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Assessment of health security zones due to overhead power lines

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Abstract Nowadays we assist to increasing requests aiming to reduce exposure to artificial electromagnetic fields and a more careful use of electrical and wireless technologies. Particular emphasis is put on the exposure to low frequency electromagnetic fields (ELF) with the aim of discovering if they have adverse consequences for health. Computational Electromagnetics can play an extremely important role in accessing security zones around High Voltage Power Lines (HVPLs). It is presented the ELF magnetic and electric field security zones around HVPLs for the limits values set by the ICNIRP and also lower levels, i.e. 100 µT and 0.4 µT for the magnetic field, and 5 kV/m and 100 V/m for the electric field. Two types of HVPLs were analyzed: 60 kV and 220 kV. This study was carried out using a 3D numeric simulation tool developed by the author as part of a Research Project financed by the Portuguese Utilities REN and EDP. The fields are calculated for general 3D Line configurations of current carrying conductors. Up to six different lines can be dealt with, with up to four pylons for each line. The magnetic field calculator used is based on the Biot-Savart law. The electric field calculator used is based on the method of images. The conductors are considered filamentary wires of arbitrary geometric configuration with known imposed voltages. The influence of the vegetation is not taken into consideration. It is presented a schematic picture of the magnetic and electric field security zones around these HVPLs.

Keywords High voltage power lines, Electromagnetic exposure, Health security zones.

Avaliação de zonas de segurança para saúde em torno de linhas elétricas aéreas

Resumo *Atualmente temos observado um grande aumento nas demandas para redução da exposição a campos eletromagnéticos artificiais e utilização mais cuidadosa de tecnologias elétricas e sem fio. Grande ênfase é dada à exposição a campos eletromagnéticos de baixa freqüência com o objetivo de descobrir se estes têm consequências adversas para a saúde. As técnicas de Eletromagnetismo Computacional podem desempenhar um papel importante na avaliação de zonas de segurança em torno de linhas elétricas de alta tensão. Neste trabalho, são apresentadas as zonas de segurança para campos eletromagnéticos de baixa freqüência e campos elétricos em torno linhas elétricas de alta tensão para os valores limites estabelecidos pela ICNIRP, como também para níveis mais baixos, ou seja, 100 µT e 0,4 µT para campo magnético, e 5 kV/m e 100 V/m para campo elétrico. Dois tipos de linhas elétricas de alta tensão foram analisados: 60 kV e 220 kV. Este estudo foi realizado utilizando-se uma ferramenta de simulação numérica 3D desenvolvida pelo autor, como parte de um projeto de pesquisa financiado pela Energias de Portugal (EDP) e pela Rede Eléctrica Nacional (REN/Portugal). Os campos são calculados para as configurações padrão de linhas 3D de condutores de corrente. Até seis linhas diferentes podem ser tratadas, com até quatro torres por linha. O cálculo do campo magnético é baseado na lei de Biot-Savart. O cálculo do campo elétrico é baseado no método das imagens. Os condutores são considerados fios filamentares com configuração geométrica arbitrária e tensões aplicadas conhecidas. A influência da vegetação não é levada em consideração nos cálculos. Por fim, é apresentado um quadro esquemático das zonas de segurança para campos magnético e elétrico em torno daquelas linhas de transmissão de alta tensão.*

Palavras-chave *Linhas de transmissão de alta tensão, Exposição eletromagnética, Zonas de segurança para a saúde.*

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Introduction

Exposure to low frequency electromagnetic fields (ELF) is a matter of great concern studied in these last years, with the aim of discovering if they have adverse consequences for health. Nowadays we assist to increasing requests aiming to reduce exposure to these artificial fields and a more careful use of electrical and wireless technologies.

Currently many countries have adopted the recommendations proposed by the ICNIRP, which correspond for the general public exposure to 50 Hz time-varying ELF the limit values of 100 μT for the magnetic field (B) and 5 kV/m for the electric field (E), as in (International..., 1998). However, many researchers consider those reference levels very conservative, proposing much lower values for these fields, as 0.4 μT and 100 V/m, as in World Health Organization (World..., 2007).

It is not our intention in this paper to consider or justify that these lower values are or should be the proposed ones bearing in mind health aspects. The idea is to share a bit of our experience in dealing with the development of software tools using computational techniques, as an aid to predict the electric and magnetic fields emanated from High Voltage Power Lines at ELF frequencies.

