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Assessment of Soil Resistivity on Grounding of Electrical Systems: A Case Study of North-East Zone, Nigeria

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Abstract

Electricity is dangerous and required proper grounding to prevent unwanted voltage from passing through personnel, critical equipment and other nearby metallic objects. This paper presents the impact of soil resistivity on earth electrode grounding by carrying out extensive measurement of tower footing earth electrode resistance and soil resistivity along the 330kV transmission line between Jos and Gombe in the North-East zone of Nigeria, using the Fall-of-Potential method and Wenner Array method. The study revealed that the values of earth electrode resistance range from 0.3 to 20 Ohms while the soil resistivity ranges from 60 to 1000 Ohm-m. The results confirmed that the values of earth electrode resistance have great impact on the types of soil in which the earth mat was grounded; hence effort should be made to improve soil resistivity for effective grounding of systems.

Keywords: Earth Electrode Resistance, Effective Grounding, Electrical Earthing Systems, Soil Resistivity

I. INTRODUCTION

Power system grounding is very important, particularly since a large majority of faults involve ground or are caused by thunderstorm/lighting strikes (Cummins, 2002). The term earthing and grounding have the same meaning and it is a means of making a connection between the equipment and the general mass of the earth. The principal purpose of grounding is to minimize potential transient overvoltage, in compliance with standards for personnel safety requirements and to assist in the rapid detection and isolation of the fault areas. Grounding connection is accomplished by driving ground electrode into several places of the earth. A earth electrode is a metal plate, metal pipe or metal conductors electrically connected to the earth. The materials generally used for earth electrodes are made of copper, aluminum, mild steel and galvanized iron in order of preference. The factors that influence the earthing resistance of an electrode or group of electrodes includes the composition of the soil in the immediate neighborhood, the temperature of the soil, the moisture content of the soil and the depth of the electrode. Thus, the composition of a soil gives a very good indication as to what order of resistivity is to be expected. Soil resistivity measurement is normally carried out to determine the actual value for the in-situ soil under the prevailing weather conditions in which an electrode is installed.

It is well known that the resistance of an earth electrode is heavily influenced by the resistivity of the soil in which it is driven and as such, soil resistivity measurements are an important parameter when designing earthing installations. In this paper, Wenner array method was used for soil resistivity measurement and fall-of-potential method for measurement of effective resistance of earth termination networks.

In 1915, Wenner demonstrated that field test measurements of soil resistivity are commonly obtained by use of the four-pin method. Blattner (1982) compared the four-pin method and concluded that the Wenner four-pin method is the simplest to perform whereas the driven rod methods are more costly and time consuming to perform. Gustafson et al (1990) focused on seasonal variations in distribution system grounding and their effect on neutral-to-earth voltage. Dawalibi et al (1994) used computer techniques to develop two layer soil methods based on field measurements.

Resistance is that property of a conductor which opposes electric current flow when a voltage is applied across the two ends. Resistance is the ratio of the applied voltage (V) to the resulting current flow (I) as defined by the well known linear equation from Ohm's Law (Nagrath et al, 2001):

$$V = I \times R \qquad (1)$$

Where

V is the Potential Difference across the conductor (Volts)

I is Current flowing through the conductor in (Amperes)

R is Resistance of the conductor in (Ohms)

The resistance (R) of a conductor can also be derived from the resistivity as (Nagrath et al, 2001):

$$R = \frac{\rho \times L}{A} \qquad (2)$$

Where

L is the Length of the conductor (m)

A is the Cross sectional Area (m^2)

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ρ is the Resistivity (Ω-m) of the conductor material

