EMC Aspects in Telecommunication Buildings Struck by Lightning

Abu Md. Ali Baker
Student Member IEEE,AMIEB

Hussein B. Ahmad
Sr. MIEEE, MCIGRE

Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 80990 JB Malaysia, Fax: +6-07-5566272, Email: alibaker@nadi.fke.utm.my

Abstract: The EMC analysis of a telecommunication buildings struck by a direct lightning stroke, based on a simulation model is presented herein. For this purpose the resulting magnetic and electric fields in the places where the higher susceptible equipment will be installed, has been determined as a function of time considering different lightning struck points. Some illustrations are presented to point out the advantages of the considered EMI prediction model during the design of the electrical and electronic installations, considering lightning effects.

INTRODUCTION

When a building is struck by lightning, the resulting current and voltages transients can cause effects that can be dangerous from various point of views. The current that flows in the columns and beams of a building produces electromagnetic fields that couples with components of electrical and electronic systems and it can results in materials damages, malfunction of equipment, alteration of information.

Thus, from the EMC point of view, it is possible to conclude that it is very important to analyse the behaviour of buildings when they are struck by lightning, so as to determine the best solutions for the lightning protection system and for the lay-out of equipment, improving the aspects related to the EMC level of all electrical and electronic systems.

The Model

One of the most important problem related to Electromagnetic Compatibility analysis is the evaluation of the electromagnetic environment around a structure struck by a direct lightning.

Beyond the classified areas, where the insurance aspects related to explosion hazards are very important, the evaluation of the effects resulting from lightning has been assuming a special concern in our modern society due to the use of high susceptibility equipment, like electronic ones, in many social activities in a wide variety of functions.

This work was proposed due to the necessity of developing an electromagnetic field calculation methodology in the interior of a lightning protection system during a lightning stroke, suitable for the evaluation of energy and interference level associated with them.

The objective of the present work is to carry out a discretization technique in the space and time that meets the need of calculating the current distribution in a lightning protection system and the flux density or electromagnetic fields inside the protected volume.

For this purpose was developed a three-dimensional element or cell, where the central node corresponds to a junction of transmission lines, forming a impedance discontinuity in each line. Figure 1 shows this element.

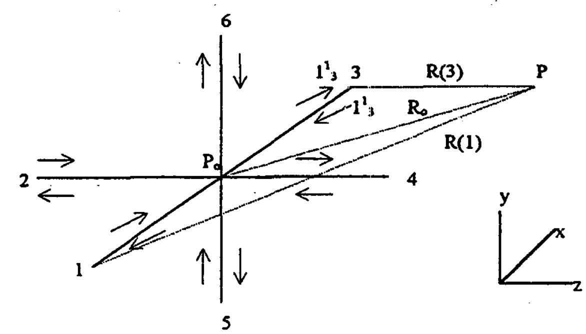

Figure 1. Proposed Three-dimensional Element

The response of the cell to incident voltage pulses and the current distribution were determined by transmission line and wave propagation theory [1].

Then, using the dipole and images theory was calculated the contribution of each reflected and incident current of the element to the electric and magnetic fields.

The total electric and magnetic fields as a function of the time, in any point of the space, can then be determined by superposition, after subdividing the protection system conductors into a finite number of elementary units, represented by the proposed three-dimensional elements or cell.

Lightning Model

The lightning stroke is simulated by an ideal unidirectional current source injected at the struck point, not taking into account the lightning channel.
For mathematical convenience, the current wave shape has been expressed by the sum of two simple ramp functions.

Impulse Response of the Cell

The impulse response of the cell at instant k, k+1 and k+2 is illustrated by figure 2. If at time $t = (k-2)\Delta\ell 2c$, voltage impulses ${}_{k-2}V_n^i$ on lines 1 to n are incident on any series node of the cell, then the reflected voltages on these lines at time $t = k\Delta\ell\, l/2c$ will be-represented by equation (1).

