Improvement of Earthing System for Sub Transmission Station

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Abstract- Earthing system for sub transmission station is actually imperative for the electric power system stability, the touch and step potential in the transmission station earthing system maintains a good grounding grid design which enable substation permissible limits, based on fibrillation discharge limit. This research aimed at improving the earthing system in Afam/IPP132/33KV sub transmission station, Afam, Rivers State, Nigeria. The improvement was chosen carefully by taking account of the physical and chemical composite of the soil with determined value of each of these details; earth grid resistance, computation of mesh potential, touch potential, step potential and ground potential rise which were achieved using Sverak method while ETAP (Electrical Transient analyzer program) simulation software was exploited in verification of the desired result. Hence the earthing system was considered to be within its safe limits. In conclusion, the earth resistance values of pit 1, 3 and 5 respectively were very high. We recommend that the earth resistance for pit 1, 3 and 5 respectively should be treated by adding 6 bags of charcoal, 1.5 bags of salt and water to various pit to avoid break down of electricity supply on the network. Earth resistance test should be carried out annually on the substation using earth resistance tester.

Indexed Terms- Electrical Transient Analyzer Program (ETAP) Software, earth grid resistance, computation of mesh potential, touch potential, step potential and ground potential rise.

I. INTRODUCTION

The most important component of any power system is the earthing system, it is design and constructedto guarantee safety of persons and devices. Earthing of generating stations, transmission substations, distribution substation and lines are of great importance, they are design for easy upgrade, the components of earth mat in Substation earthing system was fundamental not only to deliver the security of individuals working in the region of earthed facilities and hardware's against risk of electric shock yet additionally to keep up optimal power flow in electrical system [1] and [2].

In contemporary extra-high-voltage and ultra- high AC voltage, earthing is a foremost complications of system design [3].The error in the measurement of non-uniformity of the soil resistivity data affect other factors during simulation [4]. The designed impedance value of the earthing system must be patterned by the restrained earthing system construction standard [5]. Destructive soil with high dampness content, high salt substance, and high temperatures can corrupt earth poles and their links [3]. The periodic checks of increase in earth resistance using grounding tester of more than 20% should be measured to help maintain uptime with indispensable troubleshooting tools[6].

The system of earthing gives a low impedance way to electric flow to passthrough to the earth without surpassing the working furthest reaches of the gear [7]. This research aimed at improving the existing earthing system in Afam/IPP132/33KV subtransmission station in Afam, Rivers State, Nigeria, which has lost two (2) 300KVA 33/0.415KV grounding transformer due to bridge by snake on the secondary side of the 60MVA 132/33KVtransformers, these abnormal conditions can cause over voltage that may result in extensive damage of equipment or insulation failure. Achieving this research, the collection of necessary data on the existing earthing resistance values of the substation was ascertain, the determinedvalue of each of the following parameters:earth grid resistance, ground potential rise, touch potential, step potential, computation of the step voltage and mesh potential was attain using Sverak method, while Electrical transient analyzer program (ETAP) simulation software were utilized to achieved the desired result.

II. LITERATURE REVIEW

The wellbeing of electrical cables and mechanical assembly in substations and provincial control place are the general reasons for a substation which include: Voltage change, connecting point for transmission lines, switchyard for framework development, observing point for control focus [8]. The foremost determination of power scheme substation grounding is to sustain consistent process and deliver safety for employees and apparatus throughout fault conditions [9].

The old conventional ways of Power Transformer substation earthing were to dig a large pit and bury all the earth rods and just connect two or three leads which will be extended to all the power transformers and substation equipment [10]. The electrode grounding (Earthing) system resistance influencing factors includes,

a) The surface area of the rod with its diameter and the type rod material is a function of the electrode resistance.
b) The ground rod materials and dimensions have little considerable alteration in the electrode resistance [11].

The resistance of the soil is the key factor that determines proper installation of electrode grounding system, the low ground resistance of the rod must be driven and obtained by its depth, this imply that the soil varies with it resistivity depth and the electrolyte in the soil (the type of concentration of soluble chemical in the soil, the moisture content and soil temperature) [12].

- The Design of the Ground System

Single earth terminal crashed into the ground are regularly found outside our structure while the perplexing establishing frameworks are mounted at power generation stations or transmission substations, focal workplaces, and cell tower areas which involve different ground poles, ground plates and ground circles [13].

