the screen is left to the user.




*Mini enclosure shielding*

The 3D models enabled us to select the material and optimise the geometry of the box, particularly its thickness. The following map shows that the efficiency of the *mini-enclosure* is not homogeneous. However, its application range covers the standard electromagnetic environment of the MV/LV substation, i.e. B<3µT.




*3D map of the efficiency of a mini enclosure shielding*

## 4. CONCLUSION

There is therefore a wide range of solutions for reducing computer screen interference caused by the power frequency magnetic field : adjust the configuration of the source, adjust its coupling, or finally shielding the screens. It is advisable to target the weak link in the electromagnetic coupling chain, which will be either too great a source or a computer screen with insufficient immunity.

## 5. REFERENCES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