ELF Magnetic Field Security Zones around High Voltage Power Lines

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Abstract. In this paper it is presented the ELF Magnetic Field Security Zones around High Voltage Power Lines for the limits values set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), ie 100 µT, and for the lower limit value of 0.4 µT. The study was elaborated for the two types of High Voltage Power Lines more used in Portugal, ie 60 kV and 220 kV. It is also shown the ground level security zones 'vis a vis' the administrative servitude used in Portugal. It is presented a good analytical approximation for the Magnetic Field variation with distance (height) for the two types of High Voltage Power Lines. Finally it is shown a schematic picture of the Magnetic Field security zones around these High Voltage Power Lines, derived from the numeric field analysis.

Keywords

ELF Magnetic Field, High Voltage Power Lines, Security Zones, Health Effects.

1. Introduction

Exposure to low frequency electromagnetic fields (ELF) has been a matter of increasing great concern studied in these last years, with the aim of discovering if they have adverse consequences for health.

Currently many countries have adopted the recommendations proposed by the International Commission on Non Ionizing Radiation Protection (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), [1].

However, nowadays, many researchers consider those reference levels very conservative proposing as limits regarding the exposure to electromagnetic fields, much lower values, as 0.4 µT for the Magnetic Field (B) and 100V/m for the Electric Field (E), [2].

The objective of this work was to find and identify the Magnetic Field security zones around High Voltage Power Lines (HVPLs) and at ground level taking into account the values of 100 µT and the reduced value of 0.4 µT. This study was elaborated for the two most common distribution HVPLs used in Portugal, namely 60 kV and 220 kV Lines.
The work was developped using a 3D numeric simulation tool for HVPLs developped by the author and described elsewhere [3-6].

2. Formulation

The magnetic field calculator is based on the Biot-Savart law. The catenary of each HVPL is approximated by straight lineal segments defined by a cubic spline polynomial, [3-6].
The Magnetic field produced by each segment carrying an electrical phasor current $\hat{I} = I.e^{j\theta}$ is given by

$$\bar{B} = \frac{\mu_0}{4\pi}\cdot I\cdot\int_1^4 \frac{d\bar{l}\times\hat{R}}{R^2} = \frac{\mu_0\cdot I}{4\pi}\cdot\int_1^4 \frac{d\bar{l}\times\bar{R}}{R^3} \quad (1)$$

Where

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

and

$$d\bar{l} = dx\cdot\hat{a}_x + dy\cdot\hat{a}_y + dz\cdot\hat{a}_z \quad (3)$$

$\hat{a}_x$, $\hat{a}_y$, $\hat{a}_z$ 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.

For Magnetic Field exposure analysis we are mainly interested in the effective value of the Magnetic Flux Density B_{ef}, and not the instantaneous values, defined as:

$$B_{ef} = \sqrt{\frac{\bar{\bar{B}} \cdot \bar{\bar{B}}^{*}}{2}} = \sqrt{\frac{\left(B^2_{x_{Real}} + B^2_{x_{Imag}}\right) + \left(B^2_{y_{Real}} + B^2_{y_{Imag}}\right) + \left(B^2_{z_{Real}} + B^2_{z_{Imag}}\right)}{2}} \quad (4)$$

Where $\bar{\bar{B}}$ is the Magnetic Field value, which is also a complex value, and $\bar{\bar{B}}'$ is the complex conjugate of $\bar{\bar{B}}$.

A. High Voltage Power Lines Analyzed

The Magnetic Field security zones around High Voltage Power Lines were calculated for 60kV and 220kV Lines considering a balanced system of current for the 3 phases.

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

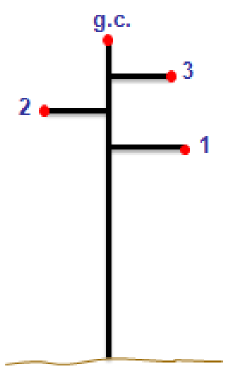

Fig. 1 – Pylon for 60kV

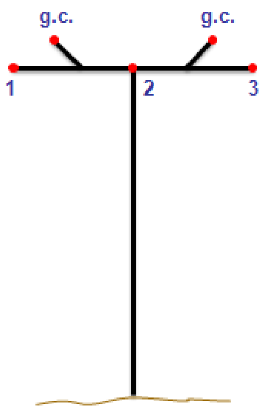

Fig. 2 - Pylon for 220kV

It is presented in TABLE I the useful geometric dimensions of the phase conductors positions for the Power Lines, where g.c. is the guard cable.

