EVALUATION OF ELECTROMAGNETIC ENVIRONMENT AROUND A STRUCTURE DURING A LIGHTNING STROKE.

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Abstract - It is introduced a discretization technique in the space and time of the phenomenon based on transmission line and wave propagation model to calculate the current distribution in a structure and on the infinitesimal time-varing dipole and image method to calculate the magnetic field around it.

I. Introdution

One of the most important problem related to Electromagnetic Compatibility analisys 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 harzards 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 equipments, 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 magnetic field inside the protected volume.

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

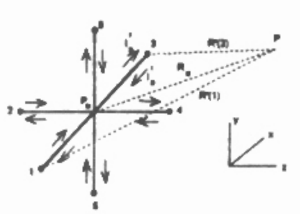

Figure 1: Proposed Three-dimensional Element

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

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

The total magnetic field 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 elementery units, represented by the proposed three-dimensional element or cell.

It was assumed in the present model some simplifications that could be reduced in a second round, without damage to the general philosophy adopted up to this moment.

Among these simplifications are the calculation of transmition line parameters through traditional formulas, not taking in account the non-linear ionization phenomena, and the simulation of the lightning stroke by a unidirectional current source. Some numerical results are shown in order to evaluate the physical and mathematical consistence of the proposed methodology.

II. Impulse Response of the Cell

The impulse response of the cell at instants k, k+1and k+2 is ilustrated by figure 2.

If at time $t = (k-2)\Delta l/2$, voltage impulses ${}_{k-2}V_n^i$ on lines 1 to n are incident on any serie node of the cell, then, the reflected voltages on these lines at time $t = k\,\Delta l/2c$ will be represented by equation 01.

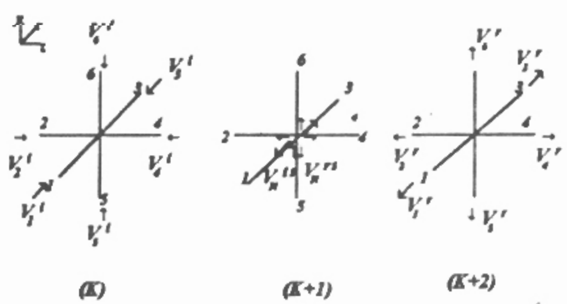

Figure 2: Impulse response of the cell at instants k, k+1and k+2

$$ {}_{K}\left[V_n^r(z,x,y)\right] = \left[\sigma(I,J)\right]_{K-2}\left[V_n^i(z,x,y)\right] \quad (01) $$

The parameter Δl is the length between two serie nodes of the cell and $\left[\sigma(I,J)\right]$ is the refraction coefficients matrix, where σ_h and σ_v are the refraction coefficients of lines 1-4 and 5-6 respectively.

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

Equation (02) shows us how reflected impulses, from neighboring cells, becomes incident impulses on the cell (z,x,y) :

$$ \begin{bmatrix} {}_K V_1^i(z,x,y) \\ {}_K V_2^i(z,x,y) \\ {}_K V_3^i(z,x,y) \\ {}_K V_4^i(z,x,y) \\ {}_K V_5^i(z,x,y) \\ {}_K V_6^i(z,x,y) \end{bmatrix} = \left[C(I,J)\right] \begin{bmatrix} {}_K V_1^r(z,x+\Delta l,y) \\ {}_K V_2^r(z+\Delta l,x,y) \\ {}_K V_3^r(z,x-\Delta l,y) \\ {}_K V_4^r(z-\Delta l,x,y) \\ {}_K V_5^r(z,x,y+\Delta l) \\ {}_K V_6^r(z,x,y-\Delta l) \end{bmatrix} \quad (02) $$

The matrix $c(i,j)$ is :

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

The boundary condition for serie nodes of cells, connected to earth, can be represented by :

$$ {}_K V_6^r(z,x,y-\Delta l) = {}_K V_5^i(z,x,y) = \frac{R_{at}-Z_v}{R_{at}+Z_v}\, {}_K V_5^r(z,x,y) \quad (03) $$

