Design of optimized LPS for a fire station by means of Conventional Protection employing a Rolling Sphere Method Design Software.

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Abstract—The design of a conventional LPS can be a very laborious task, especially when the structure to protect is complex. Even when the designer is an expert, the design made by a person is prone to human errors. As well, optimizing the design by checking different alternatives and protection strategies becomes a long task.

Nowadays, the high performance in calculus and graphics of the computers has allowed the creation of new and specific software tools. An intuitive and visual tool has been developed to optimize the lightning protection systems (LPS) design with different types of air terminals (Franklin Rods, ESE air terminals, meshed conductors and stretched wires) providing us a useful tool to design and optimize the topic of the lightning interception in a complete LPS design.

In this paper, using this tool, the advantages and disadvantages that can produce different conventional protection strategies on a real three-dimensional scenario will be discussed.

Keywords—Electro Geometric Model, Rolling Sphere Method Design Software, LPS Design, Conventional Protection.

I. INTRODUCTION

The development of a conventional LPS for large and structurally complex facilities can become a very laborious task. Based in the “Rolling Sphere Method” many issues appear, such as location, quantity and optimum height for air terminals. The rolling sphere method is the most complete procedure, but also the most complex of all the standardized protection methods.

In this paper we will apply an own-developed ‘Rolling Sphere Method Design Software’ to evaluate different solutions to apply at an important Fire Station in Bastogne (Luxembourg). The advantages and disadvantages associated with the different designs presented will be explored, with the aim of providing some assumptions when performing this type of protection projects.

II. ROLLING SPHERE METHOD

When a downward leader grows step by step from the cloud towards the earth, the electrical field in earth increases until the electrical insulating strength of the air near the ground is exceeded. So, an upward leader begins to grow towards the head of the downward leader. The starting point of the upward leader defines the point of strike of the lightning strike. [1]

The “Electro Geometric Model” (EGM) is based on the hypothesis that the head of the downward leader approaches to the objects on the ground, until it reaches the final striking distance. This method involves that the protection radius of the air terminal device is a function of a striking distance (D), which corresponds to the radius of the rolling sphere and also with the smallest distance between the head of the downward leader and the starting point of the upward leader. This striking distance is determined by the amplitude of lightning current (I). The EGM assumes that points on a structure equidistant from the striking distance are able to receive a lightning strike.

\[ D_{[m]} = 10 \cdot I_{[kA]}^{2} \]  

(1)

The centre of the “rolling sphere” (R.S.), corresponds to the head of the downward leader towards which the upward leader will approach. In application, the R.S. is rolled over the scenario under examination and the contact points are the points to be protected. The naturally protected zones resulting from the geometry of the evaluated object and its surroundings can also be clearly identified.

For different requirements for lightning protection systems, in present standards, four lightning protection levels (LPL) are defined. They differ regarding the R.S.M. in the sphere radius (LPL I D=20m; LPL II D=30m; LPL III D=45m; LPL IV D=60m). With the fixed sphere radii different smallest peak values of natural lightning flashes are covered. [2][3]
In three-dimensional scenes it is very difficult to identify the areas of a complex structure where a sphere would touch the surface. To fulfill this task it is essential the help of some protection design software. That is why, normally, 2D models or more simply methods like the Cone of Protection are employed. [4]

### III. DESCRIPTION OF THE SOFTWARE

The software used to carry out the study presented in this paper is an own-developed utility that allows lightning protection of any sort of structures in a fast and easy way.

In the first step, the program loads a 3D file where the scenario to protect is drawn, as shown in Figure 1.

The software ask for the accuracy for the discretization process, evidently the total size of the structure, the number and size of details to consider, the computational load and the desired precision are variables to consider for the designer. In this way, different options are available. At this point, also the Lightning Protection Level (LPL), namely I, II, II or IV according [5] is chosen.

When the scenario is imported, the program calculates the unprotected zones as Figure 2 shows. Thus, after this second step, the areas to be protected are clearly identified.

The software allows the placement of different air terminals, such as Franklin Rods, ESE air terminals, Meshes, and stretched Wires. Each installed element is fully editable in its features (height and ΔL in the case of ESE air terminals) and its location. In Figure 3 an example of the placement process is shown.

Once the protection is completed satisfactorily, the application provides different types of reports on the design, namely images showing if the rolling sphere touches or does not touch at the different areas, as shown in Figure 4. Also the software can provide reports with the bill of materials which is necessary for the installation or economical costs reports related with the different design criteria if more than one option is evaluated. (i.e. optimize the installation minimizing the number of air terminals or the aesthetic and mimicry of the installation)
In addition, the Rolling Sphere Method Design Software includes an algorithm for automatic location of air terminals, based on the principles of hexagonal cells area division such as the placing of mobile stations is based in. So, this software has an additional option to protect large areas with the minimum possible number of rods selecting a fixed height. An example is shown on Figure 5. [6]

IV. RESULTS IN PRACTICE

This section will present the design process of a LPS by means of conventional protection, held by the Rolling Sphere Method Design Software, of the ‘Ecole du Feu et d’un Service Régional d’ Incende’, in Bastogne, Luxembourg. The facility consists in 3 buildings as shown in Figure 5, two garages for vehicles (blue and yellow areas) and a residence building for firefighters (green area).

