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Assessment and Evaluation of Soil Effect on Electrical Earth Resistance: A Case Study of Woji Area, Port-Harcourt, Nigeria

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Abstract— **The properties of different soil types that affect the resistance of a buried electrical earthing material were studied, with the objectives of achieving a lowest possible earthing resistance by enhancing the soil at the grounding site Soil conduction mechanism, general practical earthing electrodes were analysed using known techniques for electrical earth resistance measurement. In the area under test, there is indication of previous grounding installation and how good is the aim. Based on literature review, the soil samples obtained from the sites under enhanced conditions and unenhanced condition were analysed. It was observed that each soil sample had varying characteristics under different conditions at the installation site. In view of all the factors analysed, temperature had little effect on the electrical earth resistance, whereas soil structure, chemical constituent, and electrode depth are the major contributing factors that affect electrical earth resistance of a grounding system as seen from the general assessment. Specifically, soil sample A (very moist loam soil) showed a very low earth resistance of 75Ω with electrode depth of 0.38m (1.3ft), 62Ω at 0.76m (2.6ft), and at 1.14m (3.9ft) recorded resistance was 53.7Ω. Soil sample F (dry sandy soil) has the highest earth resistance, 2483Ω. In the area of optimization (when other compounds are mixed with natural soils combination) the optimized soil sample BCH (Loamy, clay + hydrogen peroxide mix) has the lowest resistance of 241Ω at depth of 1.14m (3.9ft). Sample BFH (Clay, dry sandy soil + hydrogen Peroxide) had a reading of 318Ω at a depth of 1.14m (3.9ft), whereas the biochar optimized sample BFW (Clay, dry sandy soil + wood char) showed a resistance of 366Ω at the same depth of 1.14m (3.9ft). The optimized samples showed that electrical conduction capacity of the soil was enhanced by hydrogen peroxide compared to that of biochar as seen from the result presented in Table 2, using fall of potential, etc., method conducted in the early morning hours of the day, when temperature is 26˚C.**

Index Terms— **Conduction Mechanism, Earth soil, Earth Electrode, Fall of Potential, Intersecting, Resistance, Slope Method, Soil Resistivity.**

I. INTRODUCTION

The quality and performance of grounding systems are a major concern in modern power system design. To increase the reliability of electric power supply; grounding is a very important aspect when utilizing the worldwide benefit of electric power generation, transmission and distribution. This helps to prevent excessive voltage rise during disturbances and also provides protection for operation personnel, devices and power users, equipment, etc., from the effect of natural phenomena such as lightning strikes or fault currents in the power system. With good earthing systems there is the tendency of high reliability operation of devices thereby reducing damages to power systems components. During installation of electric power systems without installation errors and proper concern for grounding; apparatus are connected to the general mass of the earth (soil) by means of ground-embedded electrodes and grid copper bars for a number of benefits which includes: (i) to ensure correct operation of electrical devices; (ii) to provide safety during normal or abnormal (fault) conditions; (iii) to stabilize the voltage during transient conditions and to minimize the probability of a flashover during transient voltage; (iv) to dissipate lightning strokes, etc., in the electric power systems to ground [1],[2],[4].

The main aim of earthing electrical systems as described earlier is to establish a common reference (zero potential) for all steelwork of power supply system, building structure, plant, protective devices, electrical conduits, cable trays, instrumentation system, humans, etc., for safety and protection; and to achieve these, a suitable earthing system is desirable using low resistance (earth rods, ground grid, bonding earth leads, and soil) for proper connection to earth. However, in often time, it is challenging to achieve the aim for protection which depends upon numbers of factors such as soil resistivity, stratification (soil layering), size and type of electrode used, depth to which the electrode is buried, moisture and chemical content of the soil, temperature, texture, etc. These important factors which affect the earth resistance are soil constituents of the earth crust [3], [7], [8].

A. Problem Statement

Due to the variations in the soil texture and other factors, its resistance in regards to grounding system for effective passage of undesirable current to earth is a concern; how the soil affect the grounding resistance and system; the optimal location of a grounding system poses some problem in installation to some extent. However, based on the case study area, the problem of earth depth, location, types of the electrode for grounding is a problem to be addressed.

B. The aim of this Research Work

The aim of this research work is to assess and evaluate the effect of soil on electrical earth resistance under natural conditions such as (texture, temperature, depth, and type of soil) and enhanced soil conditions for better performance.

C. Objectives of this Research Work

The objectives of this research work in regards to the aim are as follows:

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i) Investigate different locations for data collection.

ii) Identify the properties of the soil (the major types in Nigeria) that affect the electrical earth resistance using analytical and experimental methods.

iii) Is to determine an enhancement mechanism to the soil properties if required, to give the lowest possible earth resistance over a prolong time applying the available standard of grounding electrode and earthing practice, etc.

D. Significant of this Research Work

This research work will provide useful standard data for soil preparation of electrical earthing sites prior to electrical grounding installation that gives an optimized lowest earth resistance for reference points.

E. The scope of this Research Work

This research shall focus on the variable soil structures and resistance at different location, and how it affects the earth resistance with its optimal constituents to provide the lowest minimum earth resistance and possibly employ a way of optimizing the soil for effective low resistance within the case study area.

II. LITERATURE ASSESSMENT

Grounding of a system involves deliberate bonding of all the metallic part of equipment to the general mass of the earth through a conductor which basically possesses its own resistance. The resistance should not be greater than the design value and should be capable of carrying the expected maximum fault current. It is, therefore, necessary to consider the various factors which affect the resistance to ground and the fault current capacity of the buried conductor, designated as the ground electrode. These include the size and shape of the ground electrode and soil in which the electrode is buried, nature of soil, what to be protected, geographical location to ascertain the dominant weather condition, etc. before deciding on the suitable technique to employ. It is also necessary to consider to current density at the surface of the ground electrode and the ground potentials at the installation site. Poor considerations and design failure have often time led to many electrical shock incidents and damaged equipment as seen in [3].

