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The Simulation Result of Modern Lightning Protective Equation for the Rolling Sphere Method

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***Abstract*— Nowadays, the rolling sphere method is a lightning protection technique that is approved through the IEC standard. Especially, it is appropriately implemented to protect the complicated building's structure. However, the rolling sphere method is complex for utilization in the practical and the mathematical correlation of the rolling sphere is slightly illustrated in the researches respectively. Therefore, these constraints are the important weak point of this method which can be improved for implementation. As mentioned above, this article presents a modern mathematical correlation of the rolling sphere method. This correlation can deliver the accuracy result for the lightning protective simulation based on the 2-dimensions. Moreover, a modern correlation can be utilized to design the height of the vertical conducting rod (air termination or lightning protection rod) for installation on the corner edge of an interesting building.**

Keywords — lightning protection, rolling sphere method, IEC62305, Air termination

I. INTRODUCTION

The building's structure above the ground level can be directly influenced by the lightning danger. Especially, the corner edge position of the structure is a high risk to attack due to the lightning flash which can occur to seriously damage, because this corner edge can be easily induced to generate the upward streamer (as illustrated in the formative positive charge) that is a focusing target of the downward moving step leader (or the lightning stepped leader as shown on the formative negative charge), therefore, the lightning stepped leader can immediately strike into the upward streamer (at a corner edge position). This process is the complete phenomenon of a lightning flash. Besides, the final jump length between the lightning stepped leader and the upward streamer can be considered to the striking distance as shown in figure 1.

Generally, the corner edge position must be installed with the vertical conducting rod (we can call Franklin's rod, air termination, or lightning protection rod) which is approved through the international standard IEC 62305-3 [1]. Moreover, the IEC standard 62305-3 recommends the technical practice for installation of the vertical conducting rod as follows: the protective angle method (PAM) and the rolling sphere method (RSM) respectively. The protective angle method is a suitable implementation based on a simplified building's structure only (such as a basic square). Thus, the rolling sphere method is the best solution for the complicated shape. Particularly, the advanced architecture building is composed of non-geometric structure (abnormal shape).

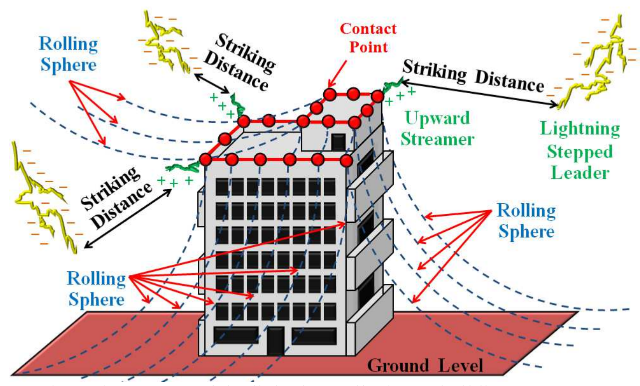

Fig.1.The process of the lightning strike into a building's structure.

According to Figure.1, the installation of the vertical conducting rod at the structure is dependent on the contact point between the circumference of a rolling sphere and a part of the building (such as the edge of a wall and rooftop).

However, the utilization of a rolling sphere method is complex to practical because we must sketch the rolling sphere (which has a radius focusing on 20 to 60 meters) in the architectural drawing plan of a building as demonstrated in figure 2. In the practical, engineers & designers can sketch the rolling sphere in the architectural drawing plan by using commercial programs such as Auto-Cad or Sketch-Up.

As mentioned above, the complexity of implementation is a weak point of the rolling sphere method and the correlation about the rolling sphere method is slightly illustrated (or show only in a basic concept). Hence, the creation of an obvious correlation for delivering simulation results in the practice is necessary.

For improvement of these problems, this article presents the modern mathematical correlation of a rolling sphere method. This correlation can be utilized to design the lightning protection based on IEC standard 62305. Moreover, the result of correlation can generate the accuracy curve of the rolling sphere which can be implemented to analyze the protective area, if and only if, the vertical conducting rod is installed at the building's structure.

