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Soil Resistivity Improvement Design for Substations Earthing Systems. A Case Study of NIBO Substation, Anambra State, Nigeria

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ABSTRACT: *This paper presents the soil resistivity test of Awka (Nibo) 132/33kv transmission substation. Soil resistivity is how much the soil resists flow of electrical current. This is a crucial factor in designing an effective and efficient earthing system with safety as a priority. For this study, the Werner Four-Pin method was implored and results obtained that enabled design. During investigation, the soil composition, moisture content, surface material used and study area temperature were considered. The results obtained were used in extrapolating the earthing resistance which includes step and touch voltages of substation earthing within the area of study.*

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I. INTRODUCTION

The substation been investigated is situated in Awka South Local Government Area of Anambra. Most of the equipment in the substation were installed and commissioned in 1976. The switch yard operates a single bus scheme electrical system. The substation receives 132/33kv from Onitsha – Nibo Orji River line. The power from main bus (132kv) directed to two power transformers (30MVA each) which steps the voltage down to 33kv. The substation equally transmits 33/11kv to neighbouring environment to meet the requirements of the end consumers at suitable voltage ratings.

The need for earthing when designing and installing a substation cannot be overemphasized. A well earthed subsystem provides a low impedance path against fault such as lightening strikes ensuring maximum safety of both equipment and personnel. Soil resistivity is a crucial factor that determines performance of an earthing system. Low soil resistivity for an earthing system is advisable and this can be achieved by placing surface materials such as gravels on ground reduce evaporation.

Some factors influence soil resistivity, these are the type of soil composition, moisture content of the soil and equally temperature of the area. This resistivity can change with changes in moisture content, temperature and chemical content. To determine soil resistivity of an area, soil resistivity measurement is taken. Thus, soil resistivity measurement is best carried out at the site at the beginning stage while designing the earthing system (Orji, G. & Pepple, G. T. (2015).

THE INVESTIGATED AREA

The area of investigation, Nibo, Awka South Local Government Area of Anambra State, South Eastern Nigeria is located geographical coordinates 60 100 0” North, 70 4” 00 East. The area lied below 300 metres above sea in a valley on the plains of the Mamu River. Two ridges or cutest as, both lying in a North-South direction, Nibo is situated within Awka capital territory and sited in a fertile tropical valley. The transmission station receives 132/33kv from Onitsha-Awka –Orji River line. Nibo transmission substation also transmits 33/11kv to four feeders.

Fig. 1: Map showing Investigated Area in Anambra Central Zone, Anambra state, Nigeria

Fig. 2: Pictorial view of Nibo substation, Awka South L.G.A, Anambra State

II. MATERIALS AND METHOD

Soil resistivity is the capacity of soil to resist flow of electrical current through it. This is a critical factor in designing the earthing system before substation installation. Uniform and two layer soil models are the most commonly used soil resistivity models.

MATERIALS REQUIRED

i. 4 pole digital – ground resistance tester
ii. Earthing rods
iii. Hammer
iv. Connecting cables
v. Measuring tape
vi. Animal waste
vii. Charcoal
viii. Water

There are two ways in determining the resistivity of the soil at the site location.

(i) Direct measurement of soil resistivity itself.

(ii) The second is to drive an earth rod of known length and diameter into the ground and to measure it earth resistance (Ώ). The reading gotten can be used in calculating the resistivity of the surrounding soil .
Area under study (Nibo substation), an earth rod is placed to earth . The depth is filled with animal waste and charcoal and also filled with water to reduce resistivity.

Notably salt are not used because of electrolyte form to avert wrong or variation in readings unlike coal which is made of carbon a good conductor minimizing earth resistant and keep the soil permanently wet.

Soil Type	Resistivity (Ω-m)
Farm land day	10 – 200
Sandy soil	50 – 100
Farmland with gravel stratum	100 – 1,000
Mountains	200 – 2,000
Gravel, pebble sea shore	1,000 – 5,000
Rocky mountains	2,000 – 5,000
Sandstone	10,000 - 107

Table 1: Soil type and respective resistivity (https://en.wikipedia.org/wiki/ lagos).

Soil resistivity equally determines the corrosiveness of soil. Corrosion varies inversely proportional to resistivity. The soil corrosiveness is classified based on a soil resistivity by the British standard, BS 1377.

