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Bibliographical Review of Monitoring and Controlling Technique for Earthing System

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ABSTRACT: Grounding is a protection method that uses a grounding electrode placed in the ground to pass leakage current from an electrical system to the earth. Rod electrodes, plate electrodes, mesh-connected electrodes, and other types of grounding electrodes can be used. To safeguard the safety of working employees and costly installed equipment in the substation, a low resistance path for the discharge of short circuit fault current is required. Furthermore, soil resistivity, mineral content, soil moisture, and temperature, particularly owing to weather fluctuations, have an impact on earth resistance value. As a result, a grounding system that can be monitored and regulated automatically is required to prevent a rise in the value of earth resistance owing to weather change. In this paper, the literature review of earthing resistance measurement and monitoring techniques, along with the designing of grounding system for the substation is presented. An electrical ground is the source point in an electrical circuit from which voltage is measured or a direct physical connection to the earth. An exhaustive literature survey has been carried out in the present study to show the present trend and the methodology used in the earthing system.

Keywords: Earthing, Continuous monitoring, earth resistance.

I. INTRODUCTION

Earthing is used to protect the equipment as well as human lives from an electric shock by providing a path for the flow of leakage current. Earthing is used to protect the equipment from high-value current flow due to any fault. The main objective of an earthing system is to provide an alternative low resistance path for fault current to flow to avoid any accidents like an electric shock and damage to the equipment [1]. It is necessary to provide a low resistance path by maintaining the resistance of earth to low value continuously. Therefore, it i s of major importance to develop a system that can monitor the health of the grounding system. Few standards have been proposed by IEEE for earthing as shown in Table 1.

Table 1: Standards for Earthing.

Standard	Points covered	Reference
IEEE 80	Safety in AC substation grounding	[2]
IEEE 81	Measuring earth resistivity, ground impedance and earth surface potentials of a grounding system	[3]
IEEE 142-2007	Recommended Practice for Grounding of Industrial and Commercial Power Systems	[4]
IEEE Std C62.92.2-1989	Application of Neutral Grounding in Electrical Utility Systems, Grounding of Synchronous Generator Systems	[5]
IS Code of Practice for Grounding	all the spheres of the grounding system	[6]

There are numerous advantages of earthing such as the system voltage will not increase in case of a ground fault, arcing grounds are eliminated, increased life of the insulation. In the power system, two types of earthings are provided: neutral earthing and equipment earthing [7]. Earthing and grounding are the same terms, however, the earthing term is used in the European, commonwealth countries and standards like IS and IEC, while grounding term is used in North American standards like IEEE, ANSI [3].

The purpose of installing a suitable grounding system is to ensure reliable power supply, the safety of equipment and people working in electrical power operation, and to limit potential elevation to a minimum. Grounding installations are essential for human safety but also the normal operation of the electrical installation. Its design is difficult because of the dependence on several parameters [8]. Protective earthing serves two functions 1) potential transfer from the soil to earthed portions of devices or circuits, 2) establishing a link between the grounded parts, and the soil used as a fault current return path.

This study focuses on the study of various techniques of earth resistance measurement, monitoring techniques of earth resistance, and methods of controlling earth resistance. Various IEEE standards related to grounding, books, IEEE transactions, peer-reviewed journals, and conference proceedings have been studied in this study. From the literature, it is observed that numerous techniques have been used for the measurement of the earth resistance, monitoring technique of earthing resistance, and controlling techniques for the same.

This paper is organized as follows. Section II presents the principle of the measurement of the earth resistance, whereas Section III brief the designing of the grounding system. Monitoring technique of earthing resistance is explained in section IV, and finally, Section V discusses the findings of this study while Section VI presents the conclusion.

II. PRINCIPLE OF EARTH RESISTANCE MEASUREMENT

Earthing can be used to discharge DC, AC, or surge currents (such as those caused by lightning). The measurement of earth resistance is important to ensure the safety and reliability of electrical equipment. In literature, numerous methods are proposed for the measurement of earth resistance. The basic method of measurement of earth resistance is using voltmeter-ammeter as shown in Fig. 1 This technique has the drawback of requiring an additional high-power power source and requires the measuring equipment to be assembled. In IEEE Standard 81-1962 [3], an IEEE recommended guide for measuring the ground resistance and potential gradients in the earth, provides the required methods as follows

(a) Two-Point Method
(b) Three Point Method
(c) Four-point Method.

