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Study of Touch and Step Voltages with Grounding Grid Using Electrolytic Tank and Analysis Program

Hyoung-Jun Gil*, Hyang-Kon Kim and Gyung-Suk Kil[1]

Electrical Safety Research Institute, a subsidiary of Korea Electrical Safety Corporation, Gyeonggi-do 477-814, Korea
[1]Department of Electrical Engineering, National Korea Maritime University, Pusan 606-791, Korea

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Abstract : In order to analyze the potential rise of ground surface of grounding grid installed in buildings, the grounding simulator has been designed and fabricated as substantial and economical measures. This paper describes the study of touch and step voltages with grounding grid where earth leakage current is injected. To assess risk voltage of grounding grid, the grounding simulator and CDEGS program were used to obtain measured data and theoretical results of this study. The grounding simulator was composed of an electrolytic tank, AC power supply, a movable potentiometer, and test grounding electrodes. The potential rise was measured by grounding simulator, and the touch and step voltages were computed by CDEGS program. As a consequence, the touch voltage and step voltage above the grounding grid were very low, but were significantly increased near the edge of grounding grid.

Key words: potential rise, touch and step voltages, grounding grid, electrolytic tank, analysis program

1. Introduction

To verify the efficiency of grounding systems the measurements of touch and step voltage and of ground resistance has been proposed. When there are produced transient overvoltage, the ground fault, bad insulation in power installation, grounding system has played an important role in protection of electric shock as well as stabilization of installation. Therefore, it is desired that a performance of grounding system should be evaluated by a touch voltage, a step voltage, should not be only ground resistance according to classification of grounding in Korea, and the research about this field is lively going on. The analytical techniques used have varied from those using simple hand calculations to those involving scale models to sophisticated digital computer programs. The technique of using scale models in an electrolytic tank determines the surface potential distribution during ground faults [1-3].

Therefore, this paper researched potential rise which was the most important factor for protection of electric shock by overvoltage of ground fault in power installation. The grounding simulator has been designed and fabricated as substantial and economical measures.

Computer program "CDEGS(Current Distribution, Electromagnetic Interference, Grounding and Soil Structure)" was also used to obtain the theoretical results of this study. Touch and step voltages for potential rise can be calculated by CDEGS program.

Scale model tests are generally employed to determine ground resistances and potential gradients in the case of complex grounding arrangements and it can be used to analyze a real grounding system.

2. Experimental Apparatus and Method

2.1 Principles of an electrolytic tank modeling

When all the physical dimensions of a grounding system are reduced in size by the same scale factor - this includes 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 a model may be used to determine the corresponding potentials on a full scale grounding electrode. A solid medium is inconvenient both from the measurement standpoint and when delicate model must be frequently removed for modification and replaced. The

*Corresponding author: fa523@paran.com

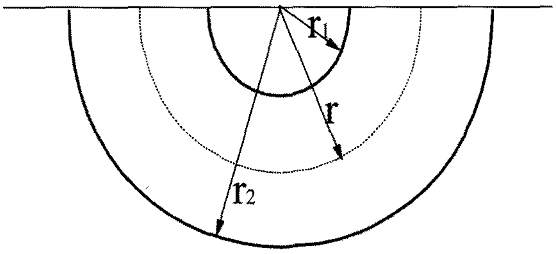


Fig. 1. Equipotential lines around hemispherical electrode in the semi-infinite earth.

electrolyte presents no particular problem for the homogeneous case; water is a convenient choice. To understand shape and size of a tank, profile of electric field and so on, consider first a hemispherical electrode, at the surface of a semi-infinite earth and of radius r_1 (Fig. 1).

If a 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 resistivity 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, that is between there and infinity. If the replacement of r_1 with r_2 is not done, i.e. 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

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

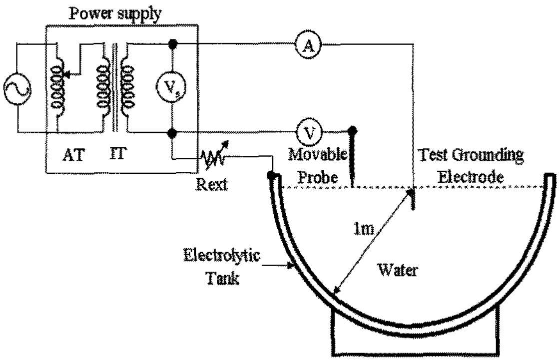
If the voltage at some other point, for example at radius r, is measured with respect to the outer hemisphere, the potential of this point with respect to infinity(Vr_2) may be obtained by simple adding a voltage(V_m)

