Pulse Magnetic Field Immunity International Standard and The Impact on Design: Consideration of a Magnetic Field Modeling as a Helpful Tool

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Abstract **- This paper describes the impact of the pulse magnetic field immunity international standard IEC 1000-4-9 on electromagnetic compatibility (EMC) design and an engineering approach to meeting the immunity requirements of equipment subjected to impulse magnetic fields. A simulation method developed by the authors is applied on the evaluation of electromagnetic environment and the immunity level of equipment is established from the aforementioned standard. As a example, the definition of the best layout of a group of equipment placed on a control room, when subjected to magnetic fields generated by a lightning stroke on the steel structure of the building, is presented.**

I. Introduction

The magnetic fields to which equipment is subjected may influence the reliable operation of equipment and system.

Pulse magnetic fields can be generated by phenomena like lightning, switching, and faults transients. The influence from such phenomena on equipment and systems, depends on immunity levels, and on specific location and installation condition of equipment and systems.

The electromagnetic (EM) immunity of equipment can be determined by EMC tests. Compliance to EMC immunity international regulation are new requirements for evaluating the performance of electrical and electronic equipment for household, commercial, and industrial applications, starting on January 1, 1996 for equipment, which will be sold in European Union market. Actually, due to the importance of the European Union market, these requirements affect all the world market. The immunity test methods are covered by the IEC standard 1000-4-X series, in which the IEC 1000-4-9 standard covers the requirements for pulse magnetic fields immunity tests.

On the other hand, the chances for EMC success are not guaranteed only by the compliance to immunity tests but also is necessary to evaluate the specific location and installation conditions regarding EMC design. That is, the evaluation of the EM environment should be carried out.

EMC modeling tools can provide EMC design team with reliable numerical results, providing the EMC engineer with the availability to consider the best layout and recommendations to achieve the EMC of the system. In this paper is presented a magnetic field simulation method developed by the authors to meeting this requirements.

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II. The International Standard IEC 1000-4-9

A. *General Considerations*

This standard presents immunity requirements and test procedures, which main object is to establish basis for evaluating the performance of electrical and electronic equipment for household, commercial, and industrial applications, when subject to "pulse magnetic fields". Special attention is given to electronic equipment to be installed in electrical plants as well in telecontrol centers.

As mentioned in this standard, the pulse magnetic fields are generated by lightning strokes on buildings and other metal structures including aerial masts, earth conductors and earth networks, and by initial faults transients in low, medium and high voltage electrical systems.

B. *Classes (Environmental Conditions) and Test Levels*

The test level should be selected in accordance with the installation and environment conditions. That is, once the test level is chosen, the immunity test will establish a performance level for the environment in which the equipment will be installed.

The standard IEC 1000-4-9 gives a guide for selecting the test level for pulse magnetic fields testing. The test levels are correlated with five classes, each of them representing a environmental condition.

The classes can be briefly described as:

Class 1: An environment characterized by sensitive devices using electron beam, like monitors, electron microscope, etc.;
Class 2: A well protected environment where there is no concerning about the influence of pulse magnetic fields;
Class 3: A Protected environment, characterized by the proximity of earth conductors of lightning protection system and metallic structure;
Class 4: It is a typical industrial environment;
Class 5: A severe industrial environment, and
Class X: Special environment.

For a better understanding, some areas, considered representative of the aforementioned classes, are given as information in this standard. For example, it is mentioned that commercial areas, control buildings, and computer rooms of high voltage sub-stations may be representative of the environment regarding class 3.

The test levels or immunity levels is given in table I. In this table, the magnetic field strength is expressed in A/m, and 1 A/m corresponds to a free space induction of 1.26 μT.

TABLE I

TEST LEVEL OR IMMUNITY LEVELS

Class	Pulse magnetic field A/m (peak)
1	Not applicable
2	Not applicable
3	100
4	300
5	1000
X	Special: open level

II. THE METHOD

A. *Description of the Method*

A brief description of the method used for simulating the electromagnetic environment, which is described with more details in references [3,4,5], is presented in this item. This method is based on the development of a three-dimensional element or cell, where the central node corresponds to a junction of transmission lines; forming a impedance discontinuity on each line. Fig. 1 shows this cell.

The length of each transmission line is chosen to be electrically short enough when compared with the impulse wavelength.

The response of the cell to incident-voltage pulses and the current distribution are determined by the transmission line and wave propagation theories [1]. Once the current distribution is determined, the contribution of each reflected and incident current of the cell to the magnetic field is calculated using the dipole and images theory [2].

After subdividing the array of conductors into a finite number of elementary units, the calculation of the total magnetic field as a function of the time at any point of the space is then determined by superposition.

