Study on Improvement of Earth Resistance Measurement Method without Auxiliary Electrodes

Yasuhiro Homma, Kazuaki Yano, Shoichi Kuramoto, and Ryuichi Kobayashi

NTT Energy and Environment Systems Laboratories
9-11 Midori-Cho 3-Chome Musashino-Shi, Tokyo 180-8585, Japan
honma.yasuhiro@lab.ntt.co.jp
yano.kazuaki@lab.ntt.co.jp
kuramoto.shoichi@lab.ntt.co.jp
kobayashi.ryuichi@lab.ntt.co.jp

Abstract— **This paper describes an earth resistance measurement method that does not require auxiliary electrodes. Conventional methods, such as the fall of potential method, are not effective for measuring the earth resistance of ground covered with asphalt because auxiliary electrodes cannot be set in the ground. A method that does not need auxiliary electrodes has been developed to solve this problem [1]-[7]. This method uses a return wire instead of the auxiliary electrodes and is able to measure earth resistance greater than 100 Ω. However, it cannot be applied to low earth resistance measurement, especially that less than 50 Ω. Thus, to measure low earth resistance, in this study, we propose an improved method that uses two return wires. We evaluated the new method compared with measured data obtained by the conventional method. The results showed that an earth resistance less than 100 Ω can be measured within an error of 15 %.**

I. Introduction

Electrical facilities, such as electric devices and lightning rods, for example, need to be connected to the ground to achieve protection or safety against over voltage. A resistance of the ground is classified in accordance with its purpose. For example, the resistance for personal safety should be less than 100 Ω, and that for a lightning conductor should be less than 10 Ω. The fall of potential method that uses two auxiliary electrodes is commonly used to measure the earth resistance. However, the surface of the ground is covered with asphalt in an urban area. Thus, finding a place where the auxiliary electrode can be set is difficult. Therefore, measuring the earth-resistance is very hard to carry out in an urban area.

To solve this problem, a method that does not need auxiliary electrodes has been developed [1]-[7]. This previous method uses a return wire instead of auxiliary electrodes and measures the earth resistance on the basis of the series resonance phenomenon. However, this method cannot measure an earth resistance of less than 100 Ω because an earth-return impedance, i.e. impedance between the return wire and the ground, is not negligible.

This paper describes an improved method that measures earth resistance less than 100 Ω. We focused on a method to evaluate an earth-return impedance and considered a way to reduce its influence. In this paper, first we explain the principle of the previous method and show results of the comparison between data obtained from both the fall-of-potential method and the previous one. Second, a theoretical background of the improved method is presented. Finally, measurement results of the improved method are evaluated and the validity of the method is presented.

II. Previous Method

A. Measurement procedure

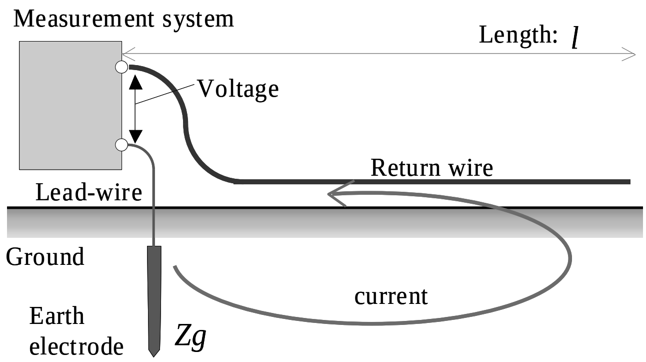

Fig. 1 Previous method of an earth-resistance measurement

The installation of the previous method, which does not need auxiliary electrodes is shown in Fig. 1. A measurement system is constructed with an impedance analyzer that measures impedance in the frequency domain and the return wire. The analyzer is connected to the lead wire and the return wire. The lead wire is connected to the earth electrode. The return wire is covered with insulating coating, and its length is about 20 m. The purpose of a return wire is electromagnetic coupling with the ground. When high-frequency voltage is applied between the lead and return wires, a current flows from the earth electrode to the return wire through the ground. This configuration can be considered as a series-resonant circuit that is constructed with the earth resistance of the earth electrode, the electromagnetic coupling of a return wire and inductances in the measurement system. The impedance of the series-resonant circuit can be calculated by

$$Z(\omega) \cong R_g + jX_g + Z_0 \frac{1+\Gamma_R e^{-2\gamma_0 \ell}}{1-\Gamma_R e^{-2\gamma_0 \ell}}, \quad (1)$$

