DESIGNING GROUND GRID FOR A 11KV SUBSTATION USING ETAP

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ABSTRACT :

ETAP (Electrical Transient Analyzer Program) is a powerful software tool utilized by power systems engineers for electrical network modeling and simulation. Its primary purpose is to create an "electrical digital twin" and analyze the dynamics, transients, and protection mechanisms within electrical power systems. ETAP is built on a comprehensive foundation that allows for efficient design, analysis, management, operations, and facilitates complete digital transformation of projects, adapting to evolving system changes. One of the modules within ETAP is the Ground Grid Systems module, which enables engineers to design and analyze ground protection accurately and swiftly. It offers flexible design methodologies, allowing for both automated layout generation and highly detailed schemes. By utilizing high-efficiency multi-core parallel calculation techniques, ETAP enables rapid analysis of large-scale renewable applications with irregular characteristics. The main objective of the ground mesh in electrical substations is to dissipate dangerously high currents that may arise due to faults in the system. The ground grid mesh data is obtained from the site using the latest 2013 IEEE 81 methods. For the modeling, analysis, and optimization of grid ground mesh, ETAP-12 employs the IEEE 80-2000 methods. These methods provide analysis methodologies to address existing problems and design solutions, allowing the ground mesh to accommodate the expansion of substations in relation to increased power requirements. In summary, ETAP is a comprehensive software tool that empowers power systems engineers to create accurate electrical digital twins, perform detailed analyses, and optimize the design of ground grids. It plays a crucial role in ensuring the stability and protection of electrical power systems, especially in the context of expanding substations and renewable energy applications.

Keywords: Ground Potential Rise (GPR), Step Voltage (Vs), Touch Voltage (Vt), Grounding Grid Resistance (Rg), Electrical Transient Analyzer Program (ETAP), Finite Element Method (FEM).

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I.INTRODUCTION

Earthing refers to the process of connecting an electrical conductor, typically a green wire or bare wire, to a non-current carrying object such as the metallic enclosure of equipment. It is done by establishing a connection to an earth electrode. Grounding, on the other hand, is closely related to earthing as it involves bonding the earth electrode to the return current carrying conductor, usually the Neutral wire. The purpose of earthing is to prevent fault conditions by diverting the fault current to the earth electrode, which acts as an effective conductor. Proper grounding is essential for all electrical equipment, whether operating at high or low voltages. It serves not only to protect against severe shock hazards but also to ensure system integrity. Maintaining a comprehensive earthing system is crucial for the smooth operation of the electrical system. Neglecting proper grounding can lead to equipment malfunction, loss of life, financial losses, service disruptions, and even explosions of equipment. Different grounding procedures and standards exist for various considerations such as static discharge, lightning protection, equipment and body grounding, and neutral grounding of transformers. This paper focuses on the design of an effective earth grid that neutralizes faults at all levels in a substation, including lightning faults, equipment and body earth faults, and unsymmetrical faults. The design guidelines and standards used are derived from IS 3043, which incorporates standards from IEEE std 80 for designing earthing systems for both AC outdoor and indoor substations.

In [2] During ground-fault situations, current flow generates voltage gradients within and around the substation. These gradients occur not only between structures and the nearby earth, but also along the ground surface. It is crucial for a well-designed system to ensure that these voltage gradients remain within safe limits that can be tolerated by the human body. The primary objective of a ground mat study is to ensure the safety and well-being of individuals who may be exposed to potential differences that can arise in a station during a severe fault. By conducting a thorough ground mat study, risks associated with these potential differences can be identified and mitigated effectively. The general requirements for grounding in industrial power systems are similar to those in utility systems under similar service conditions. Both types of systems aim to achieve safe and reliable operation by implementing appropriate grounding practices. These practices ensure that fault currents are safely dispersed, minimizing potential hazards to personnel and equipment. By adhering to the established grounding requirements and conducting comprehensive ground mat studies, industrial power systems can maintain a high level of safety, protecting individuals and equipment from the harmful effects of fault currents.

The objective of [3] is to provide a concise overview of the current practices in substation grounding and offer recommendations wherever applicable. The information presented in this guide is derived from a comprehensive questionnaire on substation grounding practices, which received responses from 61 participants representing various types of electric utilities. These utilities include large and small companies, serving both metropolitan and rural areas across the nation. By compiling and analyzing the responses received, this guide aims to provide valuable insights into the diverse range of substation grounding practices employed by electric utilities throughout the country.