< 10	Severe
10 – 50	Corrosive
50 – 100	Moderately corrosive
> 100	Slightly corrosive

Table 2: Soil resistivity classification (https://www.map.google.com).

Simple Steps in determining soil resistivity during earth design in Nibo substation
To install an earthing system the first design step is to measure the resistance of the earth. There are many factors that needs to be considered for example the resisitivity of the soil (Kind of soil), the percentage of moisture in soil the number of rids connected in parallel and the depth of electrode under the ground.
Step 1: Calculate the relative resistivity of the soil depending on the number and length of rods used and the horizontal and vertical correction factors depending on the distance between each two rods and length of rods.
Step 2: Conductor size is determined. Here, fault current should be maximum and should reflect the maximum clearing time tc.
Step 3: The step voltages are to be determined. The choice of time is based on the judgment of the designer.
Step 4: The initial design includes a conductor loop surrounding the cross sectional area. The initial estimate of conductors spicing and ground rod locations should be based on the current IG and area been grounded.

Step 5: Estimates of initial resistance of the earthing system in uniform soil can be determined. Final design; more accurate estimates of resistance may be desired.

Step 6: The grid current is determined. The current (IG) should, however, reflect the worst fault type and location.
Step 7: If the ground potential rise (GPR) of initial design is below the tolerable touch voltage. No further analysis is necessary.
Step 8: Mesh and step voltages for the grid as designed can be done by the approximate analysis techniques for uniform soil.
Step 9: If the computed mesh voltage is below the tolerable such voltage. The design may be complete see (step 10).if the computed mesh voltage is greater than the tolerable touch voltage the initial design must be revised (see step 11).
Step 10: If both the computed touch and step voltages are below the tolerable voltages, the design needs only refinements required to provide access to equipment grounds. If not, the initial design must be revised (see step 11)
Step 11: If either the step or touch tolerable limits are exceeded, revision of grid design is required.
Step 12: When the step and touch voltage requirements are met, additional grid and ground rods may be required.

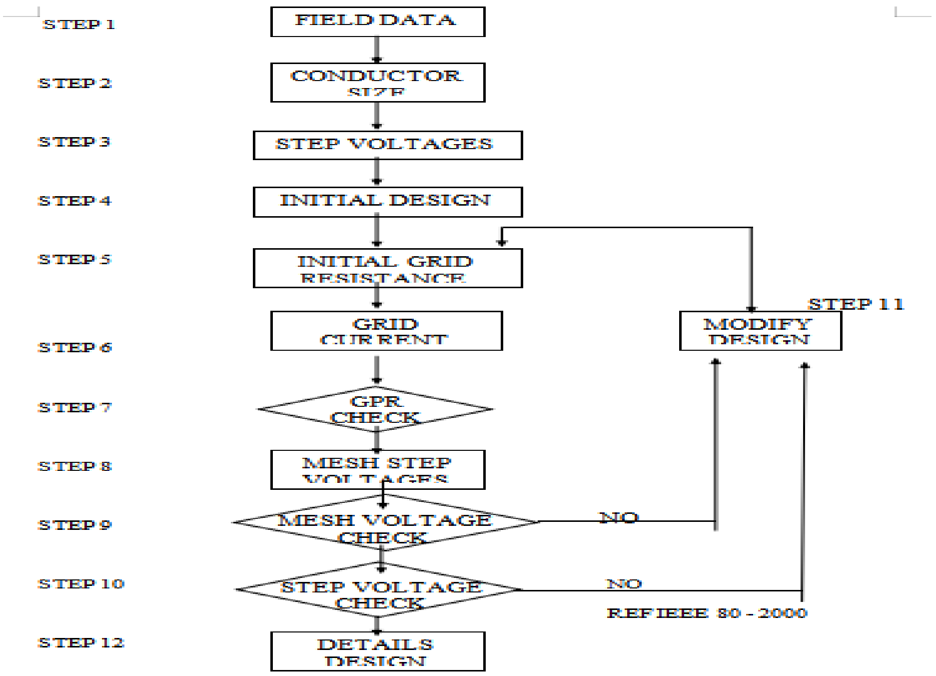

Figure 3. Block Diagram Design steps on Earthing design

III. RESULTS AND DISCUSSION

In this section, application of the grounding design is elaborated , this is to design a safe grounding grid, the step procedures on the flow chart diagram in fig 3 was taken. The following assumptions and design criteria will be stated.

