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Improvement of the Earthing System for 132/33kV Afam1 Sub-Transmission Station

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Abstract:

This work is aimed at improving the earthing system of 132/33kV Afam 1 Sub-transmissionStation using IEEE method to achieve the earthing design and ETAP Software for the simulation of the system. The touch voltage, step voltage, and mesh voltage are determined to achieved the desired result. The result shows that the substation is ina depraved state of the earthing system, out of six (6) earthing pits, three (3) pits are violated, two (2) pits are vandalized and the remaining one (1) pit cannot serve the substation adequately. The violated result indicates that the earth resistance value for Pit 1, Pit 2 and Pit 3,are 2.63Ω, 1.25Ω and 1.16Ω respectively.Six (6) bags of ashes, 1.5 bags of salt and water are used for the treatment of the soil resistivity of pits 1, 2 and 3 respectively, after performing the treatment, the soil resistance of pit 1,2 and 3 are 0.67 Ω, 0.59 Ω and 0.5 Ω respectively hence, resistivity is reduced by 70%. The earthing system of pits 4 and 5 should be replaced with a complete earthing system. The Sub transmission substation has a design of 100m x 90m square grid configuration dimensional area with a total mesh area of 9000 m. the ground rod spacingis 8m, the depth of the buried grid conductor is 0.6 m, the diameter of the grid conductor is 16 mm, the number of conductors in X-axis is 18, while the number of conductors in Y-axis is 19, the total length of conductor used for the substation is 5972 m, the thickness of crushed rock is rated as 1 m, the quantity of ground rod is 280 rods, the length of one earth rod was 3 m. The result also shows that $768\,V$is determined for 70 Kg body weight, fault duration of 0.5sec with a current division factor of 0.6. The Fault Current is 13785A. The Ambient temperature is rated as 40˚C, the Maximum allowable temperature 1084 ˚C, Temperature of thermal coefficient of resistivity at 0˚C is rated as 245 ˚C. The ground short-circuit current is 3kA, and the ratio at the fault location is to be 15, which is used in determining theallowable touch voltage as 529.29Volts and step voltage as 450.87Volts. The touch volt was 557.3 Volts, the allowable touch voltage was 872.4354 Volts and the step voltage was 205.4 Volts. The allowable step voltage was 2823.6Volts, the ground potential rise was 20998Volts, and the Ground Potential Rise (GPR) is 2098.7 Volts. The ground potential rise is lower than the tolerable limits, hence, the grid is within its safe limits. This study recommends that the soil resistivity of pit 1, 2, and 3 respectively should be treated while the replacement of earthing system of pit 4 and 5 should be done urgently to avoid break down of electrical installation and loss of life of personnel. An earth resistance test should be performed on the substation once a year using an earth resistance tester.

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NOMENCLATURE

Symbol	Description	Unit
α	Improvement constant	
β	Improvement constant	
d	Diameter of rod or wire	m
λ	Factor given in Table 1 of BS-7430	2
ρ	Soil resistivity assumed uniform	Ωm
D	Diameter of ring	m
a	Radius of each rod strip wire or round plate	m
A	Area of one face of the plate or one mesh grid	m^2
b	Length of the long side of the grid	m
d	Diameter of rod or wire	m
D	Diameter of ring	m
Dc	Diameter of the concrete shell	m
h	Burial depth of electrode	m
k1	Coefficient of the grid resistance equation	
k2	Coefficient of the grid resistance equation	

L	Total length of buried conductor rod (electrode)	
Lc	Total length of all connected grid conductors	
Ln	Nominal length of each electrode	m
Lr	Total length of the ground rod	m
LT	Total length of buried conductors used in grid	
n	Number of vertically driven rods (electrodes)	
N	Total number of joint vertical electrodes	
P	Coefficients given in Table 6 of BS-7430	2

Key Words: Improvement,earthing, system, Afam 1, sub-transmission, station

I. INTRODUCTION

Substation systems must be earthed not just to protect people working near earthed facilities and equipment from electric shock, but also to ensure that the electrical system works effectively [1]. The ground acts as an electrical conductor with varying conductivity; the earth resistance connection varies depending on the earth's configuration, chemical composition, moisture, temperature, season, rod depth and diameter, and other factors [2]. According to [3], the purpose of an earthing structure is to provide a homogeneous potential surface under and around a station (nearly zero or absolute earth potential). The movement of the earth system, according to [4], generates voltage gradients at ground level, which causes different regions of the earth and the reference system to be affected (ground round). The voltage between the earthing system and the reference earth, known as Earth Potential Rise (EPR), is proportional to the magnitude of the fault current and the earth's resistance. Designing an adequate earthing system helps to reduce the resistance value to the earth as much as possible to minimise the voltage between the earthing system and the reference earth. For distribution substations, the maximum allowed resistance value varies between 1 Ohm and 5 Ohm depending on the local conditions [5].
It is worth noting that the old conventional ways of doing Power Transformer substation earthing were to dig a large pit and bury all the earth rods and just brought out about two leads which will be extended to all the power transformers and substation equipment. Factors influencing resistance of grounding (Earthing) electrode systems include the resistance of the electrode, the surface area of the rod, the difference in ground rod sizes and the materials composition of the electrode [6].

