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Improved Design and Evaluation of Electrical Earthing Systems for Maryland 132/33 Kv Transmission Station

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Abstract:- Due to the increase in the demand for electrical power which necessitated an expansion of the existing power system call for an improved design and evaluation of electrical earthing system of the existing transmission grid. In this paper, the earthing grid mesh design and improvement of the 132/33 kV Maryland transmission station was carried out. IEEE and finite element methods were used to generate the required grid mesh structure performance parameters. The soil resistivity was measured using the wenner four-point method and gotten to be 235Ωm. ETAP software (19.0) was used to model, analyze, and simulate the data generated. The result obtained from the simulation of the existing grid showed that the maximum touch voltage using the IEEE and finite element method were 3781.7V and 3766.7V respectively higher than the tolerable touch voltage, 1581.7V. The existing design was improved by adjusting the number of rods, number of parallel conductors, diameter of ground rods and depth of ground rods. The results from the improved design showed that the maximum touch voltage of IEEE (1580.3V) and FEM (1345.8V) were lower than the tolerable touch voltage 1581.7V. Also the improved ground resistance using the IEEE (0.650Ω) and FEM (0.649Ω) were lower than that of the existing IEEE (1.626Ω) and FEM (0.777Ω) designs. The comparison of the result from the improved methods showed that the touch voltage (1345.8V), ground potential rise (10712.3V) and ground resistance (0.649Ω) of the FEM were lower than the touch voltage (1580.3V), ground potential rise (10716.1V) and ground resistance (0.65Ω) of the IEEE. It then implies that using the improved FEM designs, personnel and equipment safety is highly guaranteed Which transmit into a reliable power system to the citizenry.

I. INTRODUCTION

Earthing is the process of forming an electrical link between the equipment's metal frame, electrical structures, or circuits and a buried metallic grid in the earth. If the system's non–current–carrying metal parts are not earthed in the event of a malfunction, they will reach a high voltage with respect to earth, and anyone who comes into contact with such metal parts will be electrocuted [13].

The operation and architecture of an electrical power network are primarily concerned with its reliability and protection. These two factors are very crucial when building a substation [16]. Substations are the heart of the power grid, so they must have a well-designed earthing network to ensure their safety and dependability. The key functions of a substation's grounding structures are as follows: To begin, the ability to conduct excess electric currents through the ground without exceeding operational and equipment limits or jeopardizing service reliability. Second, to make certain that no one in close proximity to the grounded infrastructure is in danger of experiencing a fatal electric shock [13].

By deciding on the appropriate number of vertical rod, parallel conductors , and resistivity of the soil, the most suitable choice of earthing system can be designed. Also, other design parameter includes step and touch voltage requirement, earth resistance, maximum grid current, highest fault current, duration of fault, step and mesh voltage, the resistivity of surface materials and earth mat geometry.

Every year, power demand and the population of people continue to rise, to meet the demand for electricity in densely populated areas; a high voltage or medium voltage station must be built. The amount of space available for the HV/MV substation's installation is small, putting a premium on protection. To meet touch and step voltage requirements, ground potential increase, and potential differences within the station affecting secondary wiring, substation earthing resistance must be very low. Substations are now coexisting with public and residential buildings in suburban areas due to increased development and a decrease in available land. In addition, due to an increase in energy demand in the region, the station's transformer capacities have been upgraded.

The station's power capacity of extremely old transmission stations may have been upgraded many times over the years, resulting in a fault current increase higher than the maximum amount of current that the grid can dissipate without compromising the station. Differences in moisture content and temperature have also resulted in an increase in the resistivity of the station soil over time. This work is aimed at improving the design and evaluating the earthing system for Maryland 132/33 kV Transmission station. Which will involve analyzing the existing grid system of the Maryland transmission station using both IEEE std 80-2013 and Finite Element Method, determine the mesh and touch voltages as well as the ground potential rise using IEEE std 80-2013 and Finite Element Method, analyzing and simulating an improved grounding grid system for Maryland transmission station using IEEE std 80-2013 and Finite Element Method.

II. GROUND GRID TERMINOLOGIES

A. IEEE Std. 80-2013

The fifth edition of this guide is IEEE Std. 80-2013, which was initially published in the year 1961. This guide focuses on outdoor ac substations, whether conventional or gas-insulated [13]. Substations for distribution, transmission, and generation are all included. The methods shown here are also applicable to indoor parts of such substations, or to substations that are entirely indoors, if used with caution.

The following are the basic goals of this standard:

- i. Establish the safe limits for potential differences between points that can be contacted by the human body in a substation under fault conditions as a basis for design.
- ii. Examine substation grounding activities with a special focus on safety, and establish standards for a safe design..
- iii. Based on these principles, develop a method for designing realistic grounding systems.
- iv. Establish analytic techniques to assist in the comprehension as well as resolution of common gradient problems [13].

Terms are defined and illustrated below.

