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Distribution of Potential Rise as a Function of Shape of Grounding Electrodes

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Abstract

In order to analyze the potential rise of grounding systems installed in buildings, a hemispherical grounding simulation system was studied. Potential rise was measured and analyzed regarding the shape and distance of the grounding electrodes by using this system. The system was composed of a hemispherical water tank, AC power supply, a movable potentiometer, and test grounding electrodes. The potential rise was measured in real time by the horizontal moving probe of the potentiometer. The test grounding electrodes were fabricated through reducing the grounding electrode installed in real buildings such as the ground rod, grounding grid and so on. The potential rise was displayed in a two-dimensional profile and was analyzed regarding the shapes of the ground electrodes. The potential rise of the grounding grid combined with a ground rod was the lowest of every grounding electrode tested. The proposed results can be applicable to evaluating ground potential rise in grounding systems, and the analytical data can be used to stabilize the electrical installations and prevent electrical disasters.

Key Words : Potential rise, Grounding simulation system, Shape, Distance

1. Introduction

To prevent electrical accidents, modern systems depend on passive measures such as construction and management by electrical installation technical standards, safety guides and superintendence. However, electrical accidents are not reduced solely by passive measures. Grounding is one of the very important variable safety installations among temporary power installations. When grounding installation is compared with other steps, grounding installation is as easy to deal with as attached installation. When random overvoltages occur, ground faults, poor insulation in power installations, and grounding installation have all played an important role in protection from electric shock as well as stabilization of the installation as a whole. Therefore, the performance of the grounding system should be evaluated not only by ground resistance but by touch voltage, step voltage, mesh voltage, and transferred voltage. Preventive measures for electric shock as well as the protection of the installation from overvoltage through ground faults and lightning

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are presented here and further research is ongoing [1-3].

Therefore, this study researched potential rise, which was the most important factor in protection from electric shock from overvoltage in ground faults of power installations. Because it is difficult to obtain the best structure arrangement through the creation of an actual sized grounding system, a simulation of a grounding system was created and can be used to analyze a real grounding system. In the future, the resulting analytical data can be used to stabilize installations and to prevent electric shock.

2. Experimental Apparatus and Method

2.1 Principles of the Scale Model

When all physical dimensions of a grounding system are reduced in size by the same scale factor-including the conductor diameter and the depth to which the grounding electrode is buried-the pattern of current flow, and the shape of the equipotential surfaces are unaltered. This means that potential profiles measured on the model may be used to determine the corresponding potentials for the full scale grounding electrode. To model a practical value, some further changes are necessary. A full scale grounding electrode is buried in a semi-infinite earth.

A solid medium is inconvenient both from the measurement standpoint and for occasions when a delicate model must be frequently removed and replaced for modification. The electrolyte presents no particular problem for homogeneous cases and water is a convenient choice [Cadecott et al, 1975]. To understand the shape and size of the tank, the profile of electric field, and so on, the hemispherical electrode should be considered first, at the surface of a semi-infinite earth and of the radius r_1(Fig. 1).

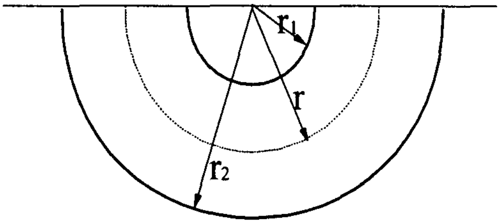


Fig. 1. Equipotential lines around hemispherical electrode in a semi-infinite earth

If voltage is applied to this hemisphere with respect to infinity, all the equipotentials will be hemispheres. A second hemisphere introduced at radius r_2 will not change the equipotentials. The resistance between the two hemispheres can be shown to be

$$R_{12} = \frac{\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \tag{1}$$

where ρ is the resistance of the medium. Similarly, by letting r_2 go to infinity and replacing r_1 with r_2 it can be shown that

$$R_2 = \frac{\rho}{2\pi r_2} \tag{2}$$

where R_2 represents the portion of the resistance external to r_2, which is between that point and infinity. If the replacement of r_1 with r_2 is not performed, for example, Eq. 2 is expressed by r_1.

