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Geo-electric Ground Earthing Investigation in Basement Complex Environment

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Abstract

The ground earthing investigation was carried out in the vicinity electrical transformer within the Iyana-emirin community, Ado Ekiti to understand the causes of incessant facility damage due to thunder strike and eventual explosion. Profiling measurement using the dipole-dipole electrode configuration was employed for three traverses around the facility while eight points along these traverses were sounded. The sounding data identified four lithologic layers (lateritic topsoil, clay, sandy clay, weathered layer, and basement) in the study area. 2D resistivity images were generated along four traverses with respect to depth. Results from the VES and 2D resistivity image indicated that the layer within the earthing medium is resistive. The study reveals that the facility damage experienced in the area is due to the high resistivity values across the study area getting above the recommended earthing standard (2 - 5 Ωm)/(5 – 25 Ωm) for substation installation. There is a need to carry out artificial enhancement by introducing conductive materials (like lime, salt, charcoal, and ashes) into the subsurface to reduce the resistivity thereby making it suitable for the intended purpose. Also, the identified low resistivity portion could be targeted for burying earthing/grounding material and further enhanced for better performance.

Keywords: Ground Earthing; Soil Resistivity; Substations; Static Buildup; Lightning Arrester; Transformer.

1.0 Introduction

During design, construction and operation of an electrical power system, safety, and reliability are the two major concerns; substation designs, creation, and implementation also draw concerns from these factors. A safe, durable, and reliable power system thrives on a properly designed, ground earthing system and it becomes the bedrock for functional substations. Therefore, ground earthing investigation in the vicinity of electrical transformers becomes an important task to understand the causes of damage due to natural phenomena like thunder strikes (Adegboyega and Odeyemi, 2011). By design and purpose, the ground earthing system is meant to prevent static buildup and to provide a shield against power surges often stemmed by nearby lightning strikes (Lim *et al.*, 2013). A static buildup triggered by friction for instance is dissipated and channeled to the earth. In case there is an occurrence of a surge, a lightning arrester, or a surge arrester acts promptly to divert the extra current to the subsurface instead of it getting into the appliances. Studies showed that equipotential bonding is permitted to all metalwork by the earthing system to avert any changes in their potential differences (Oyeleye, 2019).

When the grounding system is not properly carried out, issues such as instrumentation errors, power factor problems, the risk of electric shock, and a lot of likely recurrent problems are not ruled out. Also, fault currents find unintended paths that could include people, if a ground system that is properly designed and maintained is not available (Zvarych, 2019). Consequently, finding a way to discharge excess currents into the earth while maintaining operational and equipment thresholds is vital. This ensures the safety of anyone around the grounded facilities from critical electric shock and becomes the main reason for designing any substation ground earthing system under any condition (Amadi, 2017). Electrical earthing is a method used to protect equipment from damage or malfunction. Therefore, earthing systems are viable means to reroute high currents into the earth (Somani *et al.*, 2005). Where earthing is not properly carried out, resultant problems like lightning strikes, cause high magnitudes of voltages and currents to be transmitted into electrical power systems instead of dissipating into the earth in a timely and controlled manner. Therefore, apart from human safety, a good earthing system also totally prevents or reduces the chance of damage to industrial equipment due to fault currents or lightning. This has improved the reliability of industrial equipment thereby reducing the cost of maintenance. Thus, it is important to put in place a well-designed earthing system that could help in the dissipation of large currents into the earth while preserving life and properties (Akintorinwa and Adesoji, 2009).

Designing an earthing system is primarily to provide surge arrest by components to provide a pathway for transient currents due to power frequency earth fault conditions into the earth (Johnson, 2006). The installation of an earth electrode for dissipating high-frequency transient currents into the earth is recommended as standard. IEC 250.56 standard stipulates that, in addition to the effect of poor grounding which is an unnecessary interruption, lack of good grounding causes equipment failure and increases anger. Also, apart from related litigation costs and loss, reports indicate that billions are lost each year due to resulting fires from damaged substation facilities. By design and function, the system transmitting and distributing high voltage requires safety measures to minimize damage to electrical equipment and to offer protective shield to humans from danger (Anderson *et al.,* 2022).