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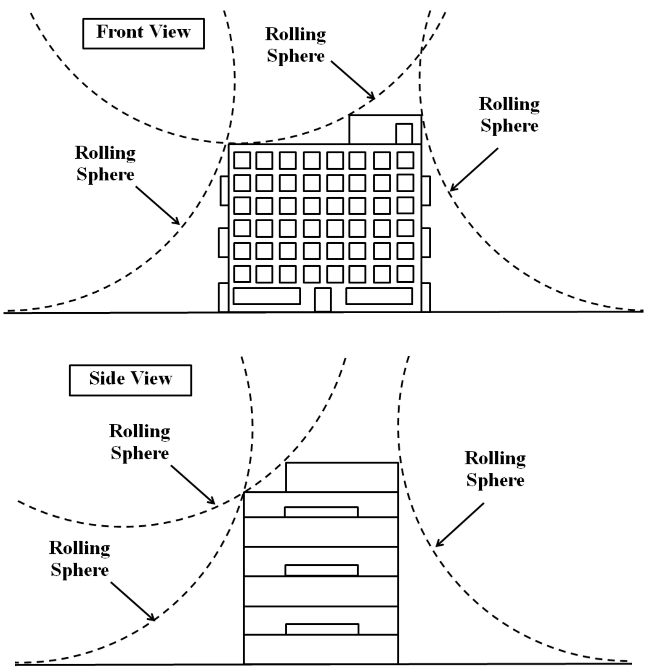


Fig.2. Sketching 2-D rolling sphere in the architectural drawing plan.

The remainder of this article is prepared as follows. The analysis of a modern rolling sphere correlation for lightning protection obviously appears in section II. In section III, the simulation result of the rolling sphere through the modern correlation is illustrated. Also, the analytical result of the lightning protective simulation is shown in section IV.

And finally, the conclusion is summarized in section V.

II. The Analysis of a Modern Rolling Sphere Correlation for Lightning Protection

The basic concept of a rolling sphere method is directly related to the process of a lightning flash. Namely, the striking distance between lightning stepped leader and an upward steamer, is considered to be a radius of a rolling sphere. Thus, the rolling sphere method is created to simulate the behavior of a lightning flash that attack an object above the ground state. Moreover, IEC standard 62305 defines the detail of striking distance as follows: 20, 30, 45, 60 meters, which can be calculated through an equation (1) [1-2]

$$\mathrm{R} = 10 \bullet \mathrm{I}^{0.65} \tag{1}$$

Where

R is the striking distance (meters)

I is the lightning current (kilo-Ampere, kA)

According to equation (1), the value of lightning current based on IEC standard can be divided into 1-4 levels, for instance 3, 5, 10, 16 kA respectively.

In this section, we can show the configuration of a rolling sphere that is closely contacted with all the sample objects above ground as shown in figure 3. Especially, the parameter of a sphere can be explained as follows: (h, k) is the center point of a circle in 2D-dimensions as x-axis and y-axis, (X_i, Y_i) is the interesting position on a circumference, and R is the radius of a sphere which is the striking distance.

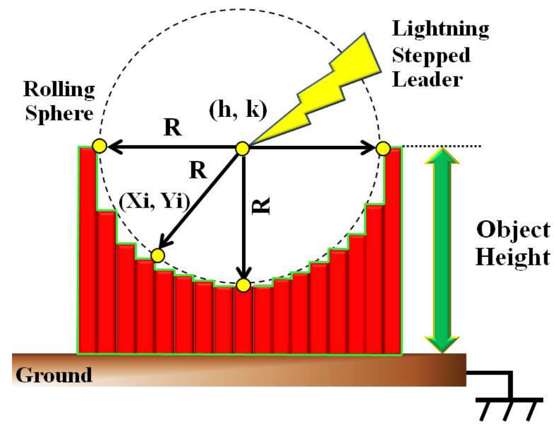


Fig.3. The configuration of a rolling sphere for analysis in this section.

