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Effects of Position of Auxiliary Probe on Ground Resistance Measurement Using Fall-of-Potential Method

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Abstract : In this paper, the effects of the position and the angle of the potential probes on the measurements of the ground resistance using the fall-of-potential method are described and the testing techniques for minimizing the measuring errors are proposed. The fall-of-potential method is theoretically based on the potential and current measuring principle and the measuring error is primarily caused by the position and angle of auxiliary probes. In order to analyze the relative error in the measured value of the ground resistance due to the position of the potential probe, the ground resistance was measured for the case in which the distance of the current probe was fixed at 50[m] and the distance of the potential probe was located from 10[m] to 50[m]. Also, the potential probe was located in turn at 30[°], 45[°], 60[°], 90[°], and 180[°]. As a consequence, relative error decreased with increasing distance of the potential probe and decreasing angle between the current probe and potential probe. The results could help to determine the position of the potential probe during the ground resistance measurement.

Key words: auxiliary probe, ground resistance, position, angle, fall-of-potential method

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 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[1-5].

Traditionally, measurements of ground resistance are based on the fall-of-potential method. This method is widely used for the measurement of grounding resistance[1-3]. Theoretically, the ground resistance Z is equal to V/I, where V is the ground potential rise(GPR) of the grounding system with respect to the remote soil and I the current injected into the grounding system. Note that the injection current I is assumed to return to the current electrode(current probe) at infinity. In practice, however, it is impossible to place a current electrode at infinity when injecting current into the grounding system. Similarly, it is impossible in practice to place a potential electrode(potential probe) at the proper position when measuring the GPR of the grounding system in such cases where buildings, paved lots or underground metallic pipes are located.

In this paper, theoretical background of fall-of-potential method was described and standards regarding locations of auxiliary current probes and potential probes were researched. The potential probe and the current electrode cannot be laid in the same direction when auxiliary probes cannot be installed in proper position by obstacle and induction error between auxiliary probes is intended to decrease. In order to simulate situation of the actual spot the same as the above statements, ground resistances were measured according to the variations of probe angles and the distances of potential probes. After that, the locations of auxiliary potential probes were compared based on relative errors.

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2. Experimental Method

In the fall-of-potential method, the current electrode is placed at a large, but finite, distance from the grounding system and the potential probe is placed at a specific location where an accurate measurement of the ground resistance can be obtained. This way, the problem of the remote electrode is solved. Usually, the potential probe and the current electrode are laid in the same direction. In this case, the exact location of the potential probe is well defined for some ideal cases such as hemispherical or very small electrode buried in soil.

As shown in Fig. 1, the fall-of-potential method involves passing a current into the electrode to be measured and noting the influence of this current in terms of voltage between the electrode under test and an auxiliary potential probe. The current I through the electrode under test E and the auxiliary current probe C, results in earth surface potential variations. Potentials are measured with respect to the electrode under test, E, which is assumed for convenience at zero potential. The potential probe is generally located on the straight line between the electrode under test(E) and the current probe(C). The grounding resistance R is obtained with current I flowing between E and C, and with voltage V between E and P, by $R = V/I$. The proper position of P for true resistance can be obtained at P where distance EP is 61.8[%] of distance EC[6-10].

A current electrode is often placed far away from the ground system to decrease the measurement error, but long wires lead to more interference. Also, in the case of voltage electrode wire being placed in parallel with the current lead wire, the longer the current electrode lead wire is, the higher the inductive voltage between the voltage and current lead wires is. In order to apply 61.8[%] method, the grounding system dimension is much smaller than distance to current probe[11-14].