TABLE I. - PYLON GEOMETRIC DATA

	Pylon 60kV	Pylon 220 kV
Pylon Name	CR	Z1
Height 1 [m]	14	19.25
Height 2 [m]	15.5	19.25
Height 3 [m]	17	19.25
Height g.c. [m]	20	24.25
Length 1 [m]	2.7	9
Length 2 [m]	2.35	0
Length 3 [m]	2.35	9
Length c.g. [m]	0	6.41

The other useful specifications used in configuration of the High Voltage Power Lines are presented in TABLE II.

TABLE II. - SPECIFICATIONS OF HIGH VOLTAGE POWER LINES

Voltage (kV)	60	220
I_{MAX} (A)	600	1140
Line type	Simple	Simple
h_u (useful height [m])	14	19.25
Catenary parameter (Guard Cable)	1450	1460
Catenary parameter (Cond. Cable)	1450	2530
Nº Guard Cable	1	2

3. Results

The 3D numerical simulations of the Magnetic Field (B) were performed with the software package CEM_ELF.LAT developed by the author [3-6]. The plan of analysis was placed at the middle of the Line and parallel to the HVPL Pylon under analysis. It is shown in Fig. 3 and Fig. 4 the distribution zone of the Magnetic Field corresponding to B ≥ 100 µT for the 60 kV and 220 kV HVPLs respectively, which correspond to the limit values proposed by the ICNIRP.

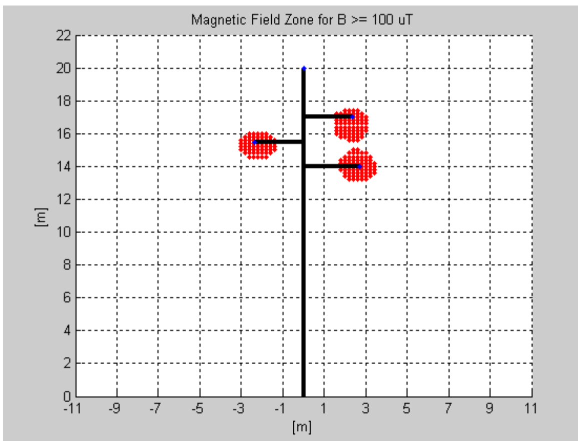

Fig. 3 - Magnetic Field Zone, B ≥ 100 µT for 60kV Line

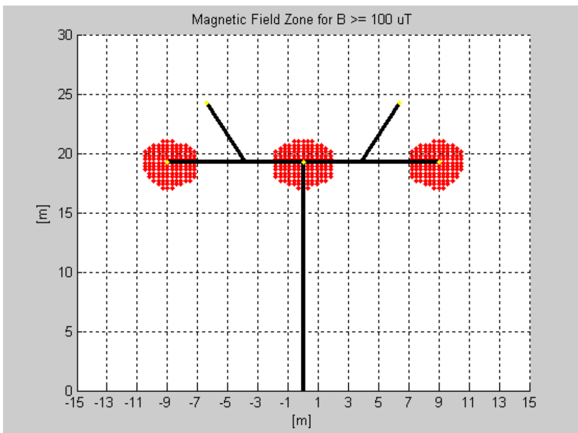

Fig. 4 - Magnetic Field Zone, B ≥ 100 µT for 220kV Line

It is also shown in Fig. 5 and Fig. 6 the different Magnetic Field distribution zones for B ≥ 0.4 µT for the 60 kV and 220 kV Lines, respectively.

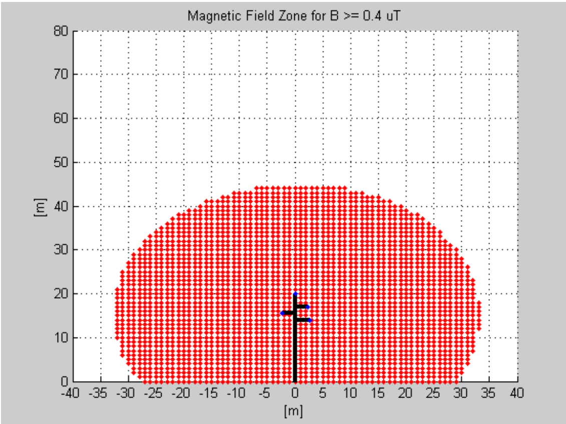

Fig. 5 - Magnetic Field Zone with B ≥ 0.4 µT for 60kV Line

In Portugal the legal administrative servitude for the construction and exploration of air High Voltage Power Lines is set to a corridor with a maximum width of 45 m. In this corridor it is conditioned, or subject to a previous authorization, the construction of buildings and planting of fast growing species.