- Oil Resistivity in Transmission Substations

The key factors of soil resistivity of earthing system design, depends on the soil type, presence of moisture, depth, temperature, electrolyte contents, etc and could vary seasonally, their change has unswerving consequence on the overall substation earth resistance [14].

- Contact Potential, Step Potential and Mesh Potential

Contact Potential is the possible distinction between the expected surface and the earth device potential where somebody is standing at that point contacting the earthed building, while the distinction in likely created when somebody connects an estimation of 1m with his body when contacting some other earthed gear is called Step Potential, while Mesh Potential is the most extreme touch expected created in the earthing matrix [15].

III. MATERIALS AND METHODS

The utilization of Materials for improving earthing system of Afam-IPP sub transmission station was picked cautiously by assessing the physical and chemical composite of the soil. The determined value of each of these details; earth grid resistance, computation of mesh potential, step potential, touch potential and ground potential rise was ascertained. [15] and[16] Method was used in calculating the earth grid resistance, which was represented in equation 3.1. The earth grid resistance R_g

$$= \rho \left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}} \left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}} \right) \right] \qquad (3.1)$$

Where; ℓ= Soil resistivity (52/m)
A= The occupied ground grid area (m^2)
L_T= The total conductors length buried (m)
h= the grid depth (m)

[16]; [17];[18];[19] and[20]

- Earth Mat Design of Afam-IPP Sub Transmission Station

The Afam-IPP sub transmission station earthing comprise of six (6) Pit, each pit has their evaluated value as shown in table 3.1-3.6, the Afam-IPP sub transmission station over all Single Line Diagram is appeared in figure 3.1

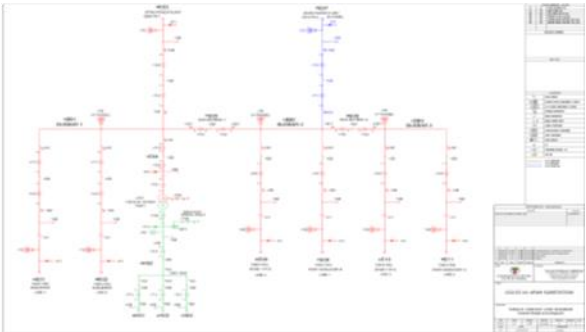

Figure 1: Afam-IPP Sub Transmission Station Single Line Diagram

- Initial Parameters Data Collected from Afam-IPP Sub Transmission Station Site

Current probe dc in all the tests carried out is placed at 20m, table 3.1 – 3.7 below shows the earth resistance values of each pit.

Table 3.1: The Distance and the Earth Resistance Values of Pit 1

S/No.	Distance (M)	Resistance (Ω)
1	4	1.17
2	8	1.24
3	12	1.39
Actual Earth Resistance for Pit 1		1.17

Table 3.2: The Distance and the Earth Resistance Values of Pit 2

S/No.	Distance (M)	Resistance (Ω)
1	4	1.21
2	8	0.57
3	12	0.64
Actual Earth Resistance for Pit 2		0.57

Table 3.3: The Distance and the Earth Resistance Values of Pit 3

S/No.	Distance (M)	Resistance (Ω)
1	4	1.25
2	8	1.29
3	12	1.41
Actual Earth Resistance for Pit 3		1.25

Table 3.4: The Distance and the Earth Resistance Values of Pit 4

S/No.	Distance (M)	Resistance (Ω)
1	4	0.69
2	8	0.45
3	12	0.34
Actual Earth Resistance for Pit 4		0.34

Table 3.5: The Distance and the Earth Resistance Rating of Pit 5

S/No.	DISTANCE (M)	RESISTANCE (Ω)
1	4	4.49
2	8	3.22
3	12	2.73
Actual Earth Resistance for Pit 5		2.73

Table 3.6: The Distance and the Earth Resistance Rating of Pit 6

S/No.	Distance (M)	Resistance (Ω)
1	4	0.24
2	8	0.55
3	12	0.72
Actual Earth Resistance for Pit 6		0.24

Table 3.7: The Earth Resistance Rating of each Pit

S/No.	Earth Resistance for Each Pit	Resistance (Ω)
1	1	1.17
2	2	0.57
3	3	1.25
4	4	0.34
5	5	2.73
6	6	0.24

