Automatic Lightning Protection Design

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***Abstract*— This paper presents equations used for an algorithm that performs automatic lightning protection design. The methods are based on the well-known Rolling Sphere Method (RSM). The principle of RSM is that a sphere is rolled up and over the structure, and any surface that is in contact with the sphere is prone to lightning strikes. Therefore, for an installation containing vulnerable equipment, the only points which should remain in contact with the rolling sphere is an earthed lightning mast or the ground itself. The new software algorithm allows designers to determine where lightning masts are required and their respective heights to directly prevent lightning strikes to protected equipment.**

***Index Terms:* Lightning protection design, Rolling Sphere Method, air terminal.**

I. Introduction

The probability of a lightning strike on a structure is estimated by calculating the striking distance. This can also be used to evaluate the effectiveness of the installed lightning protection system. The Rolling Sphere Method (RSM) is used for the design (planning, dimensioning, and positioning) of the air-terminal devices to be installed on the structure or in its vicinity. The electro-geometric model represents the striking distance as a function of the peak stroke current. The striking distance is influenced by the peak value of the lightning current and the height of the earthed object, be that a mast (pole plus air terminal) or an earthed wire. The point of strike is determined when the downward leader approaches the earth or a structure with a striking distance.

The Standards set out guidelines for the protection of persons and property from hazards arising from exposure to lightning. The whole structure is enclosed in zones protected by air terminals. The rolling sphere calculates these zones of protection. The method ensures that the shortest distance between a lightning leader tip and any part of the structure is an air terminal.

In the RSM, a sphere of specified radius ‘*R*’ is bought up to and rolled over the total structure. Any part of the structure that is in contact with the sphere is exposed to lightning and must be protected. The radius of the rolling sphere is specified for four protection levels in [1]. Table 1 shows the radius of the sphere and the minimum lightning current that will be intercepted for each protection level.

Table 1: Radius for each protection level from the Standard [1]

Protection Level	Radius of Sphere, R (m)	Lightning Current, I (kA)
I	20	2.9
II	30	5.4
III	45	10.1
IV	60	15.7

Fig.1 shows how the sphere is rolled up and over a structure with an air terminal. Since the sphere only touches the top corner of the air terminal, all structures with heights up to the arc in the protected area is protected from lightning strikes. The width of protection increases as the height of equipment to be protected is reduced.

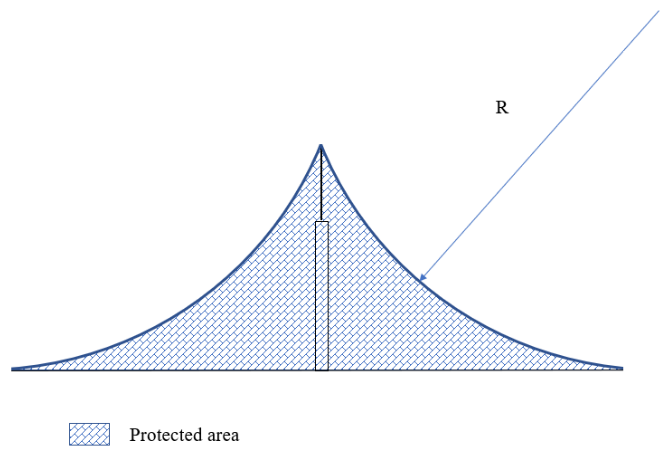


Fig 1. Sphere rolled against an air terminal installed on a structure

When the system consists of many masts, wires may be used between masts. When wires are used, all equipment less than the height of the wire is protected from strikes, provided the height of the wire is less than the diameter of the rolling sphere. The sphere is rolled between two masts at a time. The steps involved in determining the protective zone are:

1. Calculate the protective radius of the masts for the height of equipment to be protected.

2. Calculate the maximum height of equipment that can be protected by two masts and its position.
3. Consider a fictitious mast with a height equal to the maximum height and located at the same position.
4. Calculate the protective radius of the mast for the height of equipment to be protected.

II. Mathematical Formulation

A. *Calculating protective radius (R_p)*

Consider an air terminal of height H used to protect equipment of height H_e. The protective radius of the terminal at height H_e is the horizontal distance from the air terminal up to which the equipment will be protected. If the radius of the rolling sphere is R, the protective radius is represented by

$$R_p = \sqrt{2H * R - H^2} - \sqrt{2H_e * R - H_e^2} \qquad (1)$$

The protective radius is increased with an increase in the radius of the rolling sphere or decrease in the height of the equipment to be protected.

B. *Determining protected height (Y)*

The protected height Y is the height of equipment that can be protected if placed anywhere between the two masts. Consider two masts of height H and h meters, separated by a distance L meters as shown in Fig. 2.

