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Analysis of Risk Voltage for Grounding Electrode by Injection of Earth Leakage Current

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Abstract : This paper describes analysis of risk voltage for grounding electrode where earth leakage current is injected. To assess risk voltage of grounding electrode, the grounding simulator and CDEGS program were used to obtain measured data and theoretical results of this study. The grounding simulator was composed of a hemispherical water tank, AC power supply, a movable potentiometer, and test grounding electrodes. The shapes of grounding electrode model was ground rod. The potential rise was measured by grounding simulator, and the touch and step voltages were computed by CDEGS program. As a consequence, the potential rise of ground rod abruptly decreases with increasing the distance from the grounding electrode to the point to be tested. The touch voltage above the ground rod was low, but the step voltage was high. The measured results were compared with the computer calculated data and were known in good agreement.

Key words: risk voltage, grounding electronic, earth leakage current, grounding simulator

1. Introduction

There has been a strong interest in recent years regarding grounding system due to increasing use of electronic equipment in the power systems. In the light of increasing public sensitivity with regard to electrical risks for people, increases in the power available in electrical power systems and more stringent technical demands in electrical protection systems, an suitable study of grounding needs to be carried out.

When there are produced transient overvoltage, the ground fault, bad insulation in power installation, grounding installation 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. Grounding is important in prevention of electric shock as well as protection of installation from overvoltage of ground fault and lightning, 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[1-5].

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.

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2. Experimental Apparatus and method

2.1 Principles of an electrolytic tank modeling

The grounding simulator is apparatus to have a free reduced scale for conductor size and buried depth of a real scale grounding system. The simulator was constructed so that a shape of equipotential surface is nearly identified a free reduced scale model with a real scale model when current flows through grounding electrode.

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 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

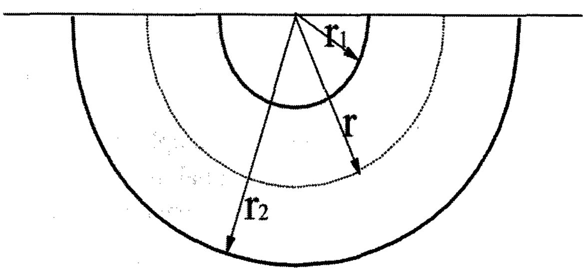


Fig. 1. Equipotential lines around hemispherical electrode in the semi-infinite earth.

$$R_2 = \frac{\rho}{2\pi_2} \tag{2}$$

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)

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

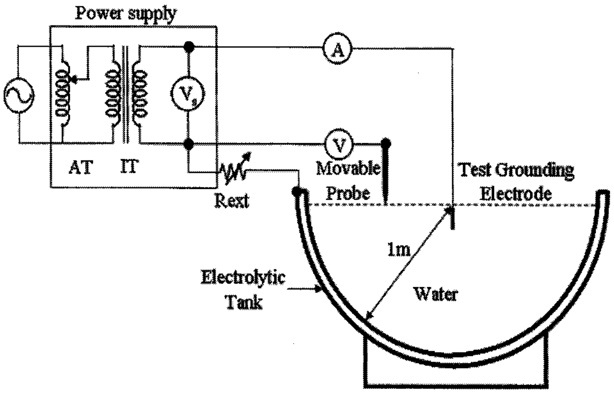
where r_1 is a grounding electrode to simulate and r_2 is a water tank without distorting the field inside it. The ideal model, which a full scale grounding electrode is reduced from infinity to finite space, is a shape to have equipotential line for making identical potential value by a fault current. 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 [6].

2.2 Constitution of simulator and experimental method

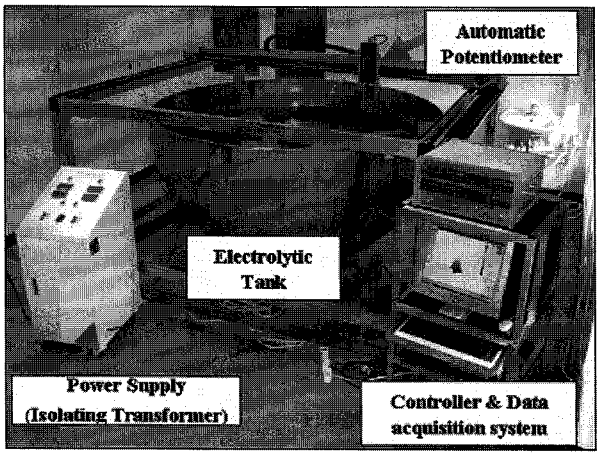
The grounding simulator was composed of an electrolytic tank, AC power supply, automatic potentio meter, controller and data acquisition system. Fig. 2 shows the measuring circuit and photograph of grounding simulator. An electrolytic tank was made of stainless and diameter of tank was 2 m. The tank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