Ideally, the potential of a neutral point of an electrical system whether three phase or single phase should be the same as that of the ground. In this case, human beings and animals are safe whenever they touch metallic structures connected to the system neutral. Unfortunately, the impedance (Z) of the grounding system to the ground is always a finite number. Thus, the potential of a grounded system may become different from the potential at other points on the ground during abnormal conditions [1], [2], [3].

According to [5], during a lightning strike, the electrical power system is subjected to a very large charging current with a peak rise in millisecond. Lightning strikes to high raised structures such as transmission towers, high-rise buildings, etc., can induce undesirable charges resulting into a very high voltage which in-turn cause insulation failure leading to electrical equipment damage and sometimes loss of lives. Thus, high voltage transmission and distribution systems require lightning protection and insulation co-ordination schemes to protect human and electrical equipment from danger and damage [5].

As seen in [7], earthing electrodes in different shapes and sizes are in most cases installed beneath the layer of soil close to the apparatus/facility in which such system is intended to protect for effective fault clearing. But properties of soil and the earthing systems configuration will indicate the performance and usefulness of the purpose. These three main constituents (*soil resistivity, soil stability* and *environmental factors)* impact on the performance of the electrical earthing when installed [7].

However, electrical systems do not rely on the earth to carry load current (this is done by the system conductors). The earth provides the return path for fault current. Therefore, all electrical equipment frames must be connected to ground, since the earth mass is so much and enough to discharge lightning stroke and fault current to ground. In general, the lower the ground resistance, the safer the system is considered to be; meaning in an event of a fault, the fault current path is not restricted. There shall be enough faults current to flow through the path to ground. In BS EN 62305-3:2011 (code of practice for protection of structures against lightening), under earth-termination system, the ground resistance recommended for practice shall not be greater than 10 ohms [9].

In BS 7430: 2011 (Code of practice for protective earthing of electrical installations), there are a few grounding techniques that are proposed for electrical installation in order to protect electrical equipment whether power or electronic part. From the stipulation, considerable effort should be made in decreasing the grounding resistance between the soil and the electrode(s) of the grounding system. As this, is very important for the wellbeing and efficiency of power generating stations and other electrical related equipment and installations [10].

In [3], two samples of soil consisting of top soil and sandy soil were examined when thoroughly dried. The samples showed a very good insulating property having resistivity in excess of 10^7 Ω-m at 0% moisture content. The resistivity of the soil samples were observed to change quite rapidly until approximately 20% when the texture was altered from being dry. In the same experiment, further observations were made. It was revealed further that the resistivity of the soil was influenced by four major determinants: temperature, soil texture, minerals and dissolved salts. The wide variation of resistivity of sandy loam soil which contained 15.2% moisture, when the temperature changed from 20˚C to -15˚C varied from 72 to 3300Ω-m. The resistivity of the soil is not consistent throughout the world and can change according to time of year; and it has to be analyzed for improvement in consistency for electrical earthing by soil maximization of the electrical installation's site [3].

As seen in [5], an earthing system refers to the metallic wire(s) of various geometrical shapes and sizes acting as electrodes and buried in the soil. The commonly used earthing electrodes are the vertical rod, horizontal electrode, ring electrode and earthing grid. For large electrical installations, the horizontal earth electrode is mainly used and is normally buried at a moderate depth where there is no significant effect of the depth on the earth resistance if the electrode length is about 10m to 50m in the case of transient and steady state conditions respectively. The ring electrode is a type of horizontal earthing grid and is sometimes used as surrounding earth conductors around large equipment earthing. To obtain even lower earth resistance, the horizontal earth grid can be reinforced with vertical rods which are normally inserted at the edge of the earthing grid [5].

According to [6], a well-designed grounding system should moderate and conserve high reliability of device operation to shunt- out damages caused by discharge from lightning stroke or fault currents in the event of disturbances. In some literature 3 ohms or less is accepted for earth resistance whereas in some literature due to soil texture 25 ohms or less is accepted. In the case of earth fault conditions, very low earth resistance enables fast protection system to isolate the power source and makes the earth potential rise (EPR) less dangerous to human's habitation [6].

The soil breakdown mechanisms assist in the conductivity of electricity and this centered on two principles: thermal operation and soil ionization. These are two major descriptions that explain the initiation of the conduction process. As current flows into the soil, there is a successive heating effect, the temperature of the soil water at the surrounding and soil conductivity expands, with a parallel decrease in the soil. Soil's thermal conductivity can be enhanced by ionic conduction which is a function of the volume of solvent, types of solutes, and composites present [5].

Also in [2],[7] wet soil mainly of clay-loam containing dissolved salts has low resistivity, which enables the free flow of earth current whereas dry soil has high resistivity since it often contains no soluble salts. Table 1 shows estimated soil resistivity range.

Table 1: Estimated Soil Resistivity Range

Glacial Sediment	Resistivity (Ω m)	Sedimentary rocks	Resistivity (Ω m)
Clays	5-100	Shales	6-14
Tilts	18-2000	Sandstone	18-1000
Gravel and sand	800-10,000	Conglomerate	1000-10,0000

(**Source**: Siow, *et. al*, 2013)

In [2] **2**-point and **4**-point method of measuring soil resistivity were presented. Resistance between two points, the **2**-point method is used and to achieve more accurate measurement the **4-**point method is preferable using ground tester meters. In the 4-point method, four electrodes are used (designated as U, Uv, W, V); they are equally spaced in distance and in-line at the test site. Now, a constant current generator (perhaps using a ground tester) with known current value is passed through the outer electrodes (U and V) and the potential drop due to soil resistance is measured across the inner electrodes (Uv and W). Utilizing this resistance in analytical equation yields the resistivity of the soil under test otherwise the ground tester digitally presents the value. Some earth meters are constructed and calibrated in ohms [2].

