# Study on Methods to Improve Transient Performance of Grounding Grid

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*Abstract*—**The transient characteristics of a grounding grid is very important for the safety of the equipment on it, which is quite different from the performance at power frequency. In this paper, based on numerical simulation, the factors due to the grounding grid that affect its transient performance were discussed. The methods to improve the transient performance of the grounding grid such as increasing the horizontal grounding conductors and vertical grounding conductors near the current injection point were presented. It shows that increasing the horizontal grounding conductors is such more effective than increasing vertical grounding conductors to decrease the ground potential rise and the potential difference in the grounding grid.**

*Keywords-Grounding grid; lighting; ground potential rise; potential difference*

## I. INTRODUCTION

The transient performance of the grounding grid is very important for lightning protection in a substation [1]. When lighting strikes the lighting rod in the substation, large amount of transient current will flow into its grounding grids. Due to the high frequency, the inductance of the grounding conductor is large, which resists the flowing of the lightning current along the grounding conductor and makes the most of the current leaked into the soil near the lighting rod. Thus, the ground potential rise (GPR) distribution along the grounding grid is quite uneven, which would threaten the electronic equipment and power apparatus in the station [2]. In order to design a suitable grounding system, it is necessary to improve the impulse performance of it.

Many researching works have discussed the transient performance of grounding systems. Based on circuit or transmission line theories and electromagnetic-field theories [3-10], there have already been many approaches to simulate the transient performance. Experiments were also done to study the transient performance [11, 12]. All the researches showed that the GPR distribution along the grounding grid is quite uneven, and there exists an effective area for the lightning current discharge [2]. But few works paid their attention to the improvement of the transient performance of the grounding grid.

In this paper, with the help of numerical simulation, the methods to improve the transient performance of a grounding grid, such as increasing the horizontal grounding conductors and vertical rods near the lightning rod, were analyzed, which may be useful for the design of a safe grounding grid.

## II. NUMERICAL APPROACH

In this paper, an approach developed by the authors based on Method of Moments is used to calculate the transient performance of grounding grid [10]. First, the grounding grid is divided into short segments, and some assumptions are introduced which are also shown in Fig. 1:

- The longitudinal current in the same segment is constant and is centralized on the axis.

- The leakage currents are distributed evenly around the nodes (the points of intersections between the segments).
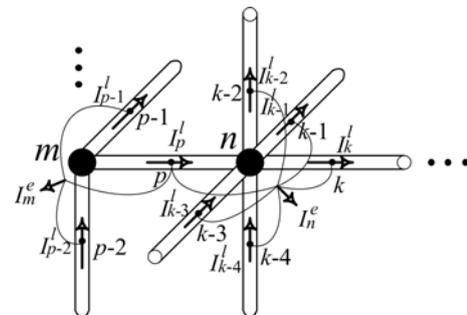


Figure 1. Current distribution on the segments.

Based on the boundary condition that the longitudinal component of the external electric field should be equal to the longitudinal component of the internal electric field on the surface of the conductor, following equation can be obtained:

$$j\omega \mathbf{M}\mathbf{I}^l + \mathbf{A}\mathbf{V}^n + \mathbf{Z}\mathbf{I}^l = 0, \tag{1}$$

where $\mathbf{M}$ is a matrix of the inductances between segments, $\mathbf{V}^n$ is a column vector of the potentials at the nodes, $\mathbf{I}^l$ is a column vector of the longitudinal currents in the segments, $\mathbf{Z}$ is a

diagonal matrix of the segments' internal self-resistances, $A$ is a matrix reflecting the connection relationship between segments and nodes. $V^n$ in (1) can be obtained by

$$V^n = RI^e, \quad (2)$$

where $I^e$ is a column vector of leakage currents around nodes as shown in Fig. 1, and $R$ is a matrix of mutual resistances between nodes and leakage currents.

According to the longitudinal current and leakage current distribution in Fig. 1, $I^l$ and $I^e$ have following relationship:

$$I^e = A^T I^l. \quad (3)$$

where $A^T$ is the transpose of $A$. By substituting (3) into (2) and then into (1), a group of equations with longitudinal currents as unknown variables is obtained:

$$j\omega M I^l + A R A^T I^l + Z I^l = 0. \quad (4)$$

By solving (4), the longitudinal currents can be obtained. Based on the currents, the potential at any point can be calculated. The above method is a frequency domain method. Then, the transient potential on the grounding grid by lightning strokes can be analyzed with the help of Fourier transform. The method has already been testified in [10].

Based on the above approach, we developed a simulation tool by ourselves with the help of MATLAB, which can take account of the layered soil, the grounding material, the arrangement of the grounding conductors, and the waveform of the injected current altogether.