1) Tolerable Step voltage

It is the known potential felt by a person crossing a one-meter distance without touching any grounded object [13]. Equation 1, 2, 3 can be used to measure the general limit for step voltage, step voltage for a 50kg person and step voltage for a 70kg person.

$$E_{step} = \left(R_B + 2 \,.\, R_f \right) . I_B \qquad (1)$$

$$E_{step\,50} = \left(1000 + 6 \,.\, C_S \,.\, \rho_s \right) \frac{0.116}{\sqrt{t_s}} \qquad (2)$$

$$E_{step\,70} = \left(1000 + 6 \,.\, C_S \,.\, \rho_s \right) \frac{0.157}{\sqrt{t_s}} \qquad (3)$$

2) Tolerable Touch voltage

When a person stands with a hand in contact with a grounded structure, the difference in potential between the ground potential rise (GPR) and the surface potential is established. For the touch voltage, the limit can be calculated as

$$E_{touch} = \left(R_B + \frac{R_f}{2} \right) . I_B \qquad (4)$$

In the case of a 50kg operator and a 70kg operator we have,

$$E_{touch\,50} = \left(1000 + 1.5 \,.\, C_S \,.\, \rho_s \right) \frac{0.116}{\sqrt{t_s}} \qquad (5)$$

$$E_{touch\,70} = \left(1000 + 1.5 \,.\, C_S \,.\, \rho_s \right) \frac{0.157}{\sqrt{t_s}} \qquad (6)$$

3) Soil Resistivity Measurement

Before the grounding system design starts, soil resistivity estimates at the substation site are needed. Soil resistivity is used to determine the soil structure at a given site, which varies greatly depending on the terrain. Since it is difficult to find uniform soil resistivity throughout the property, measurements should be taken at different locations throughout the property [12].

At the site, there are several layers of soil, each with its own resistivity. Measurements should be taken around the site to see if there are any significant shifts in depth. In places where there are more variations, the number of measurements should be increased.

a) Wenner four-pin method

It is the most widely used technique. Idea behind this strategy is to position four probes in a straight line in the earth at similar distances and depths [13]. By dividing the current between the two outer electrodes by the voltage between the two inner electrodes, the current between the two outer electrodes is divided by the current between the two inner electrodes.

Any other buried conductive artifacts that are identified should also be noted, as they can trigger incorrect reading estimates if they are close by. When the spacing between the two inner rods is increased to very high values, the magnitude of potential between them rapidly decreases. This is a drawback of the Wenner process.

Resistivity measurements interpretations

Most complicated aspect of the method is interpreting the findings collected in the field. The main objectives are to create a good approximation soil model that can be compared to real soil [13]. Because of the type of soil, depth, and seasonal variations, soil resistivity varies. The following variables are used to construct an equivalent: measurement precision and scope, applied methodology, mathematics complexity, and measurement intent.

Curve matching and analytical techniques are utilized to determine the presence of resistivity layering in soil. For field employees, graphical curve matching is helpful in detecting irregularities and identifying regions that may require thorough inspection and testing. There are also computer-based solutions, and this method can be utilized to approximate the multilayer soil if necessary.

$$\rho = \frac{4\pi aR}{1 + \frac{2a}{\sqrt{(a^2+b^2)}} - \frac{a}{\sqrt{(a^2+b^2)}}} \qquad (7)$$

If b << a, equ 7 can be written as

$$\rho = 2\pi aR \qquad (8)$$

4) Ground Resistance

Estimating the overall resistance to remote earth is the most important and initial step in estimating the shape and size of the earthing grid system [13]. Laurent and Niemann devised a method for calculating the substation's earth resistance, the upper layer can be estimated as shown in equ 9.

$$R_g = \rho \left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}} \left(1 + \frac{1}{1 + h\sqrt{20/A}} \right) \right] \qquad (9)$$

Where,

$$L_T = L_C + L_R \tag{10}$$

Where

L_c = Total length of grid conductor in meter (m)

L_R = Total length of ground rods in meter (m)

h = grid depth (m)

. p is the resistivity of the soil (Ωm)

A is the size of the ground grid's footprint (m^2)

R_g is the earth resistance of the station (Ω)

5) Protective Surface Materials

The use of surface materials helps to improve the contact resistance between people's feet in the substation. The surface material is placed outside the fence and through the substation boundaries. The aim of the surface materials outside the substation's fence is to minimize step voltages, which can become dangerously high.

$$R_f = \left(\frac{\rho_s}{4b}\right) C_s \tag{11}$$

Where, ρ_s is the surface layer resistivity (Ω.m), C_S is the surface layer derating factor, and b is the radius of the metallic disc in meter. The derating factor for the surface layer can be determined as follows:

$$C_s = 1 - \frac{0.09\left(1-\frac{\rho}{\rho_s}\right)}{2h_s+0.09} \tag{12}$$

Where,

h_s is the surface material thickness'

ρ is the ground resistivity (Ω.m)

C_S can likely be approximated by first figuring out the reflection factor

The reflection factor is determined as follows:

$$k = \frac{\rho-\rho_s}{\rho+\rho_s} \tag{13}$$

6) Earth Potential Rise

A substation's grounding grid's full electrical potential that is reached in relation to a distant grounding point believed to be at the potential of remote earth is known as ground potential rise (GPR).

$$GPR = I_G \,.\, R_g \tag{14}$$

Where

I_G = maximum current in the grid

R_g = earth resistance in the substation (Ω).