Soil Conditioning

Again in [4], it was pointed out that, different location have different soil resistivity; however, it can be high or low in some cases. To obtain a low-resistance grounding value in an area with high soil resistivity, one could have an elaborate ground system at the expense for low-resistivity. Economically, it will be wise to use ground rod system, moderate size to reduce the ground resistivity in addition with soluble chemical content into the soil occasionally. Also, note that in often time due to temperature changes, this chemically treated soil is subjected to a considerable variation in resistivity. Thus, if salt is used for the soil conditioning, it is proper to use ground rods which will resist chemical corrosion [4].

In a way to improve the soil perform for earthing system, substances such as Dead Sea water, coal and iron filling were applied around earthing electrode to reduce the earth resistance thereby enhancing the efficiency of the earthing system as in seen in [1]. The substances are soil conditioning substances and were added to a hole around the electrode with a distance not exceeding 10 cm to avoid the corrosion layer on the electrode [1].

Soil Resistivity Analysis

As presented in [3], there is need for actual resistivity measurement to fully ascertain the resistivity of a soil and its effects in relation to power systems grounding. In literature, several methods have been employed for soil resistivity measurement. However, the most commonly used technique for soil resistivity measurement was put forward by F. Wenner, the 4-point method having four ground rods equally spaced and in-line using equations (1) or (2) as presented here. This equation constitutes the apparent soil resistivity required to find, analytically as in [3],[4]. So the apparent soil resistivity is given by:

$$\rho_E = \frac{4 \cdot \pi \cdot a \cdot R_W}{\left[1 + \frac{2 \cdot a}{\sqrt{a^2 + 4 \cdot b^2}} - \frac{a}{\sqrt{a^2 + b^2}}\right]} \quad --- \quad (1)$$

The analytical equation is further simplified to:

$$\rho_E = 2 \cdot \pi \cdot a \cdot R_W \quad --- \quad (2)$$

Where:

ρ_E = the apparent soil resistivity measured in the location under consideration in (Ω-m)

a = electrode spacing distance in (m)

b = depth of the electrodes in ground in (m)

R_W = Wenner resistance measured as "V/I" [3], [4].

III. MATERIALS AND METHODS

A. The Materials Employed

For high accuracy, reliability and compatibility, the following materials will be used for carrying out the experimental measurements under *soil-unconditioned* (without enhancement) and *soil-conditioned (with enhancement)* scenarios:

A1. Electrical Meter Earth

The digital earth meter – **UT522** will be used in all the experiments. It has a resolution of 0.01 and can read to a maximum of 4000Ω. A product of **UNI-T**; it is a four-terminal digital earth meter.

A2. Earthing Electrode

Standard commercial straight type copper earthing electrode of 1.22m length is proposed.

A3. Soil Resistivity Enhancing Substances

Hydrogen peroxide and wood char are required for the enhancement of soil.

A.4 Soil Samples and Test Sites

Soil samples were collected at Woji Area, Port-Harcourt, Rivers State, Nigeria; From the topsoil 30cm depth, thereafter samples were taken to Civil Engineering Laboratory, Rivers State University, Port Harcourt, for particle size distribution analysis.

A5. Analytical Tool

MATLAB R2013a software will be used for analyzing the mathematical equations in this work.

B. The Technical Approach

B1. Soil Textural Determination and Classification (Preliminary Analysis)

The soil sieves were weighed and arranged beginning with (topsoil), one which has the biggest aperture and ending with the pan or receiver via 2.00mm, 1.00mm, 350µm, 106µm, 53µm, and pan. Now, about 500g of the soil was measured and put in the top sieve. Stack sieves were shaken for about 5 to 10 minutes, and then each set of sieve was weighed again. Mass retained, percentage passing and percentage retained were calculated. The percentage passing versus sieve diameter was also plotted, and percentages of sand, silt and clay contained in the soil were determined. The texture of the soil was then classified following the USDA soil classification method, using the soil textural triangle [11].

The experiments were conducted at different period of the day - morning, afternoon, and evening for three different experimental methods used for measuring of the electrical earth resistance. However, from the experiments conducted these alphabetical keys denoted here are as follows:

A - for very moist loam soil,
B - for loam soil,
C - for clay soil,
D - for moist sandy soil (moist sharp sand),
E - for concrete 1:5 mix,
F - for dry sandy soil (sharp sand),
H - for Hydrogen peroxide, and
W - for Wood char

All readings in this experiment greater than 4000Ω are indicated by >4k. Note: in all the Tables of result, we shall use ***tick marks*** to indicate the soil sample and combination being tested. All the optimized soil sample combinations are of equal mix proportions.

B2. Methods Utilized

Since our aim is to assess and evaluate the soil effect on electrical earth resistance: a case study at Woji area, Port-Harcourt, Nigeria was taken. We shall use three methods: Fall of Potential method, Slope method, and Intersecting curve method for evaluation. In furtherance of the evaluation, (MATLAB R2013a) software will be used for analyzing the mathematical relationship in this work.

B3. Analytical Steps

The simplified equation for predicting the electrical earth resistance with a given length of earthing rod as seen in [2] is given by

$$R = \frac{\rho_{soil}}{2\pi L} \ln\left[\left(\frac{4L}{a}\right) - 1\right] \quad \Omega \qquad \text{---} \qquad (3)$$

Where:
R= Resistance in (Ω) of the ground rod to the soil
ρ_{soil} = soil resistivity (Ωm)
L = Length of the rod (m)
a= radius of the rod (m)
ln= natural log

Equation (3) does not take into account multi-layered soils. It will only be used for obtaining the electrode resistance for each of the different experiments analytically.