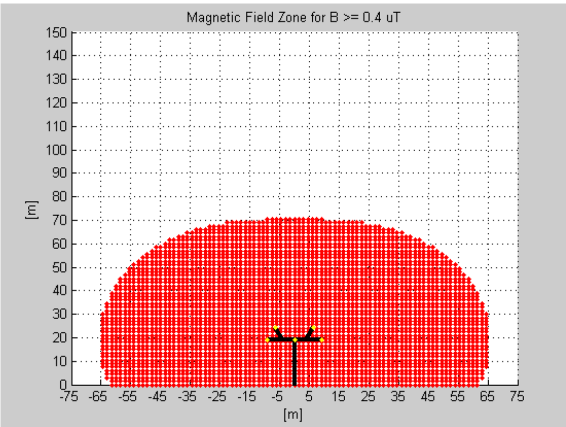

Fig. 6 - Magnetic Field Zone with B ≥ 0.4 µT for 220kV Line

It is presented in Fig. 7and Fig. 8 the administrative servitude face to the respective Magnetic Field Security Zones around High Voltage Power Lines of 60kV and 220kV.

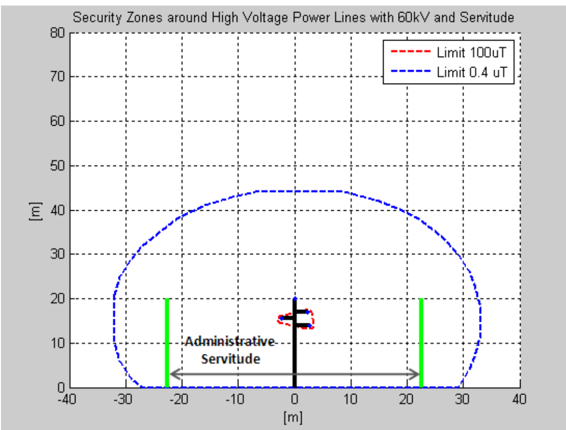

Fig. 7 - Magnetic Field Security Zones around High Voltage Power Line 60 kV and the Administrative Servitude

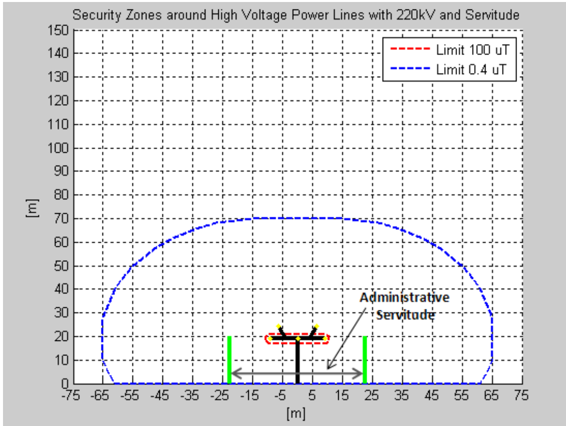

Fig. 8 - Magnetic Field Security Zones around High Voltage Power Line 220 kV and the Administrative Servitude

It is seen that this legal administrative servitude is largely exceeded for the security limits of B ≥ 0.4 µT.

It was also our interest to find a "good" analytical approximation for the Magnetic Field variation with distance (height). In TABLE III and TABLE IV it is presented the numerical results of the Magnetic Field (B) for the different heights above ground (0m) for the 60 kV and 220 kV Lines, respectively.

TABLE III - Numerical Results of the Magnetic Field for the Line 60 kV

Line 60 KV (Magnetic Field [µT])			
	Phase Conductor 2	**Center**	**Phase Conductor 1**
0 m	1,724	1,795	1,789
0,5 m	1,848	1,928	1,920
1 m	1,984	2,075	2,065
1,5 m	2,135	2,238	2,225
2 m	2,301	2,419	2,403
2,5 m	2,487	2,623	2,601
3 m	2,693	2,851	2,824

TABLE IV - Numerical Results of the Magnetic Field for the Line 220 kV

Line 220 KV (Magnetic Field [µT])			
	Left Phase Conductor 1	**Center Phase Conductor 2**	**Right Phase Conductor 3**
0 m	4,173	4,550	4,173
0,5 m	4,390	4,800	4,390
1 m	4,630	5,080	4,630
1,5 m	4,880	5,370	4,880
2 m	5,14	5,68	5,14
2,5 m	5,43	6,02	5,43
3 m	5,74	6,39	5,74

In order to find an analytical approach that describes the variation of Magnetic Field (B) with height, it was used the Lagrange polynomial interpolation.

$$P_n(x) = \sum_{i=0}^{n} a_i x^i \qquad (5$$

Were P_n is the interpolator polynomial of maximum degree n and a_i are the constants defined by the system of equations.

For this case the best fit functions are polynomials of 3rd degree and are described as follows:

$$f(x) = ax^3 + bx^2 + cx + d \qquad (6$$

It is presented in TABLE V and VI, a summary of the parameters for these functions for the High Voltage Power Lines of 60 kV and 220 kV, respectively.

