Experimental Investigation of Enhancing Earthing Through Soil Treatment Using High Material Conductivity

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***Abstract*- This study presents an experimental investigation into enhancing grounding system performance through soil treatment using high-conductivity materials, focusing primarily on sodium chloride (NaCl) and bentonite. Test were conducted at a coastal site in Sabratha, Libya—characterized by high soil resistivity—the research evaluates the effectiveness of different NaCl layer thicknesses and parallel electrode configurations in reducing earthing resistance. Field measurements demonstrate that surrounding a vertical electrode with a 3-inch NaCl layer can reduce resistance by up to 73%, while combining multiple electrodes with NaCl treatment achieves reductions as high as 83%. Additionally, a comparative analysis with bentonite revealed that although both materials significantly lower resistance, NaCl proved more effective, achieving an 85.2% reduction versus 80.3% with bentonite. The results underscore the impact of ion-rich additives in improving soil conductivity and grounding efficiency, especially in dry or sandy environments. This paper offers practical guidance for engineers designing reliable and cost-effective grounding systems in challenging soil conditions, while also highlighting the need to consider long-term environmental and performance implications of chemical soil treatments.**

Keywords— Grounding resistance, Soil treatment, Sodium chloride (NaCl), Bentonite, Low-resistivity materials, Wenner method, Earthing enhancement

I. INTRODUCTION

Earthing systems are fundamental in the development and functioning of secure and dependable electrical installations. Their main goal is to safeguard human life, prevent equipment harm, and ensure the functional integrity of electrical systems. Earthing systems ensure voltage stability and enable the efficient functioning of overcurrent protection devices by offering a low-impedance route for fault currents to reach the ground [1]. The basic idea of earthing originates from the initial days of electrical engineering, when uncontrolled electrical discharges led to disastrous failures and incidents. Gradually, standardized methods for grounding emerged, integrating thorough scientific investigation and empirical field observations. Currently, global standards such as IEEE Std 142-2007 [2] and IEC 60364 [3] assist engineers in developing and executing efficient grounding systems customized for particular installation needs and environmental factors.

In the absence of a proper earthing setup, systems are at risk of hazardous touch and step voltages, a greater chance of equipment failure, fire hazards, and interruptions to operations. As emphasized by Dugan et al. [4], grounding is not just a safety mechanism but an integral aspect of power quality management, influencing the performance of sensitive electronic equipment and protective devices.

In addition to traditional applications, earthing systems today must accommodate emerging challenges such as renewable energy integration, where distributed generation introduces new fault paths and grounding requirements [5,6,7]. Moreover, urban environments impose physical and regulatory constraints that demand innovative grounding solutions, such as deep-driven electrodes or low soil resistivity materials (LSRMs).

The results of this study provide useful advice for engineers and professionals creating grounding systems in high-resistivity settings. Utilizing NaCl, bentonite treatments and enhanced electrode configurations, the study aids in creating affordable, effective, and dependable grounding solutions.

II. EARTHING RESISTANCE

Earthing resistance (or grounding resistance) is a critical parameter in electrical safety and system performance. It represents the resistance offered by the earth electrode and the surrounding soil to the flow of fault current into the ground. A low earthing resistance ensures such as safety by preventing dangerous touch and step potentials, effective fault current dissipation to protect equipment, and stable reference voltage for electrical systems.