This method differs from others presented so far in the scientific literature. Thanks to its intrinsic aspects, it is not necessary to solve any equation system, and there are not problems regarding the convergence of the solution. Thus this method is unconditionally stable.

Another characteristic to be mentioned about this method is concerned with the determination of magnetic field through the incident and reflected current; which is not from the current resulted from the sum of them.

It is a very important characteristic of the method: first, because the field calculation is directly related to the current path; second, because the consideration of the incident and reflected current allow us to use bigger cells without introducing significant errors, specially in the near-field calculation.

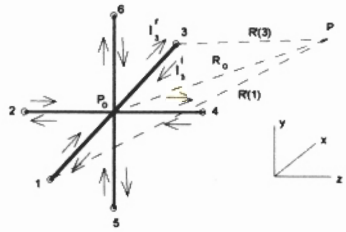

Fig. 1. The three-dimensional element or cell.

The field contribution from each dipole is delayed by the retarded or validation time, a factor that depends on the current path. If the center of each dipole is taken into account when the retarded factor is calculated, like in other methods, some restrictions should be included in the EM field calculation.

This is particularly significant when the dimension of the element and the distance from which the field is evaluated are similar.

B. *Basic Equations*

B.1. *Current Distribution*

The voltage and current wave propagation on each of transmission line of the cell are related to the inductance L and capacitance C of the line by the following equations:

$$-\frac{\partial u(z,x,y,t)}{\partial t} = L\frac{\partial i(z,x,y,t)}{\partial t} \tag{1}$$

$$-\frac{\partial i(z,x,y,t)}{\partial t} = C\frac{\partial u(z,x,y,t)}{\partial t} \tag{2}$$

The reflected and incident current are obtained from the general solution of (1) and (2), which discretized form of the equation of the currents along line "*n*" at instant "*k*" are expressed by (3) and (4). In these equations, *Zn* is the characteristic impedance of line "*n*", and SR^D is a scattering factor regarding the position and direction of the reflected-wave propagation. The space and time are represented in terms of finite, elementary units, which are related by the speed of light c .

$$_K\left[I_n^r(z,x,y)\right] = \left[\frac{1}{Z_n}\right] SR^D\ _K\left[V_n^r(z,x,y)\right] \tag{3}$$

$$ {}_{K}\left[I^{i}_{n}(z,x,y)\right] = \left[\frac{1}{Z_n}\right]\left[C(I,J)\right]SR^{D}\;{}_{K-1}\left[V^{r}_{n}(z,x,y,\Delta l)\right] \quad (4) $$

C(I,J) is a matrix that relates incident and reflected impulses. This matrix was named *Connection-Matrix* by authors.

B.2. *Magnetic Field Calculation*

The magnetic field is calculated assuming the spatial-temporal distribution of the current in each radiating dipole as a step function, the equations for the magnetic field generated by an elemental dipole of current propagating along z,x,y axis with speed v, which integration is done along each segment of line of the cell, and the method of images [2,3].

When the y axis and the geometrical factors, shown in fig. 2:, are taken into account, the field due to the distribution of current along the lines 5 and 6 of the cell is obtained after integrating properly (5) and (6):

$$ \frac{\mu_0 I_0 r}{4\pi R^3}\,dy',\; t\rangle R/c + y'/v \quad (5) $$

$$ \frac{\mu_0 I_0 r}{4\pi c[(y-y')^2+r^2]}\,\frac{1}{\left[\frac{1}{v}-\frac{(y-y')}{c\sqrt{(y-y')^2+r^2}}\right]}\,dy',\; t\rangle R/c + y'/v \quad (6) $$

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

The same procedure can be used to obtain the magnetic field owing to the current distribution along lines 1 and 3; and 2 and 4 of the cell. The total field at time t at any point P of the space is then obtained by superposition.

III. Application

To illustrate the engineering approach proposed in this paper, it is presented an example regarding a steel structure struck by lightning, which is shown in [5] as an application of the magnetic field calculation method.

Fig. 3 represents the building struck by lightning; and Fig. 4, one of the struck point and the region regarding the magnetic field analysis.

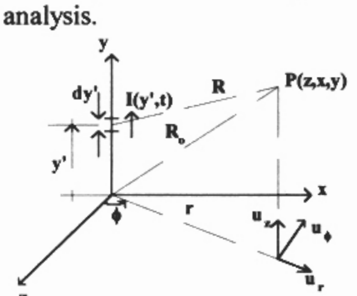

Fig. 2. Definition of geometrical factors used in the field computation.