Proposing analytical method to calculate the resistance of a multilayered soil (when the resistivity of the individual soil is found by any known approach) from the basic technique, thus: When current *I*, is injected into the soil through an electrode, the current density J around the electrode through the soil's surface area *A*, in contact with the electrode is given by:

$$J = \frac{I}{A} \quad \left({}^{A}/_{m^2}\right) \qquad \text{---} \qquad (4)$$

If the resistivity of the ground is ρ_{soil}, the electric field surrounding the electrode becomes the product of the current density and the soil's resistivity. Since the field intensity is responsible for the soil ionization, then conduction will only be possible at the break down ionization voltage. By denoting the break down conduction field intensity as E_c in (V/cm) or (in kV/cm), we have:

$$E_c = \rho_{soil}\ J \quad \left({}^{V}/_{m}\right) \qquad \text{---} \qquad (5)$$

Consider the use of the straight single electrode, the surface area of the soil surrounding the electrode is of cylindrical form and at the tip of the electrode it is hemispherical, thus,

$$A_{soil} = 2\pi rh + 2\pi r^2 \quad (m^2) \quad \text{---} \qquad (6)$$

Therefore,

$$J = \frac{I}{2\pi rh + 2\pi r^2} \qquad \left({}^{A}/_{m^2}\right) \quad \text{---} \qquad (7)$$

Assuming zero tolerance exists between the soil's cylindrical surface and the cylindrical straight single electrode for effective contact (including the hemispherical tip), then in equations (6) and (7), *r* and *h* are equivalent to the radius (*r*) and depth (*h*) of the electrode in the soil. An inverse proportionality exists between soil's electrical earth resistance and the depth to which the electrode is in contact with the soil. However, the conductivity by ionization is dependent upon the soil's surface area exposure. Thus, the soil's electrical earth resistance, R_s, is given as:

$$R_s = \frac{\rho_{soil}}{A_{soil}} \qquad \Omega/m \qquad \text{---} \qquad (8)$$

From Ohms law and equation (6), differentiating the soil's resistivity with respect to the surface area in contact with the electrode at y radius from the electrode,

$$\frac{dR_s}{dy} = \frac{\rho_{soil}}{2\pi yh + 2\pi y^2} \qquad \Omega \qquad \text{---} \qquad (9)$$

$$R_s = \int_r^1 \left(\frac{\rho_{soil}}{2\pi yh + 2\pi y^2}\right) \cdot dy \qquad \text{---} \qquad (10)$$

Therefore,

$$R_s = \frac{\rho_{soil}}{2\pi h} In\left(\frac{r+h}{r}\right) \quad --- \quad (11)$$

With respect to the soil's cylindrical area diameter, D,

$$R_s = \frac{\rho_{soil}}{2\pi h}\left[In\left(\frac{8h}{D}\right) - 1\right] \quad --- \quad (12)$$

Taking into account the cross-sectional area of the electrode under test as A_e, the resistance of the straight electrode is given by:

$$R_e = \rho_e \cdot \frac{L}{A_e} = \rho_e \cdot \frac{4L}{\pi {D_e}^2} \quad --- \quad (13)$$

Where ρ_e is the resistivity of the electrode material used, L is the full length of the electrode, and D_e is the diameter of the electrode. The parameter ρ_{soil}, in the derived equations is the soil's resistivity of the soil being analyzed. If we take account of all the other factors that contribute to the general soil resistance effect such as the electrode resistance which is dependent on its material constituents, temperature, moisture, texture, soil chemical composition etc, most of which are not dimensionally compactible with resistance. However, the soil's resistance and that of the electrode, we can attribute this contribution to the soil's resistivity effect on the overall soil resistance. Hence, the overall total electrical earth resistance R_{eer} becomes,

$$R_{eer} = R_s - R_e \quad --- \quad (14)$$

Substituting equations (12) and (13) into equation (14), we have

$$R_{eer} = \frac{\rho_{soil}}{2\pi h}\left[In\left(\frac{8h}{D}\right) - 1\right] - \frac{4L\rho_e}{\pi D_e^2} \quad \Omega \quad --- \quad (15)$$

For variable soil mixtures, the soil's resistivity ρ_{soil}, for such soil will be required using a pretested standard soil resistance method, perhaps equation (2), in that case, equation (15) can be effectively employed in the analytical determination of any soil type so long as the soil's resistivity ρ_{soil}, and the electrode parameters are available. Equation (15) was utilized after the experimental assessment of the different factors that affect the electrical earth resistance. The parameters and assumptions made in the use of equation (15) are that the electrode is made of pure copper having standard resistivity value of 1.678 x $10^{-8}\Omega$m; diameter is 15mm and length is 4feet (1.22m). In addition, zero tolerance between the soil surface area in contact with the electrode and uniform distribution of the soil particles were assumed in the analytical approach.

B4. Experimental Setup

Figure 1 show the experimental setup in this research work at the site under consideration. The placement/spacing of the electrodes was carried out using the three consecutive methods in measuring electrical earth resistance as mentioned earlier. The spacing distances adopted are presented here in sub-section B5.

B5. Electrode Distance Calculation

Specifications for electrode spacing range for the UT522 Meter:

Dm : $D_{min} \le D \le D_{max}$

$5m \le D \le 10m \ or\ 6ft \le Dm \le 30ft$

This maximum spacing range is due to the limited length of the lead wire.

Applying ***fall of Potential Method*** (3-point measurement) (Using small electrodes), we have

Let $\mathbf{D_{max}}$ = 10m (30ft), $\mathbf{D_{min}}$ = 5m and ***d*** = 5m

Applying the ***Slope Method***

Let $\mathbf{D_{max}}$ = 10m, for **R**: d = 20% of $\mathbf{D_{max}}$ = 2m; for $\mathbf{R_1}$: d = 40% of $\mathbf{D_{max}}$ = 4m; for $\mathbf{R_2}$: d = 60% of $\mathbf{D_{max}}$ = 6m

