

# Analysis of the Effect of HV Transmission Lines on the Control Room and its Proposed Shielding

Diako Azizi, Hosein Heydari, and Ahmad Gholami

**Abstract**—Today with the rapid growth of telecommunications equipment, electronic and developing more and more networks of power, influence of electromagnetic waves on one another has become hot topic discussions. So in this article, this issue and appropriate mechanisms for EMC operations have been presented. First, impact of high voltage lines on the surrounding environment especially on the control room has been investigated, then to reduce electromagnetic radiation, various methods of shielding are provided and shielding effectiveness of them has been compared. It should be expressed that simulations have been done by the finite element method (FEM).

**Keywords**—Electrical field, EMC, field distribution, finite element method

## I. INTRODUCTION

SHIELDING is a fundamental step in establishing or improving the electromagnetic compatibility of active and of passive devices. The physical principles which form the base of shielding depend on the frequency range: For static and low frequency electric fields the Faraday cage, i.e., a grounded conducting net, is used which may encounter apertures up to a certain size. The electric charges on this metallic net serve as the end points for the lines of force of the divergence-type electric field. For low-frequency magnetic fields, the induced eddy currents within the shielded enclosure material are responsible for the shielding effect. Thus, high values of the product of conductivity and permeability as well as the avoidance of resistances for the eddy currents by apertures, slits, etc., are recommended. For high-frequency and transient electromagnetic fields, the shielding principle and, consequently, the shield design are more complex. Since almost every realistic shield must have apertures, electromagnetic radiation may penetrate into the interior and interfere with the shielded device, or even cause resonances within the shielded domain. Due to these very different kinds of shielding mechanisms, different measures to quantify the overall efficiency of a shielding structure are in use [1]. The common definitions for low frequency electric and magnetic

fields base on the values of the electric and magnetic field intensity within an empty shielding enclosure and are referred to as the electric and magnetic shielding effectiveness, respectively [2]. For the electromagnetic case, IEEE Standard 299.1997 provides a method applicable to relatively large enclosures while measuring the shield's insertion-loss by using suitable broad-band antennas [3].

One problem with these definitions for high-frequency problems is addressed by finding that point or these points within the shielded domains, which are supposed to be *typical* for the total interior of the shield. Moreover, the influence of a load on the shielding effectiveness has to be clarified. Another question arises for problems where the IEEE Standard method [4] is not applicable, e.g., if the enclosure dimensions are too small. Finally, shielding effectiveness should be definable for the transient case as well.

Therefore at first the field distribution in two cases with and without shield must be provided. Different methods have been used to calculate the radiation of electromagnetic fields [3], [5]. The main difficulty is that the surrounding medium is highly inhomogeneous. The finite element method allows accurate modeling of complex structures with arbitrary shaped regions and takes easily into account inhomogeneous materials.

In this paper using the proposed method, the shielding effectiveness of different modes have been presented and compared.

## II. DEFINITIONS OF THE SHIELDING EFFECTIVENESS

The common definitions of the electric and magnetic shielding effectiveness at an arbitrary point  $q$  within the shielded domain are given by [2]:

$$SE_e|_q = 20 \log_{10} \frac{|\vec{E}^{unshield}|_q}{|\vec{E}^{shield}|_q} \text{ dB} \quad (1)$$

$$SE_m|_q = 20 \log_{10} \frac{|\vec{H}^{unshield}|_q}{|\vec{H}^{shield}|_q} \text{ dB} \quad (2)$$

respectively. The numerators in (1) and (2) represent the amplitudes of the time-harmonic electric and magnetic field intensities, measured at  $q$  in the absence of the shield, while the denominators contain their values in the shielded case at the same locations. The advantage of these definitions is that they are relatively easy to realize; however, they are intended mainly for low-frequency electric and magnetic fields. In the high-frequency case, i.e., when the dimensions of the shield are comparable or larger to the wave-length, the attenuation of the *electromagnetic* field (rather than of the electric and

