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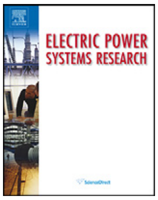

Sensitivity of lightning shielding failure of double-circuit transmission line on tower geometric structures

Zhen Li[a], Zhanqing Yu[a,*], Xi Wang[a], Xiangyang Peng[b], Zhifeng Li[b]

[a] State Key Lab of Power System, Department of Electrical Engineering, Tsinghua University, Beijing 100084, China
[b] Guangdong Electric Power Research Institute, 8 Shuijungang, Dongfengdong Road, Guangzhou 510080, China

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ABSTRACT

A numerical calculation method based on the leader propagation model of lightning is proceeded to investigate the effect of overhead line tower geometric constructions to the lightning shielding failure. In this paper, the height and the spacing of the ground wire were changed to study the sensitivity of the shielding effectiveness on tower constructions. As the conclusion, an efficient layout scheme of ground wire and phase wire was proposed. Even if the protecting angle of the ground wire keeps unchanged, if the height of the ground wire is various, the total shielding failure rate is totally different, so we should take into account other factors except for the protection angle during the design of tower structure. This paper compared the total trip out rate of four types of double-circuit towers and concluded that the concave drum-type tower is the best design.

1. Introduction

As we all know, the geometric structures of overhead line towers have enormous implications on shielding failure characteristics. Most literatures about lightning protection used protecting angle to represent the shielding effectiveness to lightning of different tower geometric structures. It is generally accepted that the shielding failure trip-out rate decreases with the decrease of the protecting angle. However, the towers with the same protecting angle can have quite different geometric structures, so it is too simple to describe the overhead line tower with the protecting angle. In this paper, we changed the height and spacing of the ground wire to study the influence of the tower geometric structures.

The traditional electro-geometric model (EGM) [1,2] treats the lightning strike process as a geometry drawing, the randomness of lightning process cannot be considered. For the transmission lines with the towers which are not very high, this randomness has little influence on the analysis results. But for 500 kV double-circuit transmission line with the tower height taller than 60 m, this randomness would have strong influence on the upward leaders from tower, shield wires and phase conductors, certainly on the downward lightning leader, too.

Based on the concept of critical corona radius, Dellera and Ericsson presented the starting criterion of the upward leader and built the leader propagation model of lightning (LPM) [3,4], which considers the whole developing process of descending leader to upward leader. After that, Rizk and other scholars did a lot of researches to improve this model [5–21]. The calculation model used in this paper is the lightning propagation model based on these literatures. The surface electric field strength of the conductors was calculated as the starting criterion of the upward leader. This paper investigates the effect of overhead line tower geometric structures to the lightning shielding failure of double-circuit transmission line. An appropriate lay out scheme of phase lines is proposed.

2. Lightning leader development model

The existing literatures about the process of lightning strike treat the electric field as static field or standard static field [5–14]. The computation results indicate that this assumption is reasonable. In this premise, there are two methods describe the lightning leader channel: voltage source and charge source.

Petrov used voltage source and the finite difference method to solve the space electric field generated by lightning leader [11]. This method can get rather accurate electric field distribution around the leader channel. It is more suitable to use fractal method to simulate the shape of the lightning leader channel [3,6]. The models in literature [3,6] used the charge source method, which is easy to build the relationship between the amplitude of the lightning current and the total charge of the leader channel. Additionally, the charge source method is more efficient in computation so that it is applied to substantial computation of trip-out rate. The two methods describe the characteristics of lightning leader channel from different aspects; the chosen of them depends on the purpose

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[*] Corresponding author. Tel.: +86 10 62788811; fax: +86 10 62784709.
E-mail address: leezhen1988@gmail.com (Z. Yu).

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and method of the calculation. The model in this paper is based on charge source method.

To simulate the leader channel with charge source, there are two key issues: the charge distribution in the leader channel and the relationship between the total charge and the amplitude of the lightning current.

It is generally acknowledged that there are three kinds of charge distribution: uniform distribution, linear distribution and exponential distribution [1–4]. The influence of different charge distribution to the lightning process was compared in [5]. Observation shows that quite a great quantity of charge concentrates in the head of the leader channel. Based on this phenomenon, Petrov simplified the structure of the leader channel as follows [10]: the charge in the leader channel is uniform distributed and the space charge in the head is simulated as concentrated charge. The ratio between the charge density in the channel and the concentrated charge can be calculated with Gauss theorem. The model in this paper used this kind of setting of charge distribution.

