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Application of charge simulation method for investigation of effects of the trees on lightning protection of structures

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Abstract

The paper deals with the principles of lightning protection of structures. The principles have been formulated on the base of application of charge simulation method (CSM) in order to investigate the effects of trees on lightning protection of buildings. The simulation results and laboratory test on scale model demonstrate the benefit of this method of computation lightning protection for structures.

Keywords: Lightning protection; Charge simulation method; Building; Striking point

1. Introduction

Early lightning research focused on the protective effect of lightning rods based on observed lightning strokes [1–3]. At the end of the 19th century this effort resulted in the definition of the protective angle in spite of the divergent observations. Beginning with the 20th century, research work aimed to estimate the protective angle [1,2]. International standards have been developed as fundamental guidance for lightning protection system design and the construction of ever day structures [4–6].

Many researchers worked in the area of lightning protection of structures in order to improve lightning protection methods [1–3,7–9]. In the present paper the leader progression model [10–12] together with the charge simulation method (CSM) [13,14], is used to analyze the effectiveness of nearby trees in reducing the number of lightning stroke to buildings.

2. Charge simulation method

The calculation of electric fields requires the solution of Laplace's equations with boundary conditions satisfied. This can be done by either analytical or numerical methods. The situation often is so complex that analytical solutions are difficult or impossible, and hence numerical methods are commonly used for engineering applications. The CSM is one of these methods [13,14].

In the simple example of Fig. 1, filled circles and stars show simulation charges and contour points, respectively:

$$\sum_{j=1}^{7} P_{ij}Q_j + \sum_{j=11}^{13} P_{ij}Q_j = \Phi_i \quad (i = 1, 2),$$
$$\sum_{j=1}^{10} P_{ij}Q_j = \Phi_i \quad (i = 3), \tag{1}$$

where Φ_i is the potential at contour point i and P_{ij} are the potential coefficients.

When boundary condition is applied at the junction of two insulators, it must be true that:

$$\varepsilon_0\varepsilon_{r1}E_{n1} = \varepsilon_0\varepsilon_{r2}E_{n2}, \tag{2}$$

where E_{n1} and E_{n2} are the normal components of electric field at the insulators surfaces.

If F_{ij} are field coefficients in the direction, normal to the dielectric boundary at the respective contour points, then

$$\sum_{j=8}^{10} P_{ij}Q_j - \sum_{j=11}^{13} P_{ij}Q_j = 0 \quad (i = 8, 9, 10), \tag{3}$$

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Nomenclature

CSM	charge simulation method
Φ_i	potential at contour i
Q_j	jth charge
P_{ij}	potential coefficient
i	counter number
j	charge number
ε_0	permitivity of the air
ε_{r1}	permitivity of dielectric 1
ε_{r2}	permitivity of dielectric 2
E_{n1}	normal component of electric field to surface of dielectric 1
D	horizontal distance between building and each tree
E_{n2}	normal component of electric field to surface of dielectric 2
F_{ij}	field coefficient
Q	total charge of a section
z	vertical distance of middle point of the charge section from the point that field is computed
r	radial distance from charge section
$2l$	section length
X, Y, Z	coordination
N	number of trees
H	height of trees
G	ground
B	building
$T1$–$T8$	tree

$$\varepsilon_{r1}\left(\sum_{j=1}^{10} F_{ij}Q_j\right) = \varepsilon_{r2}\left(\sum_{j=1}^{7} F_{ij}Q_j + \sum_{j=11}^{13} F_{ij}Q_j\right). \quad (4)$$

These equations are solved to determine the unknown charges.

In order to determine the accuracy of computation some checkpoints must be considered. Computing the potential in these points and comparing it with actual values determine the accuracy of the computation.

3. Model explanation

The mathematical explanation of leader progression model phenomena requires an evaluation of the electric field strength, repeated at several times. The calculation of the field is done by means of CSM. The computer simulation can be used to simulate the step-by-step propagation of lightning and the striking process [12]. The method of leader propagation, as explained by Horvath [12], is sufficiently accurate for this paper simulation. The simulation starts with the vertical straight section of the leader discharge developed up to a level, which is high enough to nullify the influences of the earth objects [12]. Because an object standing alone on the earth causes a distortion of the field only up to the level of double its height [12], the starting point of the simulations must be above this level. Along the leader channel an equally distributed charge is considered. The charge in the channel produces an electric field, which has its highest intensity near the bottom. Equal steps of leader with a length of 10–20 m represent the propagation. Direction of leader progression is that in, which the potential gradient is a maximum. In this method we ignored leader corona, because by considering the corona, the computation using the CSM is very difficult. Fig. 2 shows phases of propagation of the leader according to this method.

The computer simulation proceeds in the following way. The path leader is divided into sections with the length of a step (10–20 m). The charge of each section produces

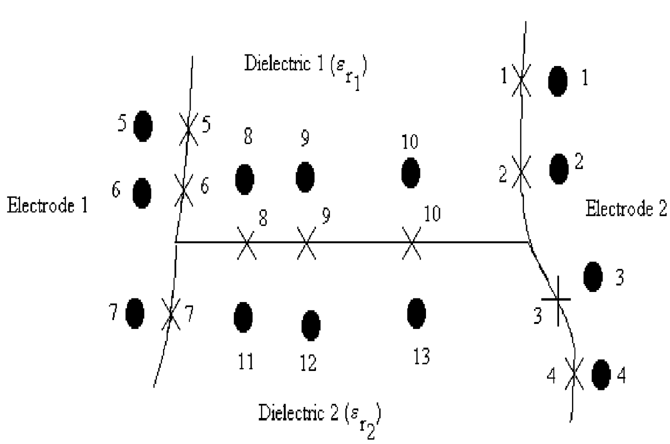

Fig. 1. Typical position of charges and contours points in multi dielectric system.

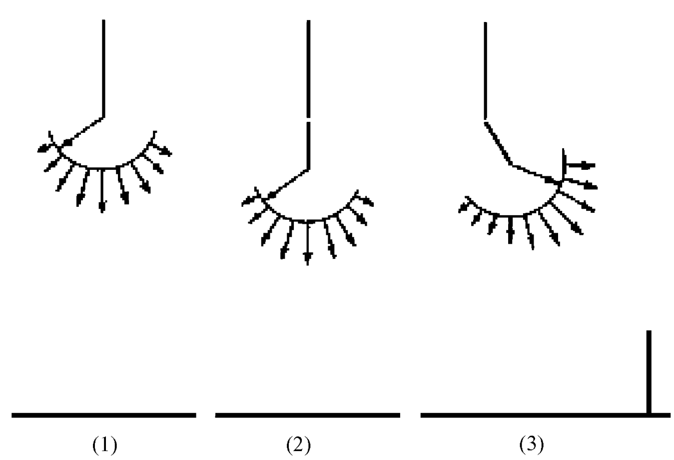

Fig. 2. Phases of propagation of the leader ((1)–(3) shows stage of propagation of leader according to present paper method. Arrays show the potential gradient on different point on above-mentioned circle).