Nevertheless, the resistivity of the soil is a major factor that governs the efficiency of these schemes. The ease with which the soil impedes or conducts electric current defines soil resistivity which is a critical factor in system designs that thrives on the flow of current through the earth, and an important parameter in locating the best position of a transmitter that operates on low frequencies (Amadi, 2017). Therefore, the proper knowledge of soil resistivity and its variation with respect to depth is crucial to designing grounding systems in electrical substations. Generally, soil resistivity varies globally, depending on the type, temperature, moisture content, and the presence of electrolytes in form of minerals and dissolved salts (Dafalla and AlFouzan, 2012). The resistivity could be good or poor. However, the impedance of the earth must not rise above certain thresholds to avoid exposing people and livestock to danger.

One proven method used for this investigation is electrical resistivity. This method measures the resistance of the soil to the flow of an electrical current and can help in determining the electrical property of the soil (resistivity/conductivity) (Murad, 2012; Falade *et al.,* 2022). By measuring the resistivity of the soil at different depths and locations, it is possible to identify any areas of poor grounding or high resistance that may be contributing to damage from thunder strikes. This information can then be used to design and implement effective grounding systems to protect transformers and other electrical equipment from damage. Meanwhile, ground rods and their connections are usually eaten away and degraded when planted in a corrosive soil environment with high moisture content, salt content, and temperatures. Although, one effective way of lowering ground resistance is driving the electrode deep into the earth below the resistive layers (Amadi, 2015; Zhang *et al.,* 2020). Another variable that affects the ground resistance of the earthing system is the length/depth of the ground electrode. Ghomi *et al.* (2019) earlier established that the availability of deep-ground resistivity models is essential for modeling large grounding grids, such as those associated with modern industrial complexes, power plants, or HVDC ground electrodes. In order to suit earthing purposes due to the non-consistency of soil and unpredictability of its resistivity, approaches to reducing soil resistivity include; doubling the length of the ground electrode that reduces the resistance level by 40%, adopting a larger diameter electrode which lowers the resistance by 10% and use of multiple ground electrodes (Sinchi *et al.,* 2022).

The resistivity range of 2 - 5 Ω-m is preferred for earthing/grounding purposes while a high resistive formation prevents easy flow of excess voltage into the earth thereby resulting in serious or total damage to the substation facilities (Adegboyega and Odeyemi, 2011; Mitolo *et al.,* 2019). Several methods have been successful when it comes to measuring soil resistance especially when earthing/grounding properties evaluation is involved. Many methods of earth resistivity investigation including the electrical resistivity method of geophysics have been adopted successfully. These include; pole-pole, dipole-dipole, pole-pole, pole-dipole, Schlumberger method, and Wenner method. A geo-electrical investigation conducted by Olayanju and Onaolapo (2015) within the Federal University of Technology, Akure, Nigeria, successfully classified the study area based on its suitability for electrical earthing.

The current study is meant to evaluate the causes of incessant substation facility (transformer) blowout by conducting ground earthing properties assessment at Iyana-Emirin community, Poly Road, Ado-Ekiti. These involve depth determination for earthing materials and resistivity variation across depths. Several investments in power substations had been lost in the past years. Reasons attributed include inferior facilities; poor expertise of the engineers and natural factors like thunder strikes. However, in many of the cases, the earthing properties of the ground that houses the facilities were not properly factored into the substation design. Substations housed on resistive soils may retard/impede the quick and easy transmission of excess voltage from thunder strikes to the subsurface, which often leads to voltage buildup and thereby destroys the entire facility. For instance, cases of facility damage under thunder strikes have been reported at Iyana Emirin and occasionally taken in flames. This attracted monthly contributions from the entire community which took them several months to achieve because they are low-income earners and they were also left in blackouts for a long time. Even though the availability of proper facilities, quality components, good planning, and skilled workers, the ground (soil) on which the earthing facilities would be buried requires proper investigation. The experience of facility damage due to thunder strikes calls for concern, hence this study.

