SOIL CHARACTERISTICS AND SUBSTATION EARTHING IN BAYELSA STATE

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Abstract

From previous investigations of soil resistivity in Bayelsa State, the soil was found to be corrosive in most part of the state. Substation which is the most sensitive part of power transmission and distribution system requires effective and safe earthing systems. A study was carried out in the three main soil divisions. The resistivity of the soil was tested at the depths of 0.5m, 0.8m, 1.2m and 1.5meters. The pH values of the soil in the area at a depth of 1.0meters were tested in the laboratory. The tests showed that the soil resistivity at a depth below 1.2meters was below 20Ω-m in the coastal site, the average pH value was about 5.8. The results of resistivities confirmed that the soil is corrosive and the value is within the corrosive soil given in all available technical literatures. From the performance of the graph of soil resistivity, the soil maintains a permanent moisture level at 1.5meters. The soil condition offers an effective fault current dissipation but is prone to corrosion effect.

For effective earthing system and for durability solid copper grid was recommended because copper is not affected by corrosion in most corrosive soil and is thermodynamically stable.

Keywords: Soil resistivity, pH value, touch and step voltage, ground rods, ground potential rise

Introduction

One of the key factors in any electrical protection scheme is earthing (grounding). If any acceptable measures of safety are to be attained correct earthing (grounding) design and application must be made. A typical ground system will take the form of grid horizontally buried conductor [1, 3]. The wide use of grid is due to several advantages. The main advantage is due to the fact that a ground system design using a combination of single electrodes (ground rods) may require a connecting network which is in effect very effective.

However, Guide IEEE 80 [1, 4, 6] agrees that ground rods are of particular value when the upper layer of soil in which the grid is buried, is of much higher resistivity than the soil beneath or may become so because of drying out or freezing.

Two things can be considered in the grid design, the first one recommends the extensive use of ground rods in grids (practically one at each cross connection). The second one in the grid design that ignores the ground rods or if necessary, a few numbers of ground rods are installed to stabilize grid resistance and annihilate the effect of the upper layer resistivity increase.

The most appropriate method depends clearly upon the soil structure and resistivities of the soil.

There are different national and international standards available which provides empirical formulae for the calculation of earthing design parameters and shock potential safety limits [1, 9]. There are three that are widely referred to:

(i) IEEE Std 80 – 2000: IEEE Guide for safety in A.C substation grounding

(ii) B.S 7354 – 1990: Code of practice for design of High Voltage Open-terminal stations.

(iii) Electricity Association, Technical Specification 41 – 74: Guide lines for the design, installation, Testing and Maintenance of main earthing system in substations ground potential rise (GPR).

The potentials on which the design limits are based will be described based on supply industry practice. It should be noted that there are differences in the design limits appertaining in the supply industry and consumer electrical installations. For example, the shock limits are lower within electrical installations than in supply industry substation.

It is important to refer to the appropriate standard to check the design limits which apply to each situation.

Tolerable Step and Touch Voltage

When a fault occurs, the flow of current to earth results in voltage gradient on the surface of the earth in the vicinity of earthing system. This voltage gradient may affect a person in two ways that is, step or foot to foot contact and hand to feet (both) or touch contact. This effect is recognized in the standard and it is the basis of the term step and touch potential.

Step voltage is when two legs are in contact with the ground surface. The potential difference shunted by the body is limited to the maximum value between two access points on the ground surfaces separated by one pace (assumed equal to 1 meter). R_f is the earthing resistance of one foot and R_b is the body resistance.

A human foot can be taken as equivalent to a circular plate electrode with a radius of about 0.08m and its earth resistance may be assumed to be $3\rho_s$ where ρ_s is the resistivity of soil near the surface of the earth. R_b is assumed to be 1000 Ohms.

Therefore the tolerable value of step voltage is

$E_{step} = (R_b + 2R_f)\ I_f$

Substituting the values of R_b, R_f and I_f

$$E_{step} = (1000 + 6\rho_s)\ 0.116/\sqrt{t}\ \text{volts} \qquad \text{(i)}$$

Touch voltage is defined as the potential difference between the grid potential rise and potential of the soil surface point where a man is standing while touching simultaneously a metallic structure connected to the grid.