7) Mesh voltage (E_m)

It is the maximum touch voltages that a substation's grounding network is capable of handling. It is an important consideration when designing a stable grounding device both inside and the substation's surroundings. It must be lower than the tolerable touch voltage for the earthing system to be secure. Otherwise, additional changes to the substation ground grid configuration would be needed

$$E_m = \frac{\rho \,.I_G \,.K_m \,.K_i}{L_M} \tag{15}$$

where

ρ : resistivity of the earth (Ω·m)

L_M : effective burial length (m)

K_m : geometrical spacing factor

K_i : irregularity factor

8) Maximum Step voltage (Es)

Since the two feet are connected in series rather than parallel, step voltages are usually lower than touch voltages. Since currents do not move or flow through vital organs like the heart, the body can withstand a greater amount of currents on a foot-to-foot line. The step voltage must be lower than the acceptable step voltage for the earth system to be secure [13].

The following formula can be used to measure the step voltage:

$$E_S = \frac{\rho \,.K_S \,.K_i \,.I_G}{L_S} \tag{16}$$

The buried effective conductor length (L_s) can be defined as:

$$L_S = 0.75 \,.\, L_C + 0.85 \,.\, L_R \tag{17}$$

Also the step factor, K_S can be computed as:

$$K_S = \frac{1}{\pi}\left[\frac{1}{2\,.h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right] \tag{18}$$

Where

D = spacing between parallel conductors (m)

h = depth of ground grid conductors (m)

n = geometric factor composed of factors n_a, n_b, n_c, and n_d

B. Finite Element (Ground Grid) Method

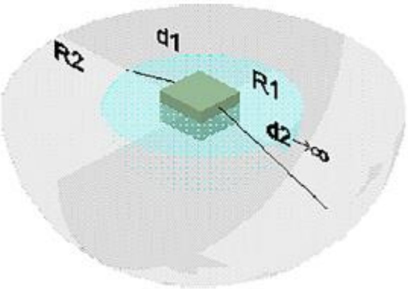


Figure 1: Finite Element Method (Ayodele, 2018)

The major difference between the IEEE method and FEM is in the calculation of ground resistance, the maximum step potential and mesh voltage potential. The potential of the grid (U_g) and the boundary potential (U_b) can be assessed from the resistances and maximum grid current:

$$U_g = R_G \times I_G \tag{19}$$

Where R_G is the ground resistance and is calculated as

$$R_G = \frac{\left(U_g-U_b\right)^2}{\int_v \left(\frac{E^2}{\rho}\right)dv} + \frac{\rho}{2\pi d_1}$$

where

$$d_1 = \frac{D}{2} + 30$$

E is the energy consumed in J

D is the grounding electrode's diagonal distance.

$$U_b = R_2 \times I_G \tag{20}$$

$$R_2 = \frac{\rho}{2\pi d_1}$$

Once the actual potential distributions in the soil have been determined, the touch and step voltage can be calculated directly using FEM by calculating nodal potentials and noting which node has the highest touch and step potential [10]. The maximum step potential and mesh potential are expressed as:

$$V_{touch}(FEM) = \max(U_g) \tag{21}$$

$$V_{step}(FEM) = \max(U_b) \tag{22}$$

III. METHODOLOGY

Maryland is located in the Kosofe local government area of Lagos State, southwest of Nigeria. It is one of the 10 wards in the Kosofe local government area; it is located in latitude 6.57712°N and longitude 3.36682°E. Kosofe has an area of 84km^2 and a population of 934,614 people from the 2006 census.

Maryland transmission station is located in Mende Maryland, Lagos state, and the grounding grid was designed in the year 1975 by SAE S.p.A Milan Italy. This station has a main busbar of 132/33 kV which is fed by two incoming feeders of 132kV rating from Egbin power station. The practical data was collected from the Maryland Transmission station. Since the ground grid infrastructure is already in place and operational, existing data and measured data (present soil resistivity) was collected and is presented in table 1.

A. Analysis of the Existing Grid

Etap 19.0 is the software framework that was used to model and simulate this project. The ground grid system in the Etap Software Program employs the five methods of computation mentioned below:

a) IEEE 80 - 2000
b) FEM - Finite Element Method
c) IEEE 80 - 2013
d) IEEE 665 – 995
e) IEEE 80 - 1986

In this project, both the Finite Element Method (FEM) and the IEEE 80 -2013 method were used. The FEM is based on an image approach and assumes that the grounding mechanism is an equipotential structure, resulting in a precise result.

Firstly the modeling and simulation of the existing ground grid system at the Maryland 132/33kv station using both FEM and IEEE 80 – 2013 will have to be performed. Then the improved design was done based on the results from both methods.