From figure 3, we can analyze the center point of a circle through the trigonometric theorems as demonstrated in equation (2). Also, this equation can be calculated into the function of the rolling sphere correlation in a direct axis term (y-function) as shown in equation (3) and equation (4).

$$(\mathrm{h, k}) = \left(\mathrm{R},\ \mathrm{Y_i} + (\mathrm{R} - \mathrm{X_i}) \cdot \tan\left(90^{\circ} - \arcsin\left(\frac{\mathrm{R} - \mathrm{X_i}}{\mathrm{R}}\right)\right)\right) \tag{2}$$

$$(x - \mathrm{h})^2 + (y - \mathrm{k})^2 = \mathrm{R}^2 \tag{3}$$

$$y = -\sqrt{\mathrm{R}^2 - (x - \mathrm{h})^2} + \mathrm{k} \tag{4}$$

Where [3]

x is the variable of a horizontal axis

y is the variable of a direct axis

According to equation (2) to (4), the modern correlation of a rolling sphere can be illustrated in equation (5)

$$y = -\sqrt{\mathrm{R}^2 - (x - \mathrm{h})^2} + \left(\mathrm{Y_i} + (\mathrm{R} - \mathrm{X_i}) \cdot \tan\left(90^{\circ} - \arcsin\left(\frac{\mathrm{R} - \mathrm{X_i}}{\mathrm{R}}\right)\right)\right) \tag{5}$$

When $(0 \le x \le (2\mathrm{R} - \mathrm{X_i}))$

The modern correlation in equation (5) is clearly shown in the mathematical term of direct axis function (y-function). It can be utilized to design the height of the vertical conducting rod that can be installed at a building's structure for the avoidance of lightning danger. Particularly, the implementation of a modern correlation can be demonstrated in the next section.

III. The Simulation Result of the Rolling Sphere Through the Modern Correlation

In section III, we can show the simulation results of the rolling sphere method by using a modern correlation in equation (5). The dimension of example building for analytical simulation can be illustrated in figure 4. This building is a complicated shape and composes multi-corner edges which highly risk damage due to the lightning strike. Therefore, it must be installed the vertical conducting rod (air termination or Franklin's rod) at all the corner edges for protect against the lightning hazard. Each vertical conducting rod is a height of 0.5 meters and it is connected between other rods by using the copper bar respectively.

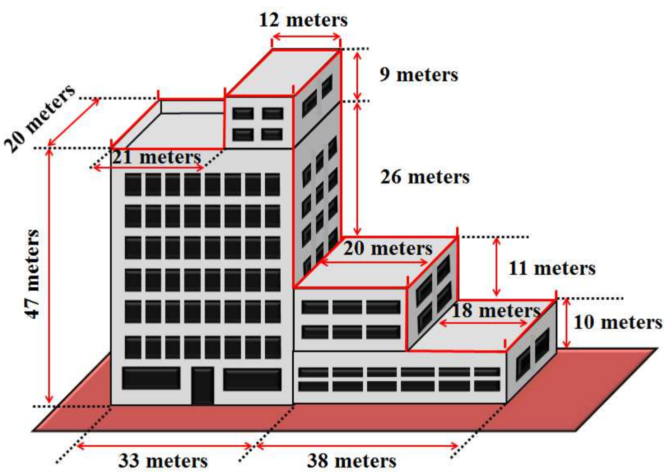


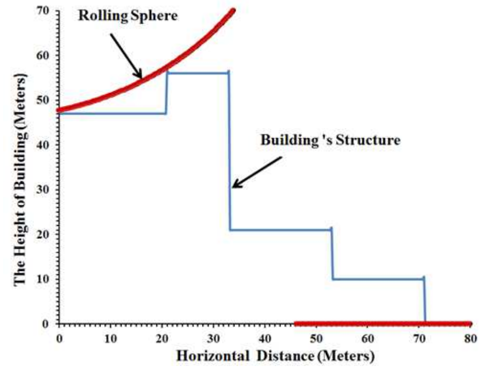
Fig.4. The example building for simulation.

