The Simulation Experiments on Impulse Characteristics of Tower Grounding Devices in Layered Soil

Leishi Xiao, Qian Li, Zhangquan Rao, Wenjun Zhou, and Jiarui Huang

Abstract—**Reducing the impulse grounding resistance of transmission line tower grounding system is the major measure to improve the lightning impulse withstand level and to ensure power system stability. For tower mainly adopts box with radiation grounding devices, this paper uses simulation experiments method based on similarity theory, researches the influence of radiation length, radiation angle and the proportion of box and radiation, branch length on the box with radiation grounding devices' impulse characteristics in layer soil model. Results of the experiments show that the branches have an effective use of length, the box and radiation have an optimal proportion, over length radiation or improper proportion will render the resistance reduction ineffective. According to the results of the experiments, we have gotten the optimal length rays add branch and put forward an impulse characteristics features better tower grounding structure which is named T2-15-25&H2-15. There are some references for engineering.**

Index Terms—**Tower grounding system, impulse grounding resistance, ground network structure, impulse characteristics, simulation experiments, resistance reduction.**

I. INTRODUCTION

Reducing the impulse grounding resistance of transmission line tower grounding system is the effective measure to improve the lightning impulse withstand level [1], the impulse grounding resistance will directly affect the line lighting protection effect [2]. Lighting current flows into the earth through the grounding conductor, it will increase the local field strength around the conductor and make the spark discharge happened when the field strength exceeds the soil breakdown electric field strength [3]. And the spark discharge will increase the equivalent grounding radius and the soil conductivity [3]. At the same time, lighting electric wave frequency component are mainly concentrated in 10~200 kHz, the conductor inductance and the inductance to the ground will prevent the current from flowing to the distant grounding part. Due to the inductive effect, the conductor will not be used sufficiently [4]. The spark effect and the inductive effect will make a large difference between the power frequency grounding resistance and the impulse grounding resistance. The method to reduce the power frequency grounding resistance is not applicable to the impulse grounding resistance.

The existing resistance reduction methods mainly include using the resistance reducing agent, replacing the local soil around the grounding conductor, changing the grounding network structure. The resistance reducing agent can improve the electrical conductivity of the soil around the grounding electrodes directly. But its low adhesion, easy solubility, corrosion to the conductor and the pollution to the soil have limited its application [5]. There has been happened to use the replacement of soil to reduce the grounding resistance in engineering [6]-[8], namely to replace the soil of high resistivity around the grounding conductor by the soil of low resistivity. The literature [9] has established a "replacement of soil" model to calculate the grounding resistance, and it indicates that the resistance reduction rate is lower than 5%. The change of grounding structure mainly includes extending the radiation length, adding some branches on the radiation and so on. For the high resistivity area, to increase the radiation length can effectively reduce the power frequency grounding resistance, but the resistance reduction effect is not obvious to the impulse grounding resistance. In some special regions, the radiation length has been more than 200m and the power frequency grounding resistance is less than 2Ω, but the accident of lighting flashover to cause the tripping operation is still happened [10]. Exceeding the electrode is not equivalent to reducing the impulse grounding resistance. There are also many applications of adding conductors on the radiation branch. The literature [11], [12] has studied the way to reduce the impulse resistance by adding the branch in the perspective of improving the flowing current distribution. But they do not take the size of conductors into account and have not gotten the optimal length of the radiation and the branch of the tower grounding system directly.

In order to optimize the impulse characteristics of the grounding network in two-layer soil [13] and reduce the impulse grounding resistance effectively, this paper adopts the method of simulation test [14] and test the usual box with radiation grounding system used in the transmission line tower. The influences of the radiation length, radiation angle, the proportion of box and radiation length to the impulse properties will be studied. At the same time, this paper researches the influence of branch length to the horizontal grounding conductor and the box grounding conductor in the condition of a total length. By comparing the impulse features of different structure of grounding systems, an optimized arrangement of grounding network has been proposed.

II. EXPERIMENTAL METHOD

The testing place is the grounding laboratory located in Chinese Electric Power Research Institute UHV AC test site.