WAs 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



(a) Measuring circuit



(b) Photograph

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

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. A probe measures surface potential or inner potential of water, and is moved by conveyer. Potential rise is measured by a movable probe and an automatic potentiometer outputs a relative position with respect to central point of grounding electrode.

Fig. 3 shows a schematic diagram of an automatic potentiometer. The variable velocity range of motor is from 0 m/s to 0.01 m/s, and 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.

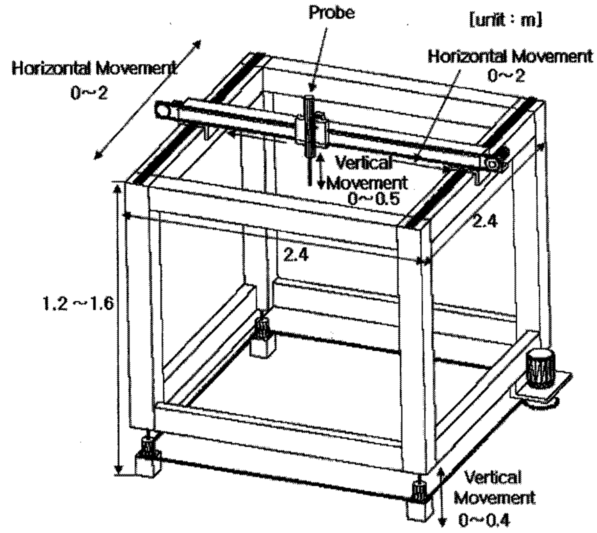


Fig. 3. Schematic diagram of automatic potentiometer.

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
Length of ground rod	8 m	0.1 m
Diameter of ground rod	0.0127 m	1 mm

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. Those diameter is 1 mm. A thickness of grounding electrode was not applied to a scale of one-eightieth because it was difficult to fabricate the test grounding electrodes by considering the thickness.

The test grounding electrodes were fabricated for shapes of ground rod. Fig. 4 shows test grounding electrodes such as ground rod. 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

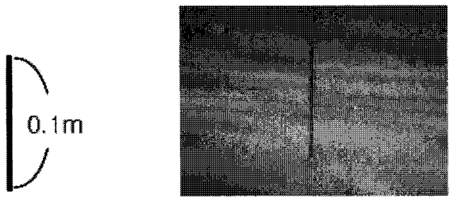


Fig. 4. Test grounding electrodes.

the grounding electrode is buried under 0.75 m from ground surface in accordance with Korea Technical Standards. After a test current has flowed through a central part of test grounding electrode, potential rise has been measured in real time according as a probe has been moved across the diameter distance horizontally.

3. Results and Discussion

If a fault current flows in a grounding electrode by occurrence of ground fault such as lightning, dielectric breakdown, the ground surface potential will rise in and around a grounding electrode. 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 [7-11].

Also, if the potential of grounding electrode rises, it will have an effect on common grounding installations as well as the hazard of electric shock, and it will result in the dielectric breakdown, the malfunction and damage of equipment. Hence, this paper researched potential rise which was the most important factor for safety of installation and human body. The test grounding electrodes were fabricated for shapes of ground rod, grounding grid, and the potential distribution was measured and analyzed about each electrode.

In case of ground rod, after the electrode has been installed under the surface of the water of a tank and earth leakage current has flowed through a central part of the electrode, potential rise has been measured at controller & data acquisition system in real time. The

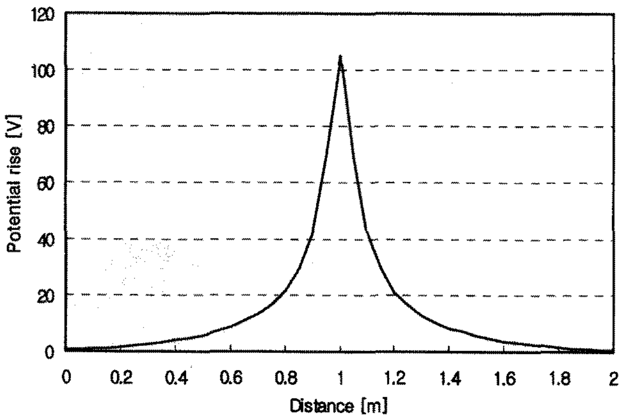


Fig. 5. Profile of surface potential rise for a ground rod.