i. There was uniformity of the soil structure between test point and test locations.
ii. Average soil resistance for Nibo substations is 1.72
iii. Total clearing time for both substations of line to ground fault is 0.5 seconds
iv. X/R ratio is 10
v. Current division factor Sf = 0.6
vi. Decrement factor Df = 1.026
vii. Switch yard operator is 50kg or heavier.
viii. initial number of rods before modification is 16 under soil conditions

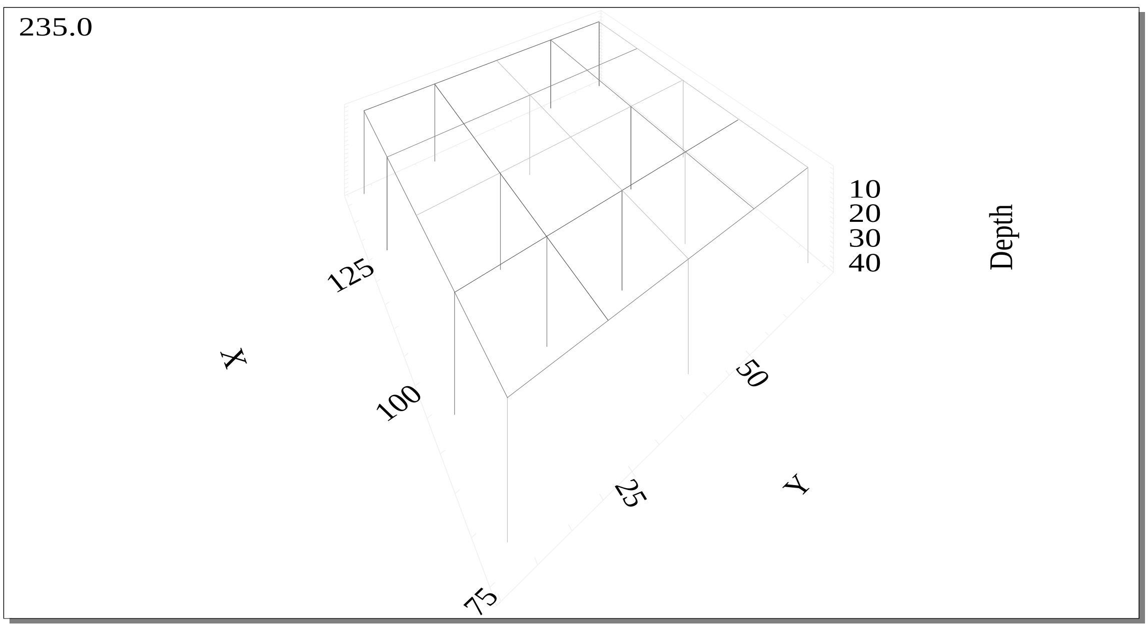

Figure 4: Nibo substation ground grid network

The result summary of the grid design

		Touch Potential			Step Potential			
Rg	GPR	Tolerable Volts	Calculated Volts	Calculated %	Tolerable Volts	Calculated Volts	Calculated %	Material type
0.08	238	2830	63.1	2.2	10653	8.1	0.1	Wet organic soil
0.802	2381.3	2832	631.3768	22.3	10663.71	80.91309	0.8	Moist soil
8.017	23812.6	2857.2	6313.8 5	221.0	10762.7	809.1 7.5	7.5	Dry soil

Table 3, shows that calculated Volts of the touch potential and step potential is the lowest for the wet organic soil and the highest for dry soil. The tolerable volts for both touch potential and step potential of different soil types varies due to the different soil resistivity. The dry soil which has the highest touch potential value is seen to exceed its tolerable value by 221%.

The purpose of optimizing the ground grid design is to minimize the cost of purchasing the grid conductors and ground rods.

Number of rods after modification

Diameter (cm)	Length (m)	no of rods	Cost $/Rod	Material Type
2.000	2.44	4	100.00	Wet organic soil
2.000	2.44	4	100	Moist Soil
2.00	2.44	4	100	Dry soil

Table 4. :The total number of rod reduced from 16 to 4 under different soil conditions.