The tolerable value of touch potential is

$E_t = (R_b = 0.5R_f)\ I_B$, when R_b, R_f and I_f are substituted

$$E_{touch} = (1000 + 1.5\,\rho_s)\ 0.116/\sqrt{t} \qquad \text{(ii)}$$

For 70kg weight, the factor 0.157 replaces the factor 0.116 (50kg).

In practical considerations the actual step and Touch voltages are always less than the tolerable values.

The minimum length of the total earth mat conductor required to keep the mesh voltages within safe limits (for grid control) is obtained by equating actual E_{mesh} to tolerable E_{touch}. The result

$$L_m = \frac{\rho k_m\, k_i\, I_g\, \sqrt{t}}{(1000 + 1.5\rho_s)(0.116)} \qquad \text{(iii)}$$

The actual (Design) Step and Touch voltages can be calculated by the following formula:

$$E_{step} = \frac{\rho k_s\, k_i\, I_g}{L} \qquad \text{(iv)}$$

$$E_{touch} = \frac{\rho k_m\, k_i\, I_g}{L} \qquad \text{(v)}$$

Where K_m = Spacing factor for touch voltage

K_s = Spacing factor for step voltage

K_i = Corrected factor for grid geometry

I_g = Maximum grid current for design purpose

L = Total length of the buried grid conductors and the total length of vertical rods in meters.

The grid Resistance $R_g = \rho / 4 \left(\sqrt{\pi / A + \rho / L}\right)$

The ground potential Rise GPR = $I_g * R_g$

The substation earth grid is used as an electrical connection to earth at zero potential reference. This connection however is not ideal due to the resistivity of the soil within which the earth grid is buried. During typical earth fault conditions, the flow of current via the grid to earth will therefore result in the grid rising in potential relative to remote earth to which other system neutrals are also connected.

The ground potential rise of a substation under earth fault conditions must be limited so that step and touch potential limits are not exceeded and is controlled by keeping the earth grid resistance as low as possible. As a result of these, the test for soil resistivity was necessary to determine the possibility of having a low resistance value.

Due to the present level of energy consumption in the state the voltage level coming into the state is 33kv line. With the proposed Federal Government Projects, the small and medium scale industries and the awareness of electricity usage, the energy consumption will rapidly increase. For good energy projection, 132kv transmission line way obviously be needed in the next ten years. This definitely will require high voltage substations. It is therefore necessary to study the soil characteristics as it affects the ground potential rise of an earthing system (grid). From previous studies on soil variation in Bayelsa State [2], the low resistivity of the soil is an indication of corrosive soil. It is also necessary to determine the corrosive level of the soil in relation to the selection of electrode materials for grid design.

For a convenient approach to this study, the soil was divided into three soil groups [7, 10]. These soil groups are:

- The coastal soil
- The fresh alluvial soil
- The tidal fresh water swamp soil

Materials and Methods

The study was carried out within the month of September 2009 and February 2010. This period was chosen because they represent the dry and the rainy seasons.

From the soil group a site was chosen and resistivity measurements were taken in five different locations at depths of 0.5m, 0.8m, 1.2m and 1.5meters.

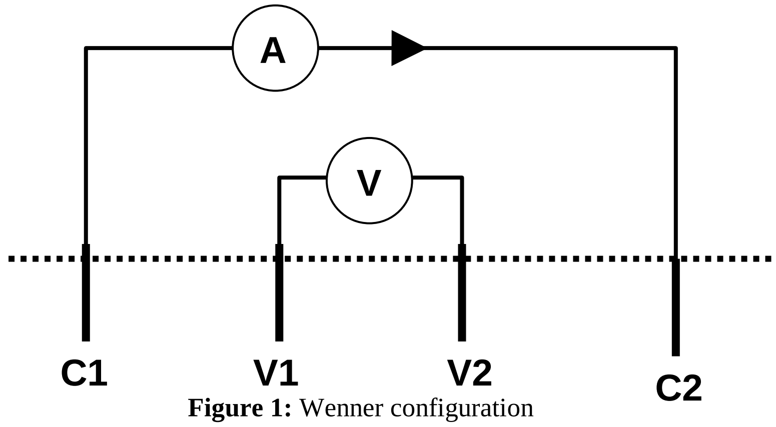

Figure 1: Wenner configuration

The instrument used was the four method test instrument (the Wenner method). Fig. 1, is the test instrument with four equally spaced electrodes connected in a single line.