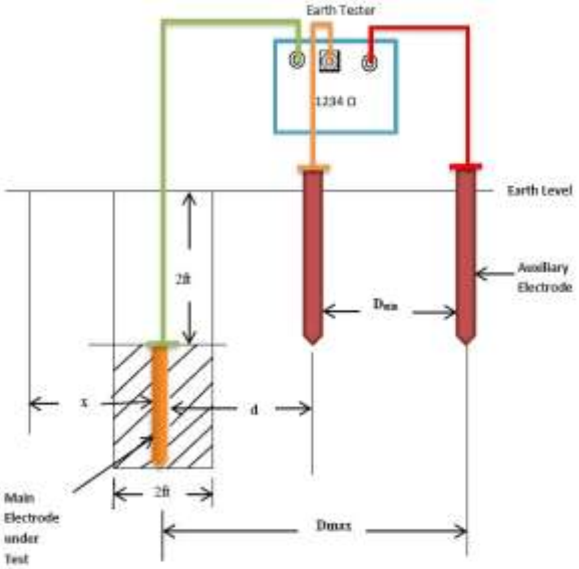

Figure 1: Experimental Setup with Electrodes Placement

Applying the ***Intersecting Curve Method***

Let **X** = 0.25m, **Dmax** = 10m,

Then, D = X + **Dmax** = 0.25m + 10m = 10.25m

d = 0. 618 (**X** + **Dmax**) – **X**

= 0.618(0.25 + 10) – 0.25

= 6.08m

Therefore, D = 10.25m and d = 6.08m

With the details of the calculations, the values of D and d were used for carrying out the experiments for each of the methods respectively.

IV. RESULTS AND DISCUSSION

A. Experimental Results

The various equations and methods were applied experimentally, and a computational program was written in MATLAB to further calculate the necessary parameters required. The electrical earth resistance was evaluated adopting the three methods: Fall of Potential, Intersecting Curve, and Slope method at a temperature of (26°C in the Morning); (40°C in the Afternoon), and (30°C in the Evening) with the different soil samples.

Tables 2, Table 3 and Table 4 are results of the **fall of potential method** showing variation in the earth resistance as temperature and electrodes' penetration depth changes. As the depth increases, each sample indicates a decrease in electrical earth resistance. However, at 40^{o}C the electrical earth resistance for the various soil types is lower than those obtained at 26^{o}C and 30^{o}C. Soil sample A at the different temperatures showed the lowest earth resistance compared to other samples. Sample F showed consistently high earth resistance. This is as a result of the fact that dry sandy soil has low moisture content with high pore spaces between the soil grains which invariably reduces the packing efficiency, thus reducing the surface area of the soil to which the electrode is exposed for effective current conduction. Hence, the soil texture for this sample poses a critical factor to its earth resistance value. For concrete 1:5 mix – sample E, at all temperatures and at 1.3ft, the earth resistances obtained were constant >4000 Ω. As the depth increases, the resistance dropped considerable due to the compactness of the concrete, increased surface area, and moisture content.

From Table 5, Table 6, and Table 7 are **intersecting curve method** also showed variation in resistance with change in temperature and depth. A decrease in electrical earth resistance can be observed as the depth increased for each sample investigated. At 40^{o}C, the electrical earth resistances for the various soils are lower than those obtained at 26^{o}C and 30^{o}C. The same trend was observed in the Fall of Potential method.

Table 8, Table 9 and Table 10 are results for the **slope method** experiment. The result obtained, exhibited the same trend as seen in the above methods, as increase in temperature and depth is inversely proportional to resistance.

Table 2: Earth Resistance Measurement using Fall-of-Potential Method at Temperature of *26^{o}C*

Test Electrode Resistance: *1.1Ω*												***Length of Rod:*** *4ft*	
Electrode Type: Straight Single copper rod													
Soil Temperature: 26^{o}C , **Soil Resistance:** 113.19 Ω , **Site Location:** Woji, Rivers State, Nigeria													
Period of Day: Morning (6:00AM)													
Electrode Spacing (m)		**Resistance at Depth (ft)**			**Soil Types**							**Chemical**	**Biochar**
D	**d**	**1.3 ft**	**2.6 ft**	**3.9 ft**	**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
		R(Ω)	**R(Ω)**	**R(Ω)**									
10	5	246.1	135.2	98.6	✓								
10	5	608	510	325.4				✓					
10	5	>4k	>4k	2483							✓		
10	5	394	386	254					✓				
10	5	611	380	396			✓						
10	5	385	302	290			✓	✓					
10	5	1498	1006	781			✓				✓		
10	5	410	289	241			✓	✓				✓	
10	5	872	498	318			✓				✓	✓	
10	5	1470	680	362			✓	✓					✓
10	5	690	384	366			✓				✓		✓
10	5	>4k	1265	324						✓			
10	5	75	62	53.7		✓							

Table 3: Earth Resistance Measurement using Fall-of-Potential Method at Temperature of 40^{o}C

Test Electrode Resistance:1.1Ω												**Length of Rod:** 4ft	
Electrode Type: Straight Single copper rod													
Soil Temperature: 40^{o}C , **Soil Resistance:** 116.58 Ω , **Site Location:** Woji, Rivers State, Nigeria													
Period of Day: Afternoon (1:00PM)													
Electrode Spacing (m)		**Resistance (Ω) at Depth (ft)**			**Soil Types**							**Chemical**	**Biochar**
D	**d**	**1.3 ft**	**2.6 ft**	**3.9 ft**	**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
		R(Ω)	**R(Ω)**	**R(Ω)**									
10	5	216.1	115.2	83.6	✓								
10	5	578	460	215.4				✓					
10	5	>4k	>4k	2183							✓		
10	5	324	306	194					✓				
10	5	538	319	316			✓						
10	5	305	220	210			✓	✓					
10	5	1267	926	701			✓				✓		
10	5	330	229	211			✓	✓				✓	
10	5	822	438	258			✓				✓	✓	
10	5	1320	620	302			✓	✓					✓
10	5	620	314	320			✓				✓		✓
10	5	>4k	1145	224						✓			
10	5	52	42	33.7		✓							

Table 4: Earth Resistance Measurement using Fall-of-Potential Method at Temperature of 30°C