Soil resistivity is defined as the resistance between the opposite faces of a cube of soil having sides of length one meter and can be expressed in Ohm-metres. Soil resistivity is the key factor that determines what the resistance of the charging electrode will be and to what depth it must be driven to obtain low ground resistance. The resistivity of the soil varies widely throughout the world and changes seasonally. Soil resistivity is determined largely by the content of its electrolyte which consists of moisture, minerals, and the dissolved salt. It figures has a direct impact on the overall sub-station resistance and how much earth electrode is required to achieve the desired values. The lower the resistivity the fewer the electrodes required to achieve the desired earth resistance value. It is an advantage to know the resistivity value at the planning stage as it gives an indication for how much electrode is likely to be required. When selecting the test technique for soil resistivity, factors such as maximum probe depths, lengths of cables required, efficiency of the measuring technique, cost and ease of interpretation of the data need to be considered. However, the Wenner array method (Wenner, 1915) is the most efficient method in terms of the ratio of received voltage per unit of transmitted current and this was adopted in this paper to measure the soil resistivity. Therefore, the apparent resistivity for the Wenner array can be obtained from the field measurements using the following formulae (Nigel, 2006).

$$\rho = 2\pi a \frac{\Delta V}{I} \quad (3)$$

$$\rho = 2\pi a R \quad (4)$$

Where

ρ is resistivity of the local soil (Ω-cm)

ΔV is the voltage measured (V)

a is distance between probes(m)

R is resistance determined by the testing device or instrument(Ω)

Resistance to the earth of any earth electrode is influenced by the resistivity of the surrounding soil. This depends to a large extent on the nature of the soil and its moisture content. Since soil exhibits a resistance to the flow of electrical current and is not an ideal

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conductor, there is always some resistance (can never be zero) between the earth electrode and "true Earth". This resistance is called earth resistance of an electrode and it depends on the soil resistivity, the type and size of the electrode and the depth to which it is buried. The most commonly used method of measuring the earth resistance of an earth electrode is the Fall-of-Potential measuring technique (Dawalib, 2002). It is the most recognized method for measuring the resistance to earth of a grounding system, or the ground system performance. This method is based on an IEEE standard and when properly performed, it gives a very accurate result. It is normally suitable for use in circumstances such as transmission line structure earths, or areas of difficult terrain, because of the shallow penetration that can be achieved in practical situations.

Earth Resistance (Rg) of a single spike, of diameter (d) and driven length (L) driven vertically into the soil of resistivity (ρ), can be calculated as follows (Nigel, 2006):

$$R_g = \frac{\rho}{2\pi L}\left[\ln\frac{8L}{d} - 1\right] \qquad (5)$$

where

ρ is the soil resistivity in Ω-m

L is the buried length of the electrode in m

d is the diameter of the electrode in m

II. MATERIAL AND METHODS

Wenner array method and Fall-of-Potential technique were used to determine the soil resistivity and tower footing earth resistance respectively at each selected tower along the transmission line. The following listed equipment was used for the field measurements in this work.

- A 4-Pole Digital Meter – (Megger Earth Tester)
- Four probes
- Four insulated wire conductors
- Measuring tape
- Hammer (to drive probes)
- User's Manual for Meter

A. Wenner Four Point Method

The best method for testing soil resistivity is the Wenner Four Point method**.** It uses a 4-pole digital ground resistance meter, such as the Megger meters, probes, and conductors. It requires inserting four probes into the test area. In this work, the probes were installed in a straight line and equally spaced at 20 meters to each other and deep into the soil by 0.5meter as shown in Figure1. In this case, the probes were used to establish an electrical contact with the earth. The Megger meter then injected a constant current through the ground via the tester and the outer two probes (C1 and C2), and the current flows through the earth (a resistive material) developed a voltage or potential difference. This voltage dropped resulting from the flow of current was then measured between the two inner probes (P1 and P2).