In the equation (3), R_{at} is the earth resistence and Z_v the characteristic impedance of the vertical lines.
The reflected and incident current along line "n", at instant "k", will be respectivily:

$$ {}_K\left[I_n^r(z,x,y)\right] = \left[\frac{1}{Z_n}\right] SR^D\, {}_K\left[V_n^r(z,x,y)\right] \quad (04) $$

$$ {}_K\left[I_n^i(z,x,y)\right] = \left[\frac{1}{Z_n}\right]\left[C(I,J)\right] SR^D\, {}_{K-1}\left[V_n^r(z,x,y,\Delta l)\right] \quad (05) $$

Z_n is the characteristic impedance of line "n" and the value of SR^D depends on the position and direction of the wave propagation. The following table shows these values, when z,x,y are positive (0) or negative (1) coordinates of the cell.

				SR (l,n)					
Z	X	Y	Nn	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	-1

Table I : Value of SR^D as a function of the coordinates of cells

III. Magnetic Field Calculation

The field generated by a elemental dipole of current propagating along y axis with speed v is given by [02], where the geometrical factores are shown in the figure 3 :

$$ dB_\phi(r,\phi,y,t) = \frac{\mu_0 dy'}{4\pi}\left(\frac{r}{R^3} i(y',t-\frac{R}{c}) + \frac{r}{cR^2}\frac{\partial i(y',t-\frac{R}{c})}{\partial t}\right) \quad (06) $$

In order to obtain the magnetic field, each current will be considered as a step function :

$$ i(y',t) = I_0 u(t-\frac{y'}{v}),\ \text{where}\ u(\xi) = \begin{cases} 0, & \xi < 0 \\ 1, & \xi \geq 0 \end{cases} \quad (07) $$

Then, the magnetic field from the reflected and incident currents along lines 5 or 6, can be found by using the image method and integrating, properly, (8) plus (9).

$$ \frac{\mu_0 I_0 r}{4\pi R^3} dy',t) R/_c + y'/_v \quad (08) $$

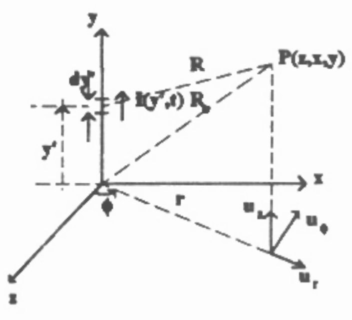

Figure 3: Definition of geometrical factores used in the field computation.

$$\frac{\mu_0 I_y r}{4\pi c[(y-y')^2+r^2]}\frac{1}{[\frac{1}{v}-\frac{(y-y')}{c\sqrt{(y-y')^2+r^2}}]}dy',t)^{R}/_{c}+^{y'}/_{v} \quad (09)$$

The same though can be used to obtain the magnetic field due to the currents along lines 1,3 and 2,4. The total field will be, then, obtained by superposition.

IV. Results

With the model described some results were obtained, like shown in the following examples:

Example 1: Represented by figure 4

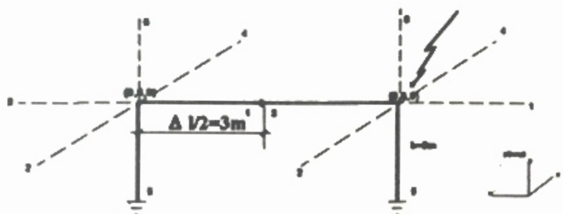

Figure 4 : Sketch of a structure struck by a lightning at point (0,0,0) and of the applied three-dimensional elements .

In this example, the characteristic impedances of vertical and horizontal lines are assumed as 112Ω and 245Ω, earth resistence (Rat) as 5Ω and the current source is represented by the function :

I = 5 t (kA) for t≤2 μs and I = 10 [0.5 t - 0.51 (t - 2)](kA) for t〉 2μs.

The current distribution in the cell (000) and the magnetic flux density as a function of time (μs) at point (0,3,-1.25) m, due the current distribution in the structure, are represented in the figures 5 and 6.