The experimental wiring arrangement is shown in Fig. 1. The grounding conductor is buried in a hemispherical simulation slot (Fig. 2) whose diameter is 8m. The slot is filled with soil and the slot wall is used for reflowing. The testing power is an impulse current generator which can produce the 60kV/10kA current. Through changing the adjustable resistance and inductance, the needed current is exported and injected into the grounding device. The current flows through the soil and is collected by the slot wall, then back into the low voltage terminal of the impulse current generator. The testing voltage divider is the weak damping resistor voltage divider whose voltage division ratio is 115.7:1, used for measuring the voltage waveform in the feed point. The shunt is the Pearson coil whose changing ratio is 0.01V/A, used for measuring the loop current waveform. The soil resistivity in the hemispherical slot is 30Ω·m. 35cm thick silver sand whose resistivity is 2180Ω·m has been laid on the soil, so a double-layer soil model is gotten. To simulate the impulse features in high soil resistivity area, the simulated grounding electrode is buried in the sand.
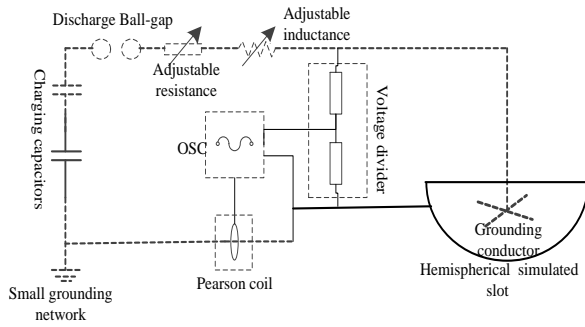

Fig. 1. Connecting diagram of experiment.

Fig. 2. Photo of the experiments site.

According to similarity theory, the paper takes the main simulation scale [15] as follows:

Soil resistivity: $\rho_1 = \rho_2$

Soil breakdown electric field strength: $E_{01} = E_{02}$

Length: $l_1 = nl_2$

Time: $t_1 = nt_2$

Amplitude of impulse current: $I_{m1} = n^2 I_{m2}$

Wave front time of impulse current: $\tau_1 = n\tau_2$

Impulse grounding resistance: $R_1 = R_2/n$

Impulse coefficient: $\alpha_1 = \alpha_2$

In each equation, the physical quantity in the subscript 1 represents the true type of grounding device and the one in the subscript 2 represents the simulated type of grounding device. And the analog scale is n. The wave front time of impulse current will greatly influence the impulse characteristic of grounding device. In order to make the wave front time of testing impulse current close to the standard lighting current and reduce the loop inductance, the current will be flowed into the earth by three copper braided straps. Because of the size of simulation test electrode shall not exceed 1/4 times the diameter of the simulated slot [16], considering to the test requirement for wave front time and the size of electrode, the simulation ratio has been set as n=50:1. The wave front time of impulse current in the test is between 0.08μs~0.14μs, as it is shown in Fig. 3. After the conversion, the wave front time is between 4μs~7μs. It is relatively close to the wave front time of standard lighting current which is 1~4μs. In the real tower grounding device whose structure is the box with radiation, the length of the box side is commonly 8m~15m, the radiation length is 0~60m. The shapes and sizes of grounding device are shown in Table I, the influence of radiation length, radiation angle and the proportion of box and radiation, branch length on the box with radiation grounding devices' impulse characteristics in layer soil model have been discussed.
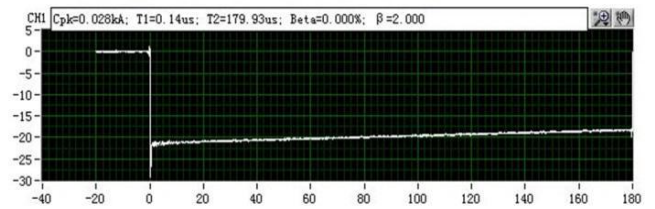

Fig. 3. Current waveform of experiment.

TABLE I: STRUCTURE OF THE EXPERIMENTS GROUNDING DEVICES

Name	Shape	Real size (m)
Box with ray T2-a-L		a=5m,10m,15m,20m,25m L=15m,25m,35m,45m,55m
Box with ray T3-15-55		a=15m L=55m

III. ANALYSIS OF TEST RESULTS

A. Influence of Radiation Length

In the high soil resistivity area, in order to reduce the grounding resistance, the radiation length is more than 60m generally. But as the radiation length had increased, the inductive effect of grounding device also increased. It makes the effective utilization rate of grounding device reduced. When the length reaches a certain value, the impulse grounding resistance will increase slowly. To explore the effective length of the radiation length in the box with radiation grounding device under the condition of high soil

resistivity, the paper will study the impulse characteristics of the condition that the radiation length is 15m,25m,35m,45m,55m with the length of the box side is 15m respectively. ZC-8 type grounding resistance shaking table is used to measure the power frequency grounding resistance of the above five kinds of grounding devices. The grounding resistances transformed by the simulation result are shown in Table II.

