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Study on electromagnetic environment analysis and lightning protection in buildings

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Abstract. When a direct strike occurs, the lightning surge current will intrude into the steel frame and steel bar of the building, forming a high lightning electromagnetic environment inside the building, which will affect the telecommunications equipment set in the building. Therefore, the problem of lightning protection in buildings becomes more and more important. In this paper, by studying the distribution law of lightning electromagnetic field in buildings, the intensity of magnetic field generated in buildings under different lightning strikes is analyzed. According to the three-dimensional diagram and equivalent diagram of the intensity of lightning magnetic field in each case, when the building encounters direct lightning, the lightning electromagnetic field is the strongest near the leadoff line, and the middle zone is weak. The lightning protection measures inside the building are put forward.

1 Introduction

Lightning overvoltage hazard, in addition to intruding into the communication station along the power lines, lightning strikes the station buildings directly. At this point, the building of the steel frame, steel bar will intrude lightning surge current, thus to the building of telecommunications equipment to generate a strong electromagnetic field. At the same time, high potential difference appears in various devices located in the same building, thus posing a great threat to communication. With the electronization of telecommunications equipment, its endurance to lightning surges has been declining. The tolerance energy of vacuum tubes widely used in the 1960s is $0.1 \sim 10J$, while the tolerance energy of large integrated circuits widely used at present is only $10^{-8} \sim 10^{-6} J$, the difference between the two is 7 orders of magnitude. Lightning is an atmospheric physical phenomenon that releases hundreds of megajoules (MJ) of energy every time. It can affect sensitive weak current equipment in various ways and sometimes even cause devastating damage. Therefore, the question of protection becomes more and more important.

2 The electromagnetic environment of a building when struck by lightning

As shown in Figure 1, a wireless tower is set on the roof of the building of the communications Bureau station, and a lightning rod is set on it. Lightning rods, wireless towers, steel frames of buildings, reinforcement bars of concrete walls, etc. are bolted to each other. Therefore, when a direct strike occurs, the lightning surge current intrudes into the steel frame and steel bar of the building, which forms a high lightning electromagnetic environment inside the building and affects the telecommunications equipment set in the building.

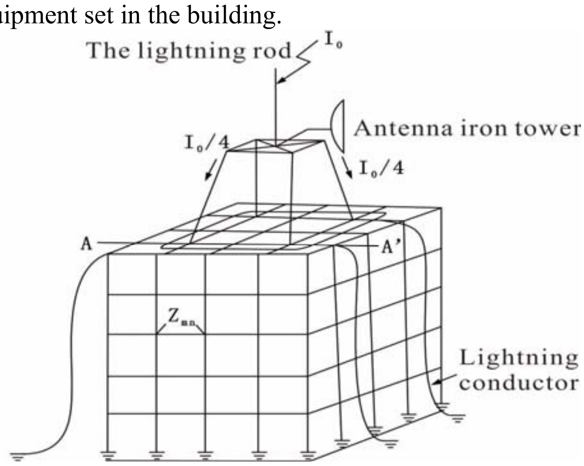

Figure 1. The building of the communication Station

Feliziani et al. have studied the distribution law of Lightning electromagnetic field around buildings[1][2][3]. They calculated and analyzed the surrounding Lightning electromagnetic field under the assumption that the Lightning current on the building's Lightning Protection System is a double exponential function. Such electromagnetic field is determined by the Lightning Protection System on the building's Lightning Protection System. Orlandi et al. numerically calculated and analyzed the lightning current on the off-line through the transmission line model [4] [5] [6] [7]. Cristina et al. used the electric field integral equation to study the induced current generated by the lightning strike near the building on the internal equipment of the building [8], and discussed the

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shielding effect of the building structure (reinforced columns, reinforced concrete walls) on lightning [9] [10].

2.1 Direct lightning surge current and voltage distribution within the building

The thunder surge current flows into the steel frame and reinforcement of the columns, beams, walls and floors of the building respectively. It's a complicated combination. It is difficult to interpret them all in equivalent circuits. Here the building simplified into columns, beams linear model representation.