If the rolling sphere is placed on top of the two masts, the position of the center of the sphere depends on the height of the two masts. If the two masts are of the same height, the X position of the center of the rolling sphere will be at $L/2$. If the two masts are at different heights, the lowest point of the arc will be towards the lower mast.

$$\Delta h = H - h$$

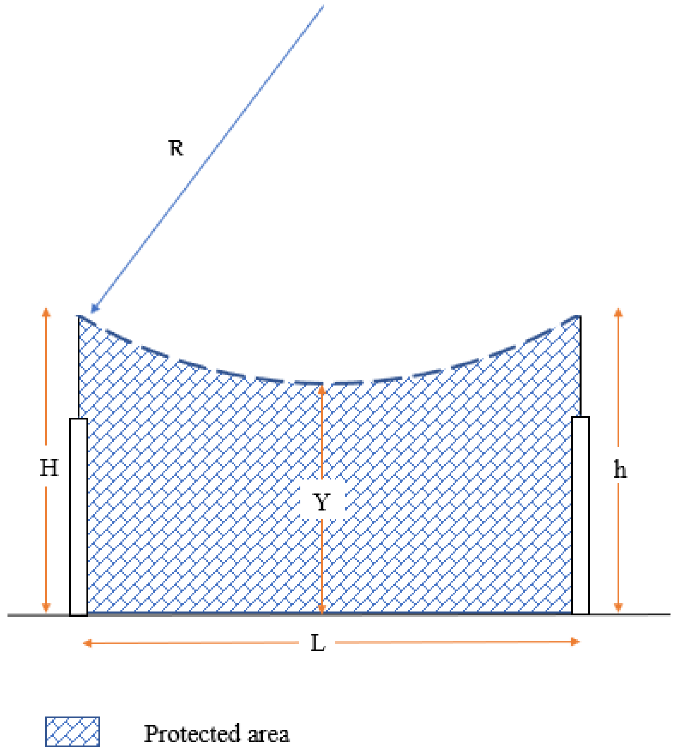
$$A = 4 \times (L^2 + \Delta h^2)$$

$$B = 4 \times \Delta h \times (L^2 + \Delta h^2)$$

$$C = (L^2 + \Delta h^2) - 4 \times L^2 \times R^2$$

$$Y_1 = \frac{-B + \sqrt{B^2 - 4AC}}{2A} + H$$

The X position of the center of the sphere is given by



$$X_c = \sqrt{R^2 - Y_1^2} \qquad (2)$$

Fig 2. Sphere rolled between 2 masts

The Y position of the center of the sphere is given by

$$Y_c = Y_1 + H \qquad (3)$$

where H is the height of the tallest mast.

Case 1: When $X_c > L$

When the X position of the sphere is greater than the distance between the masts, the protected height calculation results in an error.

Case 2: When $X_c < L$

When the X position of the sphere is less than the distance between the masts, the protected height calculation can be carried out as follows.

$$B = -2Y_c$$

$$C = Y_c^2 - R^2$$

The maximum height of equipment that can be placed anywhere between the two masts is

$$Y_{max} = \frac{-B + \sqrt{B^2 - 4C}}{2A} \qquad (4)$$

It is assumed that at position X_{max}, there exists a fictitious mast with height, Y_{max}. The protective radius of the fictitious mast for the given height of equipment to be protected, can be calculated from *(1)*.

III. Calculation Results

This section presents the results of the proposed method to evaluate the protective zones between masts. The simulations are carried out for 2 masts, 4 masts, masts connected with wires and masts in groups. The protection level III (R = 45m) is used in this study.

In the diagrams that follow the red circles indicate the locations of the masts and the blue shaded portion indicates the protected zone for the height of equipment being protected.

a. 2 masts

Consider 2 masts of heights 22.5 m separated by 20 m. If the height of equipment to be protected is 16 m and protection level III (sphere radius = 45 m) is considered, the protective zones are as shown in Fig. 3.

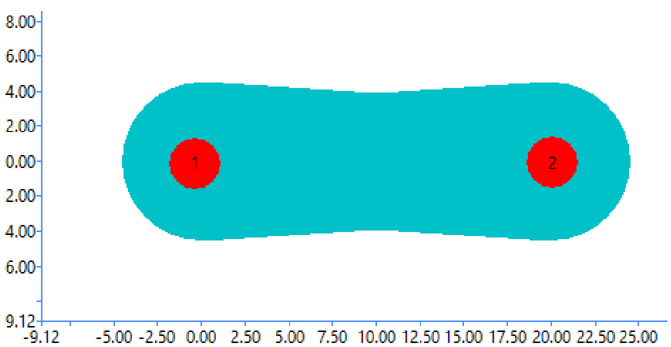


Fig 3. Two masts of the same height

Suppose the height of the second mast is reduced to 20 m. If all other parameters remain the same as above, the protective zones are as shown in Fig. 4.