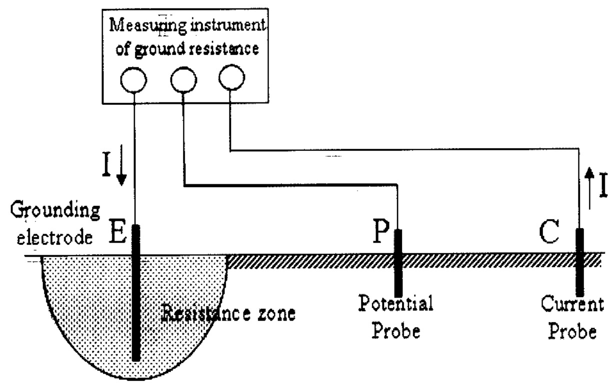

Fig. 1. Fall-of-potential method

3. Results and Discussion

3.1 Experiment area condition I

Fig. 2 shows the soil resistivity using Wenner's four electrode method in experiment area condition I.

The soil resistivity of the top layer is larger than that of bottom layer when distance between electrodes is varied from 1[m] to 30[m]. The horizontal two-layer soils are assumed by soil resistivity measurement.

Fig. 3 shows electrode and auxiliary probe position in case of experiment area condition I. A grounding electrode was buried 1[m] under the ground level, and the length and the cross section of the rod shaped copper electrode was 48[m] and 38[mm^2], respectively. The distance from electrode under test to auxiliary potential probe was varied from 10[m] to 50[m], and the angle between probes was fixed at 90[°].

Table 1 shows ground resistance measurements according to the variations of angle between probes and relative errors of ground resistance. The distance from electrode under test to auxiliary current probe was

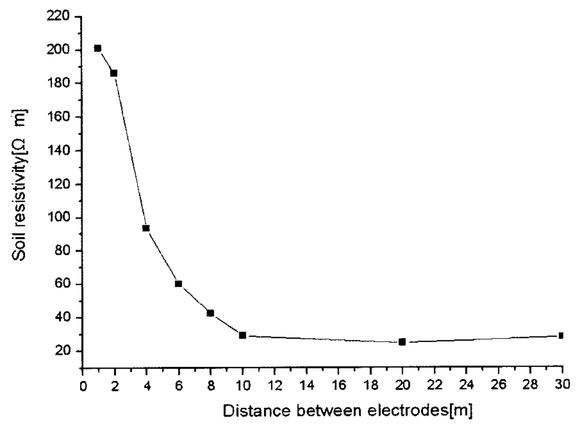

Fig. 2. Soil resistivity of experiment area condition I

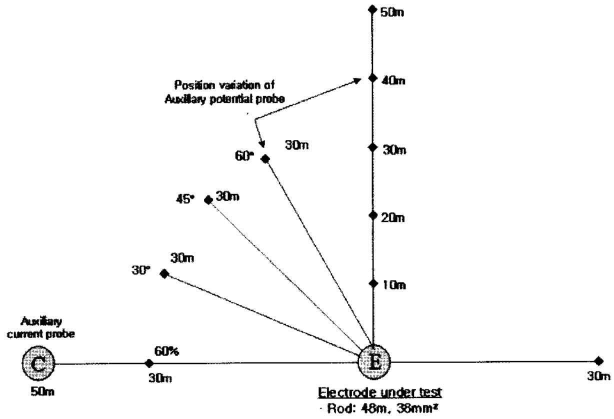

Fig. 3. Auxiliary potential probe position of experiment area condition I

Table 1. Relative errors according to variation of angle between auxiliary electrodes.

Angle [°]	Ground resistance[Ω] (Criterion value : 6.45[Ω])	Relative error[%] (Distance to potential probe : 30[m])
30	6.39	0.93
45	6.30	2.32
60	6.22	3.56
90	6.13	4.96
180	6.05	6.20