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magnetic fields alone) has to be considered. To come to a physically meaningful SE definition, suppose that the shield is not empty but (partly) filled with a test load, and define the special shielding measure  $a_p$  as the ratio of the time-averaged electromagnetic power received by the unshielded load to that one received by the shielded load, each for the same incident field, as:

$$a_p = 10 \log_{10} \frac{\bar{p}_{unshield}}{\bar{p}_{shield}} \text{ dB} \quad (3)$$

This definition considers the attenuation of the electromagnetic field induced by the shield and the influence of the (special) test load. The main drawback is obviously that a measurement of  $a_p$  would generally require a considerable expenditure. Moreover,  $a_p$  would be valid only for this special load, and it had to be remeasured or recalculated for any new one. To come to a meaningful and practicable definition which characterizes the shielding ability of the enclosure itself and which is still based on this  $a_p$ , consider a spherical load with radius  $r_L$  which is concentrically located around the point  $q$ . As shown in Appendix A, in the limiting case  $r_L \rightarrow 0$  and for an incident plane wave the special shielding measure  $a_p$  passes into the electromagnetic shielding effectiveness at the point  $q$ , defined by:

$$SE_{em}|_q = 10 \log_{10} \frac{2}{\frac{|\bar{E}^{shield}|_q^2}{|\bar{E}^{unshield}|_q^2} + \frac{|\bar{H}^{shield}|_q^2}{|\bar{H}^{unshield}|_q^2}} \quad (4)$$

Hence, the electromagnetic shielding effectiveness is calculated as a simple combination of the values of the electric and magnetic shielding effectiveness, measured at the point  $q$ . Therefore, it is easily determinable even for relatively small enclosures. Physically, the electromagnetic shielding effectiveness represents the shield-induced reduction of electromagnetic power delivered to an infinitesimal load. Note that from (4) it follows:

- $SE_{em} = SE_e = SE_m$ , if  $SE_e = SE_m$ ;
- $SE_{em} = SE_e + 10 \log_{10} 2 \text{ dB}$ , if  $SE_m \ll SE_e$ ;
- $SE_{em} = SE_m + 10 \log_{10} 2 \text{ dB}$ , if  $SE_e \ll SE_m$ .

### III. ELECTROMAGNETIC MODELS [6]

Ampere's law is the main part to derive electromagnetic system equation.

$$\nabla \times H = J + \frac{\partial D}{\partial t} = \sigma E + \sigma v \times B + J^e + \frac{\partial D}{\partial t} \quad (6)$$

Where:

- $E$  is the electric field intensity
- $D$  is the electric displacement or electric flux density
- $H$  is the magnetic field intensity
- $B$  is the magnetic flux density
- $J$  is the current density
- $J^e$  is the externally generated current
- $\sigma$  is the electrical conductivity
- $v$  is the velocity

Time variant-harmonic field's effect can be introduced by equations (2) and (3):

$$B = \nabla \times A \quad (7)$$

$$E = -\nabla V - \frac{\partial A}{\partial t} \quad (8)$$

Ampere's law is rewritten by equations (2) and (3) Combining with constitutive relationships  $B = \mu_0(H + M)$  and  $D = \epsilon_0 E + P$ , as:

$$\begin{aligned} (j\omega\sigma - \omega^2\epsilon_0)A + \nabla \times (\mu_0^{-1}\nabla \times A - M) \\ - \sigma v \times (\nabla \times A) + (\sigma + j\omega\epsilon_0)\nabla V = J^e + j\omega P \end{aligned} \quad (9)$$

In which  $\omega$ ,  $\epsilon_0$ ,  $\mu_0$ ,  $M$  and  $P$  respectively refer to Angular frequency, Relative permittivity, Relative permeability, magnetization vector and electric polarization vector.