The impulse characteristic of different grounding devices are shown in Fig. 4. The amplitude of impulse current injected into the grounding device is very high. It makes the effect of spark is stronger than the inductive effect, so the impulse coefficient are less than 1. The test results show that with the increase of current amplitude, the impulse grounding resistances of different grounding devices are reduced. Due to the increase of impulse current amplitude, the partial field strength around the grounding device will increase. When the value is higher than the soil breakdown electric field strength, the spark discharge phenomenon will appear. Ignoring the residual resistivity of the spark discharge area and assuming that the potential of the partial discharge area is the same to the potential of grounding device, it is equivalent to the condition of increasing the diameter of grounding device and expanding the area of current flow. And it will reduce the impulse grounding resistance. But if the amplitude increases to a certain degree, the spark discharge tends to be saturated. It makes that the falling trend of the impulse grounding resistance is more and more unobvious. In the condition of the same current amplitude, Fig. 5 shows the variation tendency of the grounding device with different radiation length. When the length of the ray reaches 55m, the inductive effect will be more obvious and the impulse grounding resistance will not decrease at all. All of this tells us, an effective length of the radiation length is existed. It is not useful to set a very long radiation length.

TABLE II: POWER FREQUENCY GROUNDING RESISTANCE OF DIFFERENT GROUNDING ELECTRODES

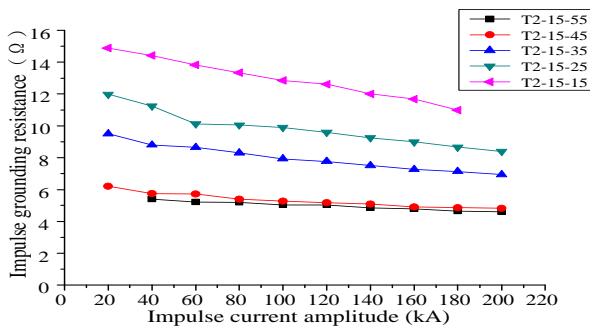| Code	T2-15-15	T2-15-25	T2-15-35	T2-15-45	T2-15-55
Power frequency grounding resistance（Ω）	23.9	17.5	13.6	11.1	9.4

Fig. 4. Impulse characteristics of box grounding devices in different radiation length.

B. Influence of Ray Angle

To study the effect of ray angle, this paper had compared the impulse characteristic of T2-15-55 and T3-15-55 in Tab. I.

The two kinds of grounding devices have the same length of box side and radiation length. The test result is shown in Fig. 6. They are almost the same. So the ray angle has a little influence when the radiation length is comparatively long.
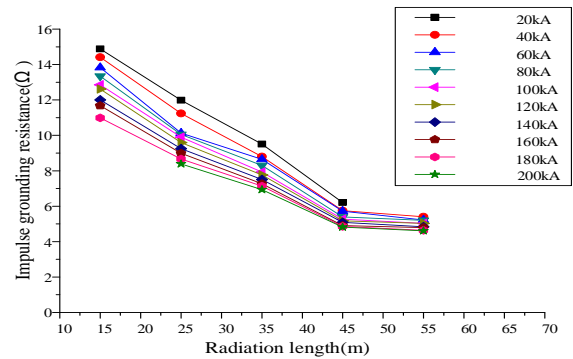

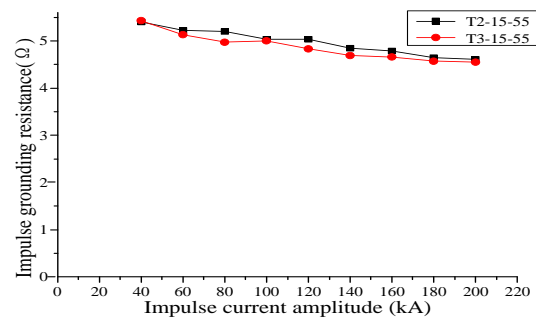Fig. 5. Effects of the length of radiation on the impulse grounding resistance.

Fig. 6. Impulse characteristics of box grounding devices in different radiation angle.

C. Influence of the Proportion of Box and Radiation

When the total length is a certain value, how to get the optimal effect by controlling the box length and the radiation length? The paper had tested the five kinds of box with radiation grounding device: T2-5-65, T2-10-60, T2-15-55, T2-20-50, T2-25-45. The total lengths of these grounding devices are 70m. The proportion of box and radiation are respectively 1/13,1/6,3/11,2/5,5/9 , the results are shown in Fig. 7. As the proportion increases from 1/13 to 5/9, the impulse grounding resistance decreases firstly and then increases. With the increase of the length of box side, the conductor spacing increases. It makes the mutual impedance decrease and the grounding resistance decrease. But the field strength generated by the impulse current also decreases, the spark effect weakens and the grounding resistance increases. When the proportion is less than 1/6, the mutual impedance plays a leading role; when the proportion is greater than 3/11, the spark effect plays a leading role. So it is appropriate to set the proportion between 1/6~3/11.