Test Electrode Resistance: 1.1Ω												**Length of Rod:** 4ft	
Electrode Type: Straight Single copper rod													
Soil Temperature: 30°C **Soil Resistance:** 115.10 Ω **Site Location:** Woji, Rivers State, Nigeria													
Period of Day: Evening (6:00PM)													
Electrode Spacing (m)		**Resistance at Depth (ft)**			**Soil Types**							**Chemical**	**Biochar**
D	**d**	**1.3 ft**	**2.6 ft**	**3.9 ft**	**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
		R(Ω)	**R(Ω)**	**R(Ω)**									
10	5	226.1	125.2	93.6	✓								
10	5	598	480	315.4				✓					
10	5	>4k	>4k	2383							✓		
10	5	364	316	204					✓				
10	5	578	339	366			✓						
10	5	325	280	250			✓	✓					
10	5	1467	996	731			✓				✓		
10	5	380	259	231			✓	✓				✓	
10	5	842	468	298			✓				✓	✓	
10	5	1420	630	312			✓	✓					✓
10	5	640	324	326			✓				✓		✓
10	5	>4k	1245	254						✓			
10	5	66	52	43.7		✓							

Table 5: Earth Resistance Measurement using Intersecting Curve Method at Temperature of 26°C

Test Electrode Resistance: 1.1Ω												**Length of Rod:** 4ft	
Electrode Type: Straight Single copper rod													
Soil Temperature: 26°C ; **Soil Resistance:** 113.19 Ω ; **Site Location:** Woji, Rivers State, Nigeria													
Period of Day: Morning (6:00AM)													
Electrode Spacing (m)		**Resistance at Depth (ft)**			**Soil Types**							**Chemical**	**Biochar**
D	**D**	**1.3 ft**	**2.6 ft**	**3.9 ft**	**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
		R(Ω)	**R(Ω)**	**R(Ω)**									
10	5	304	190.7	162.2	✓								
10	5	685	448	376				✓					
10	5	>4k	>4k	>4k							✓		
10	5	630	361	316					✓				
10	5	489	423	269			✓						
10	5	389	511	282			✓	✓					
10	5	1328	1281	807			✓				✓		
10	5	386	367	398			✓	✓				✓	
10	5	1065	880	377			✓				✓	✓	
10	5	1134	892	298			✓	✓					✓
10	5	415	274	329			✓				✓		✓
10	5	>4k	935	142						✓			
10	5	73.6	89.8	58.7		✓							

Table 6: Earth Resistance Measurement using Intersecting Curve Method at Temperature of 40°C

Test Electrode Resistance: 1.1Ω												**Length of Rod:** 4ft	
Electrode Type: Straight Single copper rod													
Soil Temperature: 40°C; **Soil Resistance:** 116. 58Ω ; **Site Location:** Woji, Rivers State, Nigeria													
Period of Day: Afternoon (1:00PM)													
Electrode Spacing (m)		**Resistance (Ω) at Depth (ft)**			**Soil Types**							**Chemical**	**Biochar**
D	**D**	**1.3 ft**	**2.6 ft**	**3.9 ft**	**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
		R(Ω)	**R(Ω)**	**R(Ω)**									
10	5	294	170.7	132.2	✓								
10	5	625	418	326				✓					
10	5	>4k	>4k	>4k							✓		
10	5	619	321	306					✓				
10	5	459	403	229			✓						
10	5	349	491	262			✓	✓					
10	5	1308	1251	779			✓				✓		
10	5	346	307	381			✓	✓				✓	
10	5	1045	850	347			✓				✓	✓	
10	5	1104	872	288			✓	✓					✓
10	5	405	264	319			✓				✓		✓
10	5	>4k	925	132						✓			
10	5	69.3	85.6	52.7		✓							

Table 7: Earth Resistance Measurement using Intersecting Curve Method at Temperature of 30^{o}C

Test Electrode Resistance: 1.1Ω												**Length of Rod:** 4ft	
Electrode Type: Straight Single copper rod													
Soil Temperature: 30^{o}C ; **Soil Resistance:** 115.10 Ω ; **Site Location:** Woji, Rivers State, Nigeria													
Period of Day: Evening (6:00PM)													
Electrode Spacing (m)		**Resistance at Depth (ft)**			**Soil Types**							**Chemical**	**Biochar**
D	**D**	**1.3 ft**	**2.6 ft**	**3.9 ft**	**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
		R(Ω)	**R(Ω)**	**R(Ω)**									
10	5	234	120.7	112.2	✓								
10	5	615	408	312				✓					
10	5	>4k	>4k	>4k							✓		
10	5	609	311	301					✓				
10	5	429	385	219			✓						
10	5	329	431	232			✓	✓					
10	5	1258	1201	729			✓				✓		
10	5	336	287	331			✓	✓				✓	
10	5	1035	820	317			✓				✓	✓	
10	5	1004	842	238			✓	✓					✓
10	5	385	234	289			✓				✓		✓
10	5	>4k	905	112						✓			
10	5	59.3	75.6	42.7		✓							

Table 8: Earth Resistance Measurement using Slope Method at Temperature of 26^{o}C

Test Electrode Resistance: 1.1Ω																					**Length of Rod:** 4ft	
Electrode Type: Straight Single cooper rod																						
Soil Temperature: 26^{o}C ; **Soil Resistance:** 113.19 Ω ; **Site Location:** Woji, Rivers State, Nigeria																						
Period of Day: Morning (6:00AM)																						
Electrode Spacing (m)				**Resistance(Ω) at Depth (ft)**									**Soil Types**								**Chemical**	**Biochar**
D	**d**	**Q**	**S**	**1.3ft**			**2.6 ft**			**3.9 ft**			**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**		**H**	**Wood**
				R	**R$_1$**	**R$_2$**	**R**	**R$_1$**	**R$_2$**	**R**	**R$_1$**	**R$_2$**										
10	5	4	6	238	249.1	293	203.7	212.2	205	120	136	135.5	✓									
10	5	4	6	627	632	645	341	348	356	324	329	336				✓						
10	5	4	6	>4k	>4k	>4k	>4k	>4k	>4k	>4k	>4k	>4k							✓			
10	5	4	6	398	405	473	297	307	320	337	319	316					✓					
10	5	4	6	569	573	582	342	350	356	229	234	239			✓							
10	5	4	6	314	330	335	383	390	398	262	268	275			✓	✓						
10	5	4	6	1466	1485	1489	1125	1148	1166	793	790	788			✓				✓			
10	5	4	6	400	425	415	271	280	303	395	397	403			✓	✓					✓	
10	5	4	6	1040	1048	1053	618	632	633	430	587	590			✓				✓		✓	
10	5	4	6	1356	1393	1406	676	653	638	288	295	309			✓	✓						✓
10	5	4	6	627	638	641	447	447	451	320	328	329			✓				✓			✓
10	5	4	6	1970	1889	1840	680	690	708	130	136	142						✓				
10	5	4	6	63	68.2	74.3	50.6	58	63	45.1	51.4	57.7		✓								