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

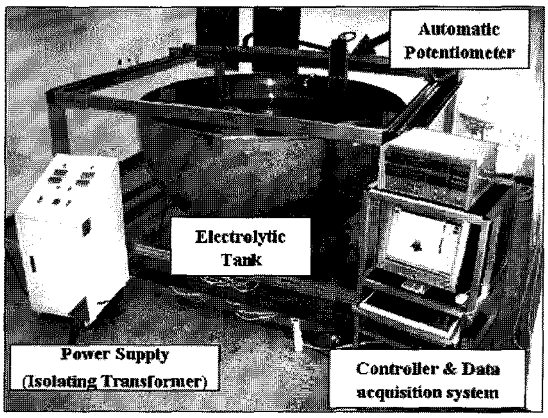
where r_1 is a grounding electrode to simulate and r_2 is a water tank without distorting the field inside it. The ideal model, which a full scale grounding electrode is reduced from infinity to finite space, is a shape to have equipotential line for making identical potential value by a fault current. A shape which is satisfied with a such condition is a hemisphere formed at finite distance that is separated from a full scale grounding electrode such as a rod type electrode, a mesh grid grounding electrode, a linear type electrode, a grounding plate and so on [4].

2.2 Constitution of simulator and experimental method

The grounding simulator was composed of an electrolytic tank, AC power supply, automatic potentiometer, controller and data acquisition system. Fig. 2 shows the measuring circuit and photograph of grounding simulator. An electrolytic tank was made of stainless and diameter of tank was 2 m. The tank was filled with water for test. After test, the water drained through a hole using the overflow and valve.



(a) Measuring circuit



(b) Photograph

Fig. 2. Measuring circuit and photograph of grounding simulator.

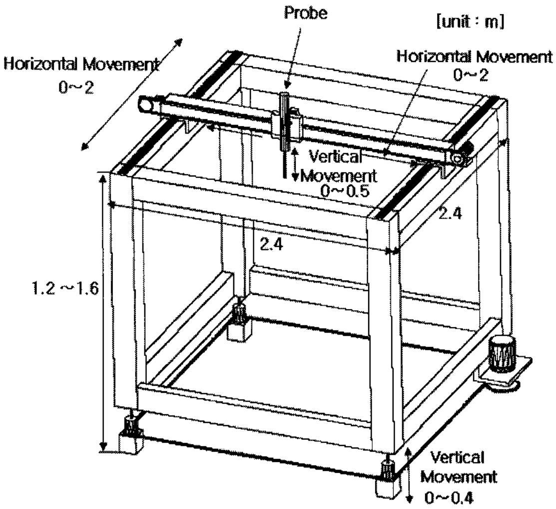


Fig. 3. Schematic diagram of automatic potentiometer.

As shown in Fig. 2(a), the power supply produces an earth leakage current. An isolation transformer was used for separation of fault current, safety of measurement, protection of circuit damage caused by noise, surge and transient phenomena. A molded case circuit breaker and an earth leakage circuit breaker were installed in order to prevent electrical shock and protect a circuit in the power supply.

The measuring circuit included an auto-transformer for varying fault current. A voltmeter(V_S) indicates an applied voltage and a voltmeter(V) measures the voltage between a test grounding electrode and a tank. An ammeter(A) measures the current between the test grounding electrode and the tank. Fig. 3 shows a schematic diagram of an automatic potentiometer. The position and the voltage are measured by moving a probe at the potentiometer. A probe was made of copper and its diameter was 5.1 mm. The probe was completely fixed by supporter so that it wasn't shaken and tilted. The automatic potentiometer has function of position tracer. The measuring position is set up by controller.

As referred for grounding electrodes at real electrical installation, we fabricated the test grounding electrodes. Table 1 shows the full scale grounding electrodes and those fabricated on a scale of one-eightieth. Water of 40 Ω·m was used to simulate earth. The test grounding electrodes were made of stainless because its material was strong in corrosion by water.