According to figure 4, all the dimensions of the building were completely installed the vertical conducting rod which can be simulated in the 2-D coordinates (x-axis and y-axis) as demonstrated in figure 5.

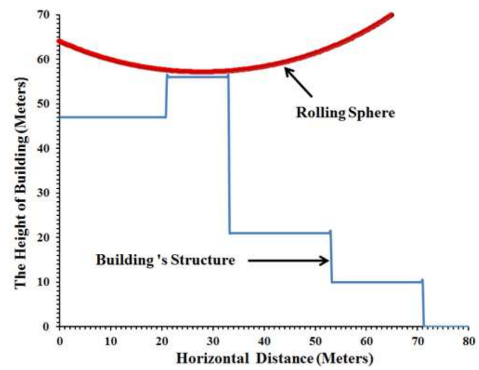
In this simulation case, the rolling sphere is only analyzed based on level 4 (the striking distance or radius of a rolling sphere is 60 meters, R = 60 meters) because the maximum height of building's structure is defined on 56 meters, while the rolling sphere levels 1-3 show off the striking distance less than the total height of a sample building (R = 20, 30, 45 meters). These striking distances are the cause of the side flash which appears no more than 2-3 percent [4]. Hence, they can be neglected for the simulation.

From equation (5), it can be utilized to analyze the step motion results of the rolling sphere as shown in figure 5 (front view) and figure 6 (side view) respectively. In an initial state, we are starting to focus on a vertical conducting rod at rooftop position as (X_i, Y_i) for the calculation. All the results of the simulation can be thoroughly shown based on a horizontal distance (x-axis).

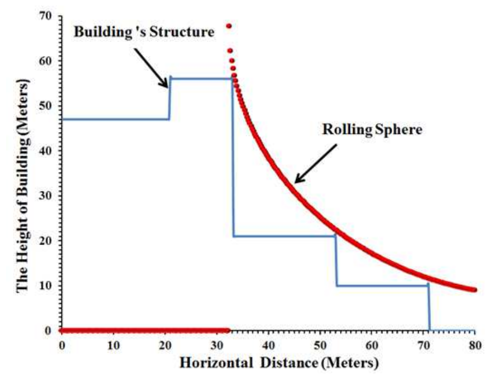
According to the result in figure 5, the first step motion of the rolling sphere is started at figure 5(a) and move on to the next step as shown in figure 5(b) to figure 5(e) respectively. All moving of the sphere are closely contact only the vertex of the vertical conduction rod. Thus, the areas below the rolling sphere can be considered to the lightning protective area of the building's structure.



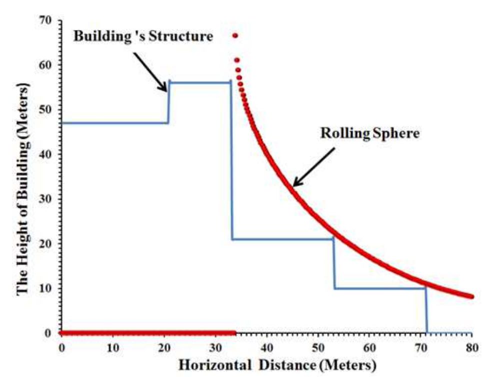
(a) Rolling sphere step I at the front view.



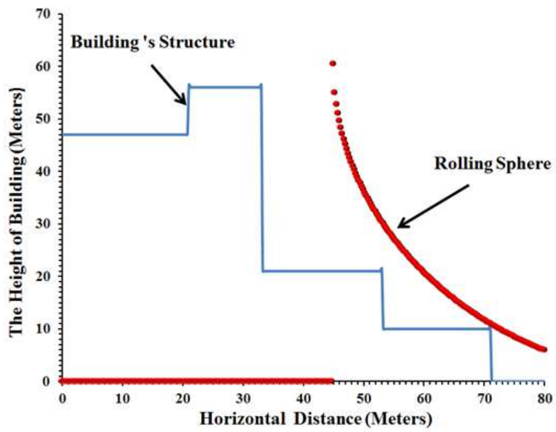
(b) Rolling sphere step II at the front view.