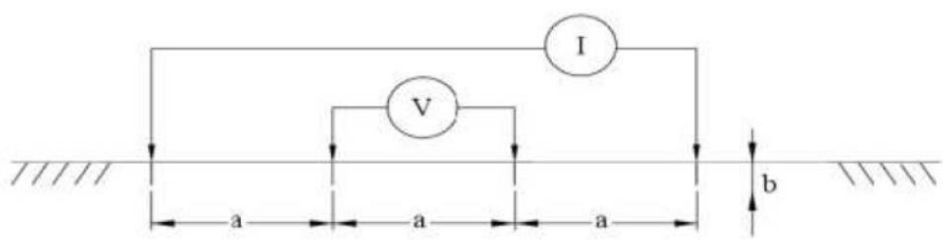
For measurement of earth resistance in terms of soil resistivity earth, the tester is used. Mathematically earth resistance is represented as [3, 4]

$$R = \frac{\rho}{2\pi L} \quad (1)$$

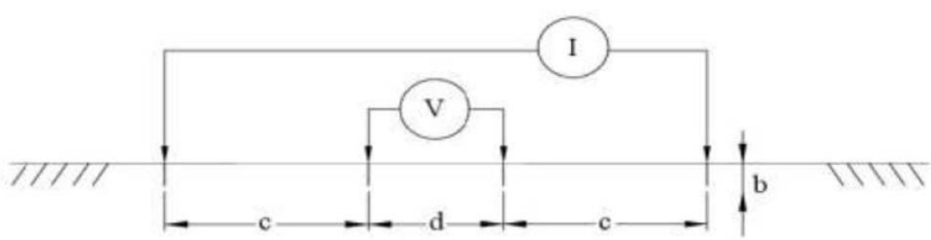
Where R represents the value of earth resistance in ohm, L is the distance between the spikes in cm and ρ is the earth resistivity ohm-cm.

From the literature on earth resistance measurement techniques, it is observed that most of the research work is carried out based on mathematical approaches and comparative study is presented for mathematical/computational techniques. Comparative study of the calculated and measured values of earth resistance for two layers soil model is presented in [9]. Wenner method is used for measurement of earth resistance for the same. Two-point, three-point, and four-point methods are used to measure the earth's resistance. From the readings using the fall-of-potential method, the earth resistance is calculated. In [10] Analysis of various methods for measuring earth resistance and soil resistivity are presented.

Earth resistivity is calculated using different methods such as the Wenner method and Schlumberger Method. Fig. 1 shows the connection diagram for both methods. The formulas derived from these methods are as below [3].



(a) Wenner Method



(b) Schlumberger Method

Fig. 1. Connection Diagram.

(i) Wenner Method- In this method soil resistivity ρ_E (Ω-m) is measured in terms of electrode spacing and depth of electrode as given below,

$$\rho_E = \frac{4\pi a\ R_w}{1+\frac{2a}{\sqrt{a^2+4b^2}}-\frac{a}{\sqrt{a^2+b^2}}} \quad (2)$$

Where,

ρ_E = measured apparent soil resistivity (Ω-m)

a = electrode spacing (m)

b = depth of the electrodes (m)

R_W = Wenner resistance measured as "V/I"

(ii) Schlumberger Method- In this method soil resistivity ρ_E (Ω-m) is measured in terms of the distance between the voltage probe is *a*, and the distances from voltage probe and current probe are *c*,

$$\rho_E = \pi\frac{c\ (c+a)}{a}R_s \quad (3)$$

Where,

ρ_E = measured apparent soil resistance (Ω - m)

a = electrode spacing (m)

c = electrode spacing between voltage and current probe (m)

R_S = Schlumberger resistance measured as "V/I"

Ref. [12] presents the three test methods to test the effectiveness of earth and presents the result of three test method to illustrate the deficiencies in the grounding electrode resistance test method. The author also discussed the various test instrument principles. The authors have provided recommendations on measurement techniques to minimize the error and ensure valid test results. This testing is accomplished to validate the connection to the earth as being sufficient to become a desirable path for lightning stroke current. It may also help indicate the expected *Step* and *Touch* potential that may develop during a line-to-earth fault. The resistance and impedance of the grounding system using ground high frequency and a resonant method are presented in [13].

In Shintaku *et al.,* [14] earth resistance measurement of the mutually bonded electrode of the telecommunication building is proposed. They estimated the earth resistances with high sensitivity compared with an earth tester. In traditional earth tester measurement becomes difficult because it uses an assistant electrode surrounded by asphalt or concrete. Kazuo Murakawa [15] discussed the new method and tool of measurement of earth resistance without using auxiliary electrodes. The results are compared with the three-point method. Salam, [16] discussed the measurement of grounding resistance based on the fall of the potential curve. The voltage distribution near the auxiliary current electrode is tested, and it is used as the main analysis and measurement parameter. First, the potential between the earthing grid and the earth surface potential near the current electrode is measured; then, the ground potential rise (GPR) of the grounding grid is calculated through hypothetical analysis and mathematical calculation; and finally, the grounding resistance is calculated by dividing by the test current. This method avoids the complexity of traditional measurement methods.