[4-7] Introduces three optimization techniques (Differential Evolution, Sine-Cosine Algorithm, and Hybrid DE SCA) for designing grounding grids with equal and unequal spacing between conductors. The objective is to achieve an optimum grounding system by minimizing the total cost involved while ensuring compliance with safety parameters outlined in ANSI/IEEE Standard 80-2000. The cost function considers factors such as grid depth, grounding rod dimensions, conductor quantity, revetment, and excavation area. The proposed method is compared with existing techniques, demonstrating its validity and efficiency. Results show that the Hybrid DE SCA technique yields lower cost and improved safety parameters compared to DE and SCA techniques when designing both equal and unequal spaced grounding grids. Unde et al. [9] mentioned, the Open Circuit Ratio (OCR) is minimal when K ($\rho 1 > \rho 2$) is positive, and it increases as K transitions from positive to negative values. In the case of a two-layer soil model, the OCR is influenced by the value of K, the depth (H) of the first layer, and the area of the grounding grid.

The objective function in the optimization problem, which aims to minimize the cost of the grounding grid being studied, relies on the fitness functions of different particles. These fitness functions consider various parameters such as the number of conductors, conductor dimensions, grid depth, and the quantity and length of ground rods, among others. References [9] and [10] provide further details on these fitness functions and their impact on the optimization process. Heuristic optimization techniques and the application of Artificial Neural Networks (ANN) have proven to be effective in handling the optimization of substation grounding grid designs, considering the diverse combinations of geometric and material parameters involved. References [10] and [11] provide insights into the use of these techniques and the application of ANN in achieving optimal solutions for substation grounding grid designs.

In [12] discussed the design of a substation grounding grid which is crucial for ensuring the safety of equipment and personnel in and around the substation. IEEE Standard 80-2000 provides guidance and formulas for designing an effective and optimized grounding grid. Engineers have developed intelligent software, such as ETAP, specifically designed for substation grounding grid design to prioritize safety, reliability, and service continuity. This study utilized ETAP's Ground Grid System (GGS) module and employed the Finite Element Method (FEM) along with Sverak's variable space technique. The results demonstrated that the optimized design achieved a significant copper saving of 63.88% in ground rods compared to a reference study. The combination of these methods has proven to be a highly effective tool for substation grounding grid optimization.

II. **ELEMENTS OF GROUND GRID DESIGN**

The installation of a grounding system is essential to ensure the safety of equipment and personnel under both normal and fault conditions. During a ground fault, fault current flows through the ground, resulting in a ground potential rise (GPR). The GPR is directly proportional to the creation of step and touch voltages. These voltages represent the potential distribution on the surface of the substation's grounding system. To maintain safe operation, it is important to keep the values of step and touch voltages within acceptable limits. The process of designing a ground grid begins with a location survey and the layout of the area to be grounded. The soil resistivity is measured using methods such as the Wenner four-point method or the fall of potential method, which help determine the ground resistance. The fault current value is also measured. The permissible values of step and touch potential are determined based on the appropriate fault clearing time. The ground potential rise (GPR) is calculated by multiplying the maximum ground grid current by the ground resistance. If the calculated GPR is below the permissible touch potential value, the design is considered safe. However, if the calculated value exceeds the limit, further calculations are required to determine the maximum touch voltage and maximum step voltage. These values must be compared against the respective permissible limits for step and touch potentials. If the maximum touch voltage and maximum step voltage values are within the acceptable limits, the design is considered safe and no further changes are necessary. If they exceed the limits, modifications to the design are required. In summary, the design of a grounding system involves a series of steps, including location survey, layout, measuring soil resistivity, calculating ground resistance, determining fault current, and assessing step and touch potential values. The goal is to ensure that the ground grid design keeps the values of step and touch voltages within acceptable limits for safe operation during normal and fault conditions.

2.1. Ground Potential Rise(GPR)

GPR, or ground potential rise, refers to the maximum electrical potential reached by a substation grounding grid in relation to a distant grounding point. It is calculated as the voltage resulting from multiplying the maximum ground grid current by the grid resistance.

$$GPR = I_G \times R_g \tag{1}$$

Where,
I_g=maximum ground grid current
R_g=grid resistance.

2.2. Permissible Step and Touch Voltage

The permissible values of step and touch voltages for a 50 kg person can be calculated using the following equation:

$$E_{Step50} = (1000 + 6C_S * \rho_s)\frac{0.116}{\sqrt{t_s}} \tag{2}$$

Where Cs= a correction factor function of ρ_s and h_s

ρ_s = surface material resistivity Ω-m

hs = is thickness of surface material in m

ts= fault clearing time in seconds.