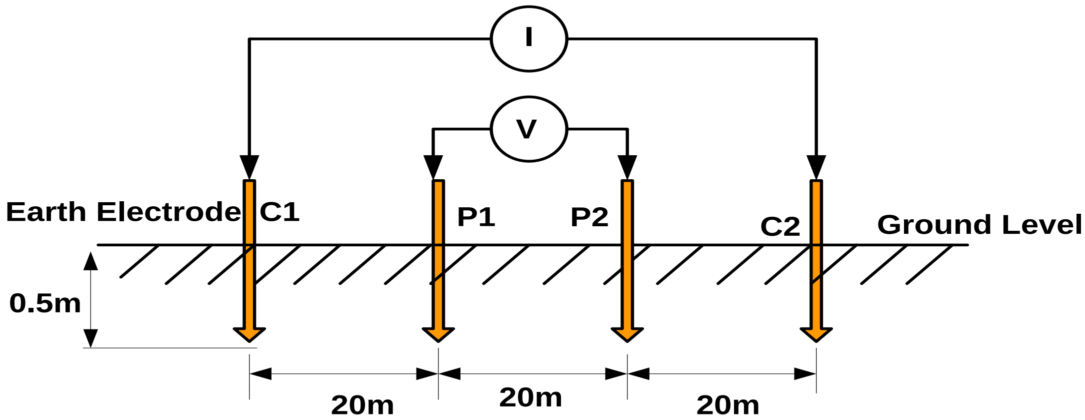

Figure 1: Wenner 4 Pin Method

Thereafter, the amount of current indicated by the meter was the current that was flowing through the earth and the voltage drop across the two center probes. The resistance obtained from the Megger meter was then used to determine the soil resistivity by using equation (4) stated above.

B. Fall of Potential Technique

In this work, three points of ground contact were considered which include the earth electrode under test (COM), a current probe (C) which was placed at some distance from the ground system under test and voltage probe (P) that was inserted at various distances between the system under test and the current probe as shown in figure2. With this method, the Megger meter was used to inject current into the tower footing earth electrode under test

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(COM). The current then flows through the earth to the remote current probe (C) and returns to the meter. As the current flows through the resistive material (earth) a voltage drop was created. This voltage drop is proportional to the amount of current flow and the resistance of the earth electrode to earth. The voltage probe (P) was used to measure this voltage drop and the meter then displays both the amount of current flow and the resulting voltage drop. The resistance measured at several locations moving the voltage probe (P) at regular intervals, each of them equal 10% distance of COM and C was then display by the Megger tester and was recorded.

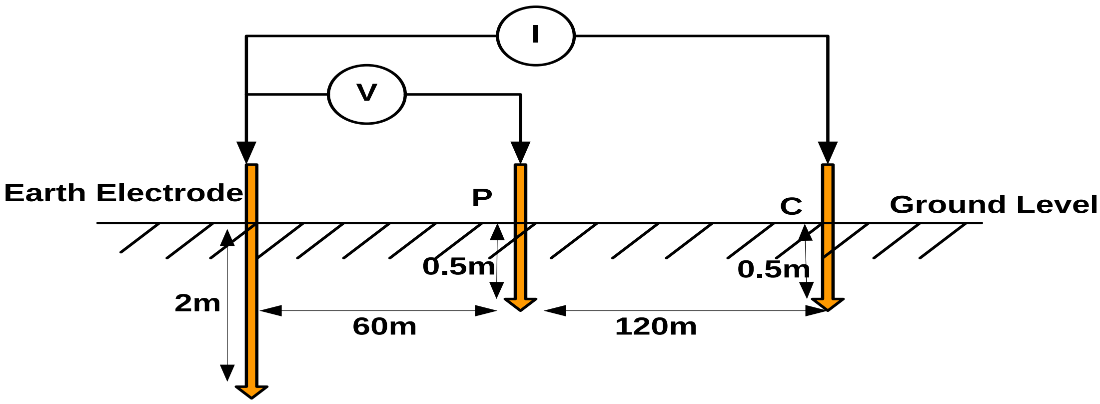

Figure 2: Fall-of-Potential Method

During measurement, the position of the current probe (C) was moved far enough away from the earth electrode under test so that the voltage probe (P) can lie outside the effective resistance areas of both the earth electrode and the other test electrode. This is because there may be overlapping of the resistance areas which can cause a steep variation in the measured resistance.