For the relationship between the total charge and the amplitude of the lightning current, different scholars proposed different expressions. Dellera and Ericsson got the expression (1) of the total charge through the integral of the lightning current waveform [3]. The expression in [6] is as expression (2).

$$Q = 76 \times 10^{-3}\, I^{0.68} \tag{1}$$

$$Q = \left(\frac{I}{25}\right)^{1/0.7} \tag{2}$$

In the lightning leader propagation method of NIPT in Russia [13], the charge in the leader channel is uniform distributed and the charge density is as expression (3). Based on the lightning leader model, the relationship between the charge density and the amplitude of the lightning current was presented as expression (4) in [10].

$$\lambda = 3.3 \times 10^{-6}\sqrt{I^2 + 500\ I} \tag{3}$$

$$\lambda = 43 \times 10^{-6}\, I^{2/3} \tag{4}$$

To get the total charge with expression (3) and (4), we take the length of the leader channel as 2 km. Through the calculation we can get that the expressions in [10] and [13] meet the calculation result of (1) very well, while the result of expression (2) is quite different. So, expression (1) is used this paper to calculate the charge in the channel. According to Dellera's model in [3], the total charge Q_h in the hemisphere area of the leader head is

$$Q_h = 2\pi\varepsilon_0 r_s^2 E_s \tag{5}$$

The charge density in the leader channel is

$$\lambda = 2\pi\varepsilon_0 r_s E_s \tag{6}$$

where r_s is the radius of the stream area and E_s is the minimum maintain field of the stream.

In this paper, the equivalent radius of the lightning channel r_s was calculated using the expression (7) in [14].

$$r_s = 3.0\ \log(I + 20) \tag{7}$$

The downward leader of the lightning channel would produce furcation in its downward developing process. There is certain randomness in the develop direction of the lightning channel. But in general, the lightning channel always develops along the largest electric field direction. In this paper, we ignored the randomness and furcation of the lightning channel and make the channel always develop along the largest electric field direction.

The generation and development of the upward leader is an important factor in the lightning strike process. For the starting criterion of the upward leader, there are lots of theories. Based on discharge theory, the electric field criterion is considered the most reasonable. This paper used corona inception field strength of the conductor with critical size as the starting criterion of the upward leader. For spherical and stick electrode, the corona inception field strength can be calculated with expressions (8) and (9).

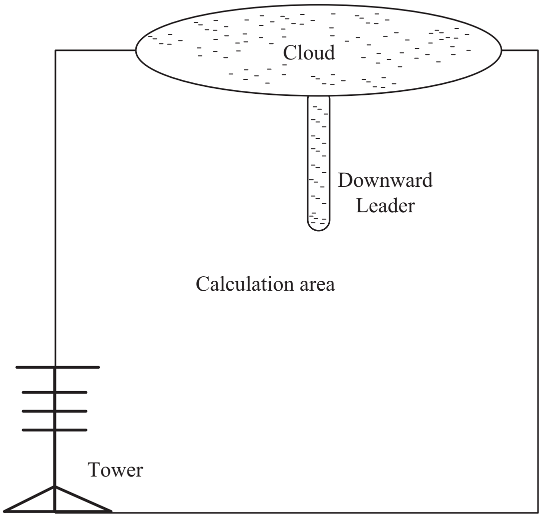

Fig. 1. Illustrate of the LPM calculation program.

$$E_c = 2300\left(1 + \frac{0.224}{r^{0.37}}\right) \tag{8}$$

$$E_c = 3000\,\delta m\left(1 + \frac{0.03}{\sqrt{\delta r}}\right) \tag{9}$$

where δ means the relative air density, for standard atmospheric pressure it is 1.0. And m is the surface roughness coefficient of the conductor, for the corona charge can homogenize the distribution of the electric field around the conductor, the value of m can be taken for 1.

With the propagation of the downward leader and the upward leader, the distance between them would shorten and the space electric field between the gap of upward and down downward leader heads would increase. When the average electric field strength of the gap is larger than the breakdown field strength of air, the gap would be broken down and the lightning striking process would be finished.

3. Shielding effectiveness of the ground wires

Based on the LPM theory above, a calculation program was built to study the characteristic of double-circuit lines under lightning strike. Due to the symmetry of double-circuit lines, we set the calculation area as a rectangle with the tower in one vertex, as illustrate in Fig. 1. The charge in the cloud is modeled with a uniform distributed unipolar negative charge with an extension of 10 km at height of 2 km [3]. According to the research in [3], the total charge of the cloud is 8 C and in the calculation, this value remains constant. The charge of the leader channel is calculated as expressions (1), (5) and (6). In the calculation, the potential of the ground lines and the conductor lines was determined and all the lines were modeled by charge simulation method. For this standard static field problem, all the charge distribution is determined, so the electric field distribution can be easily calculated.

In the program, the calculation area is divided with n segments. The downward leader is set in different position. With the same position of downward leader, different lightning currents can get