Table 2. Comparison of experimental maximum value and calculated maximum value of a ground rod

Comparative item	Maximum value(V)
Experimental value	105
Calculated value	108

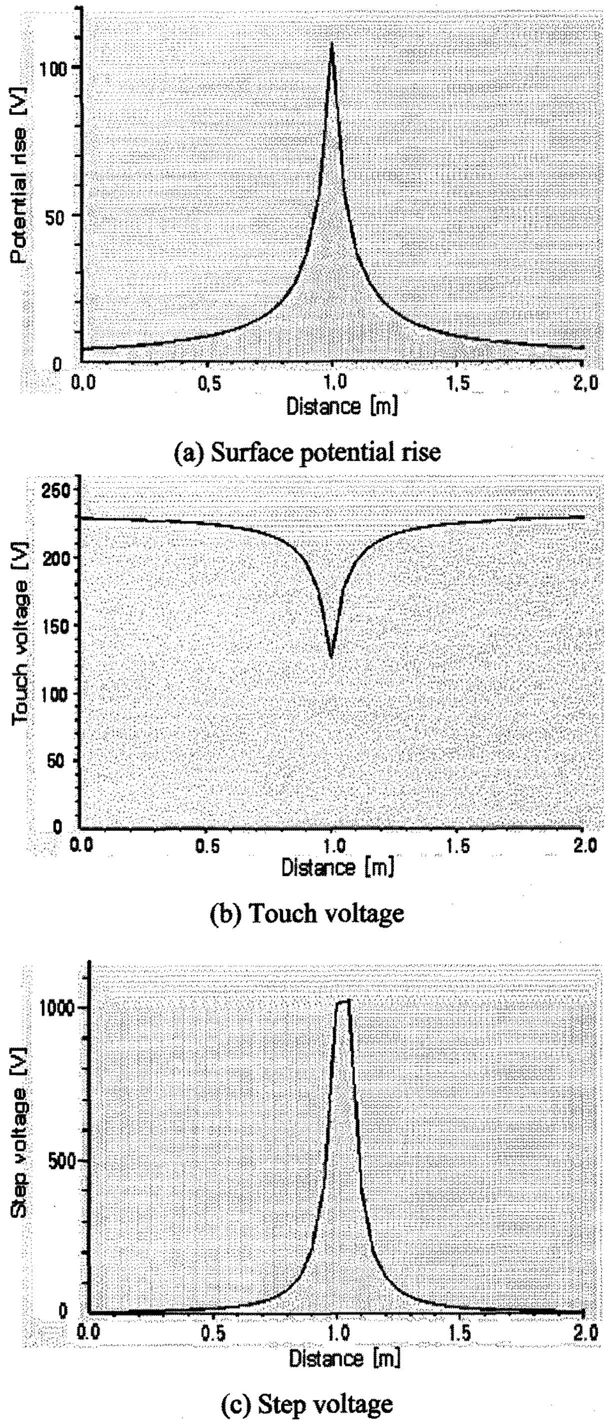


Fig. 6. Results analyzed by using the grounding design program for the ground rod.

earth leakage current is 1[A] and the same current is applied to other grounding electrodes, too. The measured value is a RMS(root-mean-square) value.

Fig. 5 shows the profile of surface potential rise for a ground rod. The surface potential rise was displayed in two-dimensional profile according to a distance. An applied voltage was 222 V. The maximum value occurred at central point(1 m) and was 105 V. As shown in Fig. 5, the potential gradient was sharp and was displayed with a symmetrical profile at 1 m.

Fig. 6 shows the results analyzed by using the grounding design program(CDEGS : Current Distribution, Electromagnetic Interference, Grounding and Soil Structure) for the ground rod. Those results are surface potential rise, touch voltage, step voltage.

When the potential rise was compared the experimental value of electrolytic tank modeling with the calculated value of program, a similar profile was showed as Fig. 5 and Fig. 6(a) [12]. Table 2 shows the comparison of experimental maximum value and calculated maximum value of a ground rod. The relative error can be defined as $|M-T|/T\times100$, where T is the calculated value by program, and M is the experimental value by grounding simulator. The relative error was 2.7%.