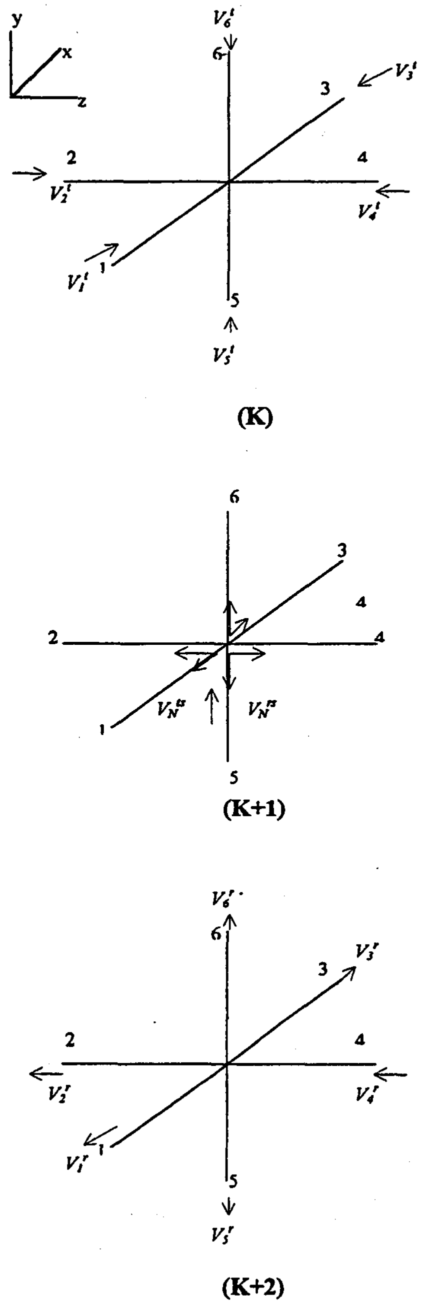

Figure 2. Impulse Response of the Cell at Instants k, k+1 and k+2.

The parameter $\Delta\ell$ l is the length between two series nodes of the cell, $\Delta\ell$ l/2c is the propagation time along each segment of transmission line, which is taken as the time step of the calculation, and [σ (I,J)] is the transmission coefficients matrix, where the coefficients σ_h and σ_v, that are used in the following equation (2), are the transmission coefficients of lines 1-4 and 5-6 respectively.

$$[\sigma(I,J)] = \begin{bmatrix} (\sigma_h-1) & \sigma_h & \sigma_h & \sigma_h & \sigma_h & \sigma_h \\ \sigma_h & (\sigma_h-1) & \sigma_h & \sigma_h & \sigma_h & \sigma_h \\ \sigma_h & \sigma_h & (\sigma_h-1) & \sigma_h & \sigma_h & \sigma_h \\ \sigma_h & \sigma_h & \sigma_h & (\sigma_h-1) & \sigma_h & \sigma_h \\ \sigma_h & \sigma_h & \sigma_h & \sigma_h & (\sigma_h-1) & \sigma_h \\ \sigma_h & \sigma_h & \sigma_h & \sigma_h & \sigma_h & (\sigma_h-1) \end{bmatrix} \quad (2)$$

Equation (3) shows us how reflected impulses, from neighboring cells, becomes incident impulses on the cell (z,x,y):

$$\begin{bmatrix} {}_kV_1^i(z,x,y) \\ {}_kV_2^i(z,x,y) \\ {}_kV_3^i(z,x,y) \\ {}_kV_4^i(z,x,y) \\ {}_kV_5^i(z,x,y) \\ {}_kV_6^i(z,x,y) \end{bmatrix} = [C(I,J)] \begin{bmatrix} {}_kV_1^r(z,x,+\Delta\ell,y) \\ {}_kV_2^r(z,+\Delta\ell,x,y) \\ {}_kV_3^r(z,x-\Delta\ell,y) \\ {}_kV_4^r(z-\Delta\ell,x,y) \\ {}_kV_5^r(z,x,y+\Delta\ell) \\ {}_kV_6^r(z,x,y-\Delta\ell) \end{bmatrix} \quad (3)$$

The matrix C(I, J) is :

$$[C(I,J)] = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

The Boundary Conditions

The boundary conditions for series nodes of cells connected to earth can be expressesed by equations (3) and (4), where in equation (4) R_{at} is the earth resistance and Z_v is the characteristics impedance of the vertical lines.

$${}_KV_6^r(z,x,y-\Delta\ell) = KV_5^i(z,x,y) = \frac{R_{at}-Z_v}{R_{at}+Z_v} kV_5^r(z,x,y) \quad (4)$$

Current Distribution

The reflected and incident current along line "n", at instant "k", is expressed respectively by equations (5) and (6), where Z_n is the characteristics impedance of line "n" and the value of SR^D depends on the position and direction of the wave propagation:

$$_K\left[I_n^r(z,x,y)\right]=\left[\frac{1}{Z_n}\right] SR^D \ _K\left[I_n^r(z,x,y)\right] \quad (5)$$

$$_K\left[I_n^i(z,x,y)\right]=\left[\frac{1}{Z_n}\right]\left[C(I,J)\right] \ SR^D \ _{k-1}\left[I_n^r.(z,x,y \ \Delta\ell)\right] \quad (6)$$

Table 1 shows the value of SR^D, when z,x,y are positive (0) or negative (1) coordinates of the cell.