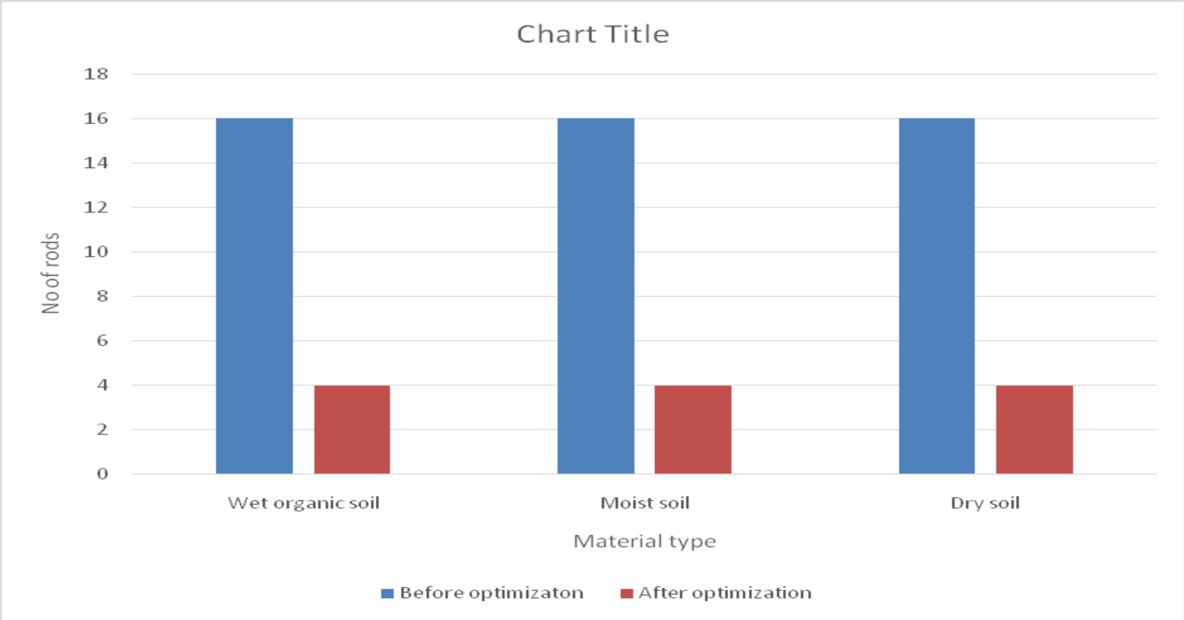

Figure 5: the number of rods of different material type..

Grid Configuration after modification of design

		Grid Length (m)		Number of conductors		Separation (m)			
conductor size (mm²)	Depth(m)	Lx	Ly	in X direction	in Y direction	In X direction	in Y direction	Cost ($/m)	Soil Materials
25	2.44	63.44	63.44	4	4	21.1	21.1	10.0	Wet organic soil
25	2.44	63.44	63.44	4	4	21.1	21.1	10	Moist Soil

25	2.44	63.44	63.44	24	24	2.8	2.8	10	Dry soil

Table 5 shows the grid configuration after the ground grid designed was modified.