The correction factor, Cs, is dependent on the depth and surface material resistivity of the soil. As the thickness of the surface material increases, the value of Cs also increases. Cs is utilized to adjust the calculated resistance of a human foot in contact with the surface material. It is employed in the calculations for determining the tolerable values of step and touch voltages. A higher value of Cs implies larger permissible values of step and touch voltages. This indicates that if the surface soil resistivity is high, the system can tolerate higher step and touch voltages without posing a hazardous shock risk.

2.3. Maximum Step and touch voltage

The maximum touch (mesh) and step voltages are calculated when the ground potential rise (GPR) exceeds the permissible value of touch voltage. In order to ensure a safe design, the values of maximum step and touch (mesh) voltages should be lower than the allowable values of step and touch voltage.

The mesh voltage can be determined using the following equation:

$$E_m = \frac{\rho * K_m * K_i * I_G}{L_M} \tag{3}$$

Where K_m= geometrical factor,

I_G= maximum ground grid current

K_i= corrective factor

L_M=effective buried length of the grounding system conductor

ρ =soil resistivity Ω-m.

Maximum step voltage is calculated by using equation,

$$\boldsymbol{E_S = \frac{\rho * K_S * I_G}{L_S}} \tag{4}$$

Where,
K_s= geometrical factor,
I_G= maximum ground grid current
K_i= corrective factor
ρ =soil resistivity Ω-m
L_s=effective buried length of the grounding system conductor.

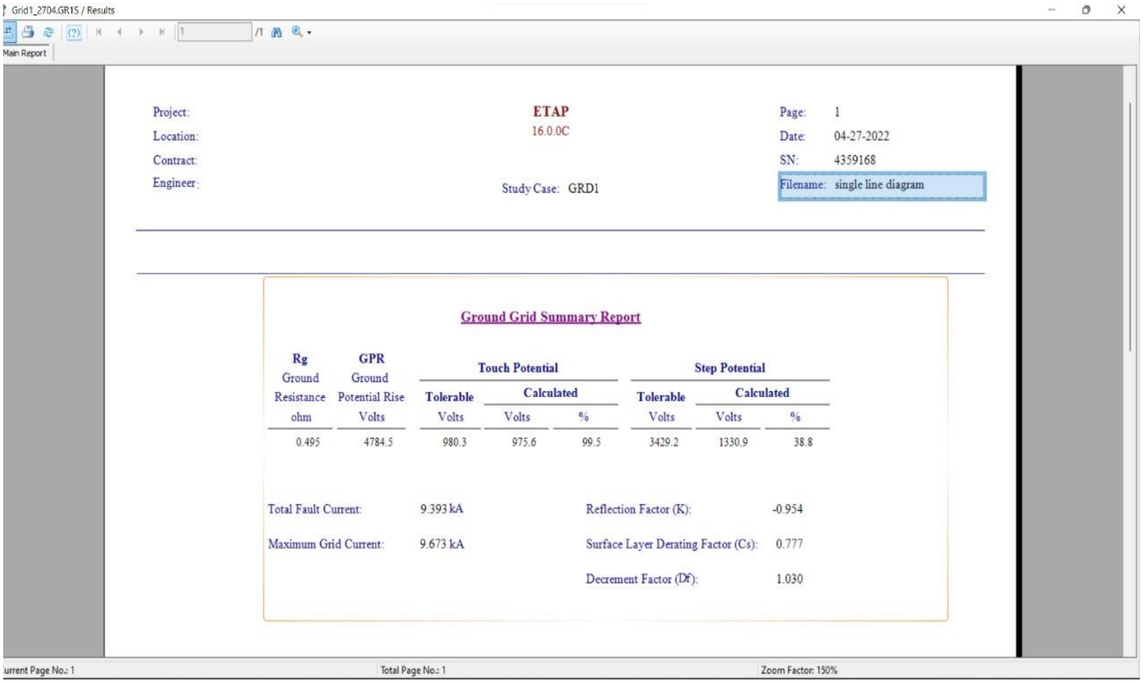
III. GROUND GRID DESIGN USING ETAP

3.1. ETAP software

ETAP is a comprehensive software package designed for Microsoft Windows Operating Systems [13]. Within ETAP, the Grounding Grid Systems (GGS) module provides engineers with efficient tools for designing and analyzing ground protection systems. The module incorporates the guidelines and specifications outlined in IEEE Standard 80-2000, IEEE-665-1995, and IEEE-80-1986. It offers both technical and economic analyses of the ground grid. When utilizing the IEEE Method study model, the GGS module utilizes a cost optimization routine to determine the optimal number of conductors and ground rods required to restrict step and touch potentials to acceptable levels.