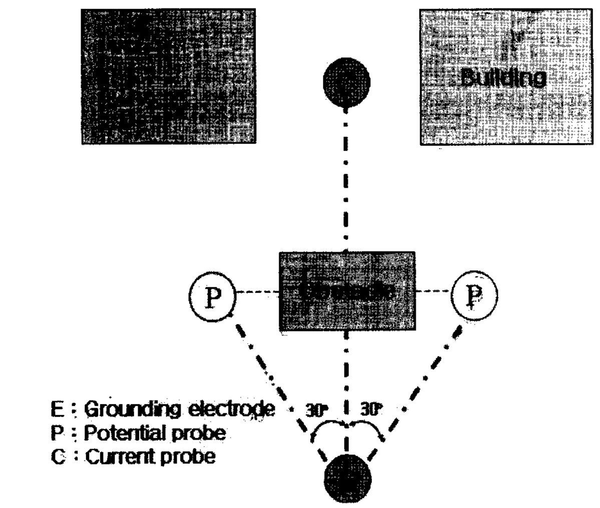

Fig. 4. Allowable separation angle of potential probe

50[m], and angle between auxiliary probes was varied from 0[°] to 180[°]. The relative error can be defined as $|R_1-R_2|/R_1$, where R_1 is the criterion ground resistance measured with 61.8[%] method, and R_2 is ground resistance measured at other positions. As a consequence, the relative error decreased with decreasing the angle between auxiliary probes.

The potential probe and the current electrode cannot be laid in the same direction when potential probe cannot be installed in proper position by obstacle and induction error between auxiliary probes is intended to decrease. It is provided that allowable separation angle of potential probe should be in the range of 30[°] in Telecommunications Technology Association Standards. Fig. 4 shows the allowable separation angle of potential probe[15].

Fig. 5 shows ground resistance measurements according to the variations of distance to potential probe. The distance from electrode under test to auxiliary current probe was 50[m], and angle between auxiliary probes was fixed at 90[°]. Table 2 shows relative errors of ground resistance in case of Fig. 5. The relative error

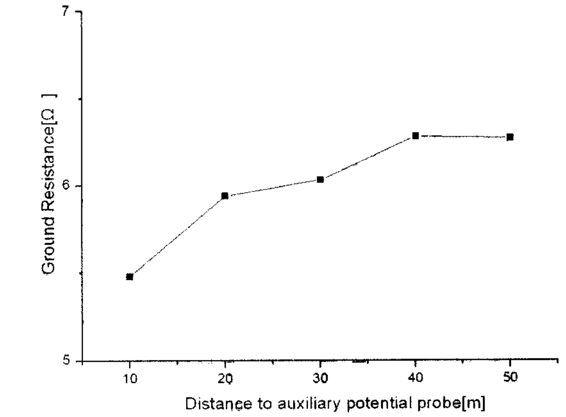

Fig. 5. Ground resistance measurements according to the variation of distance to potential probe

Table 2. Relative errors according to variation of distance to potential probe.

Distance to potential probe[m]	Relative error[%] (Angle between auxiliary probes : 90[°])
10	15.04
20	7.91
30	6.51
40	2.64
50	2.79

decreased with increasing the distance of potential probe.

3.2 Experiment area condition II

Fig. 6 shows the soil resistivity using Wenner's four electrode method in experiment area condition II. The soil resistivity was measured when distance between electrodes is varied from 1[m] to 10[m]. The horizontal three-layer soils are assumed by soil resistivity measurement.

Fig. 7 shows electrode and auxiliary probe position in case of experiment area condition II. Three rod type electrodes and one ring type electrode were buried 0.5[m] under the ground level. The length and the thickness of the rod type electrode was 1.8[m] and 1.6[mm], respectively. The diameter of ring type electrode was 1[m], and the thickness was 22[mm^2]. The distance from electrode under test to auxiliary potential probe was varied from 10[m] to 30[m], in case the angle between auxiliary probes was 90[°]. Also, in case the angle between auxiliary probes was 180[°], the distance from electrode under test to auxiliary potential probe was varied from 10[m] to 50[m]. The electrodes