Table 1
Data Gathered from the Transmission Station in Maryland

Parameters	Value	Parameters	Value
Topsoil resistivity	235Ωm	X/R ratio	15.29
Ambient temperature	40°c	Crushed rock layer depth	0.106m
The resistivity of crushed rock	8106.8	Depth of grid	0.5m
Switchyard operator	50kg	Current division factor	0.6
Soil location type	Uniform	Horizontal length	100m
Projection factor	20%	Vertical length	50m
Shock duration	0.5s	Conductor material	Copper
Fault duration	0.5s	Area of conductor (mm^2)	12
Earth rod material	Copper	Conductor total length (m)	1700
Earth rod length (m)	1.25	Earth rod total lengh (m)	15
Earth rod area (mm^2)	50	Diameter of earth rod (cm)	0.8
Horizontal conductor	8	Vertical conductors	18
Earth rod number	12	Conductor number	26
Fault current (A)	15.749	Diameter of earth rod (mm)	8

B. FEM

Using the information from table 1, the existing ground grid of the station was modeled using the finite element method. The 2-D and 3-D ground grid models are as shown in figures 3 and 4, the FEM result summary of the existing grid as shown in fig 5. The plots of the step potential, touch potential, and ground potential profile are shown in figures 6, 7, and 8, and Table 3 shows the output grid parameters of the FEM.

From the simulation results of the existing earthing grid system at Maryland transmission station, it was determined that the maximum touch voltage exceeded the required touch voltage. This means that in the event of a ground fault any individual that comes into contact with a metallic structure risks the danger electrocution as a result of difference in potential between the point of contact and the feet. Therefore an improved design is paramount.

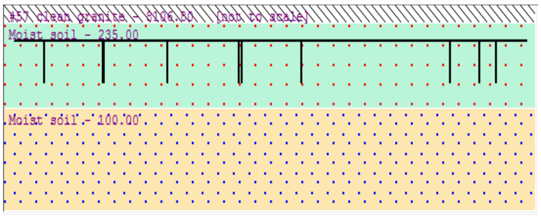


Figure 3: 2-D ground grid model

Figure 3 shows the grid and the buried gound electrode in 2 dimension, it also shows the two different soil layer that is the top and bottom soil of the transmission station.

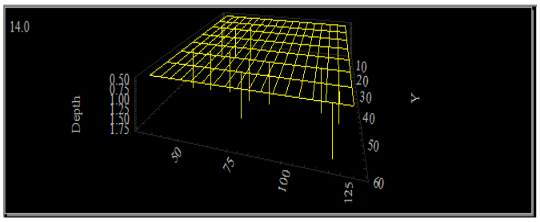
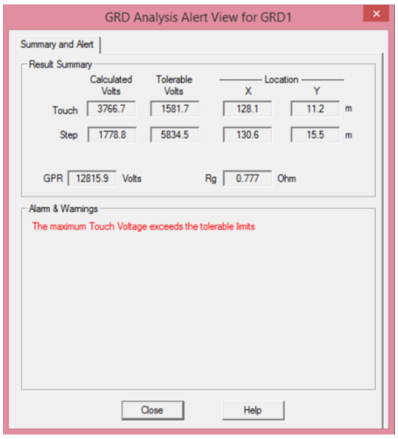


Figure 4: 3-D ground grid model

Figure 4 shows the grid shape, grid depth, the no of conductors in x and y axis, and the depth of earth rod 3 dimension,



Result Summary

	Calculated Volts	Tolerable Volts	Location X	Location Y	
Touch	3766.7	1581.7	128.1	11.2	m
Step	1778.8	5834.5	130.6	15.5	m

GPR 12815.9 Volts Rg 0.777 Ohm

Alarm & Warnings

The maximum Touch Voltage exceeds the tolerable limits

Figure 5: FEM Result Summary of the Existing Grid

Figure 5 shows the value of tolerable step and touch voltage, maximum step and touch voltages, ground potential rise, and resistance of the ground.