## III. SIMULATION MODEL

The grounding grid to be simulated is a 100 m × 100 m grid buried with a depth of 0.8 m. The grounding conductor is made of steel with a radius of 0.01m. The space of the conductors is 10 m. The structure of the soil is shown in Table 1. When a 2.6/50 μs lightning current with a peak of 1kA strikes the central point of the grounding grid, the GPR distribution will be calculated. Although usually the lightning rods are at the corner of the substation, the conclusions drawn in this paper is still suitable.

TABLE 1. STRUCTURE OF SOIL

| Layer No. | Thickness (m) | Soil Resistivity（Ω·m） |
|-----------|---------------|-------------------------|
| 1 | 0.84 | 88.1 |
| 2 | 2.89 | 807.6 |
| 3 | infinite | 213.0 |

According to the research works in the literatures, most of the lightning current was leaked into the soil from the part near the lighting striking point, which caused that the main potential drop is also concentrated around the lighting striking point [2]. Thus, the method to make the potential distribution

even is that to reduce the potential drop near the lighting striking point. Increasing the paths for current discharge is a good idea to improve the transient performance of the grounding grid. There seem two ways to realize the idea, one is to increase the horizontal grounding conductors near the lightning rods, and the other is to increase the vertical electrodes. In the following part, the effectiveness of the above two ways will be analyzed.

## IV. INCREASING HORIZONTAL GROUNDING CONDUCTORS

First, the transient performances of the grounding grids with more horizontal conductors are analyzed. The grounding grids are shown in Fig. 2. In a 40 m × 40 m area around the current injection point, the ground conductors become dense. In Fig. 2 (a), the space of the conductors is 5 m, and it is 2 m in Fig. 2 (b). The transient GPRs at the current injection point are shown in Fig. 3, and the distributions of the peaks of the GPRs along the observation line in Fig. 2 are shown in Fig. 4.



(a)  5 m space of the conductors
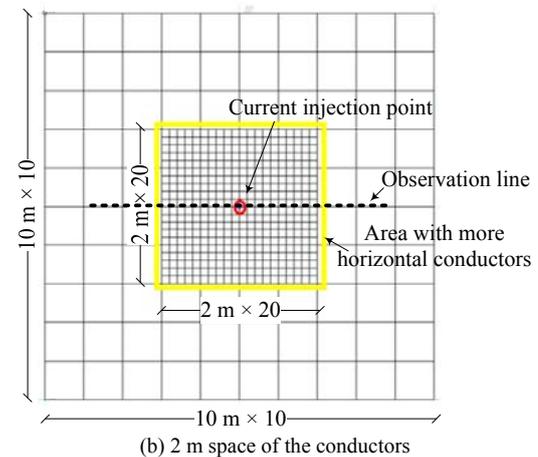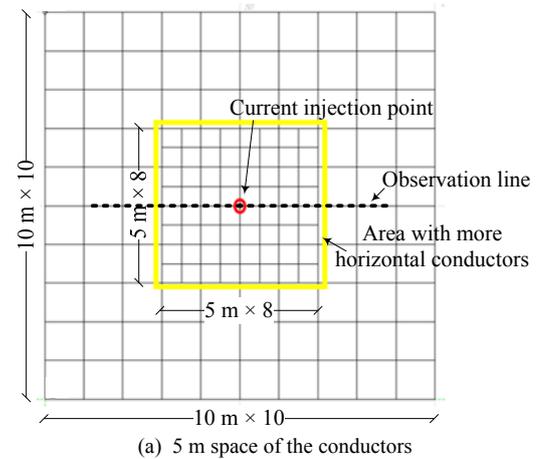


(b) 2 m space of the conductors

Figure 2.   The grounding grid with more horizontal grounding conductors

It can be seen from Fig. 3 that the space of the horizontal conductors affects the amplitude of the transient GPR greatly. More horizontal conductors near the current injection point mean small GPR. However, the waveform of the transient GPR has almost no relation with the space of the horizontal conductors.