1.1 Description and Geology of the Study Area

The area this study was carried out is located at the Emirin community, a suburb of Ado Ekiti, along Poly Road, Ado Ekiti Nigeria. It lies between longitudes $5^0$17'06" to $5^0$18'39″ and latitudes $7^0$41'13″ to $7^0$39'55″ with an Elevation of 455 m (Figure 1) above sea level. The study area lies within a tropical rainforest climatic region. It is characterized between two seasons, the wet season and the dry season. The annual rainfall is about 1600 mm while the average daily temperature is about 290^{o}c. The geology of the area belongs to the basement complex rock of Southwestern Nigeria where major rock units are mainly crystalline basement rocks.

2.0 Research Methodology

Electrical Resistivity data involving both Schlumberger (Vertical Electrical Sounding) array and dipole-dipole array were acquired to determine soil resistivity below and around the said electrical substation in the Emirin community, Ado Ekiti. Eight (8) VES data were acquired along the four established traverses and processed with WinRes software after partial curve matching was carried out (Figure 2). 2D resistivity data (dipole-dipole) were also acquired and processed using DiproWin software.

3.0 Results and Discussion

The resistivity data acquired within the study area were processed and interpreted. The results are presented as sounding curves, tables, geo-electric sections along three profile lines, and resistivity pseudo-sections along four profiles.