If a voltage V_{12} is applied between the two hemispheres, a current I_{12} will flow where

$$I_{12} = \frac{V_{12}}{R_{12}} = \frac{2\pi V_{12}}{\rho}\frac{r_1 r_2}{r_2 - r_1} \tag{3}$$

If the voltage at some other point, for example at radius r, is measured with respect to the outer hemisphere, the potential of this point with respect to infinity(Vr_2) may be obtained by simply adding the voltage(V_m)

$$Vr = Vr_2 + V_m = \frac{I\rho}{2\pi r_2} + V_m \tag{4}$$

where r_1 is the grounding electrode to be simulated and r_2 is a water tank that does not distort the field inside it. The ideal model, in which a full scale grounding electrode is reduced from infinity to a finite space, is a shape that has a equipotential line for making the identical potential value by a fault current[4-6]. The shape meeting the above requirements is a hemisphere at a finite distance that is separated from the grounding electrode.

2.2 Configuration of the Grounding Simulation System

The grounding simulation system was composed of a hemispherical water tank, an AC power supply, a movable potentiometer, and test grounding electrodes. Fig. 2 shows the measuring circuit of the grounding simulation system. As shown in Fig. 2, an isolating transformer was used to consider the separation of the fault current and the safety of measurement. The measuring circuit included an auto-transformer for varying fault currents. The variable resistance, which depends on the resistance of water, is 7.64[Ω], as in Fig. 2. The voltmeter (Vs) indicates an applied voltage while another voltmeter (V) measures the voltage between a test grounding electrode and the tank. An ammeter (A) measures the current between the test grounding electrode and the tank. The ground resistance of the grounding electrode, which is buried in a semi-infinite earth, is obtained by the ratio of V/I. A probe measures the surface potential or inner potential of the water, and is moved by a conveyer. The potential rise is measured by a movable probe and a movable potentiometer outputs a relative position with respect to the central point of the grounding electrode[7].

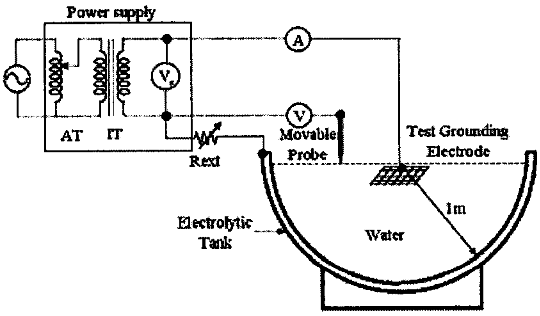


Fig. 2. Measuring circuit of the grounding simulation system

Fig. 3 shows the schematic diagram of the hemispherical water tank. The hemispherical water tank was made of stainless steel with a diameter of 2[m]. The tank was filled with water for the test. After the test, the water drained through a hole using the overflow and the valve.

A movable potentiometer was used to measure the position and voltage. The variable velocity range of the motor is from 0[m/s] to 0.01[m/s], while the position and the voltage were measured by moving a probe at the potentiometer. A conveyer can be moved horizontally across the diameter distance. The probe was made of copper and its diameter was 5.1[mm]. The probe was completely fixed by a support so that it would not be shaken or tilted. Noise was eliminated by the grounding of the case, the complete fix of the probe, and the shielding of the signal wire.

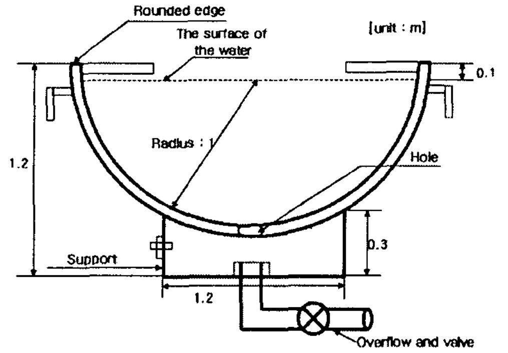


Fig. 3. Schematic diagram of hemispherical water tank

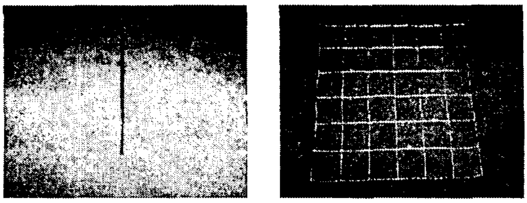
2.3 Test Grounding Electrodes

As a reference for grounding electrodes at real construction sites, test grounding electrodes were fabricated. Table 1 shows the full scale grounding electrodes and those fabricated on a scale of one-eightieth.