The ideal earthing resistance depends on the application, with typical values ranging from <1 Ω for substations to <5 Ω

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for residential installations (IEEE Std 80-2013) [8]. Grounding or earthing resistance is calculated using equations that take into account properties of soil and the length of the earth electrodes used [9]: -

$$R = \frac{\rho}{2\pi} \times \ln\left(\frac{4\ell}{d}\right) \qquad (1)$$

Where:
R: Earthing resistance (Ω)
ρ: Soil resistivity (ρ.m)
ℓ: Length of earth electrode (m)
d: Diameter of earth electrode (m)

III. SOIL TREATMENT

Soils with high resistance (such as rocky, sandy, or dry types) can affect electrical safety and system efficiency. Soil treatment techniques alter soil characteristics through chemical or physical means to reduce resistivity and enhance grounding performance. Chemical additives enhance soil conductivity by retaining moisture and increasing ion concentration. However, there are some disadvantages to using Sodium Chloride, such as its highly corrosive to metals, its potential harm vegetation and microorganisms, and its tendency to degrade soil structure and fertility. Common materials include: bentonite Clay (Low resistivity when moist (2–5 Ω·m), marconite (conductive cement) (carbon-based compound with resistivity of 0.001 Ω·m) and salt (NaCl) and charcoal [9].

IV. SOIL RESISTIVITY MEASUREMENT

Figure 1 shows a model of the Wenner arrangement as proposed by Frank Wenner in 1915 [10] is still widely used today. The Wenner technique is a commonly utilized method for evaluating the electrical resistivity of soil. It aids in assessing the soil's ability to withstand electrical current, which is essential for purposes like geophysical studies, groundwater analysis, and the creation of electrical grounding systems. The Wenner method involves injecting an electrical current (C1) into the soil and the current will be return by C2, then measuring the resulting voltage difference between P1 and P2. From these measurements, the resistivity of the soil can be calculated by this equation:

$$\rho = 2\pi \frac{V}{I} a \qquad (2)$$

Where:
ρ: the resistivity of the soil (in ohm.meters).
a: is the distance between adjacent electrodes (in meters).
V: is the measured voltage (in volts).
I: is the injected current (in amperes).

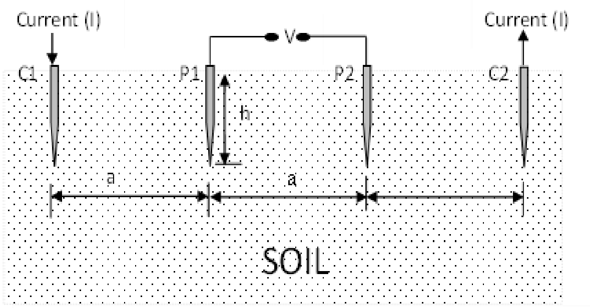

Fig. 1. Uniform-spacing four-probe measurement setup

V. LOCATION OF RESISTIVITY SURVEY

The satellite image of the location of resistivity tests is shown in Figure2. The test site around 2km from the beach (Sabratha city) was selected which are ideal for studying soil resistivity and grounding performance. The site likely has sandy or saline which usually has high soil resistivity. Another reason for choosing this site is fewer electrical interferences from buildings, buried utilities, or other grounded systems. One line perpendicular to the line route (orthogonal line) was selected, and the adopted survey line lengths were 39m for the Megger DET 4 tester [11].

Figure 3 shows the survey lines from the first round of tests using the Megger Det 4 tester. The soil resistivity in both perpendicular directions decreases significantly with depth, suggesting that the top layers are drier or less conductive, while lower layers are more conductive, possibly due to higher moisture content, clay presence, or saline water. The variation between the two profiles could be indicate soil heterogeneity, different soil types or water content in the two directions.