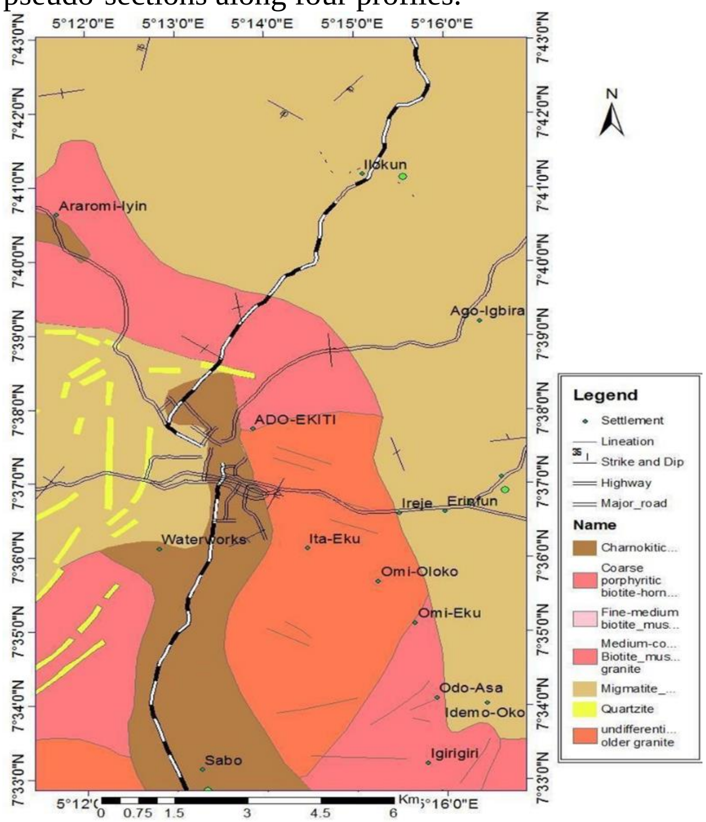


Figure 1: Geology Map of the study area

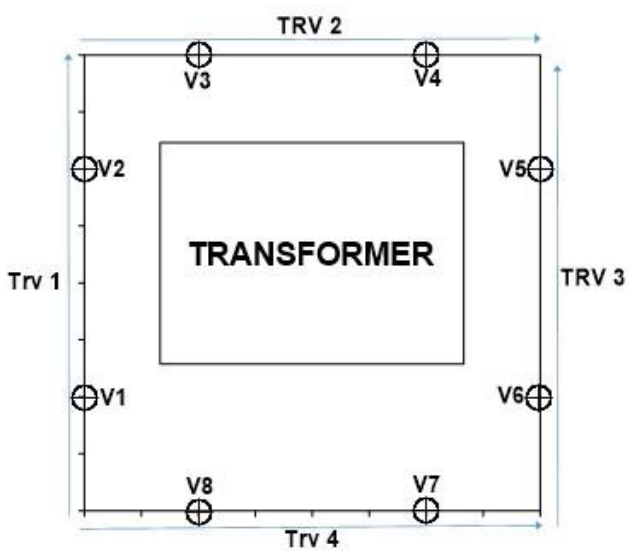
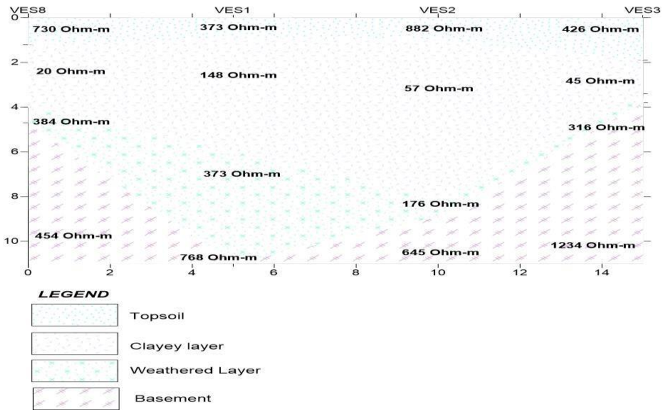


Figure 2: Base Map of the study area

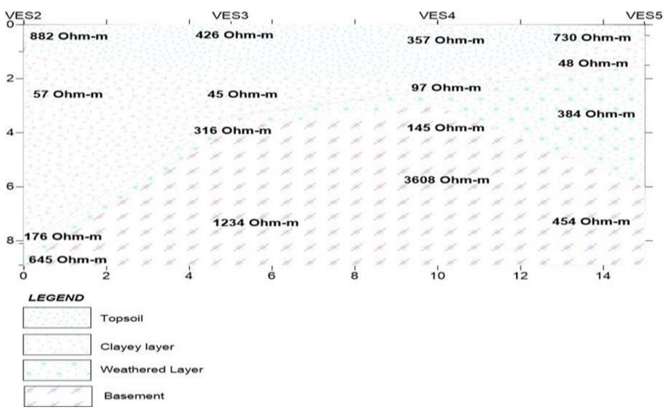
3.1 The Geo-Electric Section & Resistivity Data

Interpretation of the geo-electric section in the area shows four geo-electric layers namely: the lateritic topsoil, clayey layer, weathered layer, and weathered basement, and in some areas, fresh basement rock constitutes the last layer. Figures 3(a – d) show the various geo-sections generated from the interpreted data. The sections revealed four different subsurface geo-electric layers consisting of lateritic topsoil, clayey layer, weathered layer and the basement. Figure 3a shows the geo-section of VES stations that comprises VES8, VES1, VES2 and VES3, while the geo-section for VES2, VES3, VES4, and VES5 is shown in Figure 3b. Figure 3c shows the geo-section of VES4, VES5, VES6 and VES7. Traverse 4 comprise VES6, VES7, VES8 and VES1 (Figure 3d). The topsoil in Figure 3a is predominantly lateritic and the second layer constitutes clayey material with a resistivity value that ranges from 45.0 to 148.1 Ωm. The third layer comprises a weathered layer with resistivity ranges of 176 Ωm to 384.2 Ωm.