Unlike the power-frequency characteristic, the impulse GPR distribution on the grounding conductors varies a lot. From Fig. 4 it can be seen that near the injection point, the GPR varies greatly. If a distributed system such as the secondary system is grounded at more than one point, it should be able to withstand the potential difference of the GPR. In order to protect this kind system, measures should be taken to make the GPR distribution even. It can be seen from Fig. 4 that the space of the horizontal conductors affects the distribution of the GPR greatly. The more conductors near the current point, the more even the GPR distribution will be. Thus, increasing the horizontal grounding conductors near the lightning rods is a very effective measure to reduce the lightning effect.
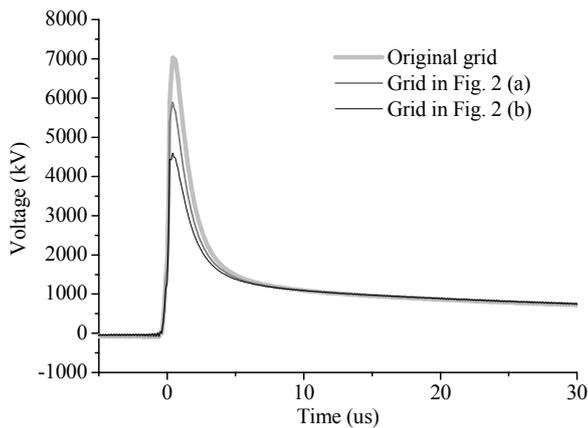


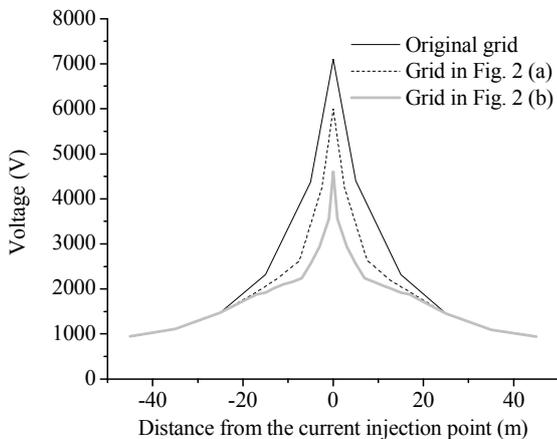Figure 3.    Transient GPRs at the current injection point



Figure 4.    Distributions of the peaks of the GPRs along the observation line

## V.    INCREASING VERTICAL GROUNDING ELECTRODES

Then, the transient performances of the grounding grids with vertical electrodes near the current injection point are analyzed. The grounding grids are shown in Fig. 5. In Fig. 5 (a), just 9 vertical electrodes are added at the cross sections of the grounding grid, while in (b) there are 25 vertical electrodes. The length of the each electrode is 2.5 m. First, the effect of the quantity of the vertical electrodes is analyzed, as shown in Fig. 6 and Fig. 7. Then the effect of the length of the vertical

electrodes is analyzed as shown in Fig. 8.



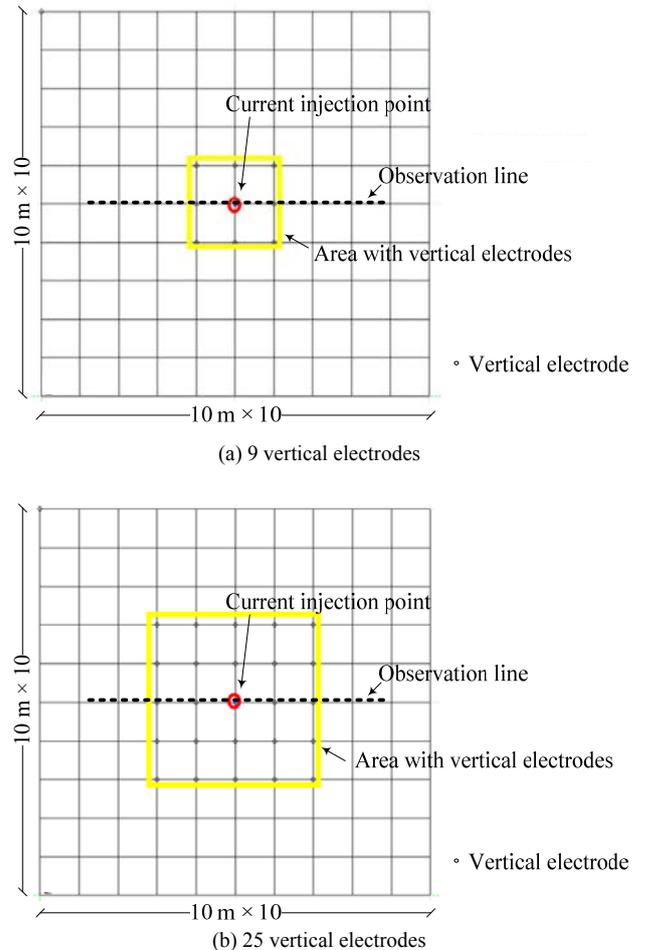(a) 9 vertical electrodes



(b) 25 vertical electrodes

Figure 5.    The grounding grid with more vertical grounding electrodes

It can be seen from Fig. 6 and Fig. 7 that the quantity of the vertical electrodes has almost no effect on the transient performance of the grounding grid. This may be because the analyzed vertical electrodes are too short, and the shielding effect of the horizontal electrode is too great. Meanwhile, the resistivity of the deep layer of the soil is much higher than that of the surface layer, which also reduces the effectiveness of the vertical electrodes.