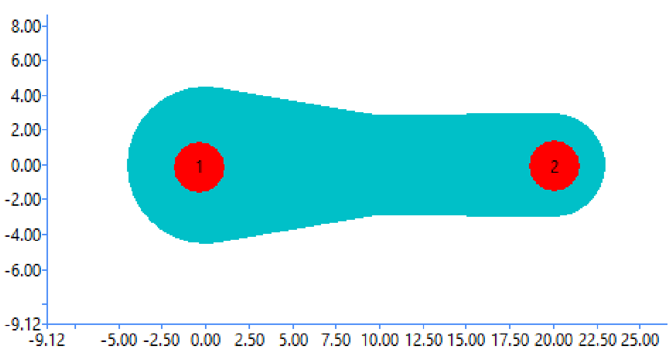


Fig 4. Two masts of different heights

b. 4 masts

Consider 4 masts of the same height used to protect an equipment with a height of 18 m. If each mast is 22 m, the protective zones are as in Fig. 5.

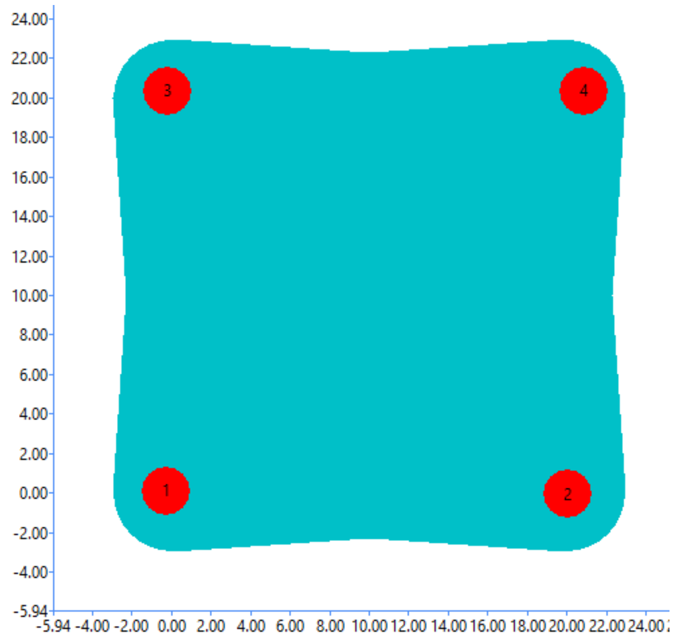


Fig 5. Four masts in a square formation

Consider that the fourth mast is placed far away from the other masts. The distance between mast 1 and mast 2 and mast 1 and mast 3 is 20 m. Mast 4 is placed at a location (40, 40). The protective height between the mast 4 and all the other masts will be zero. Hence there will not be a protective zone between mast 4 and the other masts as shown in Fig. 6.

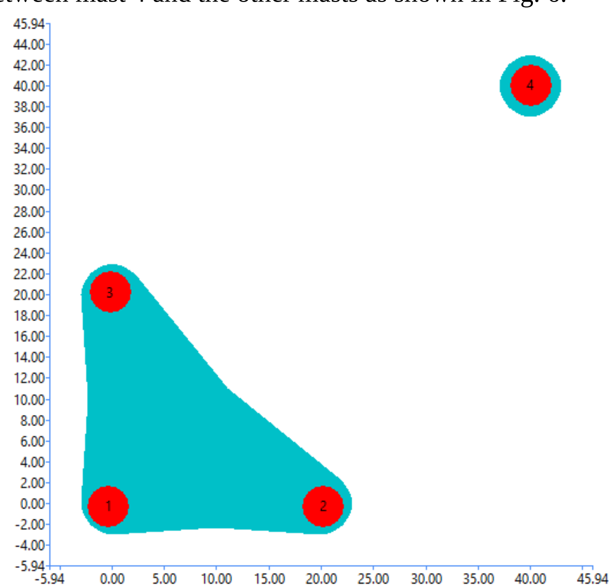


Fig 6. One mast separated by a large distance from other masts

c. Groups of masts

Masts may be grouped, and each group may be used to protect separate areas of different protective heights. Consider group 1, consisting of mast 1 and mast 2 separated by 20 m and protecting equipment of height 20 m. Similarly mast 3 and mast 4 form group 2 and is separated by 20 m. Group 2 protects equipment with height 18 m. The separation between the groups is 14 m. Since the masts are in groups and masts of separate groups will not interact (in the simulations), there is no interaction between the groups as shown in Fig. 7.