Table 1, Value SR^D as a Function of the Coordinates of Cells

				SR(I,n)					
Z	X	Y	1/n	1	2	3	4	5	6
0	0	0	1	-1	-1	1	1	-1	1
0	0	1	2	-1	-1	1	1	1	-1
0	1	0	3	1	-1	-1	1	-1	1
0	1	1	4	1	-1	-1	1	1	-1
1	0	0	5	-1	1	1	-1	-1	1
1	0	1	6	-1	1	1	-1	1	-1
1	1	0	7	1	1	-1	-1	-1	1
1	1	1	8	1	1	-1	-1	1	

If the point (z,x,y) is the node struck by lighting, then SR^D assumes the value 1, *i, e.* the direction of the wave propagation is always the same of the reflected impulses on the lines of this cell.

Grounding System

In this work, the simulation of the grounding system is carried out connecting a resistance, the earth resistance R_{at} to each down conductor of the lightning protection system. This value is handled separately before introducing it in the configuration of the system.

Characteristic Impedance

Horizontal and vertical characteristic impedance of the transmission lines can be calculated through traditional formulas given by literature review [2,3]. For example, these parameters can be calculated by the following relations, where h is height and Dc is the diameter of the conductor:

$$Z_k = 138 \log (4h/D_c) \quad (7)$$

$$Z_v = 60 \ln (2h/D_c) + 90(2h/D_c) - 60 \quad (8)$$

Magnetic Field Calculation

The field generated by a elemental dipole of current propagating along y axis with speed v is given by [4], where the geometrical factors are shown in the Figure 3.

$$dB_\phi(r,\phi,y,t)=\frac{\mu_0 dy'}{4\pi}\left(\frac{r}{R^3}i(y',t-\frac{R}{c}+\frac{r}{cR^2}\frac{\partial i(y',t-\frac{R}{c}}{\partial t}\right)$$

In order to obtain the magnetic field, the spatial temporal distribution of the current in each radiating dipole is considered as a step function.

$$i(y',t) I_0 u \left(t-\frac{y'}{v}\right), \text{where} \quad u\ (\xi)^{0,\ \xi\ (0)}_{1,\ \xi\geq 0} \quad (9)$$

Therefore, from the knowledge of the reflected and incident currents along 5 or 6 the cell, the magnetic field as a function of the time can be found by using the method of images after integrating properly (10) plus (11).

$$\left(\frac{\mu_0 I_0 r}{4\pi R^3}dy',t\right)R/c+y'/v \quad (10)$$

$$\frac{\mu_0 I_0 r}{4\pi c\left[(y-y')^2+r^2\right]}\frac{1}{\left[\frac{1}{v}-\frac{(y-y')}{c\sqrt{(y-y')^2+r^2}}\right]}dy',t>R/c+y'/v \quad (11)$$

The time (R/c+y'/v) is named retarded time or validation time.

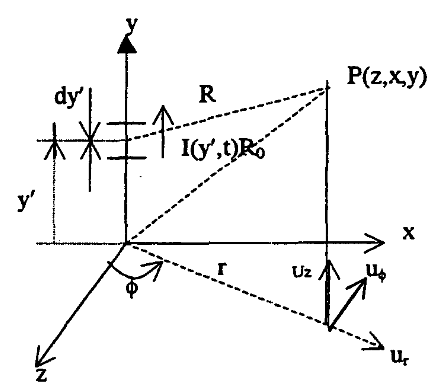

Figure 3. Definition of Geometrical Factors Used in the Field Computation.

The same through can be used to obtain the magnetic field due to the distribution of currents along lines 1,3 and 2,4 of the cell. The total field at time t in any point P of the space is then obtained by superposition.