Current is passed between the two outer electrodes (C_i C_2) and voltage between the inner electrode V_1 and V_2 (Potential electrodes). The electrode distances were maintained at 3meters to 5meters depending on the electrode depth.

The ratio of this measured potential to the calculated current for the given spacing is known as the apparent resistivity.

$D = 2\pi DR$ - when $b << D$

ρ = Soil resistivity in ohm – meter

D = Distances between two successive electrodes

R = the value of v/1 in ohms.

Before the measurements were taken the ambient temperature and humidity values were measured.

The pH values were analyzed in the laboratory and are shown in the table.

Results

The results from measurement for the three main soil divisions were taken and the average values are shown in table 1.

Depth of electrode in meters	**Resistivity values at different depth $\Omega - m$**					
	Brass		**Ogbia**		**Amassoma**	
	Feb.	Sept.	Feb.	Sept.	Feb.	Sept.
0.5	90	23	180	62	242	52
0.8	32	22	100	35	102	35
1.2	22	21	45	25	42	23
1.5	20	18	32	22	32	21
pH value	5.1	5.8	4.85	5.0	4.91	5.2
Ambient Temp. ^oC	37	31	35.8	29.4	38.1	29.0
Humidity in mmHg	71	82	70	79	77	81.2

From the table (table 1), the graphs were drawn for each soil division indicating the resistivity variation for the seasons.

The graphs are shown in fig. 2a, fig. 2b and fig. 2c.