Table 9: Earth Resistance Measurement using Slope Method at Temperature of 40^{o}C

Test Electrode Resistance: 1.1Ω																					**Length of Rod:** 4ft	
Electrode Type: Straight Single copper rod																						
Soil Temperature: 40^{o}C ; **Soil Resistance:** 116.58 Ω ; **Site Location:** Woji, Rivers State, Nigeria																						
Period of Day: Afternoon (1:00PM)																						
Electrode Spacing (m)				**Resistance(Ω) at Depth (ft)**									**Soil Types**								**Chemical**	**Biochar**
D	**d**	**Q**	**S**	**1.3 ft**			**2.6 ft**			**3.9 ft**			**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**		**H**	**Wood**
				R	**R$_1$**	**R$_2$**	**R**	**R$_1$**	**R$_2$**	**R**	**R$_1$**	**R$_2$**										
10	5	4	6	218	229.1	253	183.7	192.2	197.5	117.8	126	131.3	✓									
10	5	4	6	607	618	625	331	338	346	314	319	326				✓						
10	5	4	6	>4k	>4k	>4k	>4k	>4k	>4k	>4k	>4k	>4k							✓			
10	5	4	6	378	395	453	277	295	310	327	309	306					✓					
10	5	4	6	559	563	565	332	340	346	219	224	229			✓							
10	5	4	6	314	320	325	373	380	389	250	256	262			✓	✓						
10	5	4	6	1446	1460	1468	1105	1138	1156	783	778	779			✓				✓			
10	5	4	6	390	400	409	261	270	283	375	377	381			✓	✓					✓	
10	5	4	6	1030	1036	1045	608	616	623	415	567	570			✓				✓		✓	
10	5	4	6	1356	1383	1396	657	633	622	278	285	297			✓	✓						✓
10	5	4	6	617	628	631	437	437	441	310	318	319			✓				✓			✓
10	5	4	6	1960	1878	1830	660	680	690	120	126	132						✓				
10	5	4	6	57	63.2	69.3	45.6	53	58	40.1	46.4	52.7		✓								

Table 10: Earth Resistance Measurement using Slope Method at Temperature of 30°C

Test Electrode Resistance: 1.1Ω	**Length of Rod:** 4ft

Electrode Type: Straight Single copper rod

Soil Temperature: 30°C ; **Soil Resistance:** 115.10 Ω ; **Site Location:** Woji, Rivers State, Nigeria

Period of Day: Evening (6:00PM)

Electrode Spacing (m)				**Resistance(Ω) at Depth (ft)**									**Soil Types**							**Chemical**	**Biochar**
D	**d**	**q**	**S**	**1.3 ft**			**2.6 ft**			**3.9 ft**			**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
				R	**R_1**	**R_2**	**R**	**R_1**	**R_2**	**R**	**R_1**	**R_2**									
10	5	4	6	208	219.2	243	173.5	182.2	187.7	107.8	116	121	✓								
10	5	4	6	600	610	615	321	328	336	304	309	316				✓					
10	5	4	6	>4k	>4k	>4k	>4k	>4k	>4k	>4k	>4k	>4k							✓		
10	5	4	6	378	385	443	267	285	302	319	301	295					✓				
10	5	4	6	548	552	558	322	330	336	209	214	219			✓						
10	5	4	6	304	310	315	363	370	378	241	248	253			✓	✓					
10	5	4	6	1435	1452	1458	1101	1121	1146	772	769	768			✓				✓		
10	5	4	6	382	395	400	251	260	274	364	367	379			✓	✓				✓	
10	5	4	6	1021	1026	1036	600	609	613	405	557	560			✓				✓	✓	
10	5	4	6	1346	1373	1386	646	623	612	268	276	288			✓	✓					✓
10	5	4	6	608	619	622	428	426	431	302	310	307			✓				✓		✓
10	5	4	6	1951	1865	1820	652	671	682	111	115	122						✓			
10	5	4	6	46	54.3	58.5	36	46	49	32	36.6	44.8		✓							

Table 11: Measured Soil Resistivity at Temperature of 25°C

Soil Types									**Resistivity (Ωm)**
							Chemical	**Biochar**	
Site Soil	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**WOOD**	
✓									141.26
			✓						370.64
						✓			2452.8
				✓					289.09
		✓							375.91
		✓	✓						248.98
		✓				✓			998.65
		✓	✓				✓		239.84
		✓				✓	✓		493.55
		✓	✓					✓	811.12
		✓				✓		✓	403.3
					✓				1240.4
	✓								54.4

Table 12: Analytical Earth Resistance (using Equation 15)

Resistance at Depth (ft)			**Soil Types**							**Chemical**	**Biochar**
1.3	**2.6**	**3.9**	**Site Soil**	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**Wood**
R(Ω)	**R(Ω)**	**R(Ω)**									
246.9758	143.1495	103.1006	✓								
648.0186	375.5978	270.5168				✓					
4288.4	2485.6	1790.2							✓		
505.4384	292.9570	210.9964					✓				
657.2326	380.9383	274.3632			✓						
435.3110	252.3104	181.7215			✓	✓					
1746.0	1012.0	728.8787			✓				✓		
419.3308	243.0482	175.0506			✓	✓				✓	
862.9117	500.1519	360.2244			✓				✓	✓	
1418.1	821.9699	592.0073			✓	✓					✓
705.1206	408.6947	294.3541			✓				✓		✓
2168.7	1257.0	905.3234						✓			
95.1117	55.1276	39.7046		✓							