In the case of 2-dimensional-plane, there are no variations in z-direction, so the electric field is parallel to z-axis, therefore  $\nabla V$  is written as  $-\Delta V/L$ , where  $\Delta V$  is the potential difference over the distance  $L$ . Now these equations are simplified to:

$$\begin{aligned} -\nabla \cdot \left( \mu_0^{-1} \nabla A_z - \begin{bmatrix} -M_y \\ M_x \end{bmatrix} + \sigma v \cdot \nabla A_z + (j\omega\sigma - \omega^2\epsilon_0) \right) A_z \\ = \sigma \frac{\Delta V}{L} + J_z^e + j\omega P_z \end{aligned} \quad (10)$$

In the ax-symmetric case, another form of the electric potential gradient has been used ( $\nabla V = \frac{-V_{loop}}{2\pi r}$ ) as the electric field is only present in the azimuthally direction. The above equation, in cylindrical coordinates, becomes:

$$\begin{aligned} -\left( \left[ \frac{\partial}{\partial r} \frac{\partial}{\partial z} \right] \left( r \mu_0^{-1} \left[ \frac{\partial u}{\partial r} \right] + \mu_0^{-1} \begin{bmatrix} z \\ 0 \end{bmatrix} u - \begin{bmatrix} M_z \\ -M_r \end{bmatrix} \right) \right) \\ + r \sigma \left( v \cdot \begin{bmatrix} \frac{\partial u}{\partial r} \\ \frac{\partial u}{\partial z} \end{bmatrix} \right) + r(\sigma j\omega - \omega^2\epsilon_0)u + 2\sigma V_r u \\ = \sigma \frac{V_{loop}}{2\pi r} + J_\phi^e + j\omega P \end{aligned} \quad (11)$$

The dependent variable  $u$  is the nonzero component of the magnetic potential divided by the radial coordinate  $r$ , so that:

$$u = \frac{A_\phi}{r} \quad (12)$$

The application mode performs this transformation to avoid singularities on the symmetry axis.

### IV. SIMULATION RESULTS

In this section distribution of electrical and magnetical fields due the HV line (400 KV) at the adjacent environment especially at the control room have been presented. Fig.1 shows the potential distribution and Fig.2 shows the electrical field distribution. This review included two cases of full load and no loads.

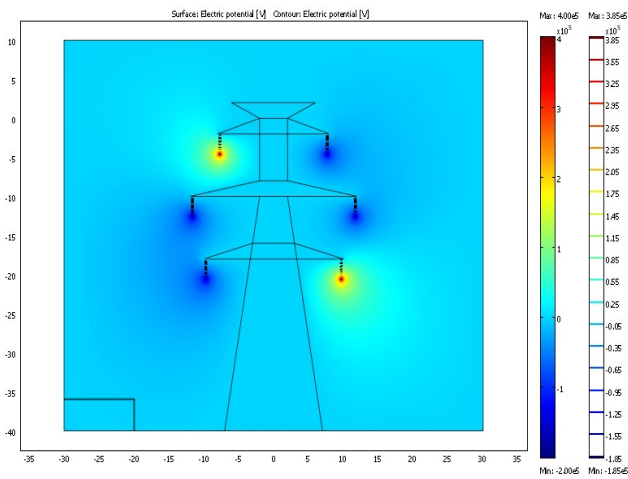


Fig. 1 Potential distribution of HV tower (V)

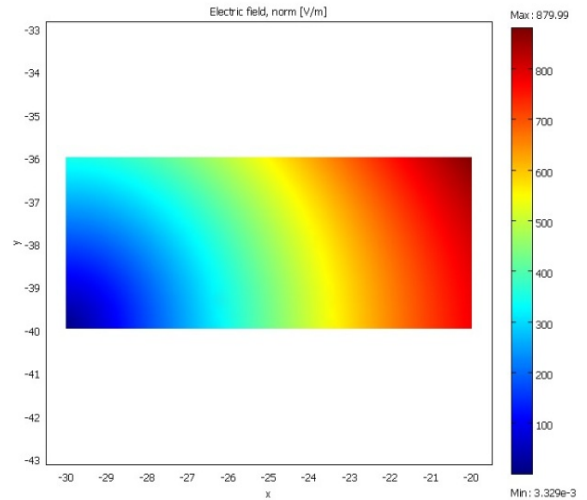


Fig. 3 Electrical field distribution in the control room (V/m)