1.1 Statement of the Problem

The earthing system of 132/33KV Afam I Sub transmission station, Rivers State, Nigeria, consists of six (6) pits, out of these six (6) pits, three (3) pits are violated while two (2) pit is vandalized.

1.2 Objectives

The main objectives of this paper are:

i. To collectall necessary earthing information of 132/33KV Afam1 Sub transmission station, Rivers State, Nigeria.
ii. To determine the earth grid resistance, Tolerable Touch and Step Potential For 70Kg Person.
iii. To use the Institute of Electrical and ElectronicEngineers' (IEEE) Method for the earthing design, and Electrical Transient Analyzer Program (ETAP) software for simulation.

1.3 Research Significance

This research work provides a practical and satisfactory sub-transmission station earthing system that permits a dangerous rise in voltage under normal and abnormal conditions.

II. LITERATURE REVIEW

Grounding practices adopted at transmission substations and lines are of great importance. Earthing systems must be well designed, properly maintained, and adequate provisions made for future expansion while choosing the dimensions of the earth mat. A well-designed earthing system plays an essential role in substation design and installation, according to [7], with the most crucial component being to safeguard humans. However, because the lack of a safe and effective earthing system might cause control and protection systems to malfunction or fail, earthing system design demands special attention during substation design and installation. As a result, a systematic approach to appropriate earthing system design is necessary to assure optimal protection from electrical system malfunctions and lightning strikes.The importance of electricity cannot be overemphasized in modern times as it is the basis for socio-economic and technological development of any society [8]. A well-designed earthing system is required in substations to ensure the protection of human life [7]. According to [9], earthing systems are used to deflect high currents to the soil. Lightning strikes, for example, can create high-amplitude transient currents and voltages with short rise times in electrical power systems, which must be dissipated to the ground in a controlled manner. It could result in devastating injuries or perhaps death in the worst-case scenario [5].

In the event that the grid design fails to meet the tolerable touch voltage requirements, it is advisable to reduce the available ground fault current [10]. This helps also to improve the power quality of the system. [11] say that power quality is the measure to which power supply quantities such as voltage, frequency and so on, maintain a statutory set limit. When a system is electrically connected to an earth-embedded metallic structure, it is said to be grounded, [5]. The earth-embedded metallic structures provide a channel for the conduction of electricity to the earth. [12] say that the low-impedance in electrical contact of the grounding systemis between the neutral of the electrical system and the earth. In a three-phase system, the earth's potential should be the same as the neutral's potential so that humans and other living beings can safely contact the metallic structures connected to the system's neutral.

Soil resistivity is one of the major factors that determine the effective performance of a grounding system. By ensuring low resistivity for a grounding system, it is advisable therefore to always consider soil resistivity variations while designing a grounding system [13].

Grids with rods at each corner are commonly used in grounding systems. In the construction of modern extra-high-voltage and ultra-high-voltage AC substations, grounding has become a serious concern. The quality and performance of grounding systems are a major concern in modern system design. To increase the reliability of electric power supply, grounding is a very important aspect when utilizing the world 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 from lighting strikes or fault currents in the power system[14]. During a fault, the voltage rise must be kept to a minimal level. In high-voltage substations, this needs extremely low ground resistance. The most popular method of creating low ground resistance values at high-voltage substations is to use interconnected ground grids [15].

Ground rods and their connections can be degraded over time by corrosive soils with high moisture content, high salt content, and high temperatures. Although the grounding system had low earth ground resistance values when it was first constructed, the resistance of the grounding system can grow if the ground rods are eaten away [16].