Where $R_g + jX_g = (Z_g)$ is the impedance of the earth electrode, Z_0 is the characteristic impedance of the return wire, γ_0 is the propagation coefficient of the return wire, and Γ_R is voltage-reflection coefficient of the return wire. The third term of eq. (1) represents an impedance of the ground. This term is called the "earth return impedance" in the following text.

When a series resonance occurs, the impedance between the lead and return wires becomes minimum. This means that the impedance given by eq. (1) is only composed of a resistive component. If we can assume that the real part of the earth return impedance is negligible, then the earth resistance of Rg can be obtained. However, the ground condition is not the same in the field. Therefore, this previous method needs to have correction factors obtained by comparison with the fall of potential method. This factor can be obtained by measuring the earth resistance at many points in Japan.

B. Result

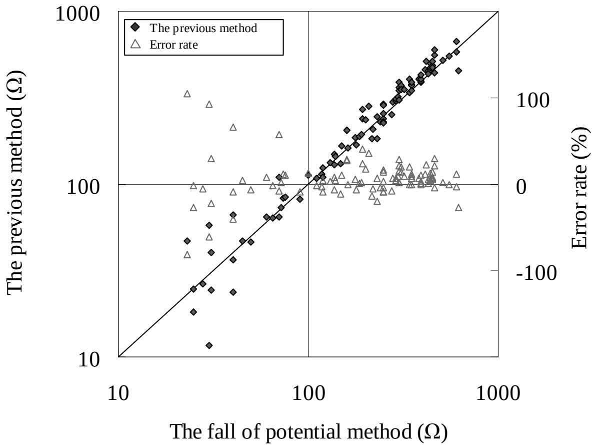

Fig. 2 Earth resistance and correlation measured by previous method

The correlation between the data measured by both the Fall-to-Potential method and the previous method is shown in Fig. 2. The x-axis indicates the earth resistance measured by the fall of potential method and the left y-axis indicates the earth-resistance measured by the previous method. The y-axis on the right side indicates the error obtained by the comparison between the data. The solid line indicates that the measured data obtained by the previous method is the same as that obtained by the conventional method. The rhombuses indicate the measured data obtained by the previous method and the triangles indicate the error.

When the earth resistance is greater than 50 Ω, the error can be ignored. However, if the resistance is less than 50 Ω, the error is not negligible. The cause of these errors is related to the ratio of the earth resistance and the earth-return impedance. The earth-return impedance is influenced by the condition of ground that is marsh soil, dry soil or covered with asphalt. Thus, the earth resistance cannot be corrected when low earth resistance is measured. The evaluation of the earth-return-impedance should be carried out to solve this problem.

III. Improved method

A. Principal

The earth-return impedance constructed with the ground and a return wire is different from the measurement circumstances. We propose the way to remove an earth-return impedance from the measurement result as an improved method.

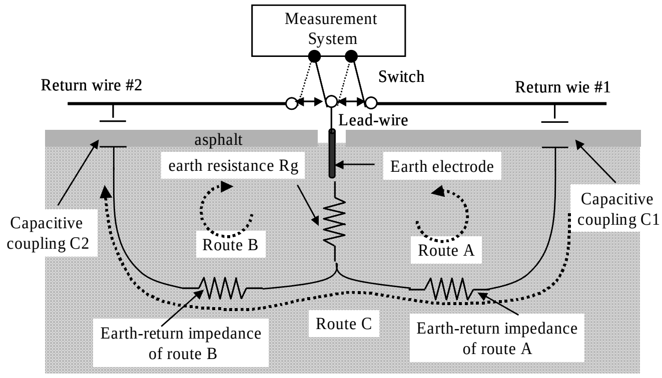

Fig. 3 Principle of earth-return impedance estimation

The principle of an earth-return impedance estimation is shown in Fig. 3. A feature of this method is adoption of an additional return wire. The purpose of this additional return wire is to increase the measuring routes. Two return wires are set on the ground and connected to the measurement system. The measurement system is constructed with an oscillator, electrical impedance meter, and inductor. The lead wire is used for connection with the measurement system and earth electrode. Return-wire 1 and 2 are conducting wire covered with insulating coating, and their lengths are 20 m.