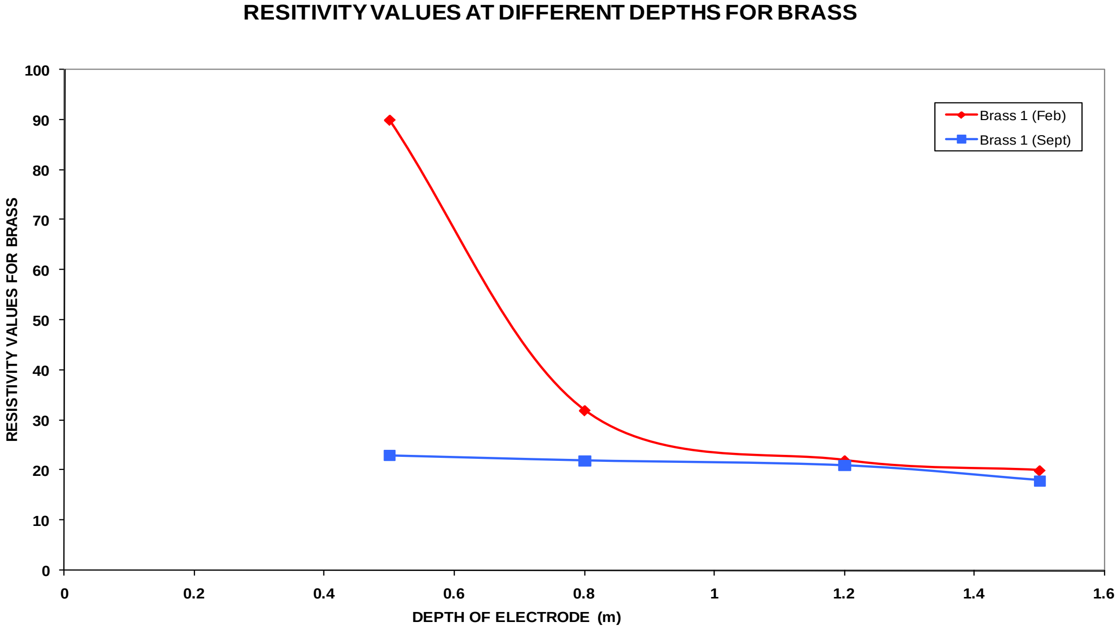

Figure 2(a): Resistivity Values at Different Depths for Brass

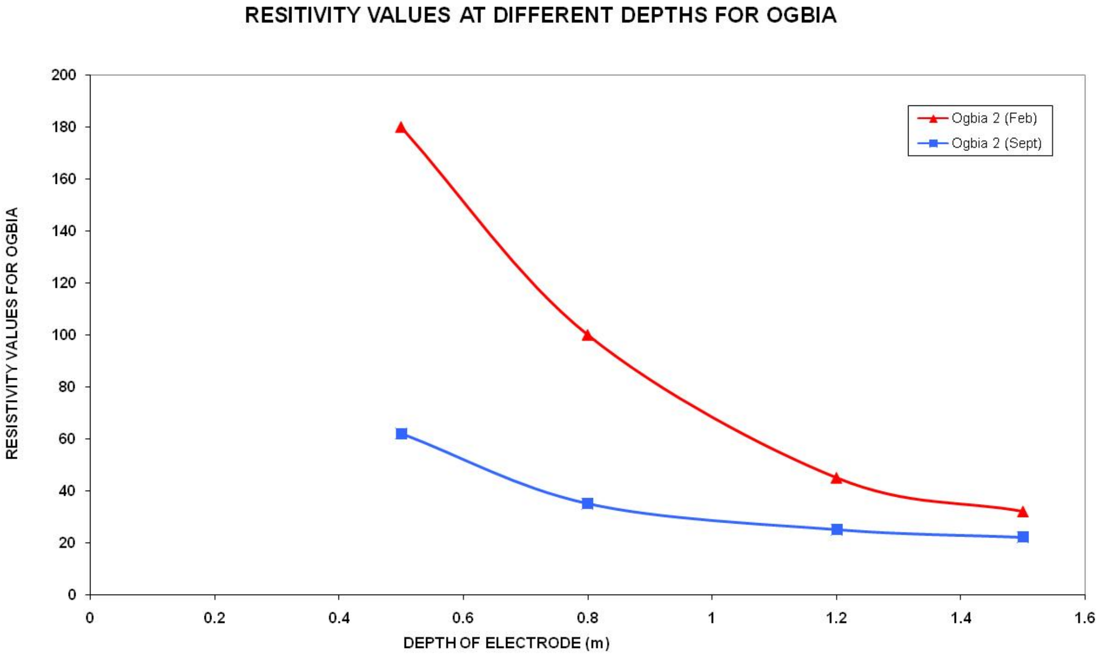

Figure 2(b): Resistivity Values at Different Depths for Ogbia

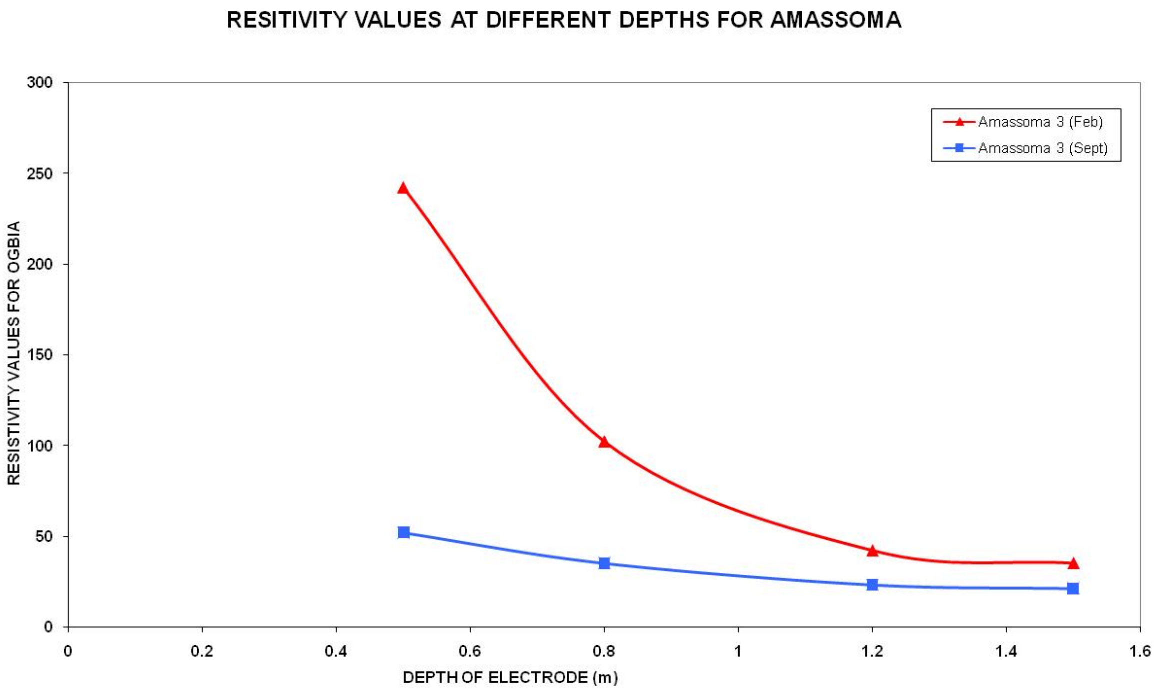

Figure 2(c): Resistivity Values at Different Depths for Amassoma

Discussion

For several parameters that control soil resistivity (porosity, permeability, mineralization of soil, ionic content and temperature of pore fluids), only water content and temperature of soil may vary in measurable time scale [3, 10, 12]. From the measurement of different depth of soil the resistivity value can be related to the moisture content in the soil.

The topsoil resistivity for the fresh alluvial soil (Amassoma) and the tidal freshwater swamp soil (Ogbia) gave very high value. This was due to temperature variation which drastically reduced during rainy seasons.

February and September are two seasons of extreme weather conditions (dry and rainy seasons), therefore the results provided us with the basic idea of seasonal variation of soil within the soil division. Table 2 gives the average season variation of the soil division.

Table 2: Seasonal Variation of Soil

Depth of electrode in meters	**Coefficient of Seasonal Variation**		
	Brass	**Ogbia**	**Amassoma**
0.5	3.9	2.9	4.6
0.8	1.5	2.8	2.9
1.2	1.05	1.8	1.8
1.5	1.11	1.45	1.6

At a depth of 1.2 meters all resistivity values at both dry and wet seasons were low. The resistivity of normal soil is a function of the water content. It could be concluded that the permanent moisture level of all soil is between 1.2 meters to 1.5 meters.

The costal soil (Brass) has low resistivity values with a coefficient of season variation of 1.5 at the depth of 0.8 meters. This is an indication that the soil of the coastal areas may have a higher water table.

Accordingly, IEEE – 80 [1, 13] recommends a uniform soil model only when there is a moderate variation of apparent resistivity.

The soil could be described as a uniform soil but the high water table and the proximity of the ocean to these lands could be responsible for the low resistivity. Salt wind drift has an effect in excess of 10km inland [2] even more in the case of exposed coasts.