D. Influence of Branch Length on the Radiation

In the actual grounding transformation, to add the branch on the radiation is often used to reduce the impulse grounding resistance. So the paper researches its rules. The result of horizontal grounding device is shown in Fig. 8. When the total length is a certain value (60m), adding the branch can reduce the impulse grounding resistance of horizontal grounding device. With the increase of the branch, the

impulse grounding resistance decreases firstly and increases then. It is similar to the proportion of box and radiation. The appropriate proportion of branch and radiation need to be explored.
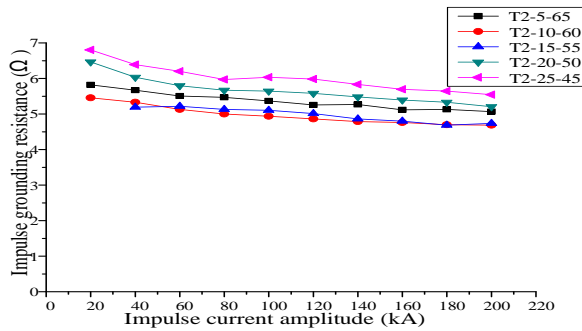

Fig. 8. Impulse characteristics of grounding devices in different proportion of box side and radiation length.
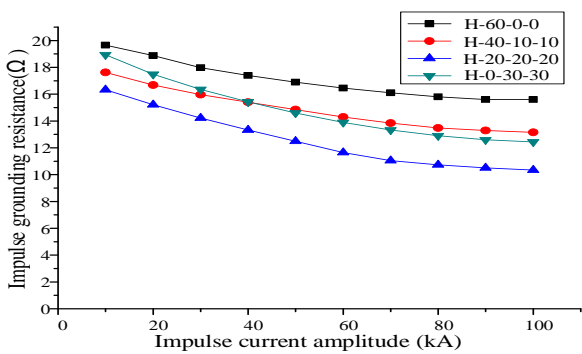

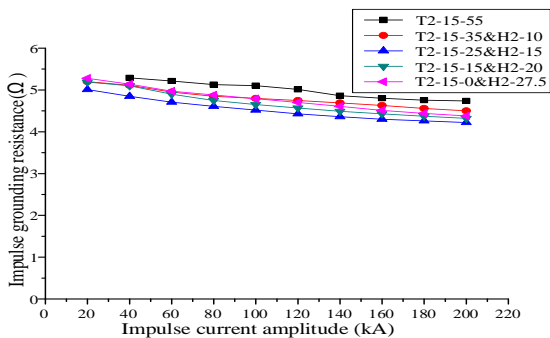Fig. 7. The impulse characteristics of horizontal grounding devices in different branch length.

Fig. 9. The impulse characteristics of box grounding devices in different branch length.

In order to explore the influence of the branch length on the radiation on the impulse characteristic, the paper selects the five kinds of grounding devices: T2-15-55, T2-15-35&H2-10, T2-15-25&H2-15, T2-15-15&H2-20 and T2-15-0&H27.5 in Tab. I (d). In these grounding devices, the length of the box side is a, equal to 15m, the total length of radiations and branches is 55m, the lengths of branches L1 are 0m,10m,15m,20m,27.5m. The special one T2-15-0&H27.5 represents that the radiation length is 0m and the branches are connected to the four vertices of the grounding system. The test result is shown in Fig. 9. It is Similar to the horizontal grounding electrode. In the same condition, with the increasing of branch length, the impulse grounding resistance decreases firstly and increases then. Among these grounding devices, the T2-15-25&H2-15 one is

the best. To a certain extent, the branches can reduce the impulse grounding resistance. But on the opposite, the branches will also influence the efficiency that the current flows into the earth. So it is necessary to choose the optimal branch length on the radiation.

IV. CONCLUSIONS

In the two-layer soil model, the method of simulation test is been used to study the impulse characteristic of the box with radiations grounding devices used by the transmission line tower grounding devices. And the influences to the impulse characteristic, including the radiation length, the radiation angle, the proportion of box and radiation and the branch, are been tested.

The radiation angle has little influence on the impulse characteristic. There is a certain value for a special radiation line, once exceeding the value, the impulse grounding resistance decreases slowly. There is an optimal proportion of box and radiation to get the best grounding resistance reducing effect. All of this could be the guidance in the design or transformation of the grounding system.

There will be some effect to add the branch on the radiation. When the total length of the radiations and branches is a certain value, there will be an optimal branch length for the best resistance reducing effect. The simulation test shows that in the two-layer soil model(the upper soil resistivity is about 2180Ω·m, the lower soil resistivity is about 30Ω·m), the T2-15-25&H2-15 kind grounding structure has the minimum impulse grounding resistance among all of the tested grounding devices. The structure and the proportion can offer some references for engineering.

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