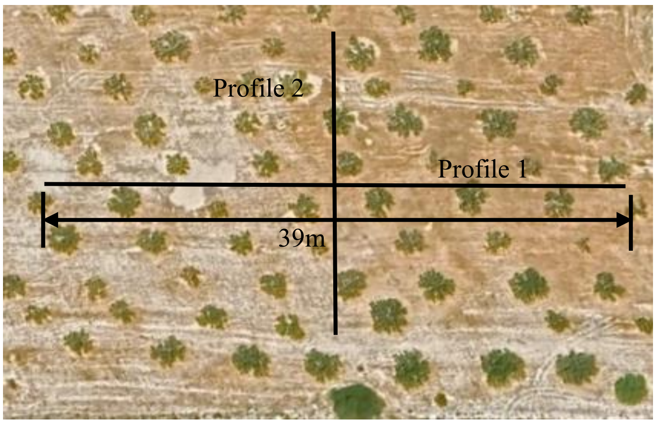

Fig. 2. Satellite image of measurement location at Sabratha test site

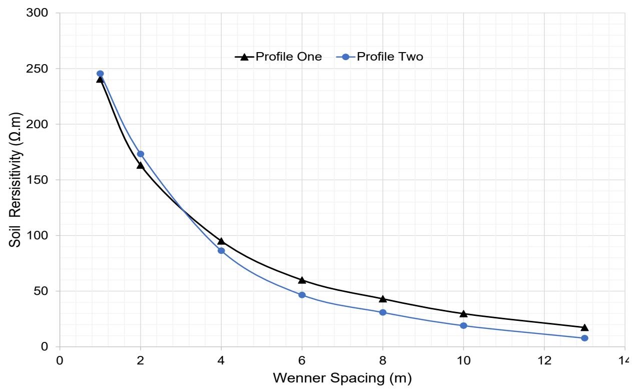

Fig. 3. Apparent soil resistivity measured by Megger Det4

Table I shows the most recently derived soil model using CDEGS software [12], of which the two-Layer Model will be used throughout this section. CDEGS software was used to obtain the soil model for the test site. As can be seen from the from table, it's clear that there are three-layer soil model. The top soil resistivity layer is 196.35 Ω·m with 1.19 m Depth. This represents the uppermost soil layer, often closest to the surface. It could indicate moderately resistive soil, such as dry topsoil or compacted ground. The second layer is the middle Layer, and the value of soil Resistivity is 2107.62 Ω·m with depth 0.92m. A highly resistive layer, possibly representing a rocky or very dry layer with minimal moisture content. The third layer is called lower layer, and its value is 55.68 Ω·m. A conductive layer likely consisting of moist soil, clay, or water-saturated materials, commonly found deeper underground.

TABLE I. SOIL RESISTIVITY MODEL

	3 Layer Model			Uniform Model
	Top	Middle	Lower	
Resistivity (Ω.m)	196.35	2107.62	55.68	196.35
Depth (m)	1.19	0.92	∞	

VI. EXPERIMENTAL SETUP DESCRIPTION FOR TEST ELECTRODES

A schematic diagram of the experimental setup for the DC test is shown in Figure 4. After the soil resistivity had been measured, the test electrode of 1m (14mm diameter) rod in length was installed. The setup uses a four-terminal method (commonly a Fall-of-Potential or 4-point method), typically with a Megger tester. The distance between the test electrode and the probes is crucial to ensure accurate measurement, avoiding interference zones. The current return electrode was positioned 15 meters from the test object, while the reference potential electrode, situated 20 meters away, was connected using a lead arranged perpendicular to the current return lead. Figure 5 shows the picture of Megger device at the test site.

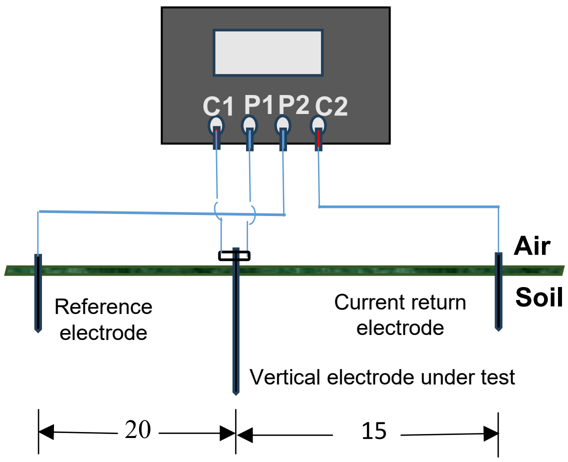

Fig. 4. Measurement Setup

Fig. 5. Pictures of Megger at the test site

VII. RESULTS AND DISCUSSION

Figure 6 depicts the fluctuation in earthing resistance (Ω) throughout the timeframe from December 2024 to June 2025.