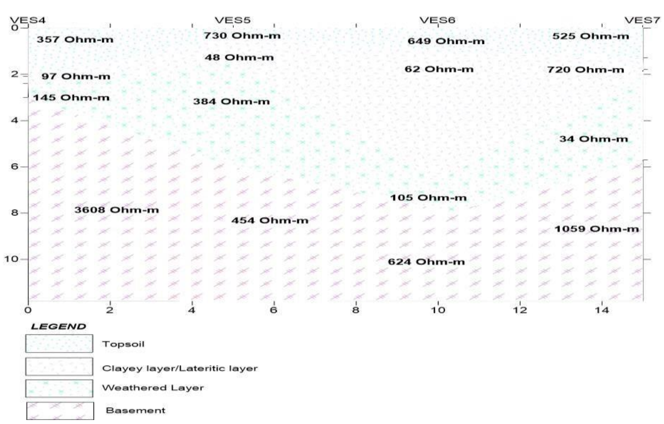
In Figure 3b, the topsoil resistivity value ranges from 373.0 to 882.2 Ωm depicting lateritic topsoil and the second layer is majorly clay with resistivity ranges from 45 to 97 Ωm while the third layer contains weathered/partly weathered basement rock with the resistivity value which ranges from 176 to 384 Ωm, the last layer is situated on basement rock. In Figure 3c the first layer contains typically lateritic material evident by the resistivity value which ranges from 357 to 730 Ωm and the second layer with a resistivity value that ranges from 48 to 97.7 Ωm is mainly a clayey layer although with some lateritic portion that indicates indurated clay, while the third layer which is weathered basement/ fresh basement rock has a resistivity value which ranges from 105 to 3609 Ωm. In Figure 3d, the resistivity of the topsoil 205 to 649 Ωm indicates the presence of lateritic material. The second layer presents a combination of clayey and lateritic layer based on the resistivity values 20 to 720 Ωm. the third layer is a clayey weathered layer and last layer fresh basement. By implication, the second layer across the geo-sections constitutes the layer that could be used for ground earthing. However, across the geo-sections, least observed resistivity is observed in VES8 (20 Ωm). Others are 45Ωm in VES3, 48 Ωm in VES5 and 57 Ωm in VES2. From the available resistivity data, 20 Ωm represents the least resistivity value within the delineated geo-electric layers, which partly agrees with the IEC and IEEE recommendation of 5 - 25 Ωm soil resistivity for earthing within 5m depth.



(a)



(b)



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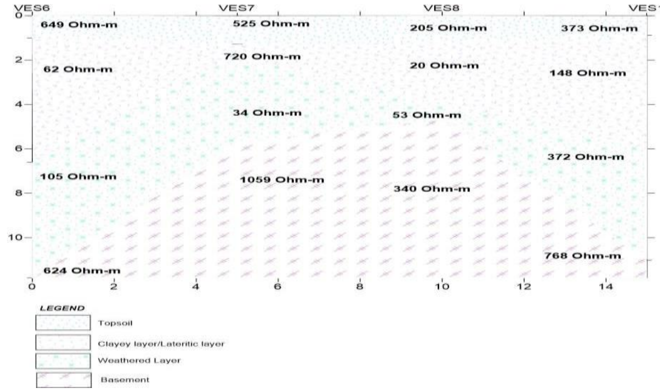


(d)

Figure 3: Geo-electric Section for (a) Traverse 1 (b) Traverse 2 (c) Traverse 3 (d) Traverse 4

Based on the summary data contained in Table 1, the topsoil within the study area is generally resistive and defies the IEC and IEEE standard that specified 5 – 25 Ωm and 5 m depth of burial for earthing material. The lowest resistivity layer below each VES station should be considered more suitable for burying earthing material, although some level of enhancement might be required as the case may be. From the interpreted data, the lowest resistivity values recorded should be considered with respect to depth for proper evaluation. VES1 (Resistivity 148 Ωm, depth 1 m), VES2 (Resistivity 56 Ωm, depth 1 m), VES3 (Resistivity 45 Ωm, depth 1.9 m), VES4 (Resistivity 97 Ωm, depth 2 m), VES5 (Resistivity 47 Ωm, depth 0.4 m), VES6 (Resistivity 62 Ωm, depth 1 m), VES7 (Resistivity 34 Ωm, depth 3.1 m) and VES8 (Resistivity 19 Ωm, depth 1.2 m). From this analysis, it could be deduced that VES1 (148 Ωm), VES2 (56.7 Ωm), VES4 (97.7 Ωm) and VES6 (62 Ωm) are not feasible for burying earthing materials because of the high resistivity value. However, VES3 (45 Ωm), VES5 (47 Ωm), VES7 (34 Ωm), and VES8 (20 Ωm) could be considered but with some level of artificial enhancement needed where necessary.