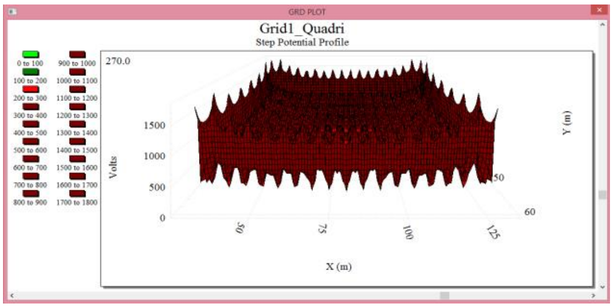


Figure 6: Existing Grid Step Potential Profile using FEM

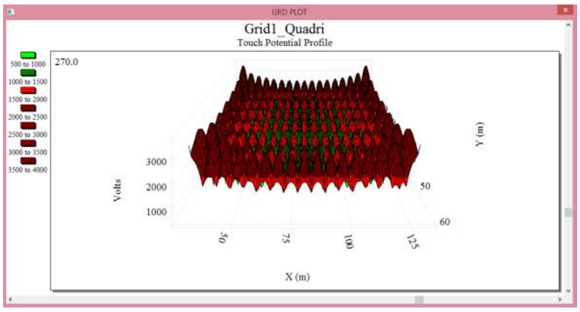


Figure7: Plot of Existing Grid Touch Voltage Profile

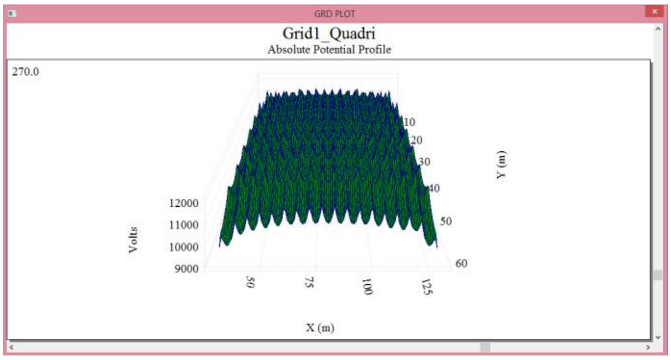


Figure 8: Existing Grid Earth Potential Rise Profile Plot

Figure 6, 7, 8 shows the magnitude of the step, touch and ground potential at different point in the grid.

The design was also improved using the finite element method on the ETAP program, and the improved design, outcome, and possible plots obtained from this procedure are depicted in figures 9 – 14. Tables 2 and 3 also demonstrate the improved configuration and performance parameters.

Table 2

Improved Grid Design Parameters using FEM

Parameters	Value
Vertical conductors	25
Horizontal conductors	50
Conductor number	75
Conductor length	5000m
No. of earth rods	11
Length of earth rods	110m
Earth rod diameter	2cm

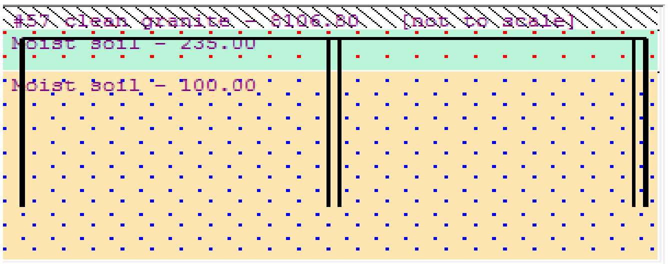


Figure 9: 2-D ground grid model

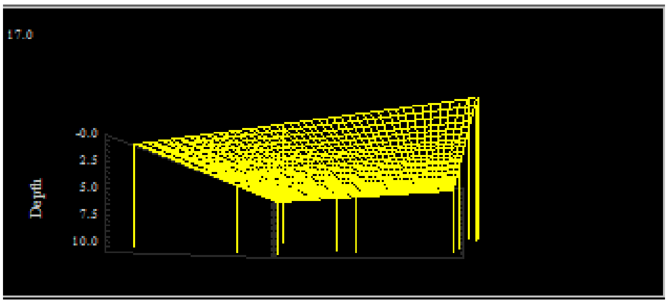
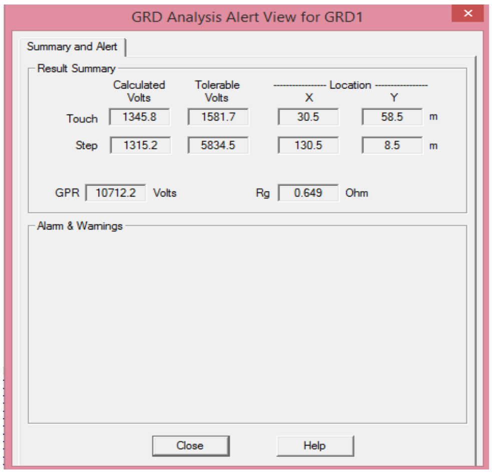


Figure 10: 2-D ground grid model



	Calculated Volts	Tolerable Volts	Location X	Location Y	
Touch	1345.8	1581.7	30.5	58.5	m
Step	1315.2	5834.5	130.5	8.5	m