Introductory Design of 132kV OHL substation establishing contextual analysis boundaries are given
Slope Coefficient, U = 0.55
Potential Probe Distance, DPT = 10.97M
Actual Resistance, R = 0.59Ω
60 MVA 132/33KV Transformer = 0.20Ω
Lightning Arresters = 0.20Ω
Line Gantry = 0.20Ω
300KVA 33/0.415KV Earthng Transformer = 0.20Ω
Transformer Body = 0.43Ω

Table 3.8: Continuity Checks of Equipment to Earthing Grid System

S/No.	Equipment	STATUS
1	All Panels in Switchgear Room	Continuous
2	All panels in battery room	Continuous
3	All panels in communication room	Continuous
4	132kv lightning arresters	Continuous
5	Perimeter lighting	Continuous
6	Perimeter fencing	Continuous
7	Control room	Continuous
8	All gantry support	Continuous

- Resistivity of Soil and Surface Layer

The soil edifice can be calculated based on its soil resistivity, (stream bank development may be 1.5 ohm-meters resistivity esteem, though dry sand or stone may have norms of 10,000 ohm-meters) [21], as shown intable 3.9

Table 3.9: The Depth of Earth Conductor [18]

No.	Soil Resistivity in ohms/meter	Economical depth Buried in meters
1	50 – 100	0.5
2	100 – 400	1.0
3	400 – 1000	1.5

- Earth Resistance Determination of Afam-IPP Sub Transmission Station Site

Soil resistivity (ℓ) = 100Ω/m
Crush rock resistivity (ℓ_s) = 2566Ω/m
Length of grid (L) = 200ft=70m
Breath of grid (B) $=$ 200ft $=$ 70m)
Parallel conductors $= 11 \times 11 = 121$
Depth of earth grid (h) $=$ 6ft $=$ 1.8288m
Number of electrodes $(N_r) = 22$
Length of electrodes $(N_l) = 6ft = 1.8288m$
Thickness of crushed rock $(h_s) = 0.5ft = 0.1524m$

- Area Occupied by the Ground Grid

$$A = L \times B \qquad (3.2)$$

- Total Buried Length of Conductors

$$(L_T) = (11 \times \mathrm{L}) + (11 \times \mathrm{B}) + (\mathrm{N_r} \times \mathrm{N_l}) \qquad (3.3)$$

- Surface Layer Derating Factor

$$\mathrm{C_s} = 1 - \frac{0.09\left(1 - \frac{\ell}{\ell_s}\right)}{2\mathrm{h_s} + 0.09} \qquad (3.4)$$

Where, ℓ = Soil resistivity
ℓ_s= Crush rock resistivity
[16];[15] and [22]

- Tolerable Touch and Step Potential For 70Kg Person

$$E_{touch_{70}} = (1000 + 1.5 \times C_s \times \ell_s) \times \frac{0.157}{\sqrt{t_s}} \qquad (3.5)$$

Where;
$E_{touch_{70}}$= touch Potential limit
C_s= surface layer derating factor
ℓ_s= resistivity of crush rock
t_s= exposure time or shock duration =0.5sec

$$E_{step_{70}} = (1000 + 6 \times C_s \times \ell_s) \times \frac{0.157}{\sqrt{t_s}} \qquad (3.6)$$

WhereE_{step}= The Step Potential
[16];[15];**[17];**[23];[22];[2];[20] and[24]

- Decremental Factor (D_f)

$$\mathrm{D_f} = \sqrt{1 + \frac{\mathrm{T_a}}{\mathrm{t_f}}\left(1 - \mathrm{e}^{\frac{-2\mathrm{t_f}}{\mathrm{T_a}}}\right)} \qquad (3.7)$$

Hence; $\mathrm{T_a}$= dc time offset in seconds (is a constant)
$\mathrm{t_f}$ = duration of fault time
[25]; [23]and [15]
Note that

$$\mathrm{T_a} = \left(\frac{\mathrm{X}}{\mathrm{R}}\right)\left(\frac{1}{2\pi\mathrm{f}}\right) \qquad (3.8)$$

Hence; $\frac{\mathrm{X}}{\mathrm{R}}$ = fault location ratio at =15
f = frequency =50$\mathrm{H_z}$
[15];[25]and [23]