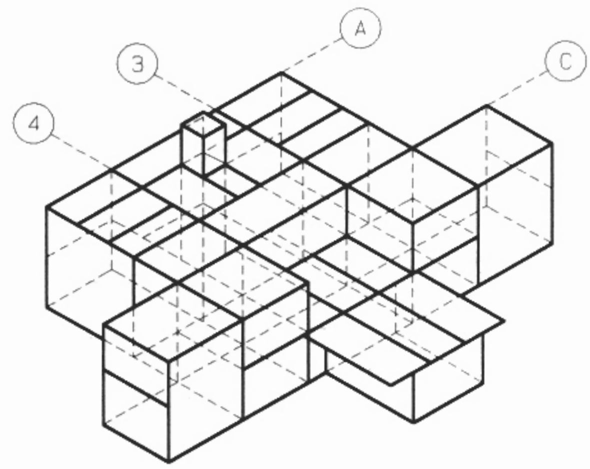

Fig. 3 : Sketch of the building, steel structure, which average dimensions are (44 x 24 x 14) m.

A. *General Criteria*

In this example, each column and beam of the structure was taken into account as part of the lightning protection system: the down-conductors and the roof-grid conductors.

Then, based on the length of beams and columns; and on the dimensions of the building, the structure was divided in identical cells, which length between two series nodes of the cell is 4m.

It was assumed in this example some simplifications without damaging the general philosophy of the method:

-The structure was divided in identical cells;
-Each conductor of the lightning protection system was assumed as characterized by a circular cross-section through the equivalent cylindrical conductors, and
-It was taken an average value for the vertical and for the horizontal characteristic impedance of beams and columns.

The average characteristic impedance of vertical and horizontal lines are 219Ω and 353Ω. They were calculated through traditional formulas [6,7], taking into account the dimensions and frequency of utilization of each columns and beams in the structure.

The lightning stroke was simulated by a unidirectional current source given by:

I = 8.3t (kA) for $t \leq 1.2\ \mu s$ and
I = 10[0.83 t - 0.84 (t - 1.2)] (kA) for $t \rangle 1.2 \mu s$ (7)

The lightning struck points was chosen applying the electrogeometric model around the region where the higher susceptibility equipment will be installed [5].

The earth resistance of the grounding system was assumed constant, equal to 5Ω.

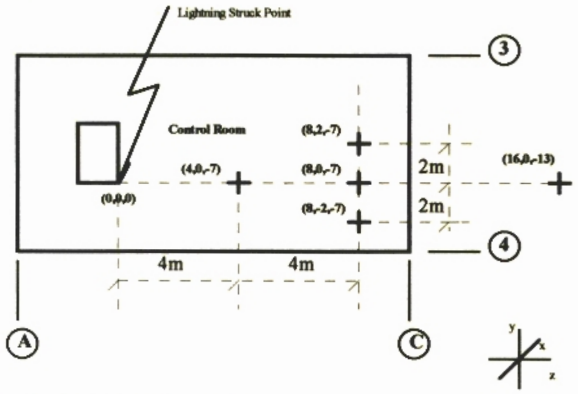

Fig. 4. Sketch of the region and one of the lightning struck point regarding the magnetic field analysis.

B. *Results*

The magnetic fields owing to the current distribution in the lightning protection system as a function of time in the points of the region represented by fig. 4 were calculated, and after comparing with established limit regarding class 3(~120 μT), the best layout was defined. It was concluded that the corner, given by the intersection of axis 4 and axis C represented in the fig. 4, is the struck point that defines the magnetic environment of the interested region, and it was emphasized that the region around this corner should be avoided.

As an example, fig. 5 shows the profile of the magnetic field as a function of time, at points represented in fig. 4, due to current distribution in the structure (fig. 3) in the case of a direct strike at point (0,0,0).

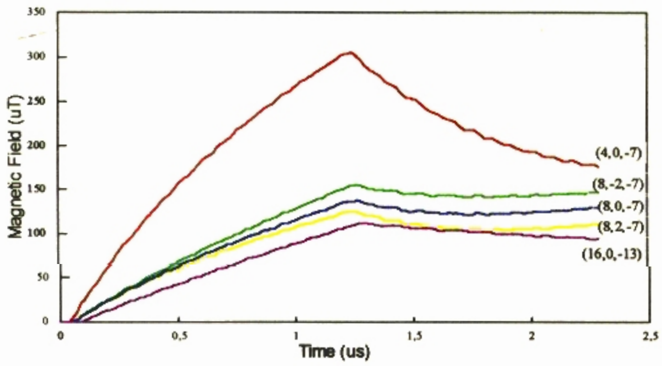

Fig. 5. Magnetic field B (μT) as a function of time (μs) at points shown in fig. 4, due the current distribution.

IV. Conclusions

It was presented in this paper an engineering approach regarding EMC design when pulse electromagnetic fields is take into account. This approach is based on information from IEC 1000-4-9 standard and on a simulation method developed by the authors, showing the importance of the aforementioned standard and modeling on EMC analysis.

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