The test grounding electrodes were fabricated for shapes of grounding grid as shown in Fig. 4. The test grounding electrodes are installed under the surface of the water of a tank. We set up about 9.5 mm in buried depth because the grounding electrode is buried under

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

Contents \ Model	Full scale model	Reduced scale model
Buried depth	0.75 m	9.5 mm
Size of grounding grid	24 m×24 m	0.3 m×0.3 m
Diameter of grounding grid	0.01 m	1 mm

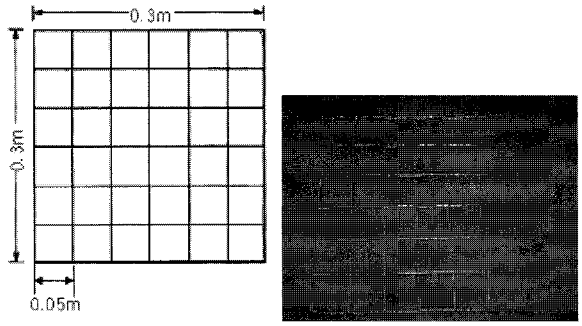


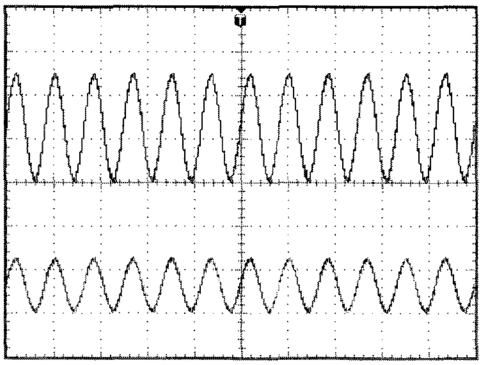
Fig. 4. Test grounding electrodes.

0.75 m from ground surface in accordance with Korea Technical Standards.

3. Results and Discussion

A potential distribution of ground surface, which is formed by ground fault, generally is displayed with value of ground surface. A potential rise of ground surface in and around a grounding electrode is influenced by a shape of grounding electrode, ground structure, the characteristics of soil, homogeneity of soil, magnitude and continuous time of the earth leakage current and so on. This paper researched GPR(Ground Potential Rise) which was the most important factor for safety of installation and human body. The test grounding electrodes were fabricated for shapes of grounding grid, and the potential gradient was measured and analyzed about grounding grid.

The test current is 1 A and constant. The same current is applied to other grounding electrodes, too. The test voltage is variable according to ground resistance of test grounding electrode. The sinusoidal waveforms are sampled and showed in Fig. 5. The waveforms of the applied voltage and GPR are recorded by the digital storage 500 MHz, 5 GS/s sampling rate oscilloscope. The upper part shows an applied voltage and the lower part shows GPR. The measured value is a RMS(root-mean-square) value. As shown in Fig. 5, the noise was eliminated by grounding of case, complete fix of probe,



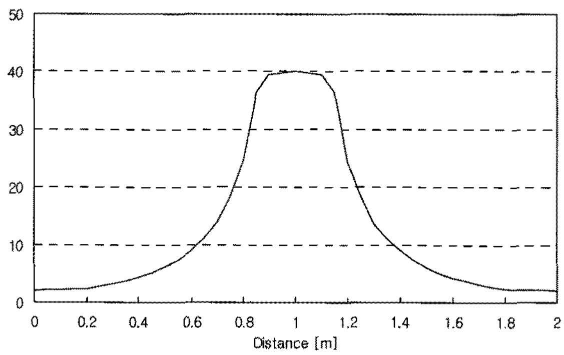
The upper part : applied voltage, 35[V/div], 20[ms/div]
The lower part : ground potential rise, 15[V/div], 20[ms/div]

Fig. 5. The waveforms of applied voltage and ground potential rise.

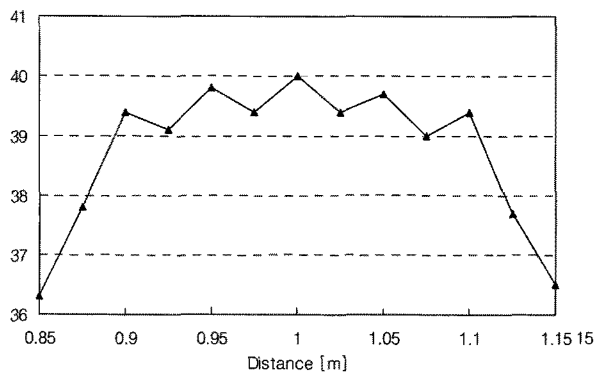
shielding of signal wire.

Fig. 6 shows the profile of ground potential for grounding grid. Fig. 6(a) shows the general view and Fig. 6(b) shows the enlarged view between 0.85 m and 1.15 m. An applied voltage is 43.2 V. As shown in Fig. 6, the potential gradient was displayed with a symmetrical profile at the center of grounding grid. The maximum value occurred at central point(1 m) and was 40 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 the distance. This proves that the equipotential is formed in the vicinity of grounding grid.