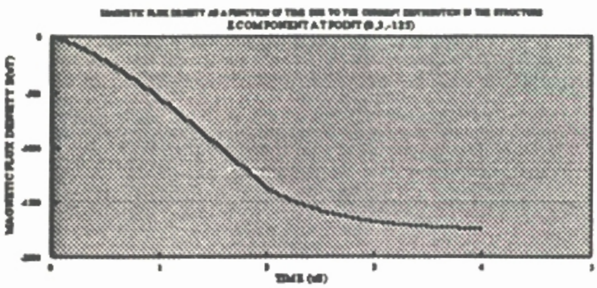

Figure 6: Magnetic flux density B (μT) as a function of time (μs) at point (0,3,-1.25) m, due the current distribution in the structure.

Example 2 : Represented by figure 7.

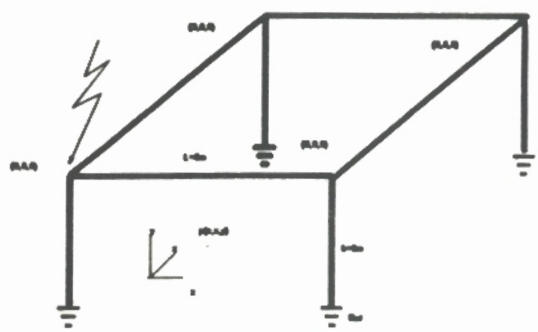

Figure 7 : Sketch of a three-dimensional structure struck by a lightning at point (0,0,0) .

In this example, the characteristic impedances of vertical and horizontal lines are assumed as 323,97Ω and 424,92Ω,the applied element, the earth resistence and the current source are the same represented in the example 1.

The current distribution in the cell (000) and the magnetic flux density as a function of time (μs) at point (0,3,-1.25) m, due the current distribution in the structure, are represented in the figures 8 and 9.

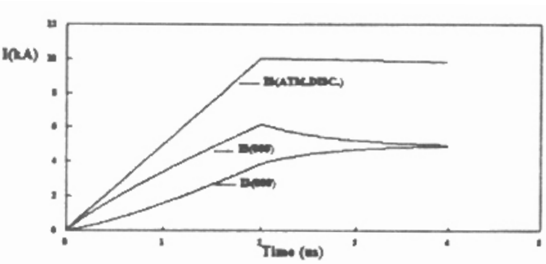

Figure 5 : Current distribution in the cell (000) (Example 1)

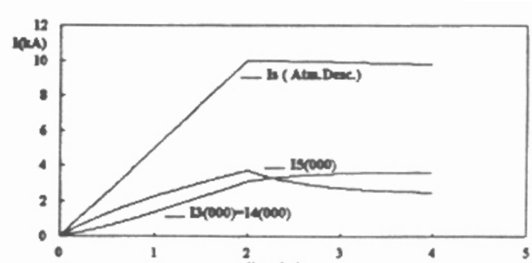

Figure 8 : Current distribution in the cell (000) (Example 2)

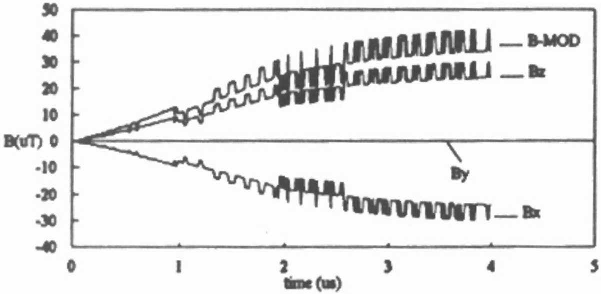

Figure 9: Magnetic flux density B (μT) and components as a function of time (μs) at point (0,3,-1.5)m, due the current distribution in the structure.

V. Conclusion

It was shown that, the proposed methodology is a suitable numerical method to be used when the evaluation of electromagnetic environment is necessary. This method will be improved, in the future, when the nonlinear and the lightning channel effects will be considered.

VI. References

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