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Positioning of lightning rods using Monte Carlo technique

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ABSTRACT

Monte Carlo simulation algorithms for electro-geometrical model are used in this work to solve the problem of complexity arising in the positioning of lightning rods on large buildings. Based on this algorithm, the probability distribution of lightning strikes on entire building structure is obtained and locations of higher lightning strike probability are determined. These spots are used to install lightning rods. The proposed work can be directly applied to protect any building structure.

1. Introduction

Lightning rods are commonly used for effective protection of building structures from lightning strikes. Installation of lightning rod according to lightning protection standard guidelines is very difficult due to the complexity of the building's construction [1]. For protection of any structure from lightning strikes, methods are typically described in four categories [2]. These methods are the electro geometrical model, mesh method, protection angle method and physical models. In the Electro geometrical model, an imaginary sphere moves towards the ground and its center is the origin of stepped leader. This downward stepped leader will attach to a ground structure [3]. It is also commonly known as rolling sphere method [4,5], as an imaginary sphere has to roll over the surface of the structure [6]. In this method, the radius of the sphere equals the striking distance, i.e. a function of return stroke peak current [7].

Because of the stochastic nature of lightning phenomenon, it takes a lot of time to study and analyze it based on data collected by instruments. In recent years, researchers have increased use of computer models and simulation of the lightning phenomenon [8]. Due to invention of modern high efficiency computers, the use of Monte Carlo computer simulation techniques has increased, mainly due to the stochastic nature of this phenomenon. Monte Carlo methods have been used for analysis of lightning strikes on buildings for the last five decades. Anderson (1961) started application of these methods in lightning phenomena to observe the outage rates of different transmission lines according to statistical data obtained from field measurements [9]. Afterwards, Johnson et al. (1963) improved Anderson's model for 500 kV line design [10] and Currie et al. (1971) used Anderson's technique for Monte-Carlo simulation of electro-geometrical model. In their work, they employed the approach angle of leader strikes [11]. Sargent (1972) performed the Monte-Carlo simulation to evaluate effectiveness of overhead sky wire and tower network for shielding substation equipments from direct lightning strikes [12]. Velazquez et al. (1982) used probabilistic calculations of lightning protection for tall buildings using transmission line lightning protection and the electro-geometric model [13]. Borghetti et al. (2004, 2007) proposed a procedure using Monte Carlo method for estimation of the statistical distributions of lightning current parameters at ground level from instrument tower data [14,16]. They studied the lightning performance of distribution lines against indirect strokes, and estimated the annual number of lightning induced flashes versus the critical flashes voltage of the line insulators. The results were compared with the IEEE Std 1410–2004 Guide for improving the lightning performance of electric power overhead distribution lines [16]. Kim et al. (2007) introduced a dielectric breakdown model that is able to do fast animation and rendering of lightning using mesh adaptation and Monte Carlo method. However, this idea could not be considered for protection of structure [17]. Beak

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(2008) prepared a 3D lightning probability program to study the probability of lightning strikes at complex structures, his calculations were based on analytical wave-pair concept of calculating the electric field strengths using Monte Carlo techniques. In this work a desired observation location was necessary [15]. Sarajcev et al. (2008) presented a mathematical model based on the experimentally determined lightning stroke development and showed the stepped leader propagation path [19]. Mata et al. (2009) presented a model of lightning stroke stepped leader propagation path development for the analysis of lightning protection systems efficiency using Monte Carlo technique [18]. The model developed in this paper is inspired by models presented by Beak, Sarajcev and Mata. This model is a combination and improvement of the above methods which will help in easy installation of lightning rods on complex building structures.

In the present work, Monte Carlo technique [20] and electro geometrical model [21] have been adopted to find locations of maximum lightning strikes over buildings. It has been shown that the lightning rods installed at these locations protect the entire building from lightning strikes. To implement this technique, authors have considered the following three building structures: the main Institute building of Birla Institute of Technology, Ranchi, India; the power substation mentioned in Ref. [22]; and the composite building mentioned in Ref. [23].

In all these cases, lightning rods have already been placed at the different position on the buildings. The objective of Monte Carlo simulation of this work is three folds: investigate the exposed area of the buildings with present installation; predict the locations of higher strikes location for the buildings; and to show that the entire building structure is protected if the lightning rods are installed at those locations.