Some difference between the experimental value and the calculated value was produced by influence of metallic things in and around the system, effect of supporting thing. The error of potential rise at the lower part of profile occurred because grounding simulator assumed 1 m distance from the center of water tank to 0 potential, while CDEGS program assumed infinite earth to reference potential.

Therefore, experimental and calculated values have pretty confidence through Fig. 5 and 6(a). When the potential rise was compared with the touch voltage, the touch voltage showed the contrary distribution against the potential rise. As the distance from earth leakage point increases, touch voltage increases and is nearly settled, and step voltage decreases.

4. Conclusion

This paper deals with the characteristics of potential rise of grounding electrodes using the grounding simulator and the grounding design program. The results are summarized as follows :

(1) In order to measure the potential rise of grounding electrode, 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 distribution can be measured using the analytical program based on WINDOWS.

(2) In case of a ground rod, the potential gradient was sharp and was displayed with a symmetrical profile at 1 m. The potential rise of ground rod abruptly decreases with increasing the distance from the grounding electrode to the point to be tested.

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

(4) The analytical program based on WINDOWS is being developed. Development of measuring system will be carried out so that reliability of measurement can be improved.

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References

[1] Hyoung-Jun Gil, Chung-Seog Choi, Hyang-Kon Kim, Bok-Hee Lee, "Characteristics of Potential Gradient for the Type of Structure Grounding Electrode", Vol.54C, No.8, pp.371-377, 2005.

[2] Hyoung-Jun Gil, Chung-Seog Choi, Hyang-Kon Kim, "Distribution of Potential Rise as a Function of Shape of Grounding Electrodes", The Korean Institute of Illuminating and Electrical Installation Engineers, Vol.21, No.4, pp.73-79, 2007.

[3] Hyoung-Jun Gil, Dong-Ook Kim, Chung-Seog Choi, "Research on Assessment of Potential Interference between Individual Grounding Electrodes Using an Electrolytic Tank Modeling Method", The Korean Institute of Illuminating and Electrical Installation Engineers, Vol.22, No.3, pp.27-33, 2008.

[4] Hyoung-Jun Gil, Dong-Woo Kim, Dong-Ook Kim, Ki-Yeon Lee, Hyang-Kon Kim, Hyun-Wook Moon, "Effects of Auxiliary Probe on Low Frequency Ground Impedance Measurement", The Autumn Conference on KIIEE, pp.367-370, 2008.

[5] R. Zeng, J. He and Z. Guan, "Novel Measurement System for Grounding Impedance of Substation", IEEE Trans. Power Delivery, Vol.21, No.2, pp.719-725, Apr. 2006.

[6] R. Cadecott, D.G. Kasten, "Scale Model Studies of Station Grounding Grids", IEEE Trans. PAS., Vol. PAS-102, No. 3, pp.558-566, 1975.

[7] C. Wang, T. Takasima, T. Sakuta and Y. Tsubota, "Grounding Resistance Measurement Using Fall-of-

Potential Method with Potential Probe Located in Opposite Direction to the Current Probe", IEEE Trans. Power Delivery, Vol.13, No.4, pp.1128-1135, 1998.

[8] K. M. Michaels, "Earth Ground Resistance Testing for Low-Voltage Power Systems", IEEE Trans. Industry Applications, Vol.31, No.1, pp.206-213, 1995.

[9] V. Dimcev, B. Handjiski, P. Vrangalov and R. Sekerinska, "Impedance Measurement of Grounding Systems with Alternative Fall-of-Potential Method", IEEE Industry Applications Conference, Vol.5, pp.3215-3219, 2000.

[10] IEEE Std 81-1983, "IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System", pp.19-23, 1983.

[11] J. Ma and F. P. Dawalibi, "Extended Analysis of Ground Impedance Measurement Using the Fall-of-Potential Method", IEEE Trans. Power Delivery, vol. 17, no. 4, pp. 881-885, 2002.

[12] F. Dawalibi, D. Mukedkar, "Optimum Design of Substation Grounding in a Earth Structure : Part II-Comparison between Theoretical and Experimental results", IEEE Trans. PAS., Vol. PAS-94, No. 2, pp.262-266, 1975.