The connection points between columns and beams in the building are taken as nodes. The voltage and current matrices of each node are expressed by $[V]$ and $[I]$ respectively, and the admittance matrix between nodes is $[Y]$. Then the following equation holds:

$$[Y]\cdot[V]=[I] \tag{1}$$

The voltage V of each node and the current I_{mn} between nodes can be obtained from the following formula

$$[V]=[Y]^{-1}\cdot[I] \tag{2}$$

$$I_{mn}=\frac{V_n-V_m}{Z_{mn}} \tag{3}$$

Where I_{mn}, Z_{mn}, V_n and V_m are the current, resistance and voltage between nodes m and n respectively. The lightning surge current is still in the form recommended in IEC 1312-1, namely, which produces the following lightning voltage waveform:

$$V(t)=[L]\cdot\left[\frac{dI}{dt}\right] \tag{4}$$

If the complex frequency is represented by S, $I_L(s)$ is the lightning current in the building lead-off line, $V(s)$ is the induced voltage in the open coil in the building, and $\chi(s)$ is the spatial distribution of the lightning electromagnetic field in the building. Then the Transfer Function T(s) is:

$$T(s)=\frac{V(s)}{I(s)}=\frac{\chi(s)V(s)}{I_L(s)\chi(s)}=T_1(s)T_2(s) \tag{5}$$

The physical meaning of the formula is clear, $I_L(s)$ is the lightning current on the vertical and horizontal components of the building lightning protection system, which generates the lightning electromagnetic field in the building $\chi(s)$ (its transfer function is $T_1(s)$), and $\chi(s)$ is the source of producing $V(s)$ (transfer function is $T_2(s)$). $T_1(s)$ for the division of lightning protection areas in buildings (IEC 1312-1), $T_2(s)$ for electromagnetic compatibility design of electronic equipment in buildings.

2.2 Electromagnetic fields in buildings

Consider several situations as shown in Figure 2. (a) For direct lightning strikes in the middle of the top of the building, lightning flows through the four columns of the building (as lead lines) and infuses the ground; (b) A lead line has been added to each side of the building, striking lightning directly in the middle; (c) A situation in which 12 leads hit a corner of the building.

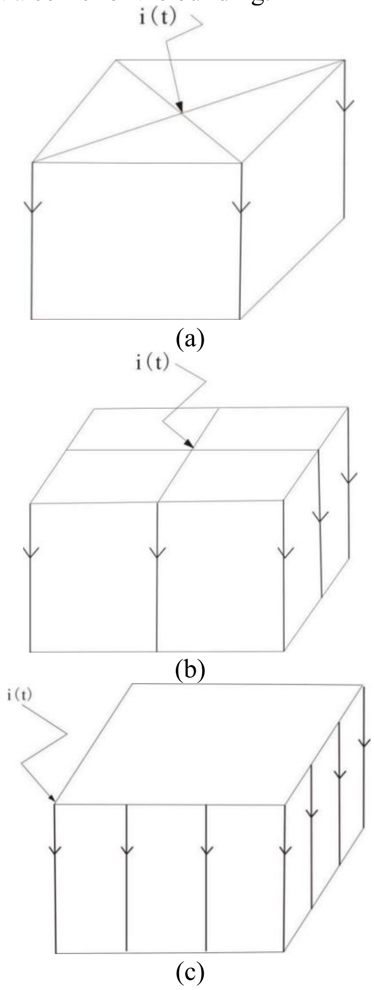

Figure 2. Several cases of lightning protection lead off-line in communication bureau station

According to Maxwell equation, when there is lightning current In on n lead-off lines, the magnetic field intensity generated In the building is:

$$H=\sum\frac{I_n}{2\pi r_n} \tag{6}$$

Where, r_n is the distance between the lead-off line of current In intrusion and the test point. In the rectangular coordinate system, the three cases shown in FIG. 2 can be concretely expressed as follows:

2.2.1 For direct lightning strikes in the middle of the top of the building, lightning flows through the four columns of the building (as lead lines) and infuses the ground.