GPR 10712.2 Volts Rg 0.649 Ohm

Figure 11: Enhanced Earth Grid Result Summary Using FEM

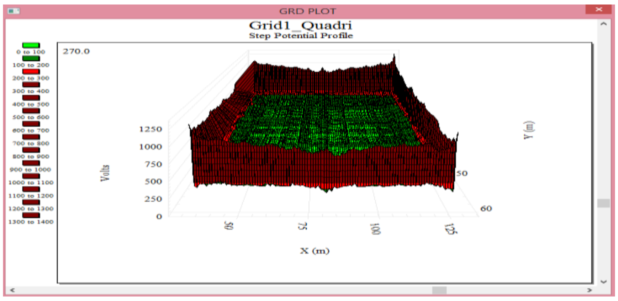


Figure 12: FEM-enhanced step potential profile

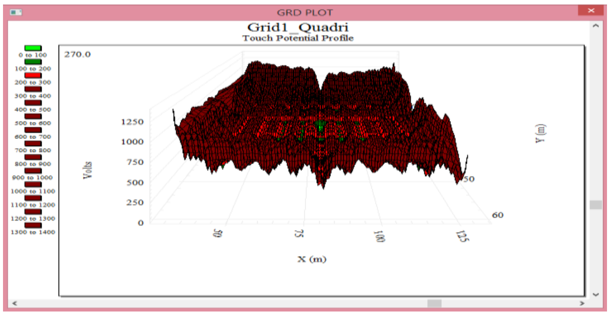


Figure 13: FEM Improved Touch Potential Profile

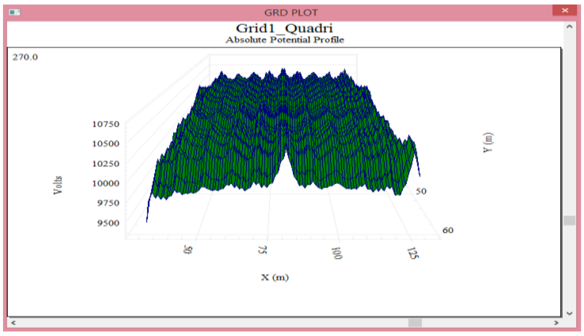


Figure 14: FEM Improved Absolute Potential Profile

Table 3
Results Obtained from the Existing and Improved Ground Grid Simulation using finite element method

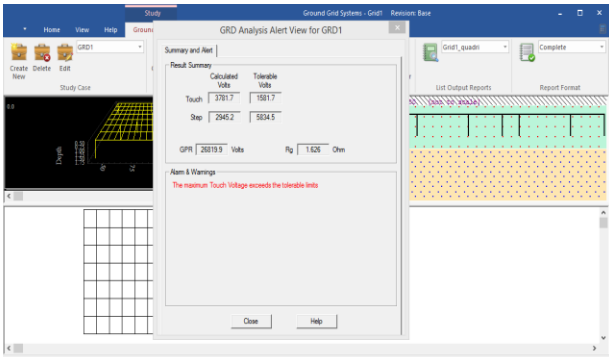
Parameters	**FEM (Existing)**	**FEM (Improved)**
Conductors depth (m)	0.5	0.5
Grid length in X- axis (m)	100	100
Grid length in Y-axis (m)	50	50
No of conductors in the X-axis	8	25
No of conductors in the Y-axis	18	50
Total number of conductors	26	75
The total length of conductors (m)	1700	5000
Total number of rods	12	11
The total length of rods (m)	15	110
Diameter of ground rods (cm)	0.8	2
Decrement Factor (D_f)	1.048	1.048
Surface Layer Derating Factor (C_s)	0.711	0.711
Reflection Factor (K)	-0.944	-0.944
Maximum Grid Current (kA)	16.498	16.498
Ground resistance (Ω)	0.777	0.649
Maximum Step voltage (V)	1778.8	1315.2
Tolerable step voltage (V)	5834.5	5834.5
Maximum Touch voltage (V)	3766.7	1345.8
Tolerable touch voltage (V)	1581.7	1581.7
Ground potential rise (V)	12815.9	10712.3

C. IEEE method

Using the data from Table 1, the station's grounding grid was simulated using the IEEE method; and the results of the simulation are shown in fig 15.Table 5 shows the performance parameter value as well as the IEEE constants parameters.

From the simulation results of the existing earthing grid system at Maryland transmission station, it was determined that the maximum touch voltage exceeded the required touch voltage which also means that in the event of a ground fault any individual that comes into contact with a metallic structure risks the danger electrocution as a result of difference in potential between the point of contact and the feet. Therefore an improved design is paramount.

This is accomplished by employing the ETAP program to maximize the number of conductors and ground rods not only for protection but also for the most cost-effective design. These modified parameters are shown in table 4. Figures 16 to 18 show the improved ground grid designs and results obtained after running the simulation with the modified parameters in table 5.



GRD Analysis Alert View for GRD1

Summary and Alert

Result Summary

	Calculated Volts	Tolerable Volts
Touch	3781.7	1581.7
Step	2945.2	5834.5

GPR 26819.9 Volts
Rg 1.626 Ohm

Alarm & Warnings

The maximum Touch Voltage exceeds the tolerable limits

Figure 15: Results of the Current Grid Simulation Using the IEEE Method

Table 4
Grid Design Parameters Improved Using IEEE Method

Parameters	Value
Horizontal conductor	4
Vertical conductor	8
Conductor number	12
conductors length	800m
Earth rod number	183
Earth rod total length (m)	1830m
Earth rod diameter	2cm