Table 1. Summary of Interpreted VES Data

VES NO	LAYER NO	RESISTIVITY (ohm-m)	THICKNESS (m)	DEPTH (m)	LITHOLOGY	CURVE
1	1	373.0	0.9	0.9	Lateritic	
	2	148.1	6.0	6.9	Topsoil	
	3	372.8	11.0	17.9	Clayey sand	HA
	4	768.3			Weathered basement	
2	1	882.2	1.0	1.0	Lateritic	
	2	56.9	8.9	9.9	Topsoil	HA
	3	176.1	8.1	18.0	Sandy Clay	
	4	645.5			Weathered basement	
3	1	426.9	1.9	1.9	Lateritic	
	2	45.0	3.8	5.7	Topsoil	
	3	316.7	3.4	9.1	Clayey layer	HA
	4	1234.6			Weathered basement	
4	1	357.2	2.1	2.1	Lateritic sand	
	2	97.7	2.4	4.6	Sandy Clay	HA
	3	144.5	3.0	7.5	Weathered	
	4	3608.0			basement	
5	1	730.8	0.4	0.4	Sandy Clay	
	2	47.5	1.5	1.9	Clayey layer	
	3	384.2	6.0	7.9	Weathered	HA
	4	454.7			basement	
6	1	649.5	1.0	1.0	Lateritic sand	
	2	62.3	11.8	12.8	Clayey Layer	HA
	3	105.2	6.6	19.4	Weathered	
	4	624.6			basement	
7	1	525.7	1.3	1.3	Sandy Topsoil	
	2	720.1	1.8	3.1	Clayey Layer	KH
	3	34.3	5.7	8.8	Weathered	
	4	1059.5			basement	
8	1	205.7	1.2	1.2	Clayey sand	
	2	19.5	4.7	5.9	Clayey Layer	HA
	3	52.5	4.0	9.9	Weathered	
	4	340.9			basement	

3.2 Electrical Resistivity Tomography

2D subsurface image showing resistivity and lithology variation are presented in Figures 4a to d along four different traverse lines. The pseudo-section (Figure 4a) embodies apparent resistivity along traverse 1 and lithological interpretation using the 2D image. The layer resistivity across the traverse is predominantly high resistivity (laterite) while some areas with low resistivity are suggestive of clay. Generally, the resistivity varies from 93 Ωm to 474 Ωm, within 2.5 m. The pseudo section reveals the presence of conductive soils within the second layer.