$$H=\frac{i(t)}{8\pi}\left[\left[\frac{10-y}{x^2+(10-y)^2}+\frac{10-y}{(10-x)^2+10-y)^2}-\frac{y}{x^2+y^2}-\frac{y}{(10-x)^2+y^2}\right]^2\right.$$
$$\left.+\left[\frac{x}{x^2+y^2}+\frac{x}{x^2+(10-y)^2}-\frac{10-x}{(10-x)^2+y^2}-\frac{10-x}{(10-x)^2+(10-y)^2}\right]^2\right]^{\frac{1}{2}} \quad (7)$$

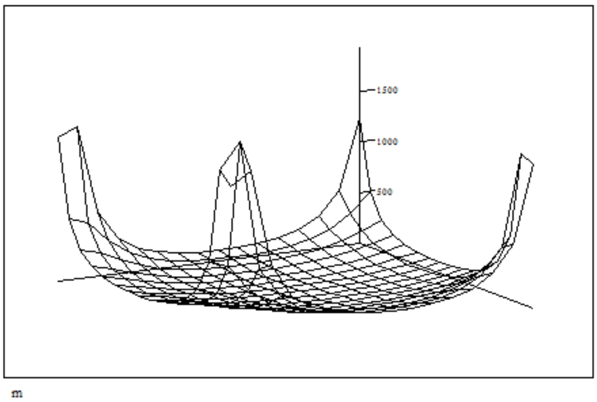

Figure 3. (a) Three-dimensional diagram of the intensity of the lightning magnetic field in the building

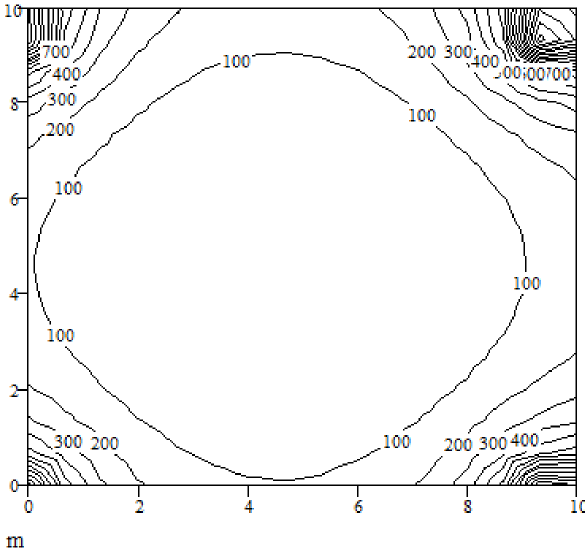

Figure 4. (a) Isogram of the intensity of the lightning magnetic field in the building

2.2.2 A lead line has been added to each side of the building, striking lightning directly in the middle.

$$H=\frac{i(t)}{16\pi}\left[\left[\frac{10-y}{x^2+(10-y)^2}+\frac{10-y}{(10-x)^2+(10-y)^2}+\frac{10-y}{(5-x)^2+(10-y)^2}-\frac{y}{x^2+y^2}\right.\right.$$
$$\left.+\frac{5-y}{(10-x)^2+(5-y)^2}+\frac{5-y}{x^2+(5-y)^2}-\frac{y}{(10-x)^2+y^2}-\frac{y}{(5-x)^2+y^2}\right]^2$$
$$+\left[\frac{x}{x^2+y^2}+\frac{x}{x^2+(10-y)^2}+\frac{x}{x^2+(5-y)^2}-\frac{10-x}{(10-x)^2+(10-y)^2}\right.$$
$$\left.\left.-\frac{10-x}{(10-x)^2+y^2}-\frac{5-x}{(5-x)^2+(10-y)^2}-\frac{5-x}{(5-x)^2+y^2}-\frac{10-x}{(10-x)^2+(5-y)^2}\right]^2\right]^{\frac{1}{2}} \quad (8)$$