Due to the general low resistivity of the soil in Bayelsa State it could be considered to influence an effective earthing of ground electrodes. These low resistivity values also give an indication of corrosive soil. Corrosion is a major problem with an earthing scheme, therefore careful selection of materials and accurate calculation of electrode size is necessary. Soil resistivity, corrosion level and allowance need for corrosive soil for steel electrode are given in table 3.

Table 3: Soil Resistivity and Corrosion Allowance

Range of soil resistivity Ω-m	**Class**	**Corrosion Allwance**
Less than 25	Severely corrosion	+ 30 percent
25 – 50	Moderately corrosion	+ 15 percent
51 – 100	Mildly corrosive	+ 15 percent
Above 100	Very mildly corrosion	No addition

Conclusion

If any factor is seen to be an advantage for the design of earthing grid, is the low resistivity values and the high moisture table. For earth grid design especially in the coastal areas, it could take the form of horizontally placed without ground rods. The soil in most periods of the year is saturated because of the high surface level and the various salt content in the soil.

The fresh alluvial soil and the tidal freshwater swamp soil, ground rods may be needed to stabilize the ground resistance and annihilate the topsoil resistance as could be seen from the seasonal soil variations. In the selection of electrode materials, due to the corrosive nature of the coastal soil it is mandatory that copper material is the best choice.

In the other soil of Ogbia and Amassoma if galvanic corrosion is considered; steel electrode can be used, noting that corrosion allowance must be taken to take care of corrosion in the next twelve years and also to maintain the necessary cross-sectional area for the flow of fault current. For the above reasons it is necessary to recommend that

(a) in order to stabilize the grid resistance, few ground rods can be used for earthing grid design in the coastal areas.

(b) Testing of earth grid is necessary and at a short duration.

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