TABLE V - Summary of Analytical Functions for the Line 60 kV

Parameter	Line 60 kV (Magnetic Field [µT])		
	Phase Conductor 2 ($f_{L60}(x)$)	Center ($f_{C60}(x)$)	Phase Conductor 1 ($f_{R60}(x)$)
a	0.003	0.004	0.004
b	0.02	0.02	0.021
c	0.238	0.256	0.252
d	1.724	1.795	1.789

TABLE VI - Summary of Analytical Functions for the Line 220 kV

Parameter	Line 220 kV (Magnetic Field [µT])	
	Left and Right Phase Conductor ($f_{L,R220}(x)$)	Center Phase Conductor ($f_{C220}(x)$)
a	0.006	0.006
b	0.008	0.02
c	0.443	0.499
d	4.173	4.55

In Fig. 9 it is presented the absolute error between the numerical and the approximated analytical value for the functions presented in the TABLE V and TABLE VI.

It is seen that this error is very low.

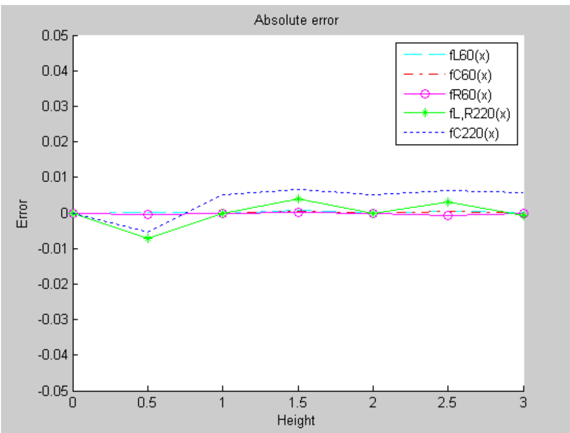

Fig. 9 – Absolute error for the approximated analytical functions

Analyzing the results for the distribution of the Magnetic Field with the limits of 100 µT (ICNIRP) and 0.4 µT 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 Fig. 10 and Fig. 11, respectively.

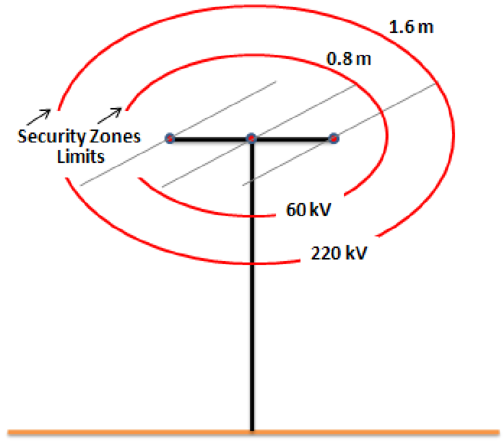

Fig. 10– Schematic Picture of Magnetic Field Security Zones around High Voltage Power Lines for B ≥ 100 µT

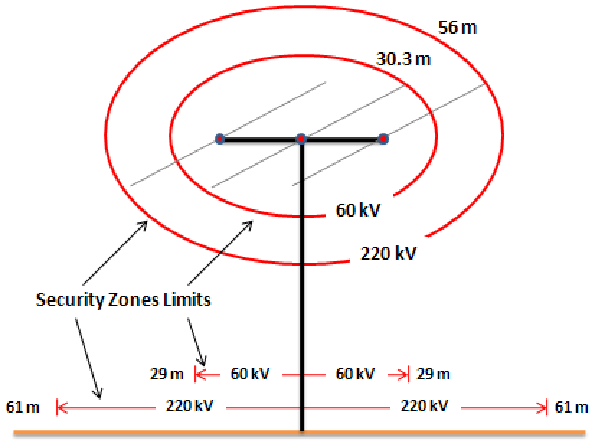

Fig. 11 – Schematic Picture of Magnetic Field Security Zones around High Voltage Power Lines for B ≥ 0.4 µT

4. Conclusions

It was presented the ELF Magnetic Field Security Zones around 60 kV and 220 kV HVPLs, for the limit values set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), ie 100 µT, and for the lower limit value of 0.4 µT. It is also shown a schematic picture of the Magnetic Field security zones around these HVPLs, derived from the numerical field solutions.

It was presented a good analytical approximation for the Magnetic Field variation with distance (height) for these two types of HVPLs, as well as the legal administrative servitude face to respective Magnetic Field security zones due to these HVPLs.

The Software tools used in this numeric simulation was developed by the author as part of a Research Project financed by the Portuguese Utilities REN and EDP.

Acknowledgements

The author is grateful to the Portuguese Utility EDP Distribuição – Energia, S.A. for the financial support received under the Research Project COIMBRA_SAÚDE-EMF.ELF and to Mr Daniel Costa Gomes that produced some of the results shown.

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