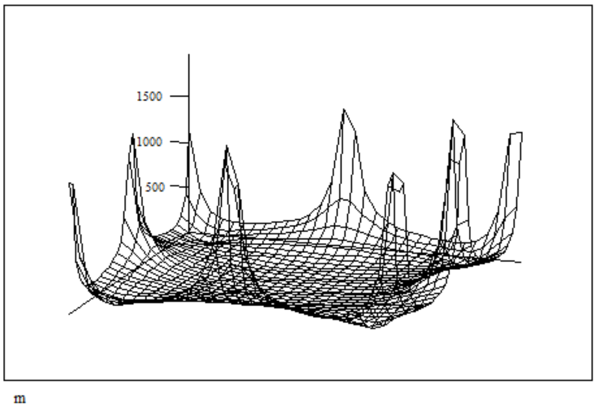

Figure 5. (b) Three-dimensional diagram of the intensity of lightning magnetic field in the building

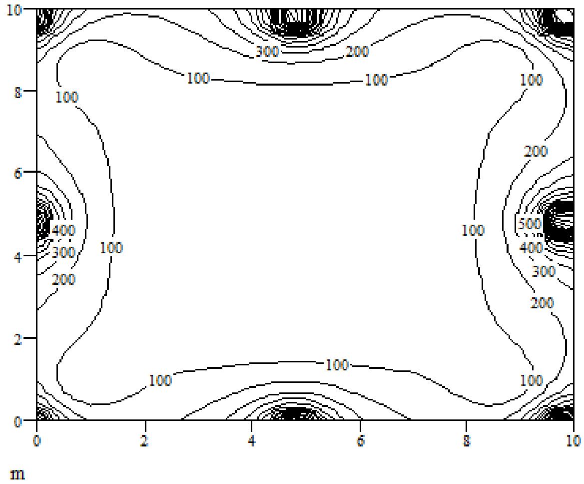

Figure 6. (b) Isogram of the intensity of the lightning magnetic field in the building

2.2.3 represents the case in which 12 leads hit a corner of the building.

$$
\begin{aligned}
H = \frac{i(t)}{1042\pi}\Bigg[\Bigg[& \frac{5(\frac{10}{3}-y)}{(10-x)^2+(\frac{10}{3}-y)^2} + \frac{2(\frac{20}{3}-y)}{(10-x)^2+(\frac{20}{3}-y)^2} + \frac{2(10-y)}{(10-x)^2+(10-y)^2} \\
& + \frac{2(10-y)}{(\frac{20}{3}-x)^2+(10-y)^2} + \frac{5(10-y)}{(\frac{10}{3}-x)^2+(10-y)^2} + \frac{13(10-y)}{x^2+(10-y)^2} - \frac{13y}{(10-x)^2+y^2} \\
& + \frac{34(\frac{20}{3}-y)}{x^2+(\frac{20}{3}-y)^2} + \frac{89(\frac{10}{3}-y)}{x^2+(\frac{10}{3}-y)^2} - \frac{89y}{(\frac{10}{3}-x)^2+y^2} - \frac{34y}{(\frac{20}{3}-x)^2+y^2} - \frac{333y}{x^2+y^2}\Bigg]^2 \\
& + \Bigg[\frac{34x}{x^2+(\frac{20}{3}-y)^2} - \frac{89(\frac{10}{3}-x)}{(\frac{10}{3}-x)^2+y^2} - \frac{5(10-x)}{(10-x)^2+(\frac{10}{3}-y)^2} - \frac{2(10-x)}{(10-x)^2+(\frac{20}{3}-y)^2} \\
& + \frac{13x}{x^2+(10-y)^2} - \frac{34(\frac{20}{3}-x)}{(\frac{20}{3}-x)^2+y^2} - \frac{2(\frac{20}{3}-x)}{(\frac{20}{3}-x)^2+(10-y)^2} - \frac{13(10-x)}{(10-x)^2+y^2} \\
& + \frac{333x}{x^2+y^2} + \frac{89x}{x^2+(\frac{10}{3}-y)^2} - \frac{5(\frac{10}{3}-x)}{(\frac{10}{3}-x)^2+(10-y)^2} + \frac{2(10-x)}{(10-x)^2+(10-y)^2}\Bigg]^2\Bigg]^{\frac{1}{2}}
\end{aligned}
\tag{9}
$$

