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Optimal design of tower footing device with combined vertical and horizontal grounding electrodes under lightning

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ABSTRACT

The property of tower footing device under lightning is an important issue for lightning protection. This paper focuses on analyzing on the optimal design of the tower footing device under lightning. Firstly, the practical effects of three kinds of common applied driven rods under lightning are researched by field testing. It is concluded that in the testing condition, the non-metal driven rod takes the best effect while the metal driven rod takes the worst. Moreover, the optimal installation position of the driven rods and the optimal structure of the horizontal electrodes are analyzed by numerical simulation, respectively. Both of them are heavily affected by soil resistivity and size scale of the tower footing. In order to solve the two practical problems, quantitative optimal criterions are put forward, which can be referred to while determining the optimal design of the tower footing device under impulse. That is very meaningful for engineering application.

1. Introduction

The grounding system plays an important role in lightning protection. The grounding system is requested to have "sufficiently low impedance and current-carrying capacity to prevent the buildup of voltages that may result in undue hazard to connected equipment and to persons" [1].

In order to satisfy the request, some driven rods are installed to decrease the grounding resistance in the course of designing the grounding system. Among many kinds of driven rods, metal driven rod, chemical driven rod and non-metal driven rod are widely used in engineering. The structures of the three kinds of driven rods are known well and to be introduced below. However, there is an argument over which kind of driven rod is the most effective in reducing the grounding impedance under the impulse condition. Up to now, there is little research on the practical effect of the driven rods that the argument has not been resolved yet.

Besides, there are many studies on the influence of the driven rods on grounding resistance [2–6]. Most of them focus on the influence in the power–frequency condition [2–4]. While installing the driven rods to the combined vertical and horizontal tower footing electrodes, the question of where to install the driven rods needs to be answered, at the central area or at the terminals? In terms of the power–frequency condition, the driven rods are usually installed at the terminals. However, under the impulse condition, the question seems more complicated and is not easy to answer. There are two factors taking effect: one is the mutual-coupling between the grounding conductors [5], and the other is the strong self-induction of the grounding conductor at high frequency [6]. On the one hand, while a driven rod is installed at a conductor-intensive position of horizontal grounding electrodes, its effect on reducing the grounding impedance will diminish because of the "shielding effect". As the center of a grounding system is usually conductor-intensive, it seems preferable to install the driven rods at the terminal. On the other hand, as the "inductive effect" prevents the impulse current from flowing far, the grounding electrode has "effective length". It seems more effective to install the driven rods at the center. Thus, the intuitive judgments based on the two factors are contradictory in determining the optimal position of the driven rods.

Moreover, in the course of designing the tower footing device, another question is often concerned: how to use a fixed amount of metal to obtain the optimal structure of the horizontal electrodes? Several typical designs are demonstrated in the standards [1,7] and applied in the practical projects, but which is the best one? It can also be analyzed based on the concepts of "the shielding effect" and "the inductive effect". But it cannot be decided by intuitive judgments.

It is noted that the optimal position of the driven rods and the optimal structure of the tower footing device can be explained by the concept of the effective length of the electrodes. It has been

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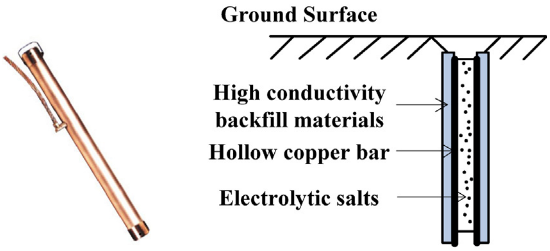

Fig. 1. Chemical driven rod.

Fig. 2. Non-metal driven rod.

maturely researched by different methods, from different angles and for different applications [8–11]. But most of the research works focused on a single electrode. Some researchers studied the effective area of the grounding grid [12,13], but few of them try to apply that concept to the optimal structure design of tower footing device.

To solve the above questions, this paper carries out field testing and numerical simulation, respectively. Firstly, to evaluate the effect of driven rods under the impulse condition, the three kinds of driven rods are installed to the horizontal tower footing device in the field testing. Secondly, to determine the optimal position of the driven rods under the impulse condition, several models with the driven rods installed at different position are simulated. The influence of the soil resistivity and the tower footing device scale on the optimal position is analyzed. On the basis, this paper puts forwards a quantitative optimal criterion for determining the optimal installation position of the driven rods to the horizontal tower footing device. Thirdly, to obtain the optimal structure of the horizontal electrodes, three typical structures are simulated in the paper. The electrodes made of steel and copper are concerned. The quantitative optimal criterion for determining the optimal structure is also proposed in the paper. This is an extended version of the paper presented at the 28th International Conference on Lightning Protection in 2012 in Vienna [14].

2. Effects of different driven rods under impulse

2.1. Structures and mechanisms of driven rods

The driven rods which the paper concerns are metal driven rod, chemical driven rod and non-metal driven rod. Those three kinds of driven rods are commonly used in engineering. They are all installed vertically to the horizontal grounding electrodes. For the readers' convenience, their structures and mechanisms are introduced below.

2.1.1. Metal driven rod

The metal driven rod is the most common one among the three kinds. They are usually composed of steel or copper conductors.

2.1.2. Chemical driven rod

The chemical driven rod used in the testing is a hollow copper bar with electrolytic salts inside. The copper bar is about 1.5 m long. Moreover, based on the product description, the electrolytic salts can absorb moisture from the soil around the bar. After deliquescence, the electrolytic salts permeate in the soil through the hole in the bar. The electrolytic salts permeating out of the bar improve the component of the soil and decrease the resistivity. When the rod is buried, high conductivity backfill materials are padding outside the bar which can help absorbing moisture, decreasing the soil resistivity and protecting the bar from rusting (Fig. 1).

2.1.3. Non-metal driven rod

The non-metal driven rod used in the testing is a coke block with electrolytic salts doping inside and a steel bar penetrating through. It is introduced that the coke increases the contact area and decreases the contact resistance between the steel bar and soil. Moreover, it is also said that the electrolytic salts can play the same role as that inside the chemical driven rod (Fig. 2).

2.2. Condition of field test

As a matter of fact, up to now there are not any recognized and reliable simulation models for the chemical and non-metal driven rods. So in order to evaluate the effect of the different driven rods under impulse, this paper carries out the field testing outdoor. A high power impulse current and a horizontal cross grounding electrode with real size are applied in the field test. Then, the three kinds of driven rods are installed to the cross grounding electrode. The condition of the testing is introduced below in detail.

2.2.1. Field test site

The field test is carried out in Huzhou, China. Huzhou is located in East China. Fig. 3 shows the actual scene of the test site. The soil of the site has two layers: the resistivity of the top layer is 355 Ω m and its thickness is 2 m; the resistivity of the bottom layer is 250 Ω m.

2.2.2. Tower footing device

A cross grounding electrode is buried horizontally with a depth of 0.9 m under ground in the field test site. The grounding electrode consists of flat steel conductors with 0.08 m in width and 0.008 m in thickness. The structure and the dimension of the horizontal grounding electrode are shown in Fig. 4. It can be seen that it is a real size scale structure.

Fig. 3. Testing site.