(c) Rolling sphere step III at the front view.

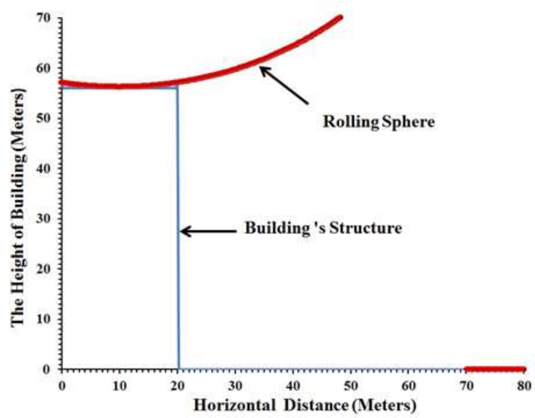


(d) Rolling sphere step IV at the front view.

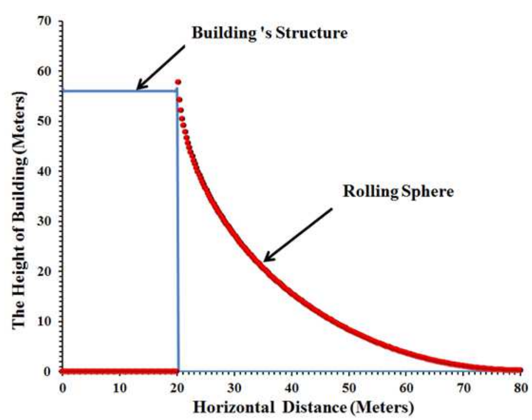


(e) Rolling sphere step V at the front view.

Fig.5. All the step motions of the rolling sphere for lightning protection based on the front view of a building's structure.



(a) Rolling sphere step I at the side view.



(b) Rolling sphere step II at the side view.

Fig.6. All the step motions of the rolling sphere for lightning protection based on the side view of a building's structure.

Moreover, the step movement of the rolling sphere at the side view of a sample building is demonstrated in figure 6. As a result, the rolling sphere can move on to contact only the vertical conducting rod while all the build's structures are not touched the sphere.

IV. The Analytical Result of the Lightning Protective Simulation

The simulation results of figure 5 and figure 6 can be analyzed as follows:

- The position of the vertical conducting rod is correctly designed for implementation which can protect against lightning damage because the movements of the rolling sphere are not directly contacted with a part of the sample building (Sphere touch only the vertex of the vertical conducting rod). Moreover, the vertical conducting rod can generate the lightning protective area that covers all building's structures. Therefore, all the external structures of a building can avoid lightning damage (such as walls, rooftops, and roof-deck).
- Each height of a vertical conducting rod is designed on 0.5 meters, which can be well utilized for lightning protection in this simulation. Hence, the height of the vertical conducting rod must be appropriately defined in the practical (maybe no more than 1.0-1.5 meters) and it must be no impact on the architecture of a building.
- The sample building in this section is a complicated shape. Therefore, the simulating rolling sphere must be moved on through all the corner edges position of a building (they were installed the vertical conducting rod) which the contact point between a rolling sphere and a vertex of vertical conducting rod is a focusing target of the lightning flash. In the practical, the contact point must install the vertical conducting rod that withstands the lightning current 3-16 kA based on the IEC 62305 [1-4].
- All the results of the rolling sphere through a modern equation are high accuracy because we can recheck to confirm the reliable results by using the trigonometric theorem.

V. Conclusion

This article presents the simulation result of a modern lightning protective equation for the rolling sphere method. All the results are obtained through the modern mathematical correlation which is derived by using the trigonometric theorem. Particularly, this correlation is never illustrated in the other researches. Moreover, the modern correlation can be utilized to analyze lightning protection which focuses on the complicated shape of a building in the practical.

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