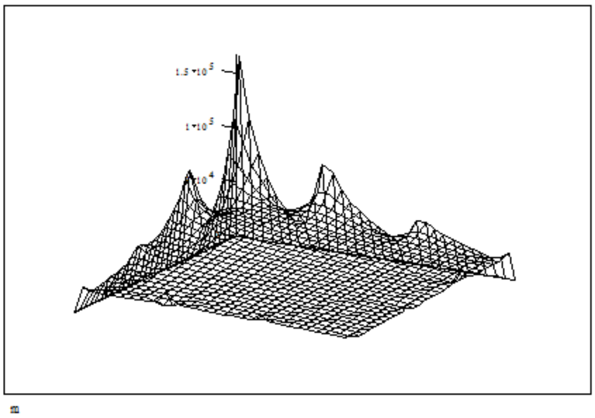

Figure 7. (c) Three-dimensional diagram of the intensityof lightning magnetic field in a building

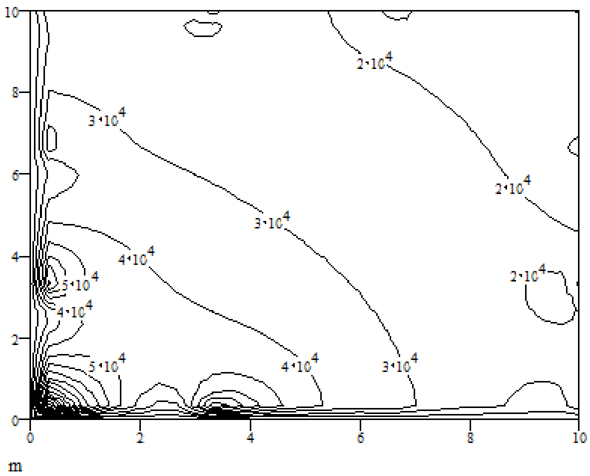

Figure 8. (c) Isogram of lightning magnetic fieldintensity in the building

Above (7), (8), (9), respectively corresponding to in figure 2 (a), (b), (c) within the building lightning magnetic field intensity distribution. Figure 3 to 8 is in each case building three-dimensional figure and contour lightning magnetic field strength. From the figure, the buildings meet with direct lightning, lightning electromagnetic field near the downlead strongest, weak middle ground.

3 The protection of the building interior

It can be seen from the above calculation results that, when the building is struck by direct lightning, the magnetic field generated inside the building by the lightning current that leads off the line is larger at the place near the lead off line no matter what kind of situation. Therefore, equipment should be placed as far as possible away from the lead-off line, especially the more sensitive and low voltage resistant electronic equipment should be placed in the middle of the building. In addition, the more the number of referrals, the stronger the magnetic field in the middle area of the building, and vice versa. From this point on, lead down line setting more, does not necessarily prevent lightning effect better. Although the lightning current is released into the ground by the off-line, the electromagnetic field generated in the building is still very large. The simulation experiment [11] shows that the over-voltage generated by the magnetic field at this time all exceeds the withstand voltage value of the equipment. Therefore, the terminal equipment in the building should also adopt shielding or equipotential equalization technology and other internal protection measures.

3.1 Shielding measures

Shielding is the use of a variety of metal shielding body to block and attenuate the application of lightning electromagnetic interference or overvoltage energy on the communication terminal equipment in the communication station. For the communication system, it can be divided into building shielding, equipment shielding and shielding of various cables (including pipes). The shielding of the building can be used to weld together the steel bars, metal frames, metal doors and Windows, floors, etc. of the building to form a Faraday cage, and the reliable electrical connection with the ground net to form a primary shielding net. This primary screen is very effective for inductive lightning protection.