III. RESULTS AND ANALYSIS

The tower footings of Jos to Gombe 330kV transmission line were properly earthed as the line passed through different land terrains. The measured value of the tower footing earth resistance and soil resistivity at the selected tower along the line are presented in table1.

TABLE I

TOWER FOOTING EARTH RESISTANCE AND SOIL RESISTIVITY ON JOS TO GOMBE ROUTE OF 330KV

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Tower Number	Earth resistance (Ω)	Soil Resistivity $\Omega - m$
2*	0.3	60
7	5.0	280
21	2.5	140
63	1.4	120
94	10.0	580
109	5.0	280
168	1.0	90
188	10.2	600
239	8.0	500
304	5.6	350
336**	20.0	1000
352	7.5	450
363	2.0	130
405	5.2	300
444	5.2	300
548	5.6	350
574	2.5	140
582	1.6	125
590	2.4	138
603	3.2	150
615***	0.9	80

*Jos Location, **Bauchi Location and *** Gombe Location

The figure 3 and 4 shows the tower footing earth electrode resistance and soil resistivity respectively. It can be seen from the graph that the earth resistance depend on the soil resistivity of the area in which the electrode is buried. This indicates that the higher the soil resistivity the higher would be the earth electrode resistance value that could be obtained for any power system in that area and vice versa. For instants, that the tower number 336 at Bauchi location was installed on the rocky environment with high soil resistivity of 1000 Ohm-meter and also the value of the earth electrode resistance of 20Ohms was high. Also, the tower number 2 located in Jos was installed on the marshy area with low soil resistivity and low earth electrode resistance value was obtained.

The implication of high soil resistivity on the transmission line footing resistance is that the distance relay circuit breaker will not operate, hence effort should made to improve the soil resistivity with artificial soil in order to obtain low soil resistivity. In this case, it will provide the means of using low earth electrode resistance for the protection of the transmission line.

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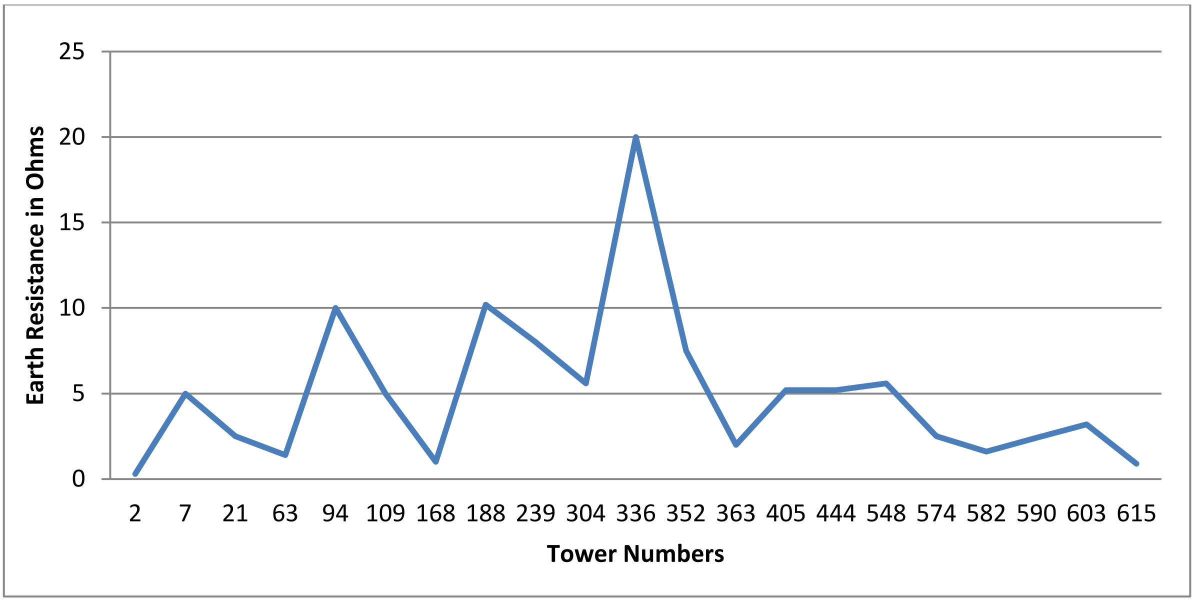