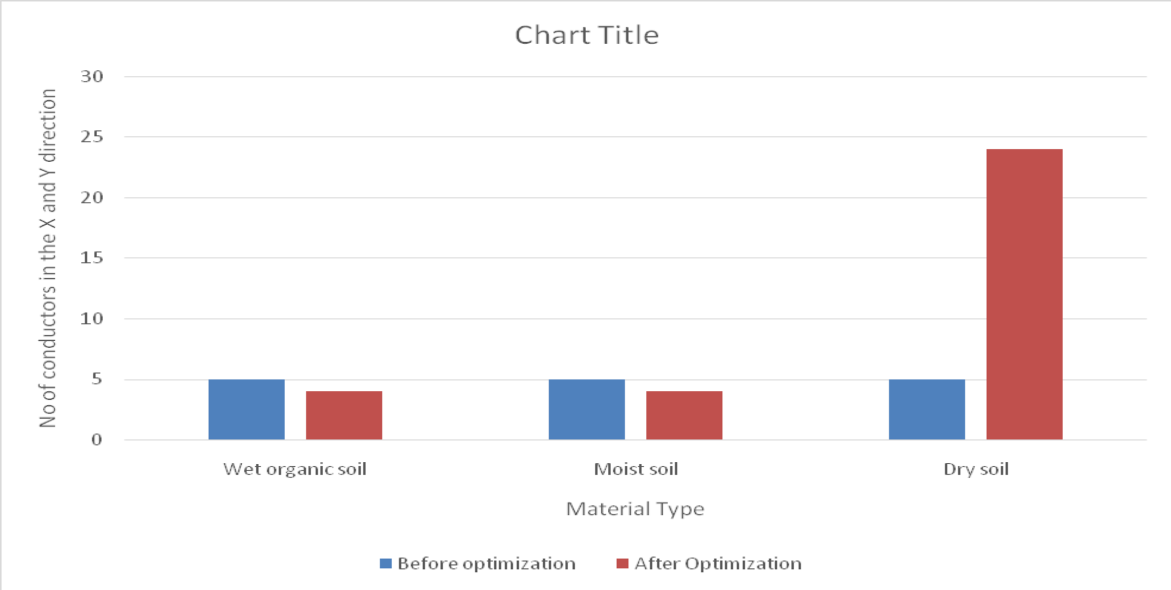

Figure 6: Grid Configuration of the number of conductors in X and Y direction before modification of design

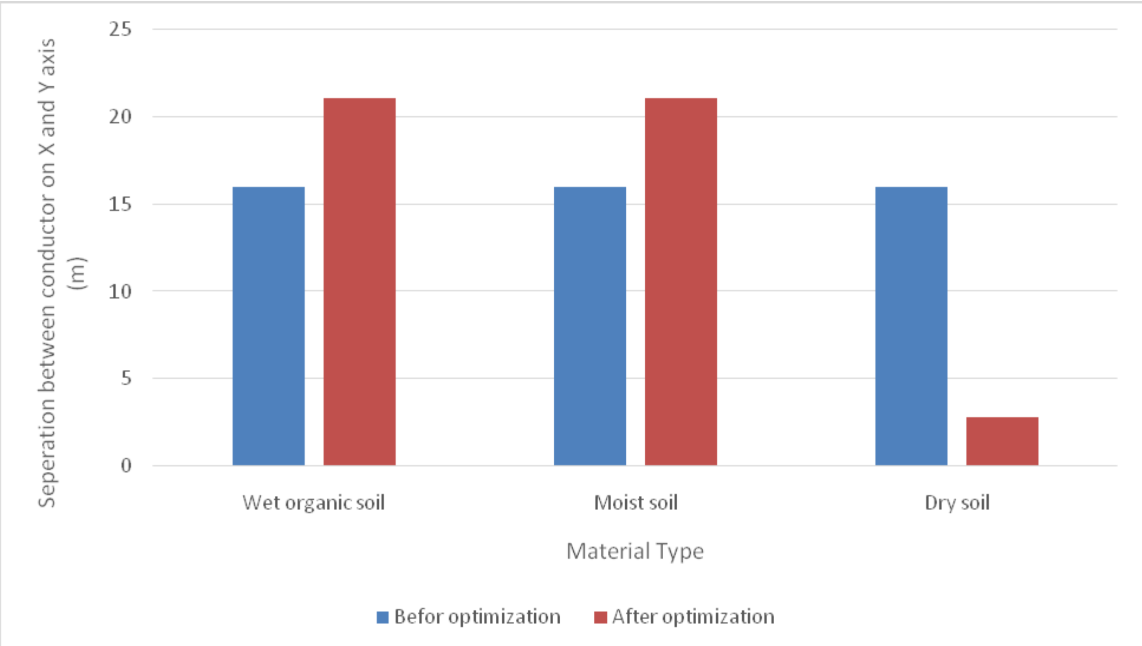

Figure7: Grid Configuration for the total number of conductors in X and Y direction after modification of design.

IV. CONCLUSION

From figure 5, the blue chart represent the number of rod under different soil conditions before optimization while the red chart represent the number of rod under different soil conditions after optimization. We can observe that the number of grounding rod remained the same after optimization under different soil conditions before and after optimization.

In figure 6 we can see that the Nibo ground grid network was optimized under three different soil conditions which are the wet organic soil condition, moist soil condition and dry soil condition. We can observe that after optimization, the total number of conductors for under the wet organic soil condition and moist soil condition reduced to four rods while the optimization of the network under dry condition was increased to 25 number of grounding conductors. This design modification is valid because it fall under our conditions for optimization. Figure 7, on separation between conductors in XY direction, the improvement under different soil conditions (wet, moist and dry) are been depicted graphically after optimization

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