- Grid Current Maximum ($\mathrm{I_G}$)

$$\mathrm{I_G} = \mathrm{S_f} \times \mathrm{D_f} \times C_p \times \mathrm{I_g} \qquad (3.9)$$

Where; $\mathrm{S_f}$ = fault current division factor
$\mathrm{D_f}$ = Decremental factor
$\mathrm{C_p}$ $= Corrective\ projection\ factor$
$\mathrm{I_g}$= Symmetrical short circuit current
[25] and [20]

- Ground Potential Rise (GRR)

$$\mathrm{GPR} = \mathrm{R_g} \times \mathrm{I_G} \qquad (3.10)$$

[16];[25];[23];[22];[20] and [24]

- Geometric Factor

$$(\mathrm{n}) = \mathrm{n_a} \times \mathrm{n_b} \times \mathrm{n_c} \times \mathrm{n_d} \qquad (3.12)$$

[16];[25];[15]and [23]

$$\mathrm{n_a} = \frac{2\mathrm{L_c}}{\mathrm{L_p}} = \frac{2 \times [(11 \times \mathrm{L}) + (11 \times \mathrm{B})]}{2(\mathrm{L} + \mathrm{B})} \qquad (3.13)$$

Where; $\mathrm{n_b}$=1, for square grids
$\mathrm{n_c}$=1, for square and rectangular

n_d=1, for square, rectangular and L-shaped grids[16];[23];[25] and [15]

- Spacing between parallel grid conductor (D)

$$D = \frac{1}{2}\left(\frac{B}{n_r-1} + \frac{L}{n_c-1}\right) \quad (3.14)$$

Where; B =width of grid
L= length of grid
n_r= number of parallel rods and
n_c = Number of parallel conducts

- Weighting Factor

The corner mesh earth electrodes for weighting factor

$$k_h = \sqrt{1+h} \quad (3.15)$$

Where k_h= weighting factor for depth of buried rod

- Geometric Spacing Factor (K_m)

$$K_m = \frac{1}{2\pi}\left(\text{In}\left[\frac{D^2}{16h\times d} + \frac{(D+2h)^2}{8D\times d} - \frac{h}{4d}\right] + \frac{K_{ii}}{K_h}\text{In}\left[\frac{8}{\pi(2n-1)}\right]\right) \quad (3.16)$$

Where; h=depth of earth grid
d= cross sectional diameter of grid conductor [15];[25];[23] and [24]

- Cross Sectional Diameter

$$d = \sqrt{\frac{4A}{\pi}} (3.15)$$

- Irregularity Factor K_i

$$K_i = 0.644 + 0.148n \quad (3.17)$$

[16];[25] and [15]

- Effective Buried Length of the Grid

$$L_m = L_c + \left[1.55 + 1.22\left(\frac{L_c}{\sqrt{L_X{}^2+L_Y{}^2}}\right)\right]L_R \quad (3.18)$$

Where; L_c= Total length of horizontal grid conductor (M)
L_R= The total length of earthing electrode/rod (M)
L_r= The total length of each earthing electrode/rod (M)
L_X and L_Y are the maximum length of the grid in X and Y direction.[23];[25] and[15].

- Computed Step Voltage

The maximum allowable step voltage was calculated from IEEE Std 80 Equation 9

$$E_s = \frac{\rho_s k_s K_i I_G}{L_s} \quad (3.19)$$

Where$E_m = Mesh\ potential$;
ρ_s= The soil resistivity (Ω.m)
k_s= The geometric spacing factor (see below) Ks
k_i= The irregularity factors
I_G= The maximum grid current (A)
L_s= The effective buried length of the grid (see below) Ls. [16];[25];[15];[23];[17] and [2]

- Effective Buried Length L_s

$$L_s = 0.75L_c + 0.85L_R \quad (3.20)$$

Where L_c= The total length of the horizontal grid conductors (m) Lc
L_R= The total length of earthing electrodes/rods (m) LR[15] and [23]

- Geometric Spacing Factor (K_s)

$$K_s = \frac{1}{\pi}\left[\frac{1}{2n} + \frac{1}{D+h} + \frac{1}{D}(1-0.5^{n-2})\right] \quad (3.21)$$

[15];[23];[20] and[24]

- Computed Mesh Potential (E_m)

$$E_m = \frac{\rho E_m K_i I_G}{L_m} \quad (3.22)$$

[23];[25];[15];[2];[20] and[24]

IV. RESULTS AND DISCUSSION

The ETAP Simulation Results on Afam-IPP_Sub Transmission Station in figure1, shows that Electrical Transient Analyzer Program (ETAP) simulation software was utilized to achieve the desired result for the improvement of the earthing system in Afam/IPP132/33KV sub transmission station, Afam, Rivers State, Nigeria.