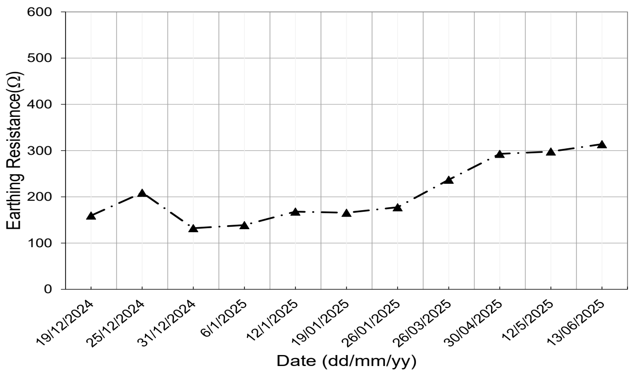

Fig. 6. Variation in Measured Earthing Resistance of Rod Electrode

The earthing resistance shows a stable over time, particularly evident starting in late January 2025. The earthing resistance increases gradually over time, especially noticeable from late January 2025 onward. Initial values are within the range of 130–210 Ω, could be due to moisture variation or soil chemical changes. However, they rise steadily to exceed 314 Ω by mid-June 2025 might be due to dry season onset, leading to reduced soil moisture.

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A. Effects of Adding Sodium Chloride on Grounding Resistance

The purpose of this setup was to observe the effect of the electrode diameter in the presence of salt on the resistance of the electrodes as seen in Figure 7. Three electrodes were placed into the ground with the same length (1 m) and diameter (14 mm), and the distance between the electrodes was 2m.

Fig. 7. Electrode with Sodium Chloride

Figure 8 illustrates a comparative analysis of earthing resistance measurements under three distinct treatment scenarios conducted. Three scenarios of electrodes are illustrated:

Scenario 1: without Sodium Chloride (rod only).
Scenario 2: rod surrounded by 1.5 inches of Sodium Chloride.
Scenario 3: rod surrounded by 3 inches of Sodium Chloride.

Sodium Chloride can enhance soil conductivity by adding more free ions electrical current. This lowers the soil's resistivity, particularly in high-resistivity soils such as sandy or rocky terrain. Also, the concentration of Sodium Chloride decreases as it dissolves and spreads, reducing its effectiveness [8].

Table II shows earthing resistance measurements for different configurations of grounding rods treated with Sodium Chloride (salt). The measurements were taken on specific dates, and the resistance values are recorded for two different voltage levels 25 V and 50 V. As can be seen from the table that, adding sodium chloride (salt) around the grounding rod significantly reduces the earthing resistance. The table further illustrates that 3-inch Sodium Chloride treatment leads to reduced resistance when compared to 1.5-inch sodium chloride, suggesting that a thicker salt layer improves conductivity even more. Nevertheless, when grounding rods are linked in parallel (for instance, rod parallel with 1.5 and 3-inch Sodium Chloride"), the earthing resistance becomes even lesser than employing just one rod could be due to parallel connections reduce the overall resistance of the system, as per the principles of electrical circuits.