2.1. Soil Resistivity

One cubic meter of earth soil measured as one ohm-meter resistivity at two different points is equivalent to one-ohm resistance. The relationship between the earth resistance and the soil resistivity is defined by the composition of the soil profile structure. The soil resistivity within the coverage area has a big impact on the planting of earth electrodes for lowering earth resistance. As a result, this characteristic is critical in determining the type of earthing strategy that should be employed to safeguard the allocated area. It is also affected by soil moisture and local meteorological conditions, with variable consequences depending on the makeup of natural minerals such as seawater or precipitation. The general guide to local soil resistivity is listed in Table 2.1

Table 2.1: Guide to Soil Resistivity (Ω·M)

Type of soil	Climatic Condition Normal and high rainfall	Underground waters
	Range of values	Range of values
Alluvium and lighter clays	Depends on water level of locality	1 to 5
Clays	5 to 20	2 to 5
Marls	10 to 30	
Porous Limestone	30 to 100	
Porous Sandstone	30 to 300	
Quartzites, compact and crystalline limestone	100 to 1000	
Clay slates and slateyshales	300 to 3000	30 to 100
Granite	1000	
Fissile states, schist, gneiss and igneous rocks	1000 upwards	

Source: [17]

To determine the actual soil resistivity, on-site measurement needs to be carried out. This is essential because soils are the main element for the dispersion of fault current. For effective earth protection, field data such as soil surface layers and the underlying geological structure should be collected. Identification of the land stratification for the feasibility of the protection scheme by weighing the specific buried depth and material of the earth electrodes being used should also be considered. Despite being impractical to change or transform the fundamental soil properties; a feasibility study should be conducted for the substation to be ideally located with a higher resistivity of the soil, the suggested order for selecting a substation location is mentioned below.

1) Wet sand, peat and marshy soils.

2) Clay, clayey soil, arable and loamy land or mixed and composite of small sands.

3) Loamy clay and composite of small stones, sands and gravels.

2.2. Requirement for Earth Conductor

The following requirements must be considered when choosing a conductor material for underground use.

i. Sufficiently low resilience to all types of weather.
ii. A current-carrying capability in normal and fault operating circumstances for all currents and durations.
iii. A current-carrying capacity for all temperatures in both normal and fault conditions.
iv. Able to discharge high-frequency currents to reduce surge impedance.
v. Material durability to avoid rusting.

III. MATERIALS AND METHOD

3.1. Materials

The data used for the improvement of the earthing system for the 132/33kVAfam1 Sub transmission stationare collected from the Maintenance crew of Transmission Company of Nigeria. The materials that are examined include the Earthing conductor, Earth Mat, the Earth connectivity, Earth Electrode, Grid configuration for Safe Operation, and the soil resistivity and surface layer are determined using the step and touch potentials. The Earth Mat is created to meet the primary criteria of an Earthing system using the Transient Analyzer Program (ETAP) simulation software taking into consideration the permissible limits of Step Potential, Touch Potential and Transfer Potential.

3.2 Method

The Institute of Electrical and Electronic Engineers' (IEEE) method is employed in this research for the earthing design, while Electrical Transient Analyzer Program (ETAP) software is used for the simulation. The Area for the substation is given as 100m x 90m, with the assumption of average soil resistivity of 57.4Ωm. The earthing condition of Afam1 132/33kV Sub-Transmission Station is in a deteriorated state, out of six (6) earthing pits, three (3) pits are violated while two (2) pits are vandalized by vandals. The earth mat in the substation comprises of Earth Mat or Grid, Earth Electrode, Earthing Conductor and Earth Connectors. The primary requirement of this earthing system is for it to have a low earth resistance.The fault current and duration are assumed to be the maximum Ground-Fault current flowing into the earthing grid, and the fault duration is the time considered for the fault current to flow via the earthing system just before the Switch Gear protects the devices and isolates the current and fault area. When developing any Sub-Station Earthing Grid for High Resistivity Top/Lower Soil, the surface layer of the high resistivity area of the substation is required for proper safety and protection against the current.