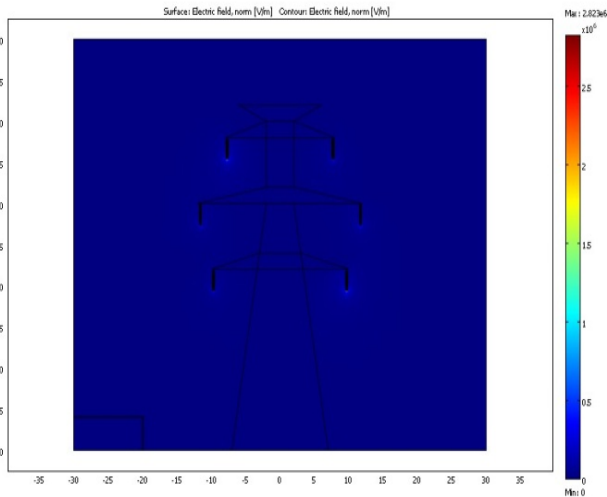


Fig. 2 Electrical field distribution of HV tower (V/m)

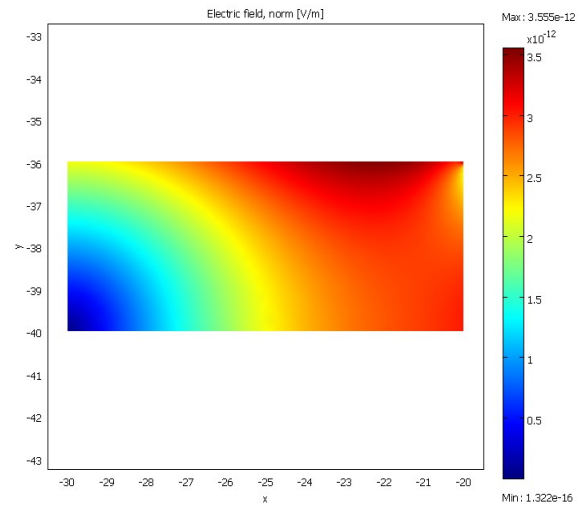


Fig. 4 Electrical field distribution in the control room at the presence of electrical shield (V/m)

Fig.3 shows the electrical field distribution in the control room without the presence of shield. Then in the Fig.4 the electrical field distribution in the control room at the presence of electrical shield (copper with the thickness of 1mm) has been presented. It is so clear that the electrical field has been decreased intensively. Fig.5 shows the electrical shielding effectiveness.

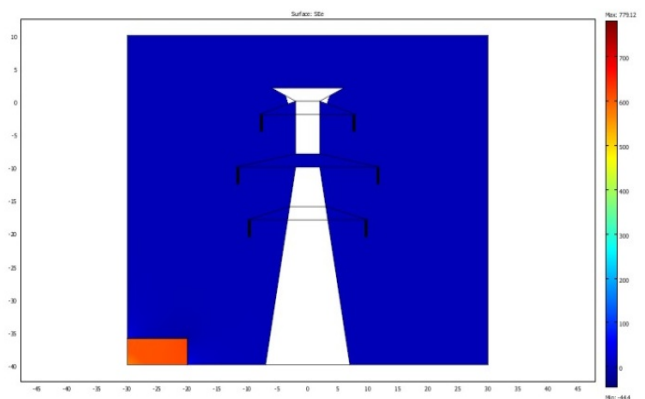


Fig. 5 Electrical shielding effectiveness (dB)

In the Fig.6 the effect of door is considered. It is obvious that SE at near the door has been decreased.