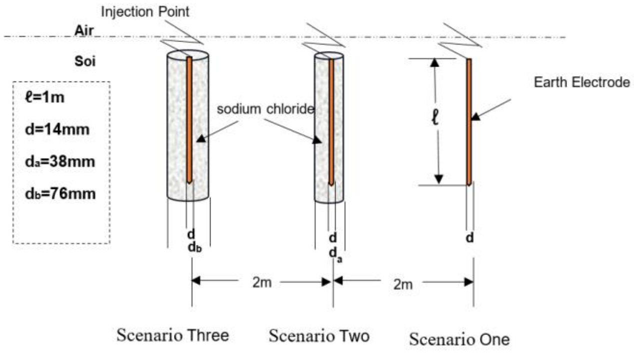

Fig. 8. Soil treatment using Sodium Chloride

TABLE II. MEASUREMENT PARALLEL ELECTRODE

Configuration	Date	Earthing Resistance (Ω)	
		25 v	50 v
Rod with 1.5inch Sodium Chloride	12-1-2025	62.8	62.8
Rod with 3-inch Sodium Chloride		47.8	47.8
Rod Parallel with 1.5and 3- inch Sodium Chloride		34.8	34.8
Rod with 1.5-inch Sodium Chloride	19-1-2025	67.5	67.4
Rod with 3-inch Sodium Chloride		42.2	41.9
Rod Parallel with 1.5and 3- inch Sodium Chloride		33.9	33.8
Rod with 1.5-inch Sodium Chloride	26-1-2025	64.4	64.4
Rod with 3-inch Sodium Chloride		38.6	38.6
Rod Parallel with 1.5and 3- inch Sodium Chloride		30.3	30.3
Rod with 1.5-inch Sodium Chloride	9-2-2025	63.9	63.9
Rod with 3-inch Sodium Chloride		37.5	37.5
Rod Parallel with 1.5and 3- inch Sodium Chloride		29.4	29.4

Table III shows the reduction in earthing resistance for different configurations of grounding rods and salt treatments. This column indicates the percentage reduction in earthing resistance compared to the reference configuration (rod only). Rod only is the reference configuration with no additional treatments. The earthing resistance of the rod alone was measured at 177.50 Ω. However, when the rod is surrounded by 1.5 inches of salt, the earthing resistance drops to 86.20 Ω,

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which is a 51.43% reduction compared to the rod-only configuration. Also, with 3 inches of salt surrounding the rod, the earthing resistance further decreases to 47.90 Ω, representing a 73% reduction. This configuration involves a rod surrounded by 1.5 inches of salt, along with an additional rod, the earthing resistance was measured at 64.4 Ω, which is a 63.72% reduction. When the rod is surrounded by 3 inches of salt, along with an additional rod, the earthing resistance drops to 38.60 Ω, representing a 78.30% reduction. Finaly, the configuration involves a rod surrounded by 3 inches of salt, with an additional 3 inches of salt and another rod. The earthing resistance is the lowest at 30.30 Ω, which is an 83% reduction.

TABLE III. REDUCTION IN EARTHING RESISTANCE WITH SODIUM CHLORIDE TREATMENT WITH PARALLEL CONFIGURATIONS

Configuration	Earthing Resistance (Ω)	Reduction Percentage %
Rod only	177.50	-----
Rod surrounding by 1.5in salt	86.20	51.43
Rod surrounding by 3in salt	47.90	73.00
Rod surrounding by 1.5in salt with rod	64.4	63.72
Rod surrounding by 3in salt with rod	38.60	78.30
Rod surrounding by 1.5in and 3in salt with rod	30.30	83.00

B. Comparison with Bentonite Treatment

To reduce the earthing (grounding) resistance for any type of earth electrode, the low soil resistivity and high conductivity materials are usually used. In the past, the Chloride Sodium was often used, but this type of the salt has some disadvantages such as causing a corrosion for the material of the vertical electrode. Today, a lot of materials were used such as the Bentonite (Clay) which has low resistivity and retain moisture, which can help to increase the conductivity. In this paper, the comparison between the chloride sodium and bentonite was performed at the field to reduce the earthing resistance of the vertical electrode, as shown in Figure 9. In this test, a 1m vertical electrode was used, and 3inchs of the Chloride Sodium and Bentonite layers are being used surrounding the vertical electrode.