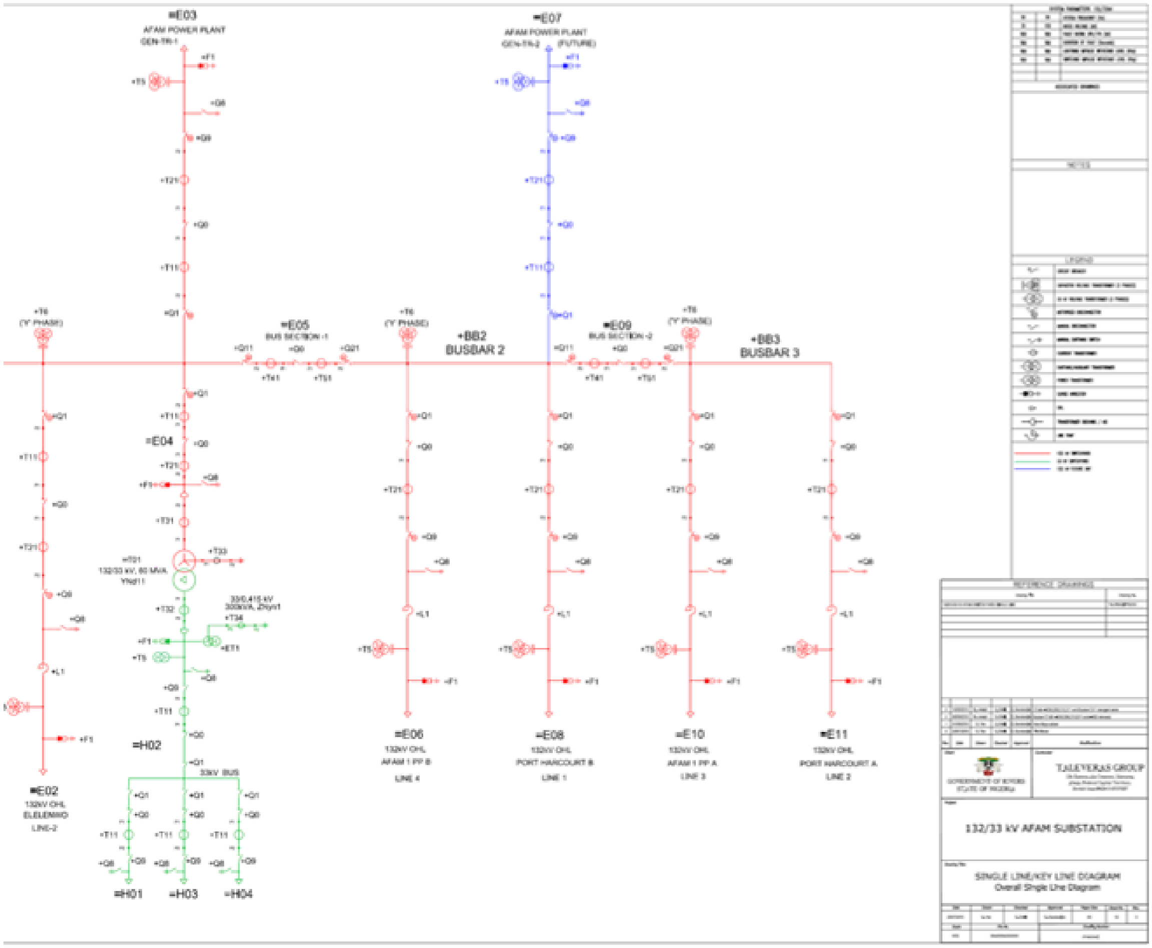

Figure 3.1: The 132/33KV Afam I Sub Transmission Station

3.2.1 Touch Potential

According to [10], when electricity is generated remotely and there are no return paths for earth faults other than the earth itself, there is a risk that earth faults can cause dangerous voltage gradients in the earth around the site of the fault (called ground potential rise). This means that someone standing near the fault can receive a dangerous electrical shock due to :

i. Touch Voltages – there is a dangerous potential difference between the earth and a metallic object that a person is touching

ii. Step Voltages –there is a dangerous voltage gradient between the feet of a person standing on Earth.

The earthing grid helps to dissipate fault currents to remote earth and reduce the voltage gradients in the earth. The touch and step potential Calculations are performed in order to assess whether the earthing grid can dissipate the fault currents so that dangerous touch and step Voltages cannot exist.

Finally, the mesh voltage, E_m , was computed as follows

$$E_m = \frac{\rho K_m \times I_g \times K_{im}}{L_S} \quad (3.1)$$

$$E_m = \frac{57.4 \times 101183.26 \times 0.736 \times 1.733}{1408.64} = 529.29\text{V}$$

With the height h= 0.472m and spacing between conductors D= 5 m and n= 7.363.

3.2.2 Spacing Factor for Step Voltage

In computing the step factor, we have :

$$K_S = \frac{1}{\pi} \times \left[\frac{1}{2 \times h} + \frac{1}{D+d} + \frac{1}{D}(1 - 0.5^{n-2})\right] \quad (3.2)$$

3.2.3 Step Potential

Step potential is lower compared to the touch potential because the feet are stepped on earth in series. Since the current path is passing foot-to-foot, rather than to the heart and other vital organs, the human body can withstand a higher current when exposed to the electric shock. The step potential must be less than the step voltage criteria to have a safe EPS. The step potential expression [18]

Now the step potentialE_S, was computed as follows

$$E_s = \frac{\rho \times K_S \times K_i \times I_G}{L_S} \tag{3.3}$$

$$E_s = \frac{57.4 \times 0.46856 \times 1.733 \times 10183.26}{1052.7} = 450.87$$