In this paper, our purpose was to find and identify the magnetic and electric field security zones around HVPLs and at ground level by taking into account the values of 100 μT and 0.4 μT for the magnetic field, and 5 kV/m and 100 V/m for the electric field. For this study we have considered the two most common distribution HVPLs used in Portugal, namely 60 kV and 220 kV lines.

The work was developed using a 3D numeric simulation tool for HVPLs developed by the author as part of a Research Project financed by the Portuguese Utilities REN and EDP and described elsewhere (Antunes, 2007; 2008; Antunes *et al*., 2008a; 2008b).

Methods

There is no method in electromagnetic field modelling that can suit any application, which in other words means that there is no best method for all applications.

In this area of research we are dealing with large structures, although very small electrically. In terms of real physical dimensions the magnetic and electric fields are calculated for general 3D Line configurations of current carrying conductors. Up to six different lines can be dealt with, with up to four pylons for each line. The catenary of each HVPL is approximated by *i* straight N_s lineal segments, each with length L_i, defined by a cubic spline polynomial of third degree (Antunes, 2007; 2008; Antunes *et al*., 2008a; 2008b).

Normalizing each segment (i.e. considering each segment with unitary length), with four interpolating nodes it is then possible to obtain the function coefficients (Antunes *et al*., 2008a).

The magnetic field calculator used is based on the Biot-Savart law. So, the magnetic field produced by each segment carrying an electrical phasor current $\hat{I}=I\cdot e^{j\theta}$ is given by equation 1:

$$\hat{\bar{B}} = \frac{\mu_0}{4\pi}\cdot\hat{I}\cdot\int_1^4 \frac{\overline{dl} * \hat{R}}{R^2} = \frac{\mu_0}{4\pi}\cdot\hat{I}\cdot\int_1^4 \frac{\overline{dl} * \overline{R}}{R^3} \quad (1)$$

with

$$\overline{R} = (x'-x)\cdot\hat{a}_x + (y'-y)\cdot\hat{a}_y + (z'-z)\cdot\hat{a}_z \quad (2)$$

$$\overline{dl} = dx\cdot\hat{a}_x + dy\cdot\hat{a}_y + dz\cdot\hat{a}_z \quad (3)$$

$\hat{a}_x$, $\hat{a}_y$, $\hat{a}_z$ are the unit vectors along the direction *x*, *y*, *z* respectively.

For each segment of a line, say *i*, the components B_{xi}, B_{yi} and B_{zi} of the magnetic field at a given point are then calculated, and the procedure repeated for all the segments of that line and for other lines. The value of the resultant components B_{xR}, B_{yR} and B_{zR} will be the arithmetic sum of the contributions of each segment.

The electric field calculator used is based on the method of images. The conductors are considered filamentary wires of arbitrary geometric configuration with known imposed voltages: phase-earth or zero if it corresponds to the guard conductor.

The earth is considered as a perfect conductor at zero voltage reference value and its influence taken into account using the method of images. The influence of the vegetation is not taken into consideration.

The phasor electric field $\hat{\bar{E}}$ at any point $P(x, y, z)$ due to a line, is calculated by equation 4, where the point $P(x, y, z)$ is defined by $\bar{r}$ and the phasor charge density at node *i* is located at $\bar{r}'$, with $\hat{a}$ as the unit vector in direction $(\bar{r}-\bar{r}')$, (Antunes, 2008; Antunes *et al*., 2008a; 2008b).

$$\hat{\bar{E}} = \frac{1}{4\pi\varepsilon_0}\cdot\sum_{i=1}^{Ns} Li\cdot\int_0^1 \frac{\hat{\lambda}_i(S)}{\left|\bar{r}-\bar{r}'\right|^2}\cdot ds\cdot\hat{a} \quad (4)$$

It is seen that the phasor linear charge density has to be previously calculated considering all the line(s) and their images. For each line segment the charge distribution is approached by a cubic spline polynomial as equation 5,

$$\hat{\lambda}(s) = c_0 + c_1 s + c_2 s^2 + c_3 s^3 \tag{5}$$

where,

$$c_0 = \left(1 - \frac{3s^2}{L_1^2} + \frac{2s^3}{L_1^3}\right),\ c_1 = \left(s - \frac{2s^2}{L_1} + \frac{s^3}{L_1^2}\right),$$
$$c_2 = \left(\frac{3s^2}{L_1^2} - \frac{2s^3}{L_1^3}\right),\ \text{and}\ c_3 = \left(-\frac{s^2}{L_1} + \frac{s^3}{L_1^2}\right) \tag{6}$$

s is an adimensional parameter ($s = 0$ at the beginning of the segment and $s = 1$ at the end of that segment).