Horizontal Electric Field Calculation

The field generated by a elemental dipole of current propagating along y axis with speed v is given by equation (12)

$$dE_r(r,\phi,y,t) = \frac{dz'}{4\pi \in_0}\left(\frac{3R(y-y')}{R^5}\right)\int_0^t y',\tau - R/c)d\tau$$

$$+\left[3r(y-y')/cR^1\right]i(y'(14)t - R/c)$$

$$+\frac{r(y-y')}{c^2R^3}\frac{\partial i(y',t-R/c)}{\partial t} \quad (12)$$

In order to obtain the horizontal electric field the spatial temporal distribution of the current in each radiating dipole is considered as a step function.

$$i(y',t)I_0 u\left(t - \frac{y'}{v}\right), \text{where } u(\xi) \begin{matrix} 0, \xi (0) \\ 1, \xi \geq 0 \end{matrix} \quad (13)$$

Therefore, from the knowledge of the reflected and incident currents along lines 5 or 6 of the cell, the horizontal electric field as a function of the time can be found by using the method of images after integrating properly (14) plus (15).

$$dE_r(r,\phi,y,t) = \frac{dz'}{4\pi \in_0}\left(\frac{3R(y-y')}{R^5}\int_{R/c+y'/v}^{t} I_o d\tau + \frac{3r(y-y')}{cR^4} I_o\right)$$

$$t > R/c + y'v = \frac{dy'}{4\pi \in_0}\left(\frac{3r(y-y')}{R^5}(t - y'/v) I_o\right) \quad (14)$$

$$E_n = \frac{I_o r(y-y')}{4\pi \in_0 c^2 R^3} x = \frac{1}{\left[\frac{1}{v} - \frac{(y-y')}{cR}\right]} \quad (15)$$

The same through can be used to obtain the horizontal electric field due to the distribution of currents along lines 1,3 and 2,4 of the cell. The total field at time t in any point P of the space is then obtained by superposition.

Vertical Electric Field Calculation

The field generated by a elemental dipole of current propagating along y axis with speed v is given by equation (16)

$$dE_{yr}(r,\phi,y,t) = \frac{dy'}{4\pi \in_0}\left(\frac{2R(y-y')^2 - r}{R^5}\int_0^t i(y',\tau - R/c)\right)d\tau \quad (16)$$

In order to obtain the vertical electric field, the spatial temporal distribution of the current in each radiating dipole is considered as a step function.

$$i(y',t) = I_o \mu\left(t - \frac{y'}{u}\right), \text{where } u(\xi) = \begin{matrix} 0,\xi(0) \\ 1,,\xi > 0 \end{matrix} \quad (17)$$

Therefore, from the knowledge of the reflected and incident currents along lines 5 or 6 of the cell, the vertical electric field as a function of the time can be found by using the method of

$$dE_y = \frac{dz'}{4\pi \in_0}\left(\frac{2(y-y')^2 - r^2}{R^5}(t - y'/v) I_o\right)$$

$$t > R/c + \frac{y'}{\partial} \quad (18)$$

$$E_y = \frac{I^o r^2}{4\pi \in_0 c^2 R'^3} x = \frac{1}{\left[\frac{1}{v} - \frac{(y-y')}{cR'}\right]} \quad (19)$$

images after integrating properly (18) plus (19).

The same through can be used to obtain the vertical electric field due to the distribution of currents along lines 1,3 and 2,4 of the cell. The total field at time t in any point P of the space is then obtained by superposition.

ILLUSTRATIONS

The three dimensional cell has been chosen based on the length of beams and columns and on the dimensions of the building. In the illustration the length between two series nodes of the cells is 4m.

The average values of the characteristic impedance of vertical and horizontal lines are 219Ω and 353Ω. They have been determined by traditional relations presented in this work, taking into account the dimensions and frequency of utilisation of each columns and beams in the structure. The lighting stroke is represented by equation (20).

I = 8.3t (kA) for t < 1.2 μs and
I = 10[0.83 t – 0.84 (t – 1.2)] (kA) for t) 1.2 μs (20)

The lighting struck points have been chosen applying the electrogeometric model around the region where the higher susceptibility equipment will be installed.

According to this model the striking distance R_c (m) is determined by equation (21), where I (kA) is the peak value of the lighting stroke current.

$$R_c = 9.4 I^{2/3} \quad (21)$$

Therefore, the lighting struck points around the interested region have been determined. One of the lighting struck points considered in the EMC analysis of the building is represented in the Figure 4. The earth resistance (R_{at}) is assumed as 5Ω.