IV. RESULTS AND DISCUSSION

4.1. Earthing Pit Position in 132/33kV Afam 1 Sub-Transmission Station

The desired result of 2500 Ωm soil resistivity level is achieved with the voltages depending on the soil resistivity, soil layer and the duration of the shock current, using ETAP simulation software. Hence, the maximum driving voltage of any accidental circuit should not exceed the step voltage and touch voltage limits. With the design of 100m x 90m square grid configuration dimensional area, the total mesh area is 9000 m, ground rod spacing is 8m, the depth of burial grid conductor is 0.6 m, the diameter of grid conductor is 16 mm, the number of conductors in X-axis is 18, while the number of conductors in X-axis is 19, the total length of conductor used for the substation is 5972 m, the thickness of crushed rock is rated as 1 m, the quantity of ground rods is280, the length of one earth rod is3 m, as shown in Figure 4.1.

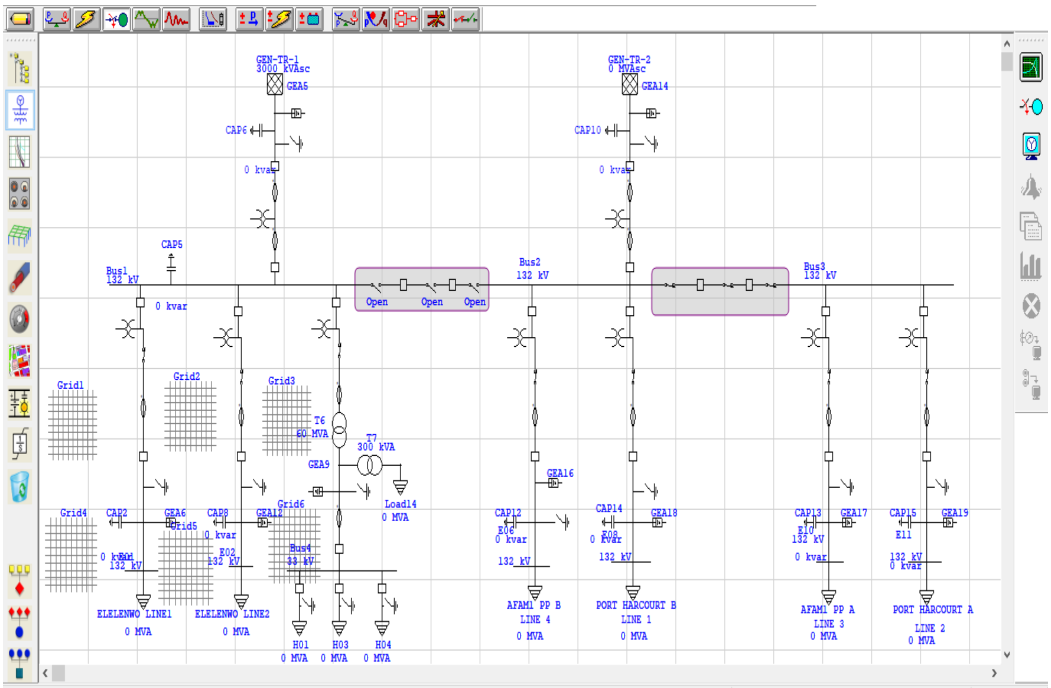

Figure 4.1: The Earthing Pit Position in 132/33KV Afam1 Sub Transmission Station

4.2 The Violated Earth Pit Resistance on 132/33KV Afam1 Sub Transmission Substation

The result in Figure 4.2 indicates that the actual violated earth resistance value for Pit 1 is 2.63Ω

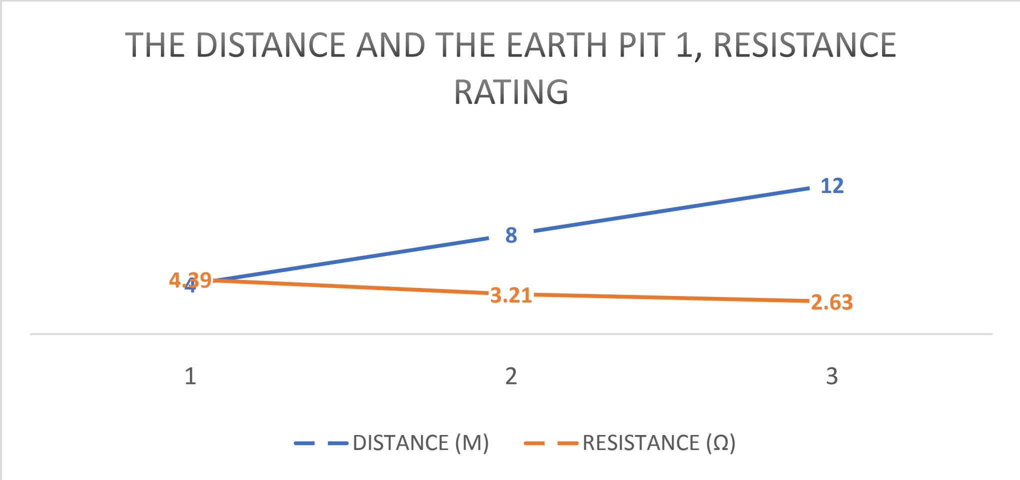

Figure 4.2: The Distance and the Violated Earth Pit 1Resistance Rating

The result in Figure 4.3 indicates that the actual violated earth resistance value for Pit 2 is 1.25Ω.