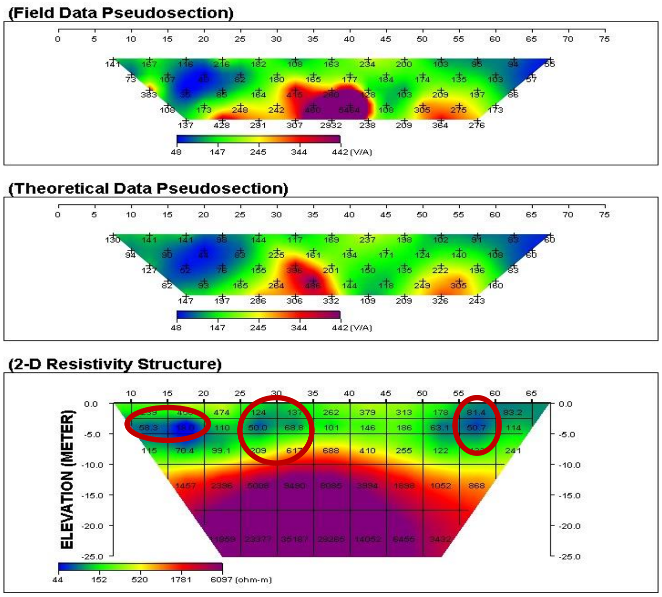
The pseudo-section (Figure 4b) shows low resistivity of 17 – 111 Ωm within 2.5 m of depth which could be interpreted as clay/clayey sand. The resistivity within the second layer across the traverse reveals a switch from laterite to clay. The pseudo-section (Figure 4c) shows that the topsoil is predominantly laterite indicated by the high resistivity values obtained within the first layer about 2.5 m deep. The transition between clay and laterite is observed along the traverse 4 pseudo-sections (Figure 4d). But generally, the topsoil of about 2.5 m along the traverse is clayey. For typical electrical earthing/grounding requirements, some portions along the four established traverses are identified to have low resistivity. Along traverse 1, between stations 20 – 30 m, ground resistivity is 19 Ωm at depth 2.5 – 5 m; at station 25 - 35, soil resistivity range between 50 – 59 Ωm at depth 2.5 – 5 m, while station 55 - 60 contains resistivity 50 – 81 Ωm at depth 1 – 5 m. On traverse 2, the resistivity at station 30 – 35 m is 26 Ωm within depth 1 – 5 m; station 40 – 50 m has a resistivity range of 10 – 19 Ωm at depth 2.5 – 10 m; at station 50 – 65 m, the resistivity 4.6 – 17 Ωm occurs at depth 1 – 5 m. On traverse 3 the resistivity at station 20 – 30 m range between 7.4 and 7.9 Ωm, occurring at depth 5 – 10 m; the resistivity of soil at station 45 – 50 m is 9.6Ωm with respect to depth 5 – 10 m. The last occurs with traverse4 between stations 20 - 25, where soil resistivity is 2.6 - 15.3 Ωm, at a depth 1 – 10 m.

3.3 Earthing Property Evaluation of the Study Area

The earthing property had been evaluated based on the resistivity of the geo-electric layers as shown through the geo-sections, information extracted from resistivity sounding curves, and the pseudo section across all the traverses. Generally, the observation from critical inspection of results across the geo-section and pseudo-sections indicate that the layer within which earthing medium i.e. where earthing material could be buried is resistive and hard evidenced by the high resistivity values as shown in the geo-electric sections and the 2D images. Therefore, resistivity values across the study area range above the recommended earthing standard (2 – 5 Ωm)/(5 – 25 Ωm) for substation installation, hence the reason for the often experienced facility damage. However, some VES stations (VES3, VES5 and VES8) have low resistivity values, which, if enhanced could serve the purpose of burying earthing materials. Along the pseudo-section on traverse 1, stations 10 - 20 m, 25 - 35 m and 60 - 65 m could potential serve burying earthing purposes to a depth of about 10 m. On traverse 2, stations 30 - 35 m, 40 - 50 m and 55 - 65 m could be considered for earthing. On traverse 3, stations 20 - 30 m and 45 - 50 m at depth of 5 - 10 m could be targeted for earthing. Finally, along traverse 4, stations 20 - 25 m and 40 - 50 m between 5 - 10 m could be used.

4.0 Conclusion

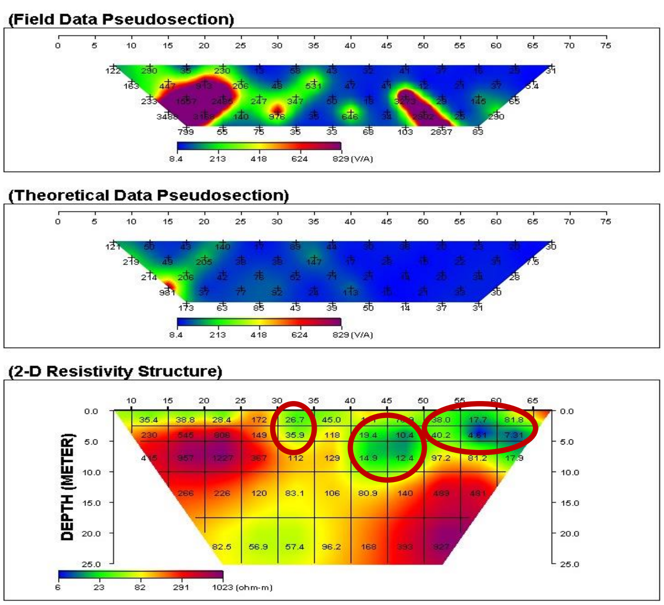
The findings of this study emphasize the critical importance of low-resistive earth for effective ground earthing/grounding systems. The predominant lateritic composition and the associated high resistivity values (>200 Ωm) observed in the topsoil across the study area provide a clear explanation for the recurring facility damages. Through thorough investigation, areas with low-resistivity soils suitable for electrical earthing/grounding were successfully identified and visually encircled in red within the pseudo-sections.