For each line node i it is required the calculation of the phasor charge density $\hat{\lambda}_i$ and its derivative $\hat{\lambda}'_i$. Continuity conditions (of level 2) at interconnection segment nodes and relaxed natural boundary conditions at extreme points defining each line segment are applied in order to make the system of equations possible to solve.

This will be done using the phasor electric potential $\hat{V}_p$ at a point $P(x, y, z)$ due to a line with N_S segments, given by equation 7,

$$\hat{V}_p = \frac{t}{4\pi\varepsilon_0}\int_0^1 \frac{\begin{bmatrix}\hat{\lambda}_0 & \hat{\lambda}_1\end{bmatrix}\cdot\begin{bmatrix}k_0(s)\\ k_1(s)\end{bmatrix}}{|\bar{r} - \bar{r}'|}ds + \frac{t}{4\pi\varepsilon_0}\int_0^1 \frac{\begin{bmatrix}\hat{\lambda}'_0 & \hat{\lambda}'_1\end{bmatrix}\cdot\begin{bmatrix}k'_0(s)\\ k'_1(s)\end{bmatrix}}{|\bar{r} - \bar{r}'|}ds \tag{7}$$

where $k(s)$ is a constant term associated with $\hat{\lambda}$, and $k'(s)$ is associated with $\hat{\lambda}'$, (Antunes *et al*., 2008a). The constant t is the length of the segment in analysis.

For exposure analysis we are mainly interested in the effective value of the field quantity. For example, for the magnetic field, we are interested in the flux density B_{ef} and not the instantaneous values, defined in equation 8 as:

$$B_{ef} = \sqrt{\frac{\bar{\hat{B}} \cdot \bar{\hat{B}}^*}{2}} = \sqrt{\frac{\left(B_{x_{Real}}^2 + B_{x_{Imag}}^2\right) + \left(B_{y_{Real}}^2 + B_{y_{Imag}}^2\right) + \left(B_{z_{Real}}^2 + B_{z_{Imag}}^2\right)}{2}} \tag{8}$$

Results

The 3D numerical simulations were performed for 60 kV and 220 kV lines considering a balanced system of current for the 3 phases, with the software package developed by the author (Antunes, 2007; 2008; Antunes *et al*., 2008a; 2008b). The plan of analysis was placed at the middle of the line and parallel to the HVPL pylon under analysis.

The accuracy test of this package have been performed and described elsewhere (Antunes *et al*., 2008a), using the professional programmable dosimeter (Enertech, model EMDEX II – High Field). It is seen that the errors found, when comparing the numerical values with the measured ones, are quite negligible.

The pylons considered in the development of this work are shown in Figures 1 and 2 for 60 kV and 220 kV lines, respectively.

It is shown in Figures 3 and 4 the distribution zone found (in grey/red) for the magnetic field corresponding to $B \geq 100$ μT and for $B \geq 0.4$ μT for 220 kV HVPLs.

In Portugal the legal administrative servitude for the construction and exploration of air High Voltage Power Lines is set to a corridor with maximum width of 45 m. In this corridor the construction of buildings and planting fast growing species is conditioned or subject to previous authorization. It is seen that this legal administrative servitude is largely exceeded for the security limits of $B \geq 0.4$ μT.

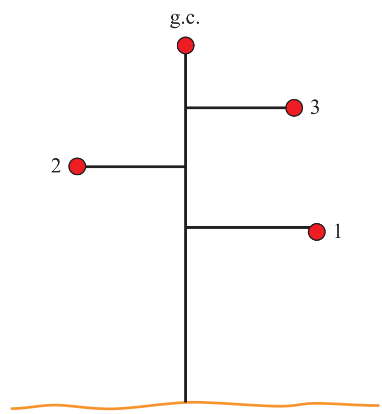

Figure 1. Pylon for 60 kV.

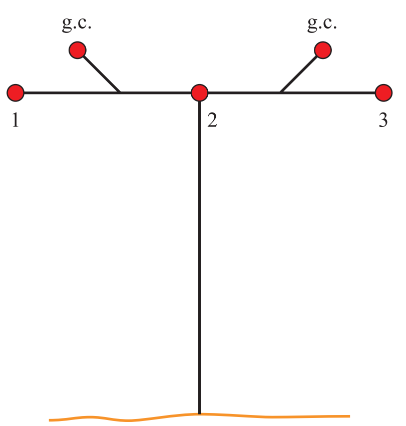

Figure 2. Pylon for 220 kV.