The procedure of the measurement is as follows.

1) Measure the impedance (Z_A) between the electrode and return wire #1. Return wire #2 disconnects the measurement systems at this moment.

2) Measure the impedance (Z_B) between the electrode and return wire #2. Return wire #1 disconnects the measurement systems at this moment.

3) Measure the impedance (Z_C) between the return wires. The lead wire disconnects the measurement system.

4) The impedance of these measurements can be obtained by the following equations.

$$Z_A(\omega) \cong R_g + jX_g + Z_0 \frac{1+\Gamma_R e^{-2\gamma_0 \ell_1}}{1-\Gamma_R e^{-2\gamma_0 \ell_1}}, \quad (2)$$

$$Z_B(\omega) \cong R_g + jX_g + Z_0 \frac{1+\Gamma_R e^{-2\gamma_0 \ell_2}}{1-\Gamma_R e^{-2\gamma_0 \ell_2}}, \quad (3)$$

$$Z_C(\omega) = Z_0 \frac{1+\Gamma_R e^{-2\gamma_0 \ell_1}}{1-\Gamma_R e^{-2\gamma_0 \ell_1}} + Z_0 \frac{1+\Gamma_R e^{-2\gamma_0 \ell_2}}{1-\Gamma_R e^{-2\gamma_0 \ell_2}}, \quad (4)$$

Where ω is the angular frequency at the measurement, and the others are the same parameters as eq. (1).

5) The resonance frequency of each measurement should be set to the same value, and the impedances are measured. The impedance of the earth is given by

$$Z_g = \{Z_A(\omega_0) + Z_B(\omega_0) - Z_C(\omega_0)\}/2, \quad (5)$$

6) We assumed that the earth return impedances, i.e., terms that include Z0, are the same in each measurement. Then, the right terms of equation (5), which are resistive components, remain.

B. Result of measurement

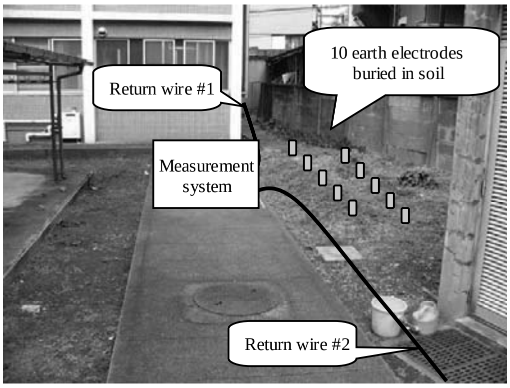

Fig. 4 Overview of experiment setting

Measurements of earth resistance were carried out to check the validity of the improved method. An overview of the experimental set up is shown in Fig. 4. Ten earth electrodes were buried in the soil and of the resistance by the fall of potential method to evaluate the accuracy of improved the method. The earth resistance can be changed in the range from 13.7 to 200 Ω by the combination of the earth electrodes. The measurement system used the Agilent 4294A impedance analyzer. External inductors were prepared for tuning the resonance frequency. In this measurement, the resonance frequency is tuned at 94 kHz.