Clark *et al.* [17] have studied the calculation of grounding resistance using the grid and rods of the substation. The soil resistivity is calculated near the test site and the fall-off-potential method is used to estimate the grounding resistance.

III. DESIGNING OF GROUNDING SYSTEM

As the fault level of substations rises dramatically owing to load increase, the design of grounding systems for HV substations utilizing various computer software has attracted a lot of scientific research in the recent two decades. The entire grounding system design focuses on soil modeling, safety parameter computation utilizing two or more soil resistivity models, and parametric analysis of grounding mat design for best results.

The grounding system design process begins with substation soil modeling. An efficient approach to producing an ideal two-layer soil model utilizing soil resistivity measurement data obtained by the Wenner method is presented in [18]. The study discusses a computer program called Soil Parameter Estimation Using Finite Expression (SPEF), which was created using finite expressions. The importance of having a low-resistance connection to the grounding grid to restrict the substation's potential rise with respect to the potential of the surrounding ground is discussed in [19]. The various soil resistivity testing methods and soil modeling methodologies were also discussed in this paper. The model development of single and two-layer soil resistivity structures was also investigated in this article. A high voltage (HV) grounding design is presented in [20, 21]. Working conditions in the substation are hazardous due to the high voltage system. In determining the tolerated and real step/touch potentials, the soil model plays a vital role. These papers supplied important information for a two-layer soil model and emphasized that accurate soil resistivity data is critical for proper grounding system design. According to [22] Wenner's 4-point method of measurement of soil resistivity is the most accurate method. The accuracy is mainly dependent upon the spacing between the rods. Experimental work using scale models for various earthing system configurations such as vertical rods with different shapes and grounding grids to measure the Earth Surface Potential (ESP) in uniform and two-layer soil resistivity model is presented in [23-26].

Author in [27] proposes a measurement of earth resistance of ground grid using finite element method (FEM). Several grounding grids in two-layer soil with different dimensions and soil resistivity values were simulated using FEM.

IV. MONITORING TECHNIQUE OF EARTHING RESISTANCE

Grounding is the only security precaution to transfer, leakage electrical energy on an electrical system to the ground via electrodes and panels placed under the ground. The monitoring of electrical equipment is needed to extend the safety and life of equipment without any disturbance to the other system. Many monitoring solutions are available in the literature such as Zigbee, GSM-based, Wireless data acquisition system, etc. The poor earthing system results in unnecessary transient damage, and also causes data and equipment loss, plant shut down, as well as increases personal risk [28]. As a result, utility companies are actively trying to find techniques that can effectively and reliably evaluate the ground grid condition to ensure personal safety and prevent equipment damage. So, there is an intense necessity to monitor the earthing resistance continuously. Due to many natural conditions, the earth resistance gets increased to a value higher than the limits suggested by standards. Proper monitoring and rectification of this problem need to be done spontaneously to save equipment damage. Many strategies to monitor and maintain the earth's resistance have been demonstrated in [29]. The basic methodology for grounding impedance measurement is the Fall-of-Potential (FOP) method, which has been used for many years [3]. Its most important aspect is to appropriately find the potential probe, which takes a long time. Many different ways to enhance this technique have been presented, such as employing a variable frequency source [30] or implementing multiple electrodes [31]. The techniques for correctly measuring the impedance of in-service substations that take into account the current split in transmission and distribution grounding systems are further explored in [32, 33]. Potential probes, on the other hand, are still required in these FOP-based methods. Several improved grounding grid computer models have recently been developed, some of which take into account the soil layer depth [34, 35], or are based on electromagnetic field approaches [36, 37]. The accuracy of these models, however, is dependent on soil resistivity measurements. When the soil condition changes [38], the potential electrode must be repositioned, which adds to the labor work. Another technique to assess the functioning of the grounding grid is to monitor its integrity [39, 40]. However, the computation of this technique is subject to a number of unknown variables, including soil conductivity, humidity, and climate [41].

The grounding grid corrosion is diagnosed using a device that measures the magnetic induction intensity [42]. To boost accuracy, it necessitates current injection between all available grounding leads on the ground surface, which is impractical in a large-scale substation.

The design and development of a wireless-based remote system for continuous monitoring of leakage currents are investigated in [43]. Based on the wireless area network technology, the system can be continuously monitored. It is composed transmitter module with a data acquisition system connected to leakage current and voltage sensor and a receiver module connected to a remote controller for data processing and storage. At the receiving end, data processing is carried out, and then the monitored quality is displayed continued.

Dasong *et al.* [44] have analyzed the power earth line monitoring system using GSM technology to record, collect and display the data of earth line. In this, by using the Microsoft, net2005 database, and GSM SMS technology, they developed a power earth-line monitoring system based on B/S Module.