The results were tabulated in Table IV. as can be seen from the table that, using the sodium chloride dropped the resistance significantly to 44.10 Ω, resulting in an 85.2% reduction. However, bentonite reduced the resistance to 58.70 Ω, which is also a strong improvement, with an 80.3% reduction which slightly less effective than NaCl, it is beneficial in environments where long-term moisture retention is needed.

TABLE IV. IMPACT OF SODIUM CHLORIDE AND BENTONITE ON EARTHING ELECTRODE PERFORMANCE

Configuration	Earthing Resistance (Ω)	Reduction Percentage (%)
Rod only	298.00	-------
Rod with 3inch Sodium Chloride	44.10	85.20
Rod with 3inch Bentonite	58.70	80.30

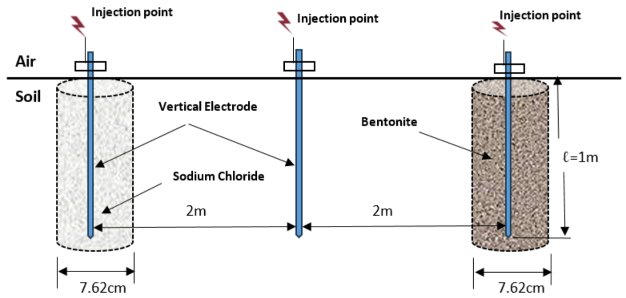

Fig. 9. Experimental Setup for Treated Vertical Earthing Electrode in Soil

C. *Comparison with Previous Studies*

The 85.2% reduction in grounding resistance achieved with 3-inch NaCl layer in this study substantially exceeds the 70% maximum reduction reported by Thomson et al. [13] in similar sandy soil conditions. This superior performance can be attributed to the optimized layer thickness and the specific coastal environment of Sabratha, which may enhance ionmobility due to existing salinity. Compared to Kumar et al. [14] who achieved 70% reduction in rocky soil using chemical electrodes, our NaCl treatment method shows 15.2% better performance while using more cost-effective materials.

Our results with bentonite (80.3% reduction) demonstrate improved effectiveness over Salam et al. [15] who reported 65-75% reduction across various soil types. The higher performance in our study may result from the moisture retention properties of bentonite being particularly effective in the dry, sandy coastal environment where natural moisture is limited.

The 83% reduction achieved with parallel electrode configurations combined with NaCl treatment shows significant improvement over Rodrigues et al. [16] who reported 72.5% reduction using multiple electrodes in urban soil conditions. This suggests that material treatment combined with optimal electrode spacing provides synergistic benefits. The results confirm that proper material selection and configuration optimization can achieve grounding resistance reductions exceeding 80%, providing practical solutions for high-resistivity environments while highlighting the need for balanced consideration of performance, cost, and environmental factors.

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VIII. CONCLUSION

This paper has experimentally demonstrated that soil treatment using sodium chloride (NaCl) significantly enhances the performance of grounding systems, especially in high-resistivity environments. By applying different NaCl layer thicknesses and electrode configurations, a substantial reduction in earthing resistance was achieved. A 3-inch NaCl treatment alone yielded a 73% reduction, while combining parallel electrodes with this treatment further reduced resistance by up to 83%. These results validate the effectiveness of NaCl as a low-cost and practical soil additive for grounding enhancement.

Additionally, the research verified that higher ion levels from NaCl enhance soil conductivity and promote improved current dispersion. Although the impact is short-lived and affected by external conditions like soil moisture and seasonal variations. The incorporation of parallel electrode arrangements showed additional optimization opportunities, consistent with theoretical predictions of lower resistance in parallel routes. The findings also indicate that the Chloride Sodium reduced the earthing resistance more than the bentonite could be due to the NaCl has superior conductivity and ability to lower earthing resistance than the bentonite.

Consequently, this study provides practical recommendations for engineers and utility experts focused on creating economical, efficient, and dependable grounding systems in difficult soil environments. Subsequent research may investigate the lasting ecological effects of chemical soil treatments and evaluate combined approaches utilizing additional low-resistivity substances.

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