Then, the transient performances of the grounding grid in Fig. 5 (a) with different lengths of the vertical electrodes are analyzed. The results are shown in Fig. 8. It can be seen that the length of the vertical electrodes affects the amplitude of the transient GPR to a certain extent. The longer the vertical electrodes are, the lower the peak of the GPR will be, and the more even the GPR distribution will be.

However, increasing vertical grounding electrodes is not so effective to improve the transient performance of the grounding grid as increasing the horizontal grounding conductors. This may be because the transient lightning current is more likely to flow away from the surface of the earth. Thus, to effectively improve the transient performance of the grounding grid, it is necessary to increase the horizontal

grounding conductors near the lightning rods, which will discharge the lightning current more easily compared other measures.
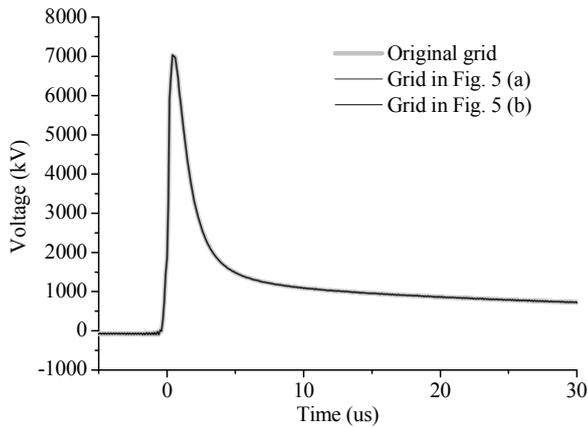


Figure 6.   Transient GPRs at the current injection point of the grounding grids with differnet quantities of the vertical electrodes
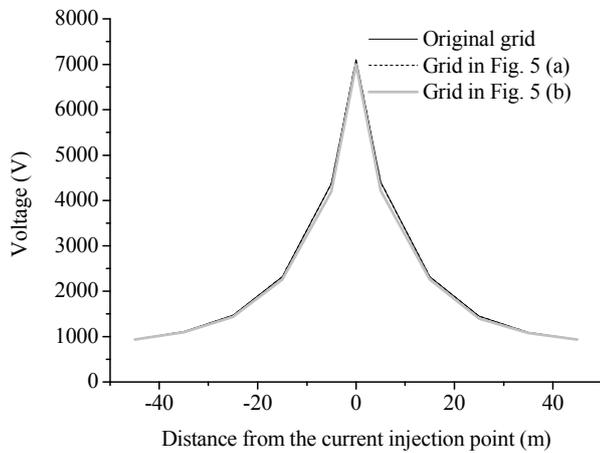


Figure 7.   Distributions of the peaks of the GPRs along the observation line of the grounding grids with differnet quantities of the vertical electrodes
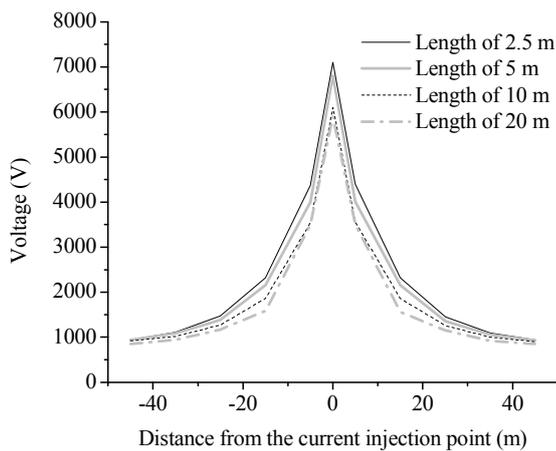


Figure 8.   Distributions of the peaks of the GPRs along the observation line of the grounding grids with differnet lengthes of the vertical electrodes

## VI.   CONCLUSION

In this paper, with the help of numerical simulation, the methods to improve the transient performance of the grounding grid such as increasing the horizontal grounding conductors and vertical rods near the current injection point were analyzed, and following conclusions can be drawn:

1) The transient GPR of the grounding grid under the lightning strike is distributed quite uneven. The more the point close to the injection point, the more greatly the GPR varies. This may be dangerous for the distributed system which is grounded at more than one point.

2) Increasing the ground conductors near the lightning rods is a good measure to improve the transient performance of the grounding grid. Increasing the horizontal grounding conductors is much more effective than increasing the vertical grounding electrodes.

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