The standard employed to calculate the protection level is described in [5]. Calculations carried out for all areas of the building, resulted in the need of a Lightning Protection Level IV.

In the first step, the software calculates and displays the risk areas according the previously calculated level of protection, as shown in Figure 6. It should be noted that the area of flat roof is actually full of skylights, and cannot be covered by meshes, so Franklin Rods are necessary.

First all areas of the facility are covered by Franklin Rods of the same height, checking different solutions.

Half-meter Franklin Rods (Figure 7), 1.5-meter Franklin Rods (Figure 8), 2-meters Franklin Rods (Figure 9), and 3-meters Franklin Rods (Figure 10) were checked in order to evaluate the minimum number of Franklin Rods for each option. The results showed a number of Franklin rods of 30, 15, 15 and 11 respectively to complete the design.
As shown in the previous figures, in all the cases the scenario is protected, except for the cornices, which will be protected by conductors in order to minimize the number of Franklin rods and consequently the visual impact.

The criteria used for this design was based on minimizing the number of rods, especially in the gable roofs, where anchoring air terminals is more difficult.

Taking into account the initial results, it was decided to employ air terminals with different heights as detailed below:

- 3 rods of 1.5 meters were employed to protect the central part one more to cover the roof of the entrance.
- In order to cover the lower building (green building in Figure 5), 0.5 meter rods are situated at the corners of the building. Besides, one 0.5 meter rod was located in a corner that was likely to be impacted. [7]

Finally all the necessary cable to connect the Franklin rods installed and to cover the unprotected cornices is extended, as shown in Figure 11. Materials for the grounding system (downward conductors, etc…) are not considered here.

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<table>
<thead>
<tr>
<th>Number of 0.5 m F.R.</th>
<th>Number of 1.5 m F.R.</th>
<th>Number of 2 m F.R.</th>
<th>Number of 3 m F.R.</th>
<th>Meters of cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIRST SOLUTION</td>
<td>5</td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>SECOND SOLUTION</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Material used in the first solution proposed and in the final design.

Due to customer's feedback of the first solution, some new design criteria were changed, in order to optimize aesthetic aspects, so some changes were done in this way:

- The maximum height was fixed at 2 meters, so 3-meters Franklin rod employed previously were removed.
- The roof of the yellow structure has to be covered with smallest possible rods
- Finally, it was decided to increase the height of the rods located on the flat roof, to ensure that the height of the skylights (which is about 0.5m) do not affect the calculations for protection made.

Thus, the final solution can be seen in Figure 13.
V. CUANTIFICATION OF DIFFERENT DESIGN CRITERIA

As noted previously, different design criteria could be considered, in the example of above, the first criteria employed was the optimization of the cost, so higher and fewer points were employed. Afterwards, the criterion was changed prioritizing the aesthetic and mimicry, so a higher number of shorter rods was employed.

In this way, is possible the evaluation of different design criteria minimizing or maximizing different parameters of the installation. The ease in the use and the velocity to check the adopted solution by means of the Rolling Sphere Method Design Software, allows this evaluation.

As general rules, in table 2 are presented variables to maximize or minimize in order to optimize a design when different criteria are chosen.

<table>
<thead>
<tr>
<th>Nº of air terminals</th>
<th>Cost Effective</th>
<th>Aesthetic</th>
<th>Ease in installation</th>
<th>Noninterference with walkways</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Height of terminals</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>=</td>
</tr>
<tr>
<td>Location in flat roofs</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Location in corners</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2: General rules to optimize a design according different criteria.

VI. DISCUSSION AND CONCLUSIONS

Very diverse considerations (technical, aesthetical, economical, ...) can influence the design of a LPS, changing the characteristics and position of the conductors and rods that are used. At the end it as to be assured that all the structure is protected. This leads to a long and difficult work for which computer applications can be really helpful.

From the cost-effectiveness point of view, the objective may be to minimize the number of air terminals, with larger rods located in prominent points. For systems with low visual impact, a greater amount Franklin rods may be used, but with the lowest possible height. In this last case it is recommended to begin the protection locating the outdoor areas and then protecting the remaining central zones. For systems with difficult access and maintenance, the interest is to minimize the number of terminals but placing them at accessible points such as flat roofs, in this case the parameter to maximize is the protected area with each terminal.

Firstly, in the design of this LPS was tried to find an optimal solution minimizing costs and facilitating, as much as possible, the installation i.e., using the minimum number air terminals in each area, especially in the gable roofs where the anchor of the rods is more complicated than on flat surfaces. However, after the customer feedback, this solution had to be modified for aesthetic and mimicry criteria. This modification could be done easily and quickly thanks to design software, which allows a complete editing of all items installed on the scenario.

As it has been observed, the buildings to protect were quite complex in their geometry, doing the calculations manually to detect areas at risk for a lightning strike on the basis of the rolling sphere method is a virtually insufferable task. Also it has to keep in mind that with the inclusion of each new element of protection, or with any variation in the characteristics of them, a recalculation of the protected areas is necessary. This task is also evaluated automatically by the software.

The designer seeks the optimization during the development of a LPS. Important factors such as ease of installation ease of checking and maintenance, number of items on the roof, etc. are taken into account.

In most cases, the preferred criteria are cost-effective installations or the aesthetic aspects. In this way a tool is needed not only for finding an optimized solution, but also, having the capability of being totally edited by the designer to suit to any environment.

REFERENCES