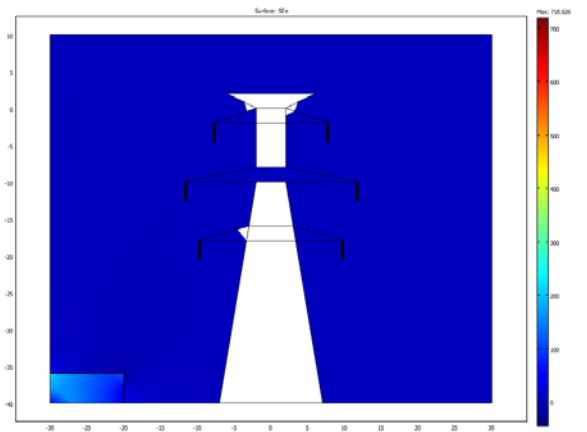


Fig. 6 Electrical shielding effectiveness at the presence of door (dB)

At the next step the effect of loading and its proposed shielding will be presented. Fig.7 shows the magnetical field distribution. Fig.8 presents the SEM for proposed shield (magnetic iron) and Fig.9 shows SEM at the presence of door.

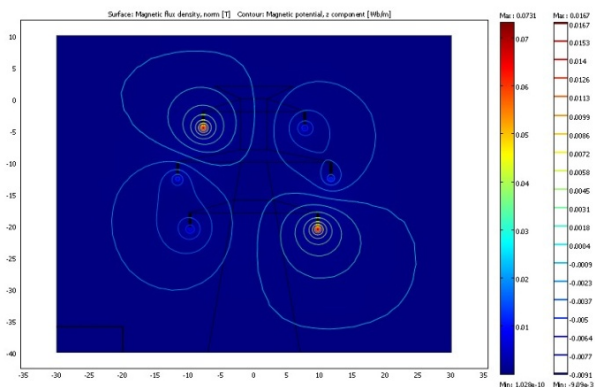


Fig.7 magnetical field distribution and flux lines (T)

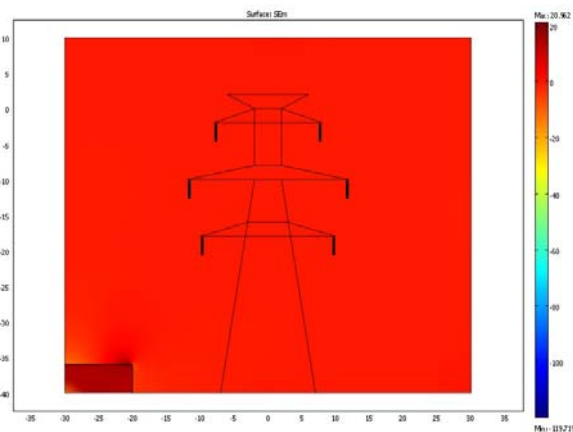


Fig. 8 Magnetic shielding effectiveness (dB)

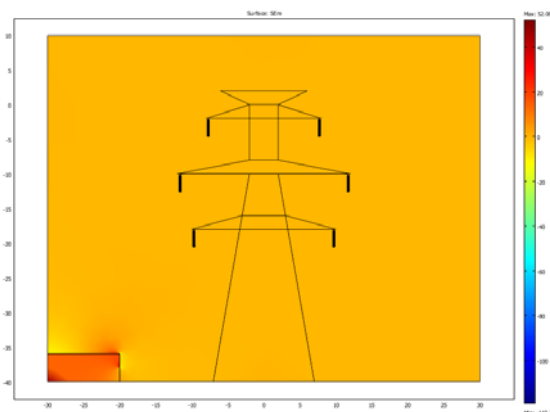


Fig. 9 Magnetic shielding effectiveness at the presence of door (dB)

## V. CONCLUSION

- The effect of electrical field is stronger compared the magnetic field in the HV lines.
- At the full load mode, the effect of magnetic field in the 3 $\phi$  towers is higher than 1 $\phi$  towers.
- Very little electric Shield thickness is sufficient whereas the thickness of magnetic shield must be further.
- Presence of door causes that SE reduced.

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