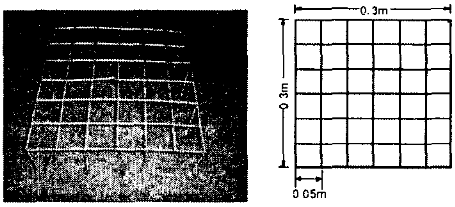
Table 1. A full scale model and a reduced scale model of one-eightieth

Model Contents	Full scale model	Reduced scale model
Buried depth	0.75[m]	9.5[mm]
Size of grounding grid	24×24[m]	0.3×0.3[m]
Length of ground rod	8[m]	0.1[m]
Diameter	0.01[m]	1[mm]

Water(42[Ω · m] was used to simulate the earth. The test grounding electrodes were made of stainless steel 1mm in diameter. The test grounding electrodes were fabricated for the shapes of the ground rod, the grounding grid, and a combination. Fig. 4 shows an example of the test grounding electrode such as the ground rod, grounding grid, and combined types.



(a) Ground rod (b) Grounding grid



(c) Combined type

Fig. 4. An example of a test grounding electrode

3. Results and Discussion

3.1 Potential Rise of Ground Rod

The potential rise of the ground surface in and around the grounding electrode is influenced by the shape of the grounding electrode, the ground structure, the characteristics of the soil, the homogeneity of the soil, the magnitude and continuous time of the earth leakage current and so on. Also, if the potential of the grounding electrode rises, it will have an effect on the common grounding installations as well as on the hazards of electrical shock. It will also result in a dielectric breakdown, malfunctions, and damage to the equipment[8-9]. Hence, this study researched the potential rise that was the most important factor for the safety of installation and for human safety. Test grounding electrodes were fabricated for the shapes of the ground rod, the grounding grid, and a combined type.

In the case of the ground rod, after the electrode was installed under the water surface in the tank and the test current was passed through the central part of the electrode, the potential rise was measured in real time. The test current was 1[A] and constant. The same current was applied to other grounding electrodes, as well. The test voltage varied according to the ground resistance of the test grounding electrode. Fig. 5 shcws the profile of the potential rise for the ground rod. The potential rise was displayed in a two-dimensional profile according to distance. The applied voltage was 223[V]. The maximum value occurred at the central point(1[m]) and was 103[V] per 1[A]. As shown in Fig. 5, the potential gradient was sharp and was displayed with a symmetrical profile at 1[m].

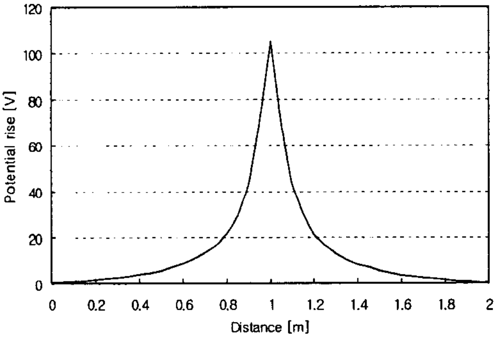


Fig. 5. Profile of the potential rise for a ground rod

3.2 The Potential Rise of the Grounding Grid

A grounding grid is basically made of round steel rods that form two-dimensional(2-D) grids (normally square or rectangular in shape) buried 0.75[m] deep in the soil. Each grid comprises a number of meshes. The ground resistance of the ground fault current determines what hazardous voltages can be found inside or around the electrical power system. It is therefore an important technical parameter linked to the safety of both people and equipment. If a ground fault occurs in an electrical power system where the ground resistance is too high, personnel may be killed or injured and equipment may be damaged.

Grounding grids are, without doubt, the most important part of an electrical system from the point of view of the safety. The safety, reliability, and correct operation of electrical power systems depend on the standard of design and construction of their grounding grids.

The grounding grid is used to ensure equipotential and to obtain a small ground resistance value in power installations and large buildings. Recently, the grounding grid has been used in most substations. Fig. 6 shows the profile of the potential rise for a grounding grid.

The applied voltage was 43[V]. As shown in Fig. 6, the potential gradient was displayed with a symmetrical profile at the center of the grounding grid. The maximum value occurred at the central point(1[m]) and was 39.1[V] per 1[A]. The potential gradient was nearly regular from 0.85[m] to 1.15[m] and the grounding electrode was installed at that distance. This proves that the equipotential is formed in the vicinity of the grounding grid. As the distance between the mesh conductors narrows, the touch voltage and step voltage become lower.