Figure 3: Tower Footing Earthing Resistance

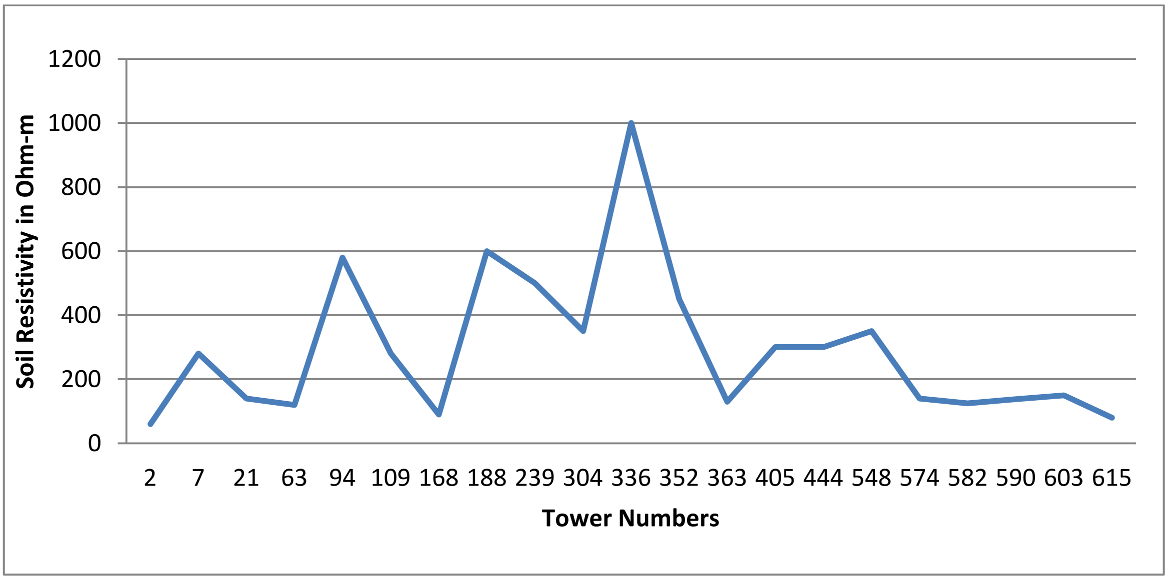

Figure 4: Tower Footing Soil Resistivity

The results of these measurements also provide us the broad classification of the soil types and their resistivities along the transmission line in the area as presented in table2 for future research.

TABLE II

Soil Types and Resistivity Values

Soil Types	Resistivity (Ohm-Meter)		
	Minimum	Mean	Maximum
Clay	5	27.2	60
Sand/Clay	6.28	215.0	346.83
Limestone	36.4	50.2	95.8
Sand	50	270	476.58
Laterite	961.3	1200	1528.7
Rock	1557	2500	19,012.92

IV. CONCLUSION

The Jos to Gombe 330kV transmission line tower footing resistance measurement are carried out at selected points along its route. The selected points include rocky terrains and marshy areas. The earthing resistance profile varied between 0.3 Ohms at Jos area and 20 Ohms around Bauchi. Broad engineering soil identifications as well as programmed intensive field measurements of soil resistivities and earthing systems at some selected sites proved that soil resistivities values depend on the type of soil. In rocky areas, resistance of tower footing could be lowered by a buried network of well designed earth mat or by a network of buried counterpoise earth wire in order to reduce the effect of lightning stroke terminating on transmission line. For good grounding of electrical systems the soil resistivties should be improved for effective earthing of systems. In addition, in rocky area the best result can be obtained by digging a trench of approximately 600mm deep and 300mm wide to bury the earth electrode and cover it with fine loamy soil or fine sand in order to obtain lower soil resistivity and enable low earth electrode resistance.

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