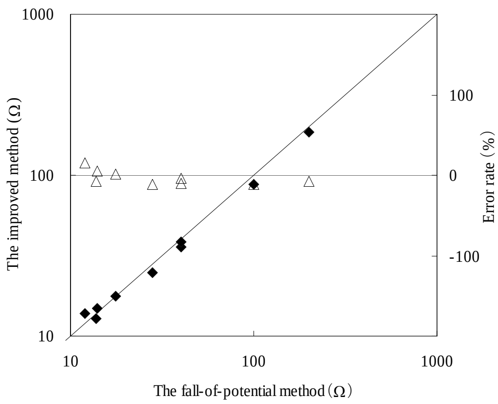

Fig. 5 Earth-resistance and correction measured by improved method

The correlation between the data measured by both the conventional and improved methods is shown in Fig. 5. The x-axis indicates the earth resistance measured by the fall of potential method. of The y-axis on the left is the earth resistance obtained by the improved method, and the y-axis on the right indicates error calculated by the comparison of these data. As shown in this figure, the improved method that used two return wires can measure the earth resistance within the range from 6 to –12 %. Therefore, the new method improves the measurement accuracy.

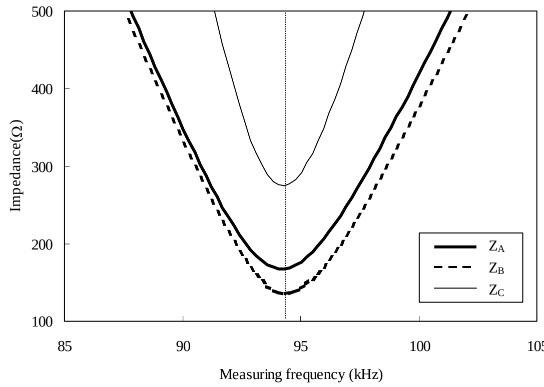

Fig. 6 Characteristic of Z_A, Z_B, and Z_C

Characteristics of Z_A, Z_B, and Z_C are shown in Fig. 6. This measurement was carried out when the earth resistance of 13.7 Ω was obtained by the fall of potential method. Resonance frequencies of routes A, B, and C were tuned at 94 kHz by using external inductors. The results Z_A is 135.8 Ω, Z_B is 167.6 Ω and Z_C is 275.0 Ω. Inserting these results into eq. (5), we obtained 14.2 Ω as the earth resistance. The error rate is 4 % in this case.

C Evaluation in field

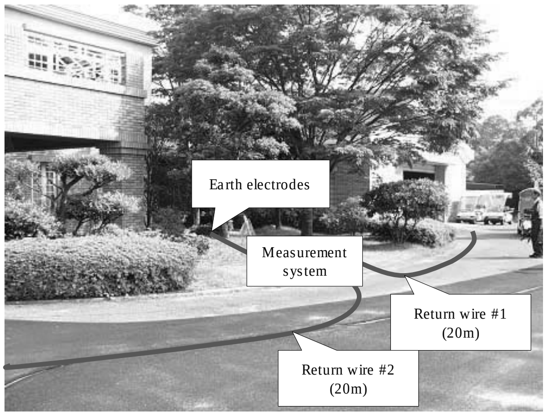

Fig. 7 Measuring of earth-electrodes in service

To check the effectiveness of the improved method, we measure the earth resistance of the actual earth electrodes that were buried in close proximity to a telecommunication center building. There were 13 electrodes, and the ground at the measurement site was almost covered with asphalt. Measured results of the earth resistance obtained by two different methods are shown in table 1. The earth-resistance measured by conventional method is 12 Ω. The earth resistance obtained by the new method is 11.4 Ω, and its error rate is -5 %.

Table 1 Measured results of the earth resistance in the field

Method	Fall of potential method	Improved method
Value [Ω]	12	11.4

IV. SUMMARY OF RESULTS

In this paper, we have explored the improvement of the earth-resistance measuring method without auxiliary electrodes. The following points have been confirmed by this study.

1) The previous method, which does not need auxiliary electrodes, cannot measure the earth resistance less than 100 Ω. The error is in the range from -100 to 100%. The cause of this error is handled by the earth-return impedance that depends on the ground condition.

2) The Proposed method that uses two return wires is effective for measuring earth resistances less than 100 Ω. The measurement accuracy can be improved by this method. The error rate that is obtained by the comparison of the conventional method is in the range from 5 to –12 %. This means that the improved method measures earth resistances less than 100 Ω within the error of less than 15%.

Further studies will focus on increasing the number of samples to confirm the improved method can be used even in any other situation.

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