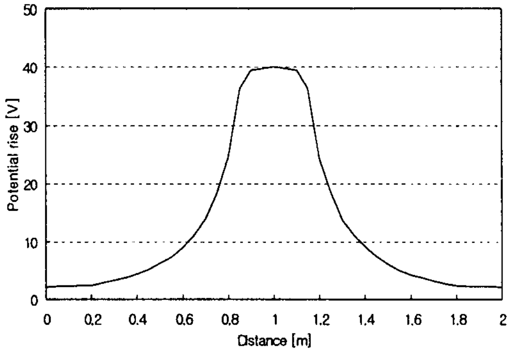


Fig. 6. Profile of the potential rise for a grounding grid

3.3 The Potential Rise of the Combined Type

A shape that combines a grounding grid with a ground rod is used to a great extent in large buildings. A combined type was fabricated for this study. Fig. 7 shows the profile of the potential rise for a combined type. The applied voltage was 42[V] and the maximum value was 37.9[V] per 1[A]. The combined type shows the lowest potential rise, and can be extremely suitable for protection from electric shock as well as the stabilization of the installation.

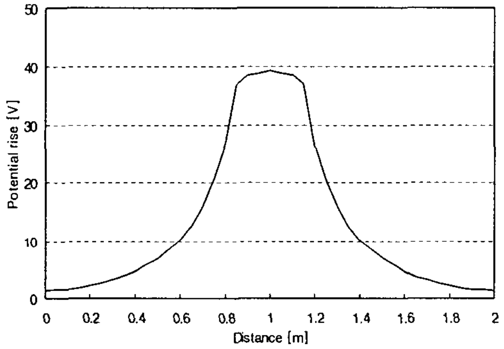


Fig. 7. Profile of the potential rise for a combined type

Fig. 8 shows the comparative profiles of potential rise for the three shapes. As shown in Fig. 8, the potential gradient was extremely sharp for the ground rod. In the case of the grounding grid and the combined type, the equipotential was formed mostly in the vicinity of the grounding electrodes. As shown in Fig. 8, a difference in profiles existed only between the grounding grid and the combined type, but the combined type was smoother than the grounding grid at the potential gradient between 35[V] and 40[V]. Hence, the combined type could be more profitable than the grounding grid for protection from electric shock and the stabilization of the installation.

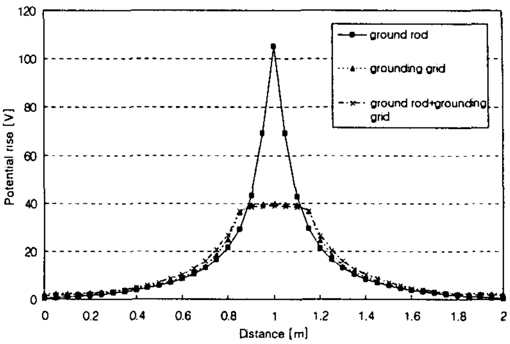


Fig. 8. Profile of the potential rise for 3 grounding electrodes

The ground resistance of the grounding grid is lower when the grid is made of mesh and ground rods, particularly if the mesh are buried in highly resistant soil and a significant proportion of the length of the ground rods is in contact with low resistant soil[10].

The main tasks of the grounding grid are:

- to protect against electrical risks by limiting the overvoltages to which personnel may be exposed if ground faults occur in electrical installations;
- to ensure the safety and continuity of electrical equipment by limiting the overvoltages that can appear under extreme operation conditions or during accidents.

4. Conclusion

This paper deals with the profiles of the potential rise for three grounding electrodes. The results are summarized as follows:

(1) In the case of the ground rod, the potential gradient was sharp and was displayed in a symmetrical profile at 1[m], When the potential rise of the grounding grid and the combined type were measured, the equipotential was formed most nearly in the vicinity of the grounding electrodes.

(2) The potential rise of the ground rod abruptly

decreased, but the potential rises of the grounding grid and combined type gradually decreased with an increasing distance from the grounding electrode to the point to be tested.

(3) The combined type showed the lowest potential rise, and could be extremely suitable as protection from electric shock as well as for the stabilization of the installation.

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Biography

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