2. Methodology

The work is inspired by electro-geometrical model and the application of Monte Carlo simulation to reduce the complexity in the positioning of the rod. The simulation of stochastic processes on a computer by use of generation of random numbers is called the Monte Carlo (MC) method. These methods belong to the most popular numerical statistical methods. It uses sequences of random numbers to perform simulations [20]. To apply the Monte Carlo method on any physical phenomena, the random quantities are identified and then defined as random variables with suitable probability distribution functions. In this paper, the origin of the stepped leader in the cloud and the return stroke peak current are random variables.

The concept of striking distance is the basis of the rolling sphere method, associated with the electro-geometric method (EGM). Around the stepped leader origin, a spherical region is formed. The radius of this sphere is equal to the striking distance. For computing the striking distance, the return stroke peak current is randomly generated with a suitable probability distribution function. The striking distance is given by

$$d = AI^{\alpha} \tag{1}$$

where I is the return stroke peak current and A, α are constants.

The tip of the stepped leader starts from an origin in the cloud and propagates vertically downwards in steps. The step size is a fraction of the striking distance. At every step it checks for any structure, to which it can attach itself, within a spherical region of radius equal to the striking distance d. If it finds no structure to attach to within the sphere, it takes a step vertically downwards; if it finds one, it attaches to it in any direction with respect to the tip (which is the center of the sphere). If the stepped leader finds ground within the sphere, it attaches to the ground vertically downwards. In any case, the point of attachment is the striking point of the lightning strike, and its (x, y) coordinates are calculated, as shown in Fig. 1. The process is repeated several times with random values of origins of the leader and the return stroke peak current with suitable probability distributions.

3. Procedure for simulation

To perform the Monte Carlo simulation to predict the optimum location for installation of lightning rods, following considerations are made for modeling:

3.1 The cumulonimbus type clouds are associated with thunderstorm, atmospheric electricity charge separation and lightning [24]. Lightning leaders are initiated at altitudes of 5–7 km that are typical cloud charge source heights, and charge separation exists in lower level of water droplets at a height of 1–2 km from ground level [25]. On the other hand, for lightning attachment studies, it is not important how exactly the leader propagates between its origin (about 5–7 km) and about 1–2 km above ground. In this problem, the lower level that will create opposite charges on earth surface is taken to be 1000 m above ground [26]. Therefore, the height of origin of stepped leader from ground is taken as 1000 m to start the simulation.

3.2 Collisions of the ice crystal with water droplets produce uniform dipole charges [27]. These charges are responsible for the origin of the stepped leader. Therefore the origins of the stepped leader in the clouds are random variables uniformly distributed over the cloud at a height of 1000 m above ground.

3.3 The return stroke peak current is a log-normally distributed random variable. Here, values taken for the log-normally distribution are $\mu = 30$ kA and $\sigma = 0.265$ where μ and σ are the geometric mean and logarithmic (base 10) standard deviation, respectively [18,28,30].

3.4 The constants in (1) describing the striking distance are $A = 10$ and $\alpha = 0.65$ [18,28,30].

3.5 The stepped leader travels vertically downwards with a step size that varies from 5% to 100% of the striking distance [18,29,30]. The size of step length in the attachment process only decides the center of the imaginary sphere of the last step.

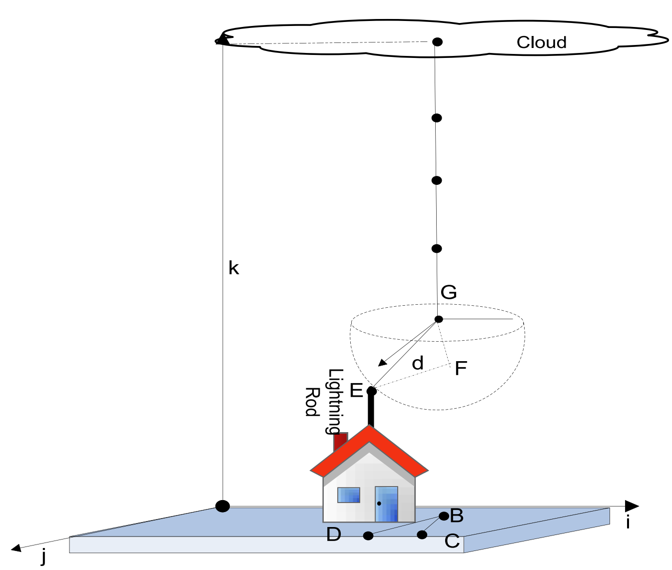

Fig. 1. Spherical region attachment process with grounded structure.