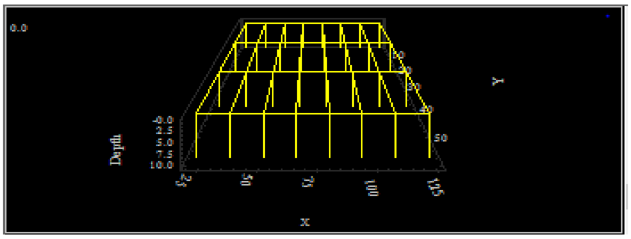


Figure 16: 3-D Improved Earth Grid Model Using IEEE Method

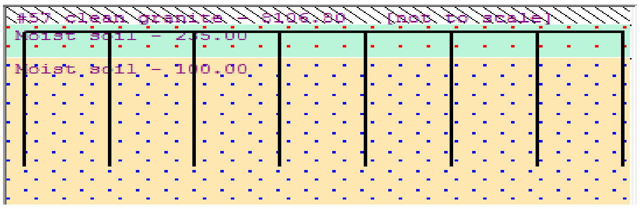
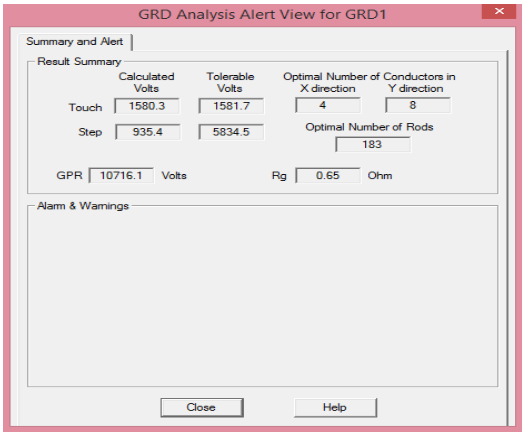


Figure 17: IEEE Method for a 2-D Improved Earth Grid Model



GRD Analysis Alert View for GRD1

Summary and Alert

Result Summary

	Calculated Volts	Tolerable Volts
Touch	1580.3	1581.7
Step	935.4	5834.5

Optimal Number of Conductors in
X direction 4
Y direction 8

Optimal Number of Rods 183

GPR 10716.1 Volts
Rg 0.65 Ohm

Alarm & Warnings

Figure 18: Enhanced Design Result Summarization Using the IEEE Method

Table 5
Results Obtained from the Existing and Improved Ground Grid Simulation using IEEE method

Parameters	IEEE (Existing)	IEEE (Improved)
Conductors depth (m)	0.5	0.5
Grid length in X- axis (m)	100	100
Grid length in Y-axis (m)	50	50
Conductors in the X-axis	8	4
Conductors in the Y-axis	18	8
Total number of conductors	26	12
The total length of conductors (m)	1700	800
Total number of rods	12	183
The total length of rods (m)	15	1830
Diameter of ground rods (cm)	0.8	2
Correction factor for grid geometry regarding touch voltage (Kim)	2.371	1.457
Correction factor for grid geometry regarding step voltage (Kis)	2.371	1.457
The spacing factor for touch voltage (Km)	0.709	1.073
Spacing factor for step voltage (Ks)	0.413	0.357
The corrective weighing factor that adjusts for the effects of inner conductors on the corner mesh (Kii)	1.000	1.000
Constants 1 related to the geometry of the system (K1)	1.329	1.329
Constants 2 related to the geometry of the system (K2)	5.667	5.667
Decrement Factor (D_f)	1.048	1.048
Surface Layer Derating Factor (C_s)	0.711	0.711
Reflection Factor (K)	-0.944	-0.944
Maximum Grid Current (kA)	16.498	16.498
Ground resistance (Ω)	1.626	0.650
Maximum Step voltage (V)	2945.2	935.4
Tolerable step voltage (V)	5834.5	5834.5
Maximum Touch voltage (V)	3781.7	1580.3
Tolerable touch voltage (V)	1581.7	1581.7
Ground potential rise (V)	26820.0	10716.1

IV. RESULTS AND DISCUSSION

A. Initial Design Results (IEEE vs FEM)

This section compares the existing ground grid simulation results of the FEM and IEEE method(i.e second column of table 3 and 5) as follows: (1) The decrement factor, reflection factor, surface derating factor, and maximum grid current of both methods were the same. (2) The ground resistance of the IEEE method was higher than that of the Fem and also the finite element ground resistance is closer to zero than the IEEE method, which means that the rate of dissipation of short circuit current will be higher for grid mesh designed by FEM. (3) The maximum step voltage potential of both methods was lower than the tolerable step voltage potential (5834.5V) for both methods thereby posing no safety risks, although that of the FEM was less than that of the IEEE method, making FEM more effective in terms of protecting against the dangers of step voltages. (4) The maximum touch voltage potential of both methods was higher than the tolerable touch voltage potential (1581.7V) thereby making the existing grid design unsafe, although the maximum touch voltage potential of the FEM was less than that of the IEEE method. (5) The ground potential rise of the IEEE method was higher than that of the Fem making the FEM better in terms of safety.