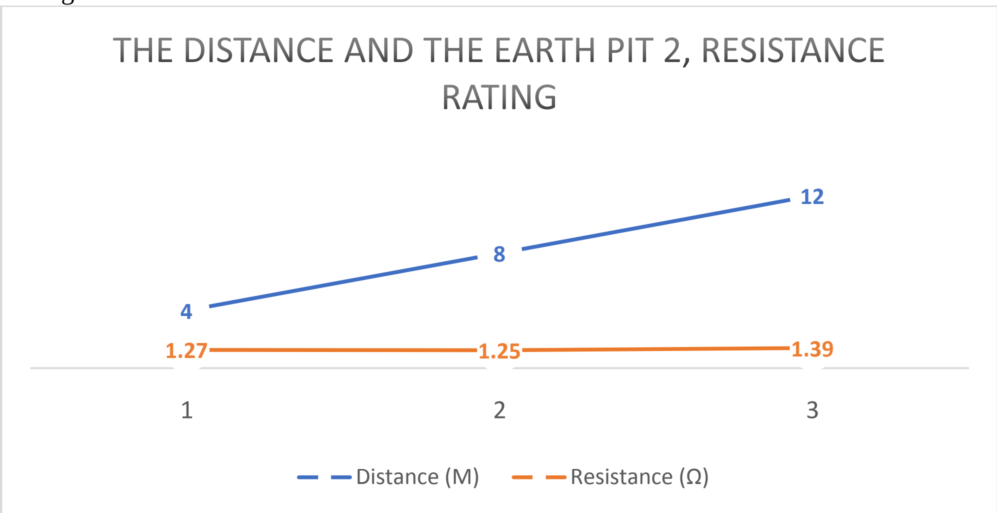

Figure 4.3: The Distance and the Violated Earth Pit 2, Resistance Rating

4.3 Treatment of Three (3) Violated Earth Pit on 132/33KV Afam1, Sub Transmission Substation

The 132/33kV Afam 1 sub-transmission stationearthing result shows that the substationis in a depraved state of the earthing system, out of six (6) earthing pits, three (3) pits are violated, two (2) pits are vandalized by vandals and the remaining one (1) pit cannot serve the substation adequately. Six (6) bags of ashes and 1.5 bags of salt and water are used for the treatment of the soil resistivity of pit 1, 2 and 3 respectively, after performing the treatment, the soil resistivity is reduced by 70%. The earthing system of pits 4 and 5 should be replaced with a complete earthing system. The result in Figure 4.4 and 4.5indicatethe treated earth resistance value for Pit 1 as 0.67Ωand Pit 2 as 0.59Ω as shown also in Table 4.1,and 4.2 below.