3.2 Equipotential connection

It is stated in the IEC standard that equipotential connections are part of the lightning protection measures within buildings to reduce potential differences caused by lightning currents. Equipotential, is by connecting wires or over voltage surge protector, lightning protection device will be in need of lightning protection space and the structure of the metal frame, metal equipment, external conductor, electrical device, such as telecommunications devices connected, forming a network of equipotential connection, in order to realize the equalizing potential, such as the need to prevent lightning protection space of fire, explosion, danger and equipment damage.

For equipotential connections and the installation of surge Protection, IEC standards divide the space to be protected into different Lightning Protection zones (LPZ), stipulating the severity of different Lightning Electromagnetic Pulse (LEMP) and the location of equipotential connections at the junction of various areas. As shown in Figure 9, equipotential connections of each lightning protection area within the building are shown.

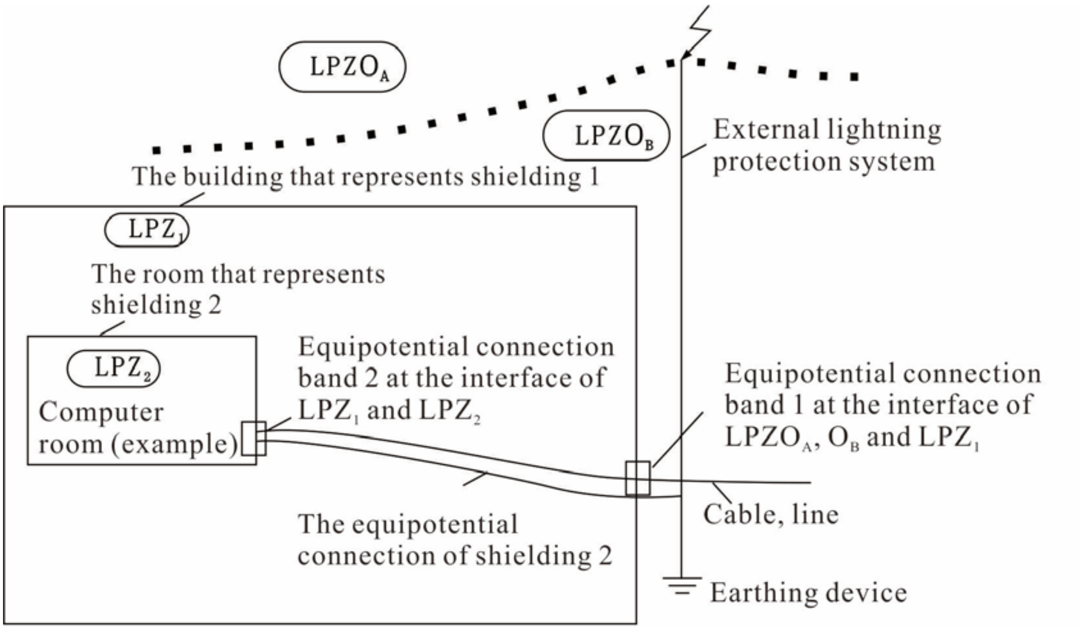

Figure 9. Divide a building into several minefields and make equipotential connections as required

4 Conclusion

Lightning protection is a very complex problem, it is impossible to rely on one or two advanced lightning protection measures will be able to suppress the thunder, to adopt a comprehensive management method, the appropriate medicine, all kinds of factors may produce lightning strike exclusion, in order to reduce the lightning damage to the minimum. In communication systems, electronic equipment is sometimes required to be individually grounded, which is referred to as a DC working ground or signal ground or logic ground. It is essentially a ground for high-frequency signals. The purpose of the single signal ground is to prevent the stray current or transient current in the ground network from interfering with the normal operation of the communication equipment.

All the big size of the internal conductive material, such as SPC exchange of metal shell, the host shell, UPC and battery box metal shell, metal, metal door frame, floor facilities line, cable tray of the equipotential connection, should be in the shortest route to the nearest equipotential connection with, or other have done on the bonding of metal.

In a word, the protective measures taken in the building are aimed at suppressing the lightning electromagnetic field in the building, reducing the damage of lightning overvoltage and enabling the communication equipment to work normally.

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