B. IEEE (Existing) vs IEEE (Improved)

This section compares the ground grid simulation results of the existing and improved design using the IEEE method as follows: 1) The modified design had a lesser number of conductors than the existing design (meaning more grid mesh spacing) and decreased total length of the rod. 2) The modified design had more number of ground rods, an increased depth of ground rods, and also an increased diameter of rods than the existing design leading to a reduced ground resistance allowing it to dissipate more current deep into the earth more effectively. 3) The correction factor and spacing factor for touch and step voltage of the modified design were lesser than that of the existing design leading to a reduced maximum step and touch voltages. 4) The decrement factor, reflection factor, surface derating factor, and maximum grid current of both designs were the same. 5) The ground resistance of the modified design was lesser than that of the existing grid and, closer to zero which means that the rate of dissipation of short circuit current will be higher for the modified design. 6) The maximum step voltage potential of both designs was lower than the tolerable step voltage potential (5834.5v) for both designs thereby posing no safety risks, although that of the modified design was less than that of the existing design, making the modified design more effective in terms of protecting against the dangers of step voltages .7) The maximum touch voltage potential of the improved design was less than the tolerable touch voltage potential (1581.7V) making the design safe and very effective at protecting personnel in the station from critical electric shock u while the maximum touch voltage potential of the existing design was higher than the tolerable touch voltage potential (1581.7V) thereby making the existing grid design unsafe and ineffective. 8) The ground potential rise of the modified design was less than that of the existing design leading to a lesser maximum step and touch voltage potential and a more effective design.

C. FEM (Existing) vs FEM (Improved)

This section compares the ground grid simulation results of the existing and improved design using the finite element method as follows: 1) The modified design had more conductors than the existing design (meaning less grid mesh spacing) and increased the total length of the conductor which will help reduce the ground resistance. (2) The modified design had less number of ground rods, increased depth of ground rods, and also increased diameter of rods than the existing design allowing it to dissipate more current deep into the earth more effectively. (3) The decrement factor, reflection factor, surface derating factor, and maximum grid current of both designs were the same. 4) The ground resistance of the modified design was lesser than that of the existing grid and, closer to zero which means that the rate of dissipation of short circuit current will be higher for the modified design. 5) The maximum step voltage potential of both designs were lower than the tolerable step voltage potential (5834.5V) for both designs thereby posing no safety risks, although that of the modified design was less than that of the existing design, making the modified design more effective in terms protecting against the dangers of step voltages. 6) The maximum touch voltage potential of the improved design was less than the tolerable touch voltage potential (1581.7V) making the design safe and very effective at protecting personnel in the station from critical electric shock while the maximum touch voltage potential of the existing design was higher than the tolerable touch voltage potential (1581.7V) thereby making the existing grid design unsafe and ineffective. 7) The ground potential rise of the modified design was less than that of the existing design leading to a lesser maximum step and touch voltage potential and a more effective design.

D. IEEE (Improved) vs FEM (Improved)

The outcomes of the improved design using the FEM and IEEE methods will be addressed in this section. The results of both methods have been presented, and the two have been compared based on these results to identify the most effective method for ground grid mesh design, as follows: (1) The results show that the total length of conductors is more when using FEM (5000m) than the IEEE method (800m). (2) The quantity of rod and the complete length of conductor is more for the IEEE technique than FEM, consequently making the poles for IEEE more compelling than FEM, since IEEE compasses to the earth's lower layers which are less influenced by natural factors, for example, moisture content and temperature. (3) The final result showed that the ground resistance (R_g) of ground grid mesh structure design using IEEE is (0.649Ω) lower than FEM (0.65). (4) The decrement factor, reflection factor, surface derating factor, and maximum grid current of both designs were the same. (5) The improved maximum step voltage potential of both methods was lower than the tolerable step voltage potential (5834.5V) for both methods thereby posing no danger. The modified design using the IEEE method was less than that of the FEM, making the IEEE method more effective in terms of protecting against the dangers of step voltages. (6) The improved maximum touch voltage potential of both methods was lower than the tolerable step voltage potential (1581.7V) for both methods thereby posing no danger. The improved maximum touch voltage potential using FEM was less than that of the IEEE method, making the FEM more effective in terms of protecting against the dangers of touch voltages. (7) The improved ground potential rise using FEM was less than that of the IEEE method.

V. CONCLUSION

This study successfully planned an improvement of the earth grid system based on the existing soil and increased fault current. The methodology was carried out during the dry season in Lagos, Nigeria and used ETAP 19.0 software for its simulation. The step voltage, the touch voltage, grid conductor total length, grid conductor size and the overall number of earth rods were easily modified and calculated to ensure the most reliable and safest possible design. The station grid was simulated with the FEM and IEEE method for improving the grounding grid system. The outcomes of the simulation using the IEEE method showed that an increment in mesh distance, no. of earth rods, earth rod depth and diameter of earth rod could result in an efficient drop in the maximum touch and step voltages, earth potential, and also a decrease in ground resistance. Also based on the simulation results obtained using FEM, it was determined that increasing ground rod depth, diameter, and mesh spacing would result in a significant reduction in maximum mesh and step voltages, ground potential rise, and ground resistance.

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