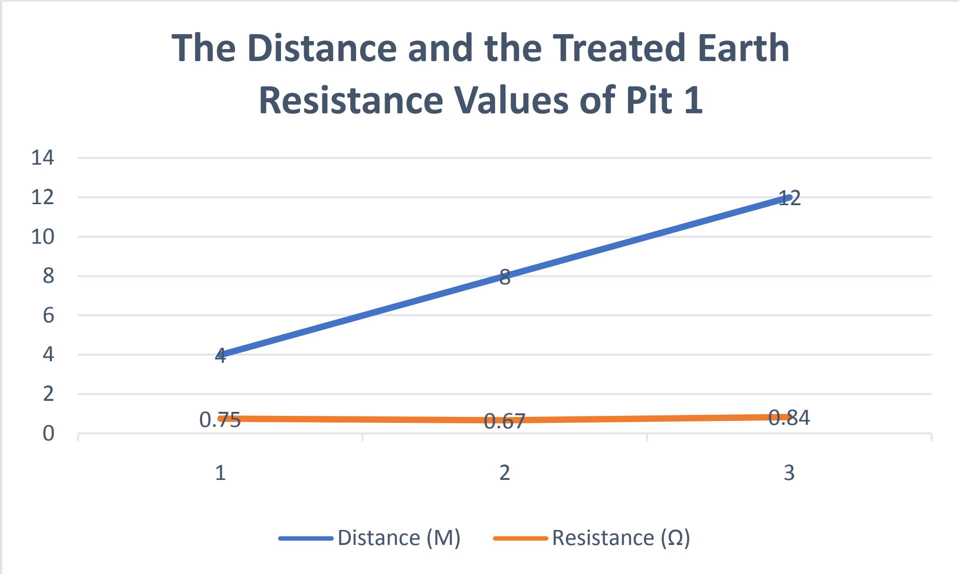

Figure 4.4: The Distance and the Treated Earth Pit 1 Resistance Values

The result in Figure 4.5 indicates that the actual violated earth resistance value for Pit 2 is 0.59Ω.

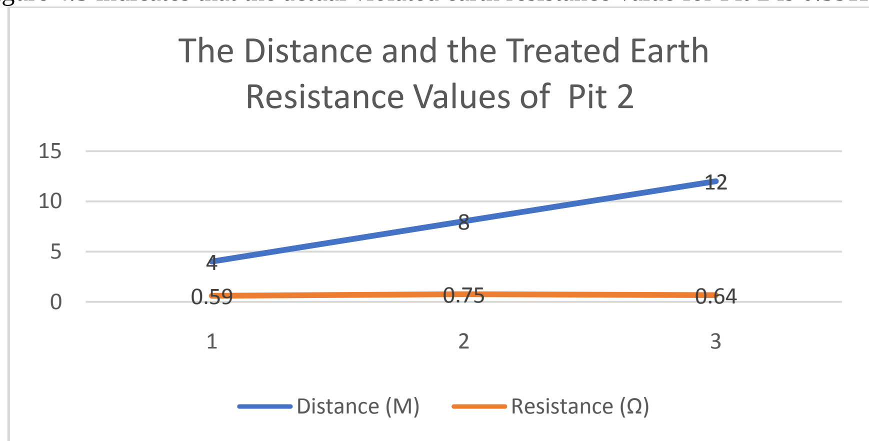

Figure 4.5: The Distance and the Treated Earth Pit 2. Resistance Values

Table 4.1: The Distance and the Treated Earth Resistance Values of Pit 1

S/No.	Distance (M)	Resistance (Ω)
1	4	0.75
2	8	0.67
3	12	0.84
Actual Earth Resistance for Pit 1		**0.67**

Table 4.2: The Distance and the Treated Earth Resistance Values of Pit 2

S/No.	Distance (M)	Resistance (Ω)
1	4	0.59
2	8	0.75

3	12	0.64
Actual Earth Resistance for Pit 2		**0.59**

4.4 The Difference in Violated and Treated Earth Pit of 132/33KV Afam1 Sub-Transmission Substation

The result in Figure 4.6 shows the difference between the violated earth pit and the treated earth Pit 1, which indicates that pit 1 resistanceis 100% normal.

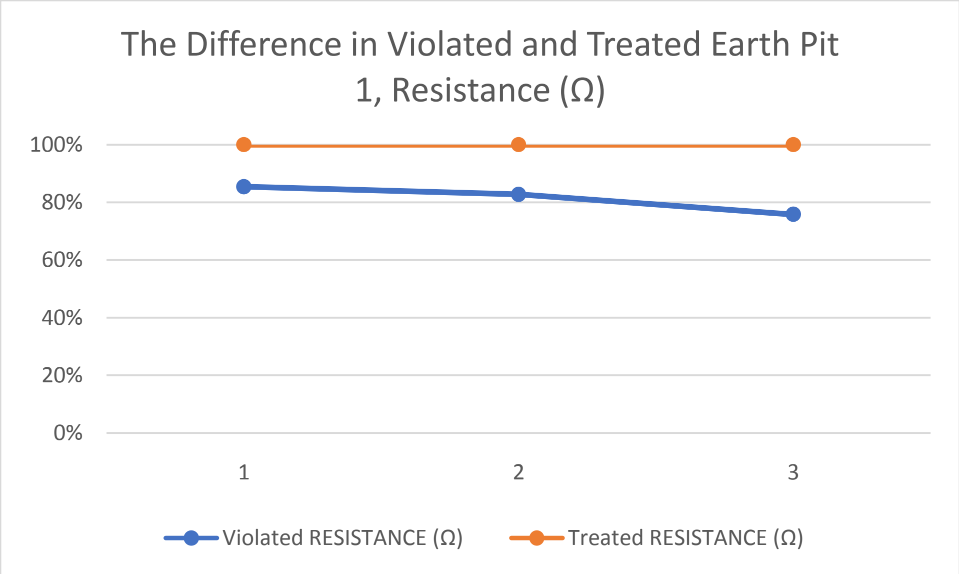

Figure 4.6: The Difference between Violated and Treated Earth Pit 1 Resistance (Ω)

The result in Figure 4.7 shows the difference between the violated earth pit and the treated earth Pit 2, which indicates that pit 2, resistance was 100% normal.