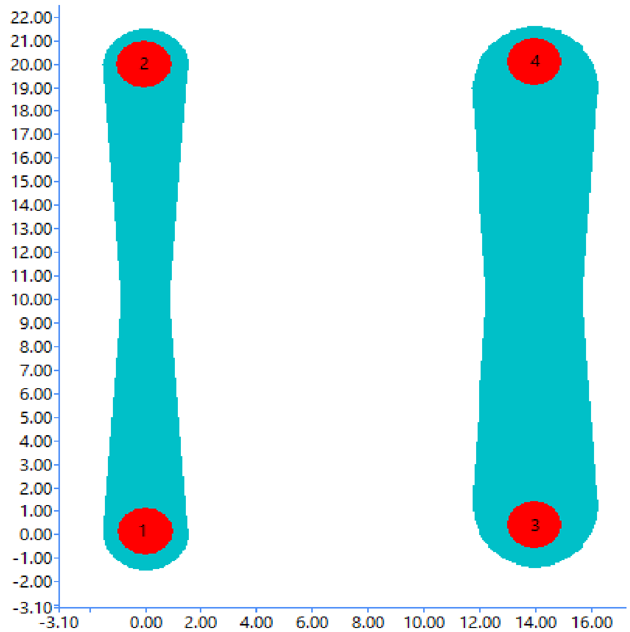


Fig 7. Masts in groups with different protective heights

d. Masts with wires

Wires are used between masts to protect areas between masts that are placed farther away from each other. Consider 4 masts at the following positions.

Table 2: Masts and their positions.

Masts	X pos (m)	Y pos (m)
1	0	0
2	70	0
3	0	20
4	70	70

Wires that are connected between masts may or may not have a sag. Sag is expressed in percentage of the distance between the masts. The wires between masts are as follows

Table 3: Wires between masts.

From Mast	To Mast	Sag (%)
1	2	5
2	4	0

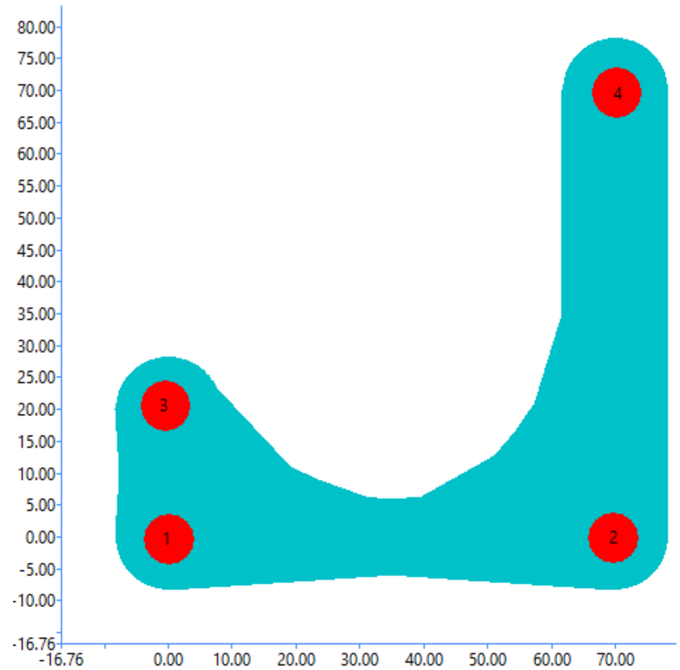


Fig 8. Masts with wires

Mast 1 and mast 2 are placed far apart from each other such that without a wire there would not be any interaction between them. The wire has a sag of 5% and hence the crest formed by the wire is deeper than that between mast1 and mast 3, that are closer and without a wire between them. Similarly, although mast 2 and 4 are far apart, the masts form a protective zone. This is due to the wire connecting them which has 0% sag and hence there is no crest formation.

IV. Conclusion

The results indicate that the protective zone between masts is a function of the rolling sphere radius, distance between the masts and the height of equipment to be protected. The protective radius of masts increases when the height of equipment to be protected is low. Hence for a low protected height, the protected zone will be wider and vice versa.

The calculations for protecting equipment and modelling of the interactions of lightning masts during lightning phenomena are complex. This new algorithm (and the engineering design software built around it) allows an unlimited number of masts and interactions to be easily modelled ensuring adequate protection and providing confidence that vulnerable equipment will be shielded from direct lightning strikes.

V. REFERNCES

[1] AS/NZS 1768:2007, Lightning protection
[2] BS EN/IEC 62305:2011 Protection against lightning