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From the analysis of the numeric results we can define a schematic picture of the magnetic field security zones around High Voltage Power Lines (60 kV and 220 kV) which is presented in Figures 5 and 6, respectively.

It is also shown in Figures 7 and 8 the distribution zone found, (in grey/red), for the electric field corresponding to $E \geq 5$ kV/m and for $E \geq 100$ V/m for 220 kV HVPLs.

From the analysis of the numeric results we can define a schematic picture of the electric field security zones around High Voltage Power Lines (60 kV and 220 kV) which is presented in Figures 9 and 10, respectively.

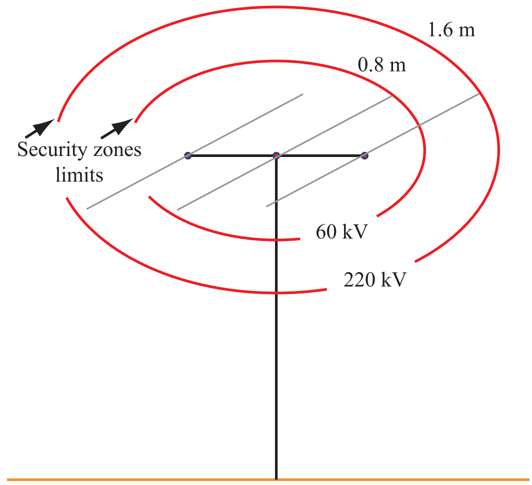

Figure 5. Schematic picture of magnetic field security zones around High Voltage Power Lines (for $B \geq 100$ µT).

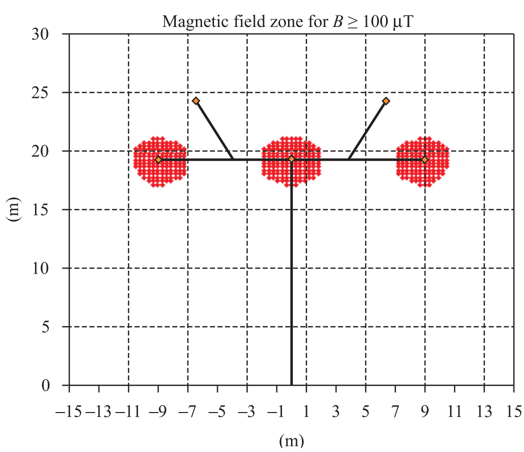

Figure 3. Magnetic field zone, $B \geq 100$ µT for 220 kV line.

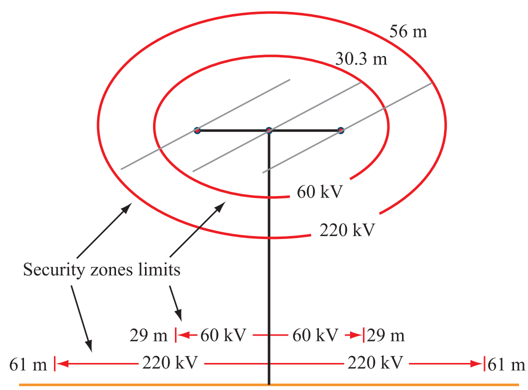

Figure 6. Schematic picture of magnetic field security zones around High Voltage Power Lines (for $B \geq 0.4$ µT).

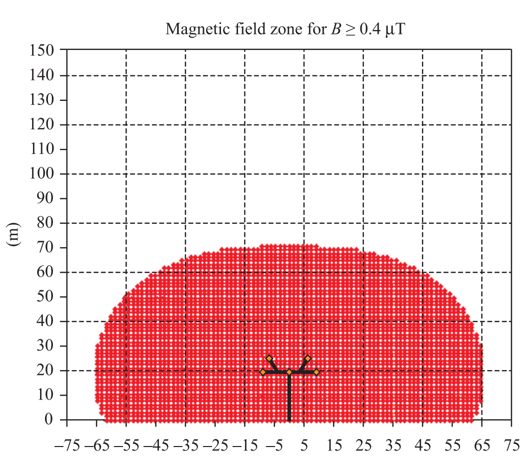

Figure 4. Magnetic field zone with $B \geq 0.4$ µT for 220 kV line.