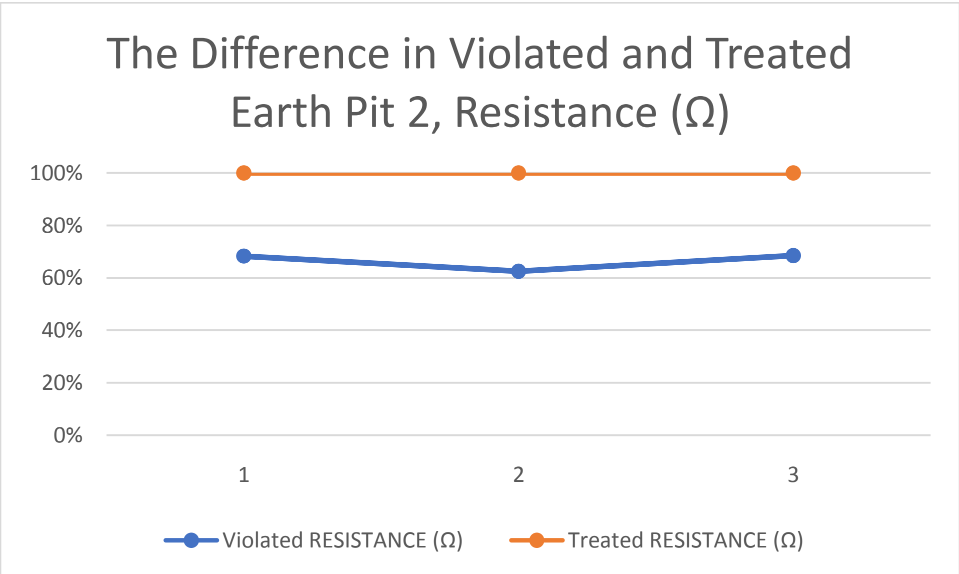

Figure 4.7: The Difference between Violated and Treated Earth Pit 2, Resistance (Ω)

Table 4.3:The Difference between Violated and Treated Earth Pit 1, Resistance (Ω)

DISTANCE (M)	Violated RESISTANCE (Ω)	Treated RESISTANCE (Ω)
I4	4.39	0.75
8	3.21	0.67
12	2.63	0.84

Table 4.4: The Difference between Violated and Treated Earth Pit 2, Resistance (Ω)

DISTANCE (M)	Violated RESISTANCE (Ω)	Treated RESISTANCE (Ω)
4	1.27	0.59
8	1.25	0.75
12	1.39	0.64

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The improvement of 132/33KV Afam1 Sub-transmission Substation in Nigeria, is modelled using the Institute of Electrical and Electronics Engineers' (IEEE) Method and simulated with the Electrical Transient Analyzer Program (ETAP) software to achieve the desired result. The design process: touch voltage, step voltage, and mesh voltage with their determined values are achieved.

The result shows that the substation is in a depraved state of the earthing system, out of six (6) earthing pits, three (3) pits are violated, two (2) pits are vandalized and the remaining one (1) pit cannot serve the substation adequately. The violated result indicates that the earth resistance value for Pit 1, Pit 2 and Pit 3, are 2.63Ω, 1.25Ω and 1.16Ω respectively. Six (6) bags of ashes and 1.5 bags of salt and water are used for the treatment of the soil resistivity of pit 1, 2 and 3 respectively. After performing the treatment,the soil resistivity is reduced by 70%. The result also show 768Vdetermined for 70 Kg body weight, fault duration of 0.5sec with a current division factor of 0.6, fault Current of 13785A, rated Ambient temperature of 40˚C, Maximum allowable temperature of 1084 ˚C, Temperature of thermal coefficient of resistivity at 0˚C rated as 245 ˚C,ground short-circuits current of 3kA, and the ratio at the fault location as 15, which is used in determining allowable touch voltage of 529.29 Volts and step voltage of 450.87 volts. The Ground Potential Rise (GPR) is 2098.7 Volts. The ground potential rise is lower than the tolerable limits, hence, the grid is considered to be within its safe limits.

5.2. Recommendations

To ensure optimum performance and reliability of 132/33KV Afam1 Sub Transmission Substation in Nigeria, we recommend that the soil resistivity of pit 1, 2, and 3 respectively should be treated while the replacement of earthing system pit 4 and 5 should be done urgently to avoid break down of electrical installation on the network.

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