Legend

Low resistivity zone

(a)



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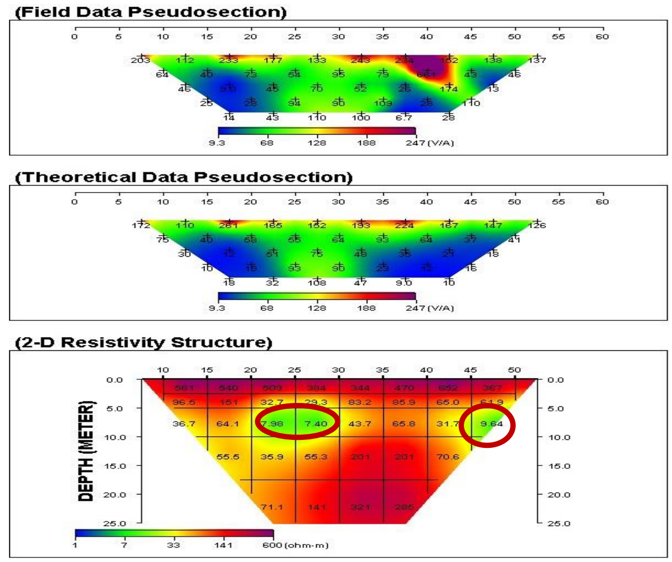
Low resistivity zone

(b)



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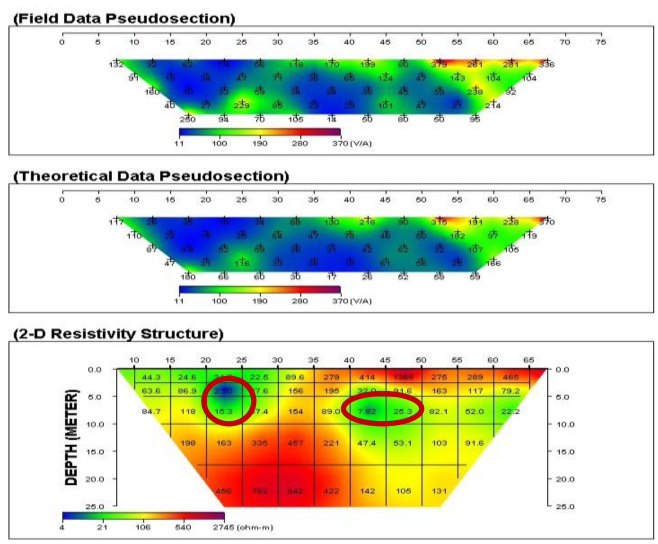
Low resistivity zone

(c)



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Low resistivity zone

(d)

Figure 4: ERT for (a) Traverse 1 (b) Traverse 2 (c) Traverse 3 (d) Traverse 4

The study also revealed variations in the resistivity values within these identified areas, indicating a need for potential enhancements to meet the recommended depth of approximately 2 m for optimal performance. As such, this research underscores the necessity for careful consideration and potential modification of the existing grounding infrastructure to ensure the reliable and efficient operation of electrical facilities in the study area.

From the results of the investigation, it is evident that the resistivity values exceed the recommended standard value of 2 – 5 Ωm/5 – 25 Ωm suitable for ground earthing. Therefore, a need for artificial enhancement like lime, salt, charcoal, and ashes, to reduce the resistivity further in order to be used for the intended purpose. Also, the identified low resistivity portion could be targeted for burying earthing/grounding material and further enhanced for better performance.

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