When a fault current flows in a grounding electrode by ground fault or lightning, the ground surface potential rises in and around a grounding electrode. The hazard of electrical shock is generally evaluated by a touch voltage, a step voltage during GPR. A touch voltage is a potential difference between facility and ground surface when a

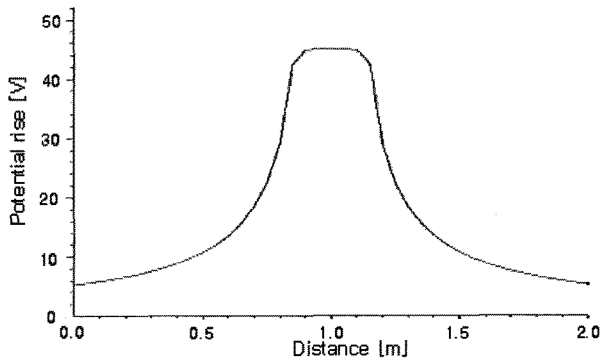


(a) General view

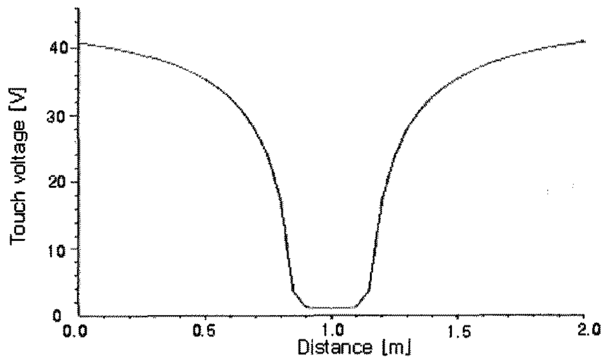


(b) Enlarged view

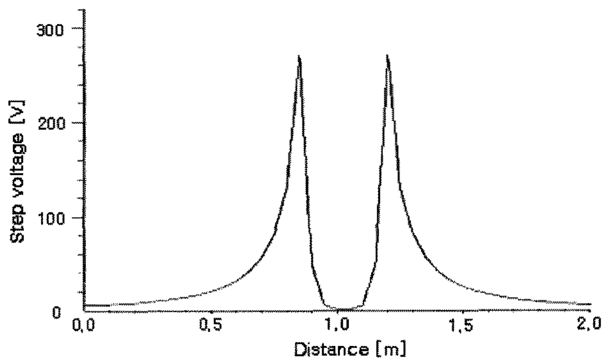
Fig. 6. Profile of ground potential rise for grounding grid.



(a) Ground potential rise



(b) Touch voltage



(c) Step voltage

Fig. 7. The analytical result through program on grounding grid.

human body is touched with the grounded facilities, and a step voltage is a potential difference between the two feet when the potential difference is produced by the test current in the vicinity of a grounding electrode. As a distance between mesh electrodes is narrow, a touch voltage and a step voltage grow lower. In result, the electrical shock accidents can be decreased [5-8].

Fig. 7 shows the analytical results on the mesh grid type by the analysis program(CDEGS : Current Distribution, Electromagnetic Interference, Grounding and Soil Structure, Canada). Those results are ground potential rise, touch voltage, step voltage.

When GPR was compared the measuring value of reduced scale model with the computing value of program, a similar profile was showed as Fig. 6(a) and Fig. 7(a). Some difference between the measuring value and the computing value was produced by influence of metallic things in and around the system, effect of supporting thing. Therefore, measuring and computing values have pretty confidence through Fig. 6(a) and 7(a). When GPR was compared with the touch voltage, the touch voltage showed the contrary distribution against GPR. In the case of the step voltage, the maximum value appeared at the boundaries of grounding grid, and the minimum value appeared in the vicinity of its center.

Because touch and step voltages are decreased by equipotential of grounding grid, the electrical shock accidents can be prevented.

4. Conclusion

This paper deals with a study of touch and step voltages with grounding grid using the electrolytic tank and the analysis program. The results are summarized as follows :

(1) In order to analyze the potential rise of grounding grid, the grounding simulator having function of position tracer is presented. Once both the shape of grounding electrode and ground fault current are known, the actual potential rise can be measured using automatic potentiometer having control program.

(2) The potential rise of grounding grid was displayed with a symmetrical profile at 1 m, and when we measured GPR of grounding grid, the equipotential was nearly formed in the vicinity of grounding grid. The touch voltage and step voltage above the grounding grid were very low, but were significantly increased near the edge of grounding grid.

(3) The risk factors such as ground potential rise, touch voltage, step voltage, were analyzed by analysis program. Through a comparison of the measuring value and the computing value, the confidence of measurement was obtained.

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