B. Discussion

From results obtained from Fall-of-Potential method experiment Tables 2, 3 and 4. In Table 2, the effect of Temperature change is clearly seen when the test was carried out in the early morning hour (6am) and afternoon hour (1pm), the resistance at a depth and length of earth rod of 1.3ft (0.38m) is seen to be 246.1Ω (6am), and 216.1Ω (1pm) respectively, observing the natural site soil. Hence, increase in temperature leads to decrease in resistance. This is due to increase in ionization of the soil which occurred when the heat from sunlight became higher. Similarly, observing the site soil in Table 2, when the depth of earth rod into the soil was 0.38m (1.3ft), 0.76m (2.6ft) and 1.14m (3.9ft) respectively, it was discovered that the corresponding resistance was 241.6, 135.2 and 98.6(Ω) respectively. This shows that, increase in depth of earth rod leads to decrease in electrical earth resistance, because the surface area of electrode in contact with the soil increases with depth, thus increasing conductivity.

Comparing the result of the soil samples in Table 2, Specimen A, B, C, D, E, and F at a constant depth of 3.9ft (1.14m), the soil samples yielded results like: A-(very moist soil) gave 53.7Ω reading, B-(loamy soil) 396Ω, C-(clay soil) 325.4Ω, D-(moist sandy soil) 254Ω, E-(concrete mix) 324Ω, F-(dry sandy soil) 2,483Ω.

The above soil samples result at a constant depth (1.14m) indicates that moist soil is the best for electrical earthing. This is because of the decomposed organic materials and different types of salts dissolved in it, and a very high amount of water it contains. In the absence of a moist soil, a clay soil becomes an option. Hence, from the result obtained, Dry Sandy Soil should not be a considerable option. In a sandy area, it is recommended that a back fill using loamy and clay soil should be employed, perhaps, an addition of a biochar.

From the soil optimization sample mixtures, still in Table 2, sample BC (loam + clay) gave 290Ω, BF (loam + dry sandy) 781Ω, BCH (loam + clay + hydrogen peroxide) 241Ω, BFH (loam + dry sandy + hydrogen peroxide) 318Ω, BCW (loam + clay + wood char) 362Ω, BFW (loam + dry sandy + wood char) 366Ω. Samples BCH are (loam + clay + hydrogen peroxide). Loam, clay and hydrogen peroxide mix yielded a low resistance of 241Ω, followed by specimen BC 290Ω, BFH 318Ω and BCW 362Ω respectively at a constant temperature and depth of 26˚C, 3.9ft respectively. The above varied samples showed that, soil enhancement yielded better result in which the combination of hydrogen peroxide gave the lowest resistance followed by samples BC. Hence, the experiment showed clearly that soil mix is a very good option in electrical earthing, as loam soil and clay soil yielded a low resistance which will further be enhanced when the depth is increased. It is evident that the soil samples mixed with hydrogen peroxide (H) gave a much lower resistance when compared with sample BCW 362Ω (loam + clay + wood char). But the optimization samples involving wood char (W) is preferred, since it is most economical and does not degrade so easily with time. It maintains the resistivity of the earth within the acceptable range as long as the standard precautions are maintained.

In all the experiment, it is evident that soil enhancement gives the lowest possible resistance when compared to the results of the un-optimized soil samples (ie. unenhanced samples). The same pattern was observed in intersection and slope method experiments as shown in Tables 5 to 10. Comparing the results obtained for both experimental and analytical methods, (Table 2 and Table 12) Table 12 showed that the results from analytical equation (number 15) were close to that of the experimental results. However, based on the soil optimization, the different soil samples exhibited variable resistivity values as shown in Table 11 which invariably has effect on the calculations using analytical equation number 15. Consequently, the variations between the experimental and analytical earth resistance values showed wide deviations for soil sample E (concrete mix). For natural site soil, the variation is minimal at a depth of 1.14m (3.9ft). In all, there is either a minimal difference, or a wide range in value between the analytical and experimental results. Note that due to the number of pages required for publication, the percentage error calculation and comparison of results between fall of potential method, intersecting curve method and slope method will not be attached herein.

V. CONCLUSION

A. Conclusion

Based on the experimental results from Table 2 to Table 10 generated from the MATLAB software (R2013a) using equation 3, the following conclusions were drawn:

1) The results obtained in the course of this work proved that soil resistivity which is a measure of the soils resistance to the free flow of electricity, is the key factor that determines what the resistance of a ground electrode will be, and to what depth it must be driven to obtain low ground resistance.
2) The number of dissolved electrolytes (moisture, minerals and dissolved salts) in the ground determines the hardness of the soil. When the test soil was hard, the reading was excessively high. When the test soil was moisture-like, the reading was very low.
3) To achieve a very low earth resistance, backfilling the earth pit employing the soil mix method like, loamy and clay soil mix whose porosity is high, yields the desired result.
4) A prediction to calculate the resistance of a multilayered soil was advanced, given as:

$$R = \frac{\rho}{2\pi h}\left[In\left(\frac{8h}{D}\right) - 1\right] - \frac{4L\rho_g}{\pi D_g^2}$$

In view of the above conclusion, the decisive measures outlined in this research work have to be followed uncompromisingly. This will ensure that avoidable system breakdown will be minimized. Continuity of power supply will be maintained. Death incidents as a result of electrocution will be reduced to the very minimum.

B. Recommendation

To achieve a good resistance during earthing, it is very necessary to test the soil compatibility. If earth tester is not available, bury more earth rods and endeavor to go deeper if possible. It is necessary to periodically test the resistance of the earth electrode with respect to the ground. The danger of poor earthing or/and negligence of earthing (grounding) will cause more than good. As lives and expensive equipment will be lost in the event of fault or during lightning strike on buildings/installations that are not earthed or well earthed.

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