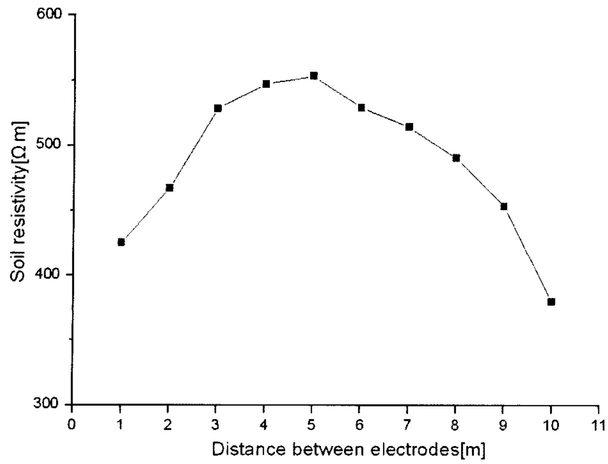

Fig. 6. Soil resistivity of experiment area condition II

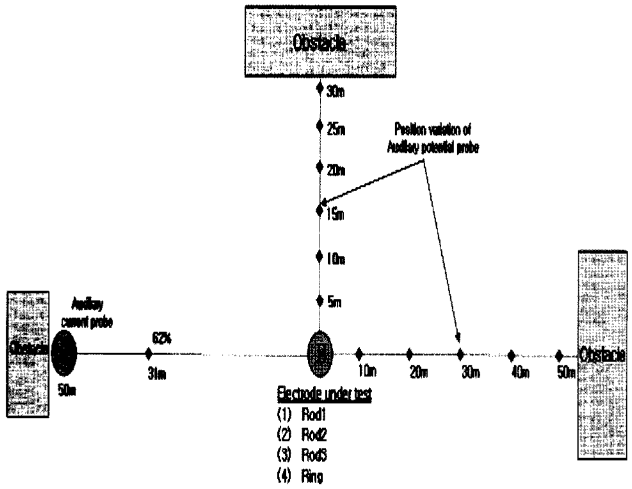

Fig. 7. Auxiliary potential probe position of experiment area condition II

under test were divided into 4 conditions such as one rod, combination of two rods in parallel, combination of three rods in parallel, ring type.

Fig. 8 shows comparison of ground resistance measured with 61.8[%] method. The distance from electrode under test to auxiliary current probe and potential probe was 50[m] and 31[m], respectively. As shown in this figure, ground resistance decreased drastically in case of combination of two rods in parallel and combination of three rods in parallel.

Fig. 9 shows comparison of ground resistance according to the variation of distance to potential probe. Distance to potential probe was limited to 30[m] because the obstacle blocked the path. Angle between auxiliary probes was 90[°]. As shown in Fig. 9, ground resistance rose gradually, as distance to potential probe increased. Table 3 shows relative errors of ground resistance in case of Fig. 9.

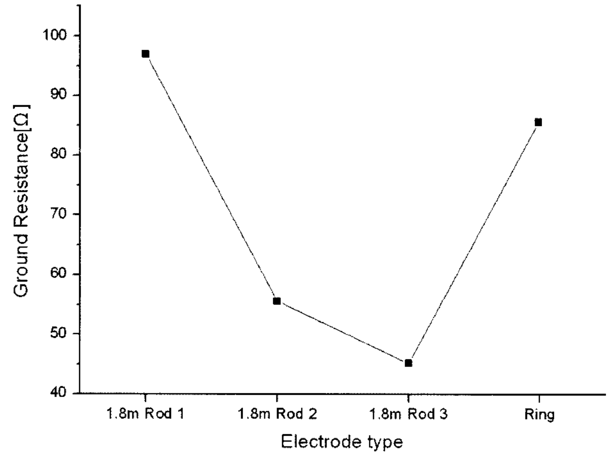

Fig. 8. Comparison of ground resistance measured with 61.8[%] method according to electrode type

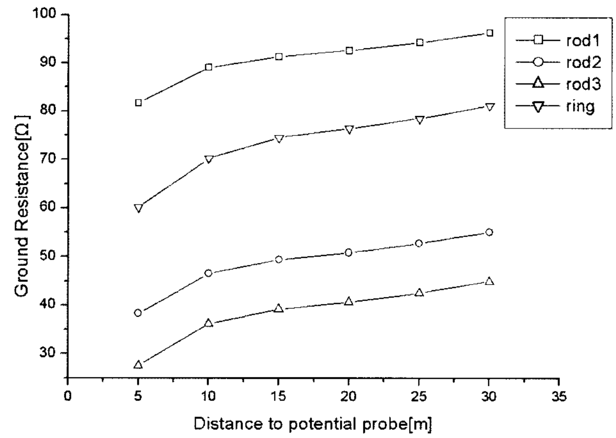

Fig. 9. Comparison of ground resistance according to the variation of distance to potential probe (Angle : 90[°])

Table 3. Relative errors according to variation of distance to potential probe(Angle : 90[°]).