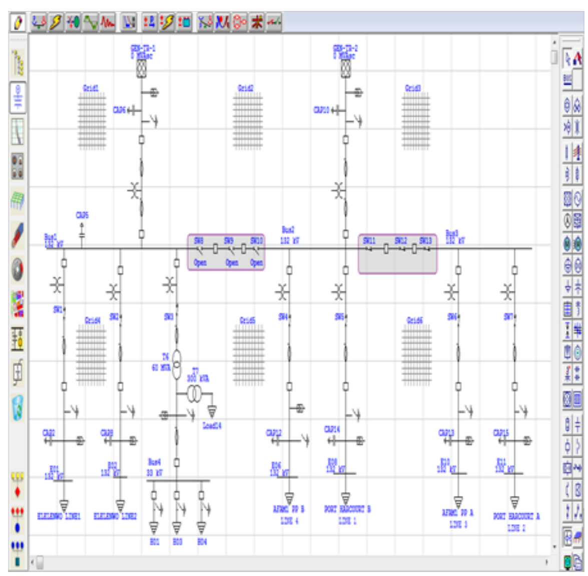

Figure 1: Afam-IPP Sub Transmission Station Earthing Position

The result in figure 2 shows 70Kg weight of a person was considered with fault duration of 0.5sec, 3.1KA ground short-circuit current was considered, the ratio at the fault location was measured to be 15.

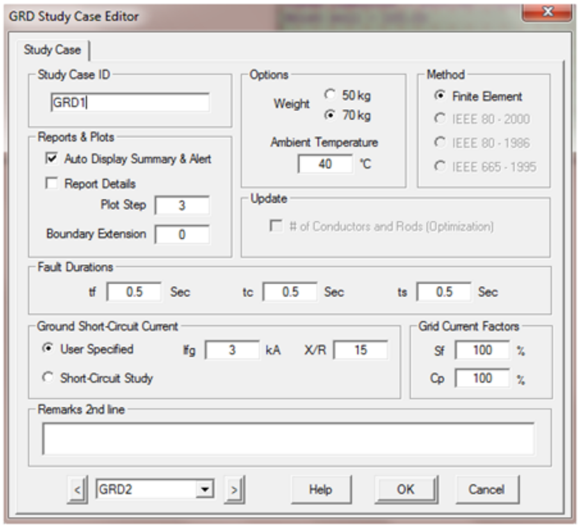

Figure 2 GRD on Afam-IPP_Sub Transmission Station.

The result in figure 3, shows 6ft length of 22 grid rods with diameter of (0.75inch) made of copper was used to achieve the desired result.

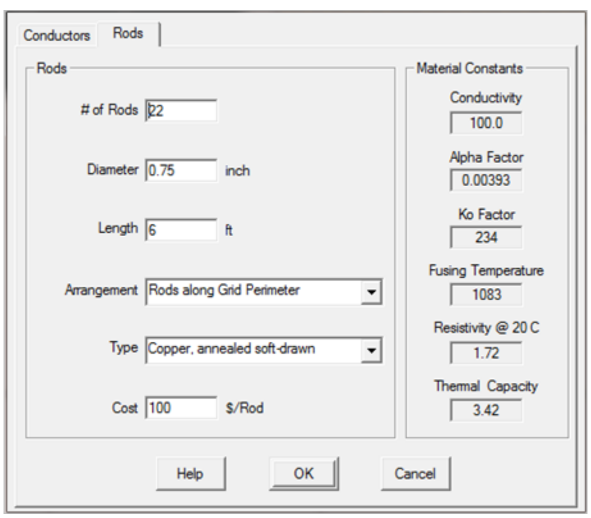

Figure 3 Rod on Afam-IPP_Sub Transmission Station

The determined touch potential was 557.3Volts while the tolerable touch potential was determined as 872.4Volts and step voltage was determined as 205.4Volts while the tolerable step potential was 2823.6Volts. The Ground Potential Rise (GPR) was determined as 2098.7Volts while the earth grid resistance was determined as 0.668Ohm's as shown in figure 4. Hence the earthing system is safe.