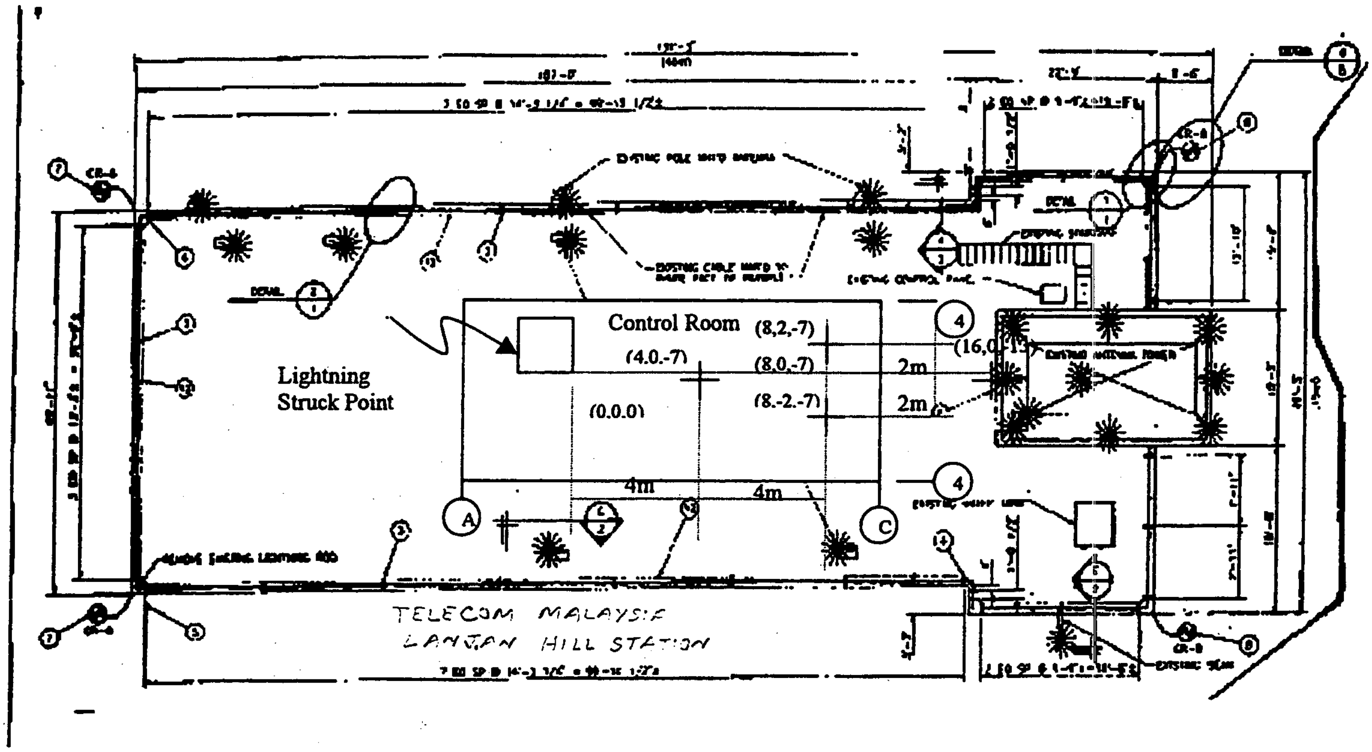

Figure 4. Sketch of the Considered Region and the Lighting Struck Point.

The behaviour of the electromagnetic field has been analysed taking into consideration the maximum value and the front steepness of the field waveform and different lighting struck points.

The current distribution in the cell (000), the magnetic flux density, horizontal electric field and vertical electric fields as a function of time (μs) at point (8,0,-7)m due to the current distribution in the structure, are presented in the Figures 5,6,7 and 8.