The MDS4 index-based EGS resources to monitor the earth resistance are presented in [45]. The MDS4 trigger service checks specified failure conditions and notify when a failure occurs. The global toolkit version four monitoring and discovery system is used for monitoring infrastructure used by the earth system.

When a short circuit and lightning strike occurs, the earthing grid can quickly drain the impact current, so that the ground potential is lowered in the transformer. In [46] the corrosion monitoring system based on the cloud platform is designed which also uses automatic detection technology. This system uses the internet to send the collected data and the status of the earthing grid through the mobile terminal.

In [47] the authors develop an algorithm for monitoring the earthing grid condition and the device that locates the point of failure. The main contribution is to introduce a new approach and technique to monitor the earthing grid. But they are not able to pinpoint the exact location point of the failure itself. It detects only damaged elements and shows the point of failure.

It is recommended that the ground – conductors monitors should be resistance reactive and the resistance trip level should be determined by the allowable ground-fault voltage and the operating value of the ground fault relay. A ground fault detection system will operate only if the grounding conductor is required to ensure good conductor continuity [48].

Earthing system is important to maintain the security and definitive operation of power networks and ensure the safety of power apparatus and operators. In [49] deep ground well method is presented to decline the grounding resistance of substations to reduce the grounding resistance. The ground well is formed by a metal tube with water percolation apertures in the soil to groundwater, which has the ability to gather the groundwater and wet the surrounding soil**.** Jafari *et al*. [50] describe the new monitoring techniques to measure the grounding resistance. The performance of the monitoring method will be analyzed under various conditions considering different configurations of the power system. The situations that the monitoring method fails to monitor correctly will be highlighted followed by a potential solution. The high resistance neutral grounding resistors fail due to vibration, intermittent arcs, corrosion, etc., and cause the risk of the system being ungrounded, or solidly grounded. In this, two efficient solutions are introduced that provide continuous monitoring of such resistors installed at the neutral of the two most common configurations of the unit-connected generators. The first proposed method relies on the third harmonic of neutral and residual voltages, and the second technique employs the sub-harmonic injection-based generator stator ground protection. The methods are shown satisfying performance under different conditions of the resistor and generator, observed through comprehensive software analysis and further hardware validations. The first monitoring method has been retrofitted to an industrial generator protection relay, which no longer mal-operates due to a failed-short neutral grounding resistor. The techniques can be incorporated into digital protective relays, which will monitor and alarm in case of a failed grounding resistor [50].

Neutral grounding resistors play a critical but often undervalued role in the power system by controlling the severe transients that appear in the neural system. Continuity of service of these key assets should be ensured since the defected neutral grounding resistors leave the system unprotected against transient over-voltages and over-currents and cause a false sense of security. An efficient solution is proposed to detect this issue for the unit-connected generators that are equipped with sub-harmonic injection-based generator stator ground protection. Various conditions of the resistor and power system were observed through comprehensive software analysis [51].

V. DISCUSSION

From the literature review, it is concluded that when it comes to the optimal grounding design of any substations, there are several areas that require further attention or inquiry. Some of the key findings are listed below:

— More study is needed to investigate a multi-layered soil model design.

— Design engineers will need certain empirical formulae to make design calculations simple and quick.

From the papers studied for earth resistance measurement, it is concluded that the most common inconsistencies in earth resistance measurements are due to

— Incorrect distribution of measuring electrodes,

— Incorrect selection of measurement system elements,

— Incorrect positioning of the measuring system relative to underground conducting elements changing the flow of the measuring current,

— Incorrect positioning of the measuring system wires relative to nearby overhead line wires

Improper measuring electrode spacing can cause the following effects:

— Too close placement of the current electrode, limiting the zero potential zones and making it impossible to locate it, or

— Positioning the voltage electrode outside the zero potential zone and measuring voltages lower or higher than the earthing voltage.

From the literature, it is found that there is no universal method for the measurement of earthing resistance for any type of soil. To avoid typical errors in the measurement following points can be considered while earth resistance measurement.

— The measuring techniques used to control the condition of earthing should be selected based on the conditions under which earthing is expected to perform its function.

— Earth loop resistance measurements should be taken with caution, especially if the findings appear to show a flawless earthing condition.

— The efficacy of protective and working earthing is completely characterized by the static resistance and impedance measured by measuring currents with a technical frequency.

— The surge impedance (including earthing inductions) best describes lightning protection grounding.

CONCLUSIONS

This paper presents an overview of designing grounding systems and earth resistance monitoring techniques. This study presents the different techniques for monitoring and controlling earthing system of substation, grounding grid, etc. The paper provides the current trend in grounding which is useful for the researcher and utilities working in the field of electrical earthing.

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