Distance to potential probe[m]	Relative error[%]			
	Rod 1	Rod 2	Rod 3	Ring
5	15.8	31.1	38.9	29.8
10	8.2	16.4	19.9	18.0
15	5.9	11.2	13.3	13.0
20	4.5	8.5	10.0	10.7
25	2.8	5.0	5.8	8.3
30	0.7	0.9	0.7	5.3

Ground resistance was compared in Fig. 10 in a similar way to Fig. 9. Distance to potential probe was limited to 50[m] because the obstacle blocked the path. Angle between auxiliary probes was 180[°]. As shown in Fig. 10, ground resistance went up slowly, as dis-

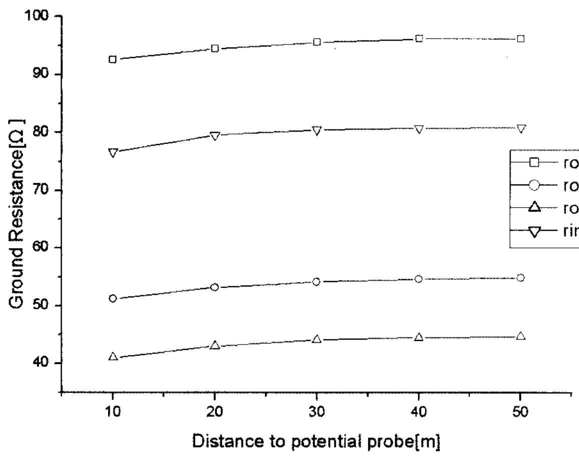

Fig. 10. Comparison of ground resistance according to the variation of distance to potential probe (Angle : 180[°])

Table 4. Relative errors according to variation of distance to potential probe(Angle : 180[°]).

Distance to potential probe[m]	Relative error[%]			
	Rod 1	Rod 2	Rod 3	Ring
10	4.5	7.9	9.3	10.4
20	2.6	4.3	4.9	7.0
30	1.4	2.5	2.4	6.0
40	0.8	1.6	1.5	5.6
50	0.8	1.3	1.1	5.5

tance to potential probe increased. Table 4 shows relative errors of ground resistance in case of Fig. 10. The relative error decreased with increasing the distance of potential probe.

4. Conclusion

This paper describes the effect of the position of the auxiliary probe on ground resistance measurement using the fall-of-potential method. The ground resistances were measured by varying the probe angles and the distances of potential probes. The measured values for the position of the potential probe were compared based on relative errors. The results are summarized as follows.

(1) In the case of experiment area condition I, when distance to current probe was 50[m], angle between probes is 90[°] and potential probe were varied from 10[m] to 50[m], the relative error decreased with increase in the distance of the potential probe. When the distance from the electrode under test to the current probe was at 50[m] and the angle between the auxiliary probes was varied from 0[°] to 180[°], the relative error decreased with decreasing angle between the auxiliary probes.

When the potential probe and the current electrode cannot be laid in the same direction due to the presence of an obstacle, it is required that the allowed separation angle of the potential probe should be in the range of 30[°].

(2) In the case of experiment area condition II, combination of two rods in parallel and combination of tree rods in parallel showed low ground resistance. When distance to the current probe is 50[m], angle between probes is 90[°] and potential probe were varied from 5[m] to 30[m], the relative error of the ground resistance showed the smallest value at the potential probe distance of 30[m]. When the angle between the probes is 180[°] and the potential probe was moved from 10[m] to 50[m], the relative error of the ground resistance showed the smallest value at the potential probe distance of 50[m]. The ground resistance rose gradually with increase in the distance to the potential probe.

In the future, an assessment guide for grounding system will be presented using the above results, and the basic data can be applied to the measurement of the ground resistance at the actual spot.

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