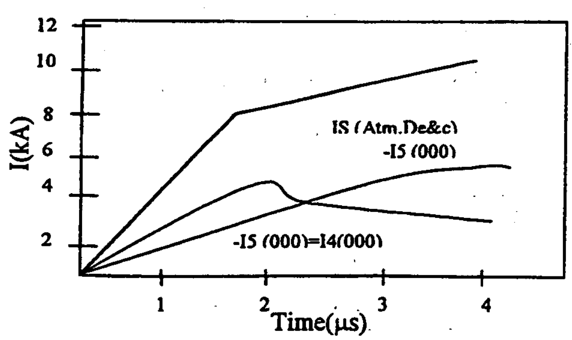

Figure 5: Current Distribution in the Cell (000)

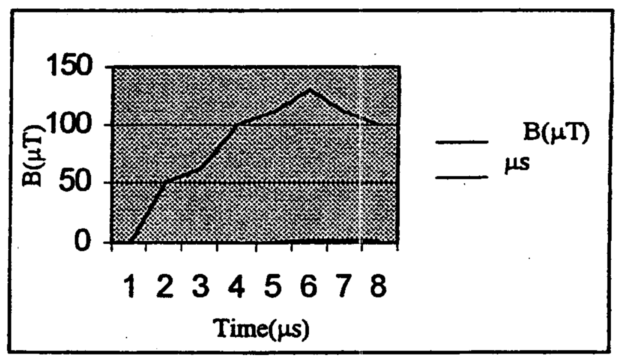

Figure 6: Magnetic Field B(μT) as a Function of Time (μs) at Point (8,0,-7)m.

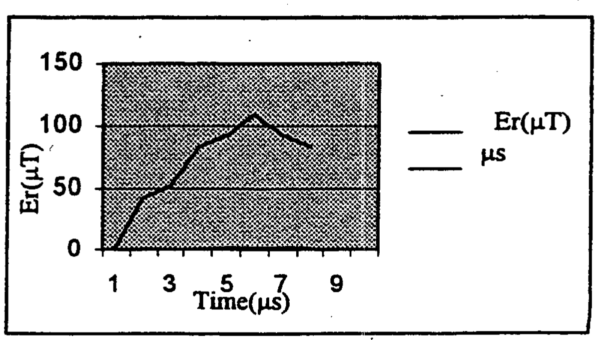

Figure 7: Horizontal Electric Field Er(μT) as a Function of Time (μs) at Point (8,0,-7)m.

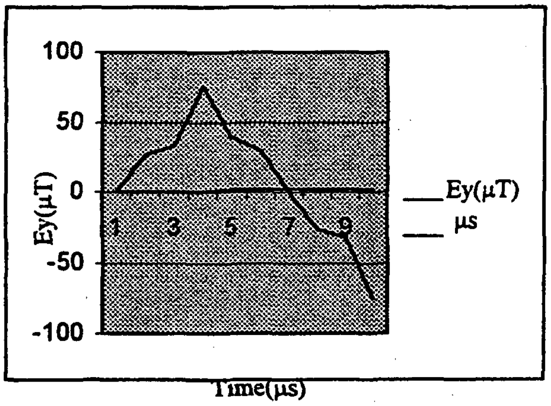

Figure 8: Vertical Electric Field Ey(μT) as a Function of Time (μs) at Point (8,0,-7)m.

CONCLUSION

A numerical model based on transmission line and wave propagation theory to calculate the current distribution in a structure struck by a direct lighting and on infinitesimal time varying dipole theory and method of images to calculate the electromagnetic field around it, has been presented.

With this model and EMC analyses has been carried out and some results have been presented. It has been shown that the proposed methodology is simple but it is a suitable numerical method for electromagnetic compatibility studies.

Some of the advantages of this methodology are:

- It is fast and direct method, when computational aspects are considered;
- It is possible to represent almost all kinds of configuration by appropriate composition of the elementary cell and
- The electromagnetic field can be predicted, helping the designer to take best decisions during an EMC study, when many parameters are involved.

REFERENCES

[1] Sartori, carlos A. F.; cardoso, J. R. evaluation of electromagnetic environment around a structure during a lightning stroke. In: 1994 International Symposium on EMC, Roma-Italy, Sept. 1994. Proceedings, pp. 746-749.

[2] lay, M. v. et al. Application guide for surge arrested on distribution systems. Report for The Canadian Electrical Association.Toronto, Ontarip Hydro. Sept. 1988.

[3] Anderson, J. G. Lightning performance of EHV-UHV lines. In: Electrical Power Research Institute. Transmission line reference book 345 kV and above. 2nd ed. Palo Alto, EPRI, 1982, chap. 12, pp. 545-97.

[4] Rubinstein M.: uman, M. A. Transient electric and magnetic fields associated with establishing a finite electrostatic dipole, revised. IEEE Transactions on Electromagnetic Compatibility, v.33, n.4, p.312-20, Nov.1991.