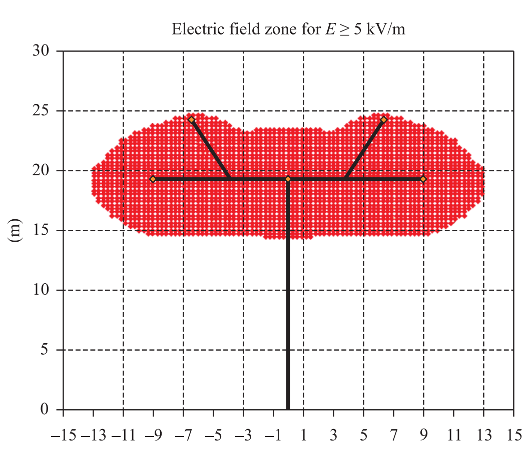

Figure 7. $E \geq 5$ kV/m for 220 kV HVPL.

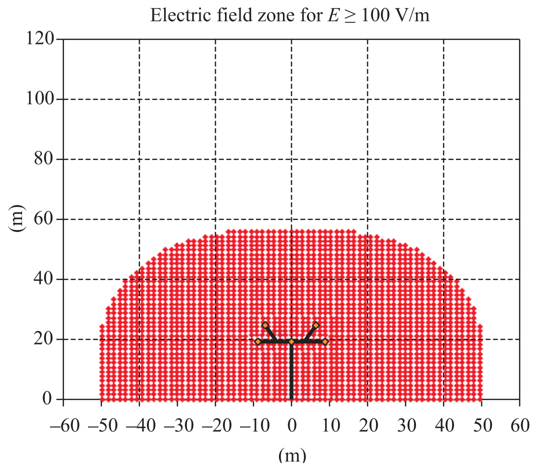

Figure 8. $E \geq 100$ V/m for 220 kV HVPL.

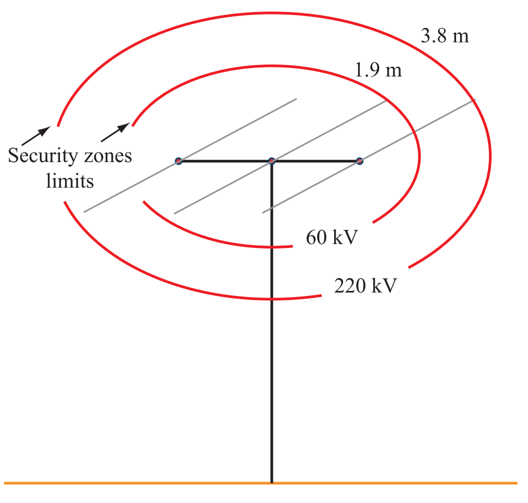

Figure 9. Electric field security zones ($E \geq 5$ kV/m).

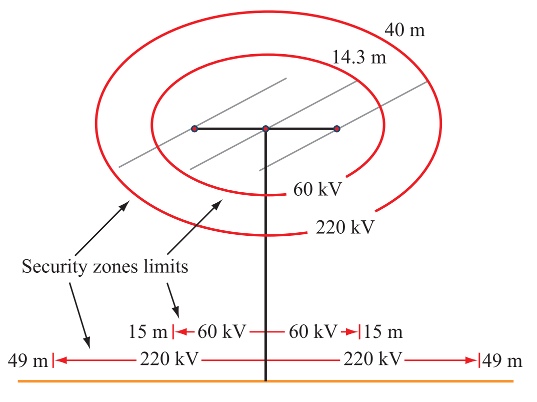

Figure 10. Electric field security zones ($E \geq 100$ V/m).

Conclusions

There were presented the ELF magnetic and electric field security zones corresponding to two different limits, i.e. the values of 100 μT and 0.4 μT for the magnetic field, and 5 kV/m and 100 V/m for the electric field, for the two types of HVPLs more used in Portugal (60 kV and 220 kV).

It is seen that these limits affect significantly the administrative servitude as well as the security field zones around these HVPLs. Certainly other limit values could be considered that would lead obviously to different answers.

Virtually all fields of engineering design today use preferably computer based evaluation before other commitments are taken, either due to time consuming or cost issues.

According to our experience it is our firm belief that computational electromagnetic techniques have here also an important role to play in the clear definition of these security zones, by helping the electrical utilities and health authorities to reach agreements on this very delicate and actual issue for the population in general (Estacio *et al*., 2008; Pereira Filho and Cardoso, 2006; 2008).

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