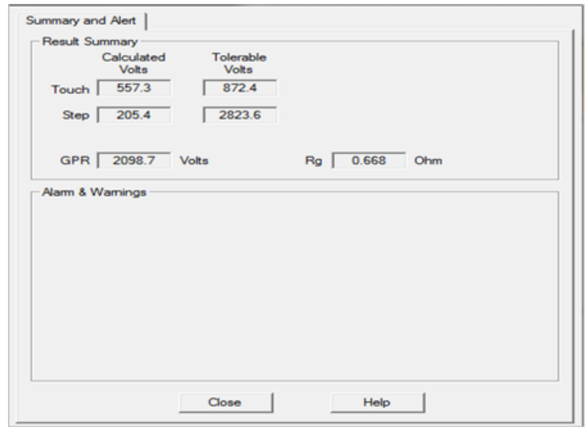

Figure 4: The Afam-IPP_Sub Transmission Station Earthing System Result

The result in figure 5, illustrate that the grid ground potential rise of the earthing formation was determine as 2098.7Volts while the earth grid resistance was determined as 0.668Ohm's which was less than the tolerable limits. therefore, the grid was thought of to be within its safe limits.

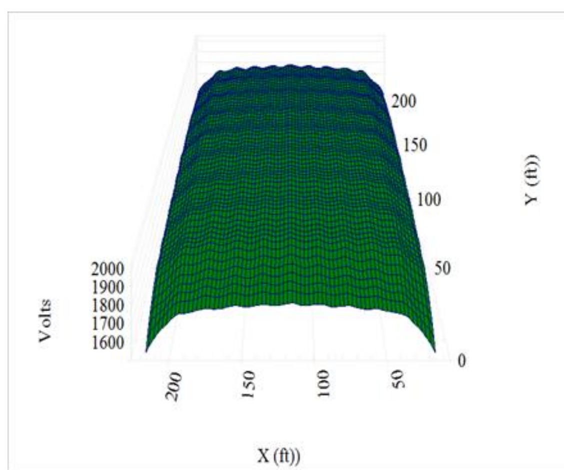

Figure 5: Ground Potential Rise Profile on Afam-IPP_Sub Transmission Station

The touch potential graph shows that, the light green colour on the touch potential falls between 50-100 Volts, the dark green colour designates that the touch potential falls between 100-150 Volts, the red colour shows that the touch potential falls between 150-200 Volts, while the brown colour indicates that the touch potential falls between 200-550 Volts, as shown in figure 6.

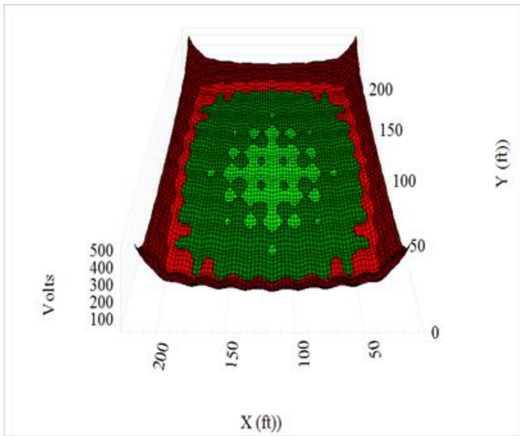

Figure 6: Touch Potential Profile on Afam-IPP_Sub Transmission Station

The graph that illustrate the step potential shows that, The light green colour on step potential falls between 0-10 Volts, Dark green colour designates that the step potential falls between 10-20 Volts, Red colour indicates that the step potential falls between 20-30 Volts, while the Brown colour specifies that the step potential falls between 30-210 Volts, as shown in figure 7:

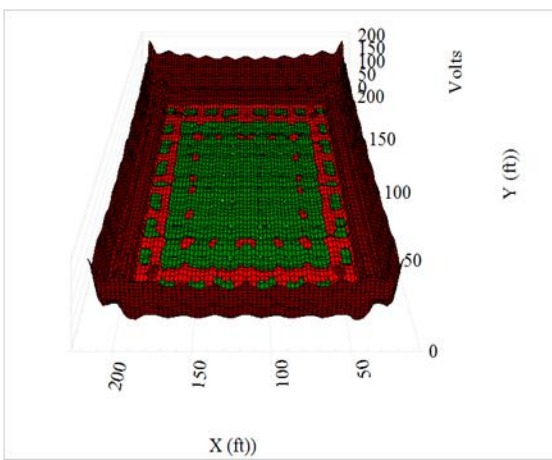

Figure 7: Step Potential profile on Afam-IPP_Sub Transmission Station

The graph in figure 8, shows that Step Potentialprofile voltage was higher than that of the touch potential voltage with respect to the length of the rod used.

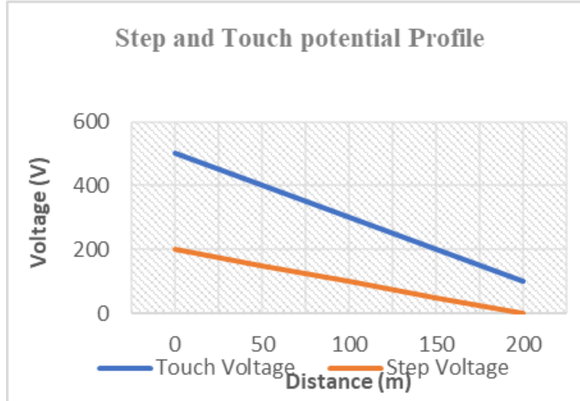

Figure 8: Step and Touch potential Profile Chat Treatment of Violated Earth Pit

The result shows that the violated earth resistant treatment of pit 1 and 3 respectively was lowered by adding 6bags of ashes, 1.5 bags of salt and water. After performing the treatment, the earth resistant was found to be reduced by 20%. While the violated earth resistant treatment of pit 5 was lowered by adding double of more ashes, salt and water. After performing the treatment, the earth resistant was found to be reduced by 40% as shown in figure 9.

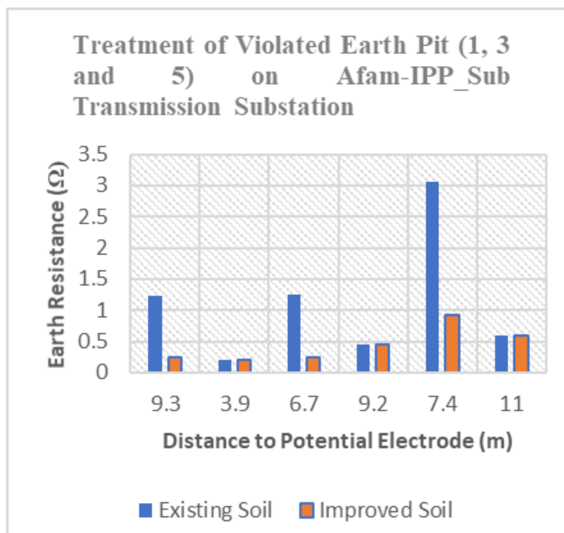

Figure 9: Treatment of Violated Earth Pit (1, 3 and 5) on Afam-IPP_Sub TransmissionSubstation

CONCLUSION

In conclusion, the designed square grid configuration dimension of 200 m × 200 m with 7m spacing, 22 parallel grid ground conductors rod was made of copper with diameter of 0.75inch, the depth of earth grid (h) was 6ft after conversion it became 1.8288m, the thickness of upper soil layer was 100. Two-layer soil models were thought of with upper- and lower-layer soil resistivity of 52ohm-m respectively and body weight of 70Kg with fault duration of 0.5sec. The touch potential value is 557.3Volts, step potential value is 205.4Volts, Ground Potential Rise (GPR) of 2098.7Volts and earth grid resistance of 0.668Ohm's which are lower than the tolerable limits.The grid conductor sizing at X and Y axis were 200ft respectively with 11 numbers of conductors at the direction of X and Y axis respectively, 6ftdepth of earth grid, 22 grid rods with diameter of (0.75inch) made of copper was used to achieve the desired result. The step, the profile of touch potential and the profile of the ground potential rise was achieved. Thus, the safe grid limits were achieved.

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