The GGS module in ETAP offers a range of graphical features that facilitate the arrangement of conductors and ground rods, allowing for fast and efficient grounding grid design studies. It provides a visual representation of the physical environment through the Top View, Soil View, and 3-D View options. The module supports both uniform and two-layer soil views, which can be used in conjunction with the Finite Element Method (FEM) study model. The FEM Group Editor allows for the customization of each conductor and ground rod, specifying their length, diameter, material, and other properties. Additionally, ETAP includes a user-expandable conductor library, providing flexibility in designing grids of any shape and allowing for individual case studies to achieve optimization.

The Ground Grid Systems module in ETAP empowers engineers to design and analyze ground protection with speed and accuracy. It offers flexible design methodologies, allowing for both quick auto-generated layouts and highly detailed schemes. The module's high-efficiency multi-core parallel calculation capability enables fast analysis of irregular large-scale renewable applications. The results are presented in color-coded graphical plots, providing impressive visual representations. The Soil Analysis tools in ETAP automate the generation of a two-layer soil model based on soil measurement data obtained using the Wenner four-pin method. Figures (1) to (4) display the results of various parameters, such as Ground Potential Rise, Touch Potential, Step Potential, Short Circuit Current, Data, Material Constants, Rod Data, Grid Configuration, and Cost, all obtained through the use of ETAP. Finally, Figure (5) showcases the optimized grid design derived from the analysis. Overall, the Ground Grid Systems module in ETAP streamlines the design and analysis process for ground protection, provides comprehensive visualization of results, and incorporates advanced tools for soil analysis and grid optimization.



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Ground Grid Summary Report

Rg Ground Resistance ohm	GPR Ground Potential Rise Volts	Touch Potential			Step Potential		
		Tolerable	**Calculated**		**Tolerable**	**Calculated**	
		Volts	Volts	%	Volts	Volts	%
0.495	4784.5	980.3	975.6	99.5	3429.2	1330.9	38.8

Total Fault Current: 9.393 kA

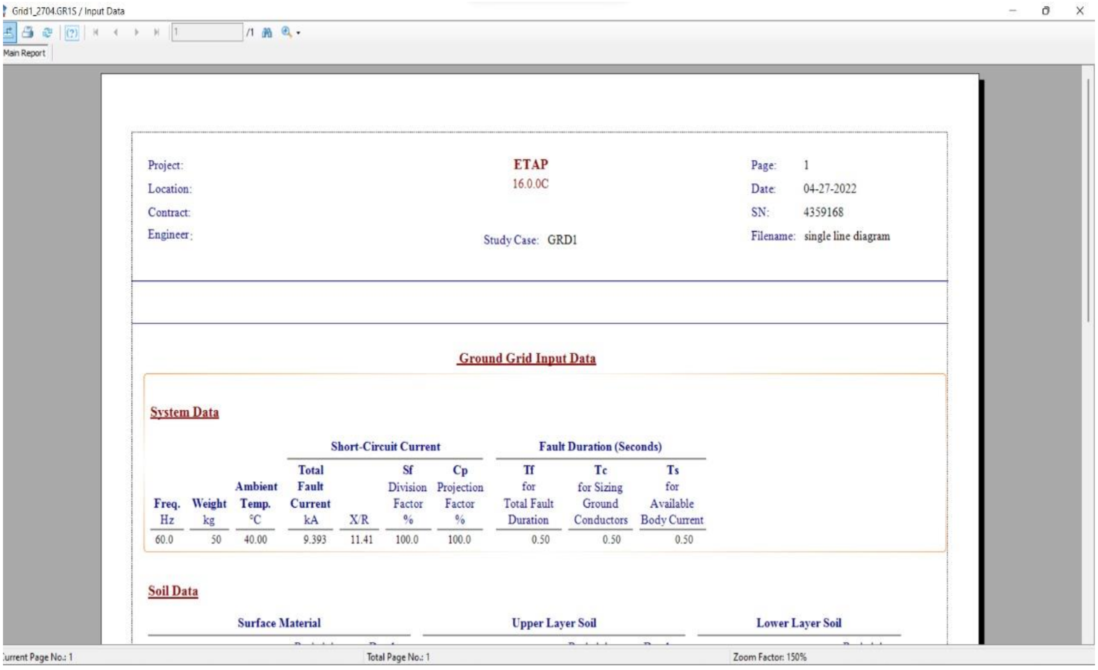
Maximum Grid Current: 9.673 kA

Reflection Factor (K): -0.954

Surface Layer Derating Factor (Cs): 0.777

Decrement Factor (Df): 1.030

Fig (1). Results of Ground potential rise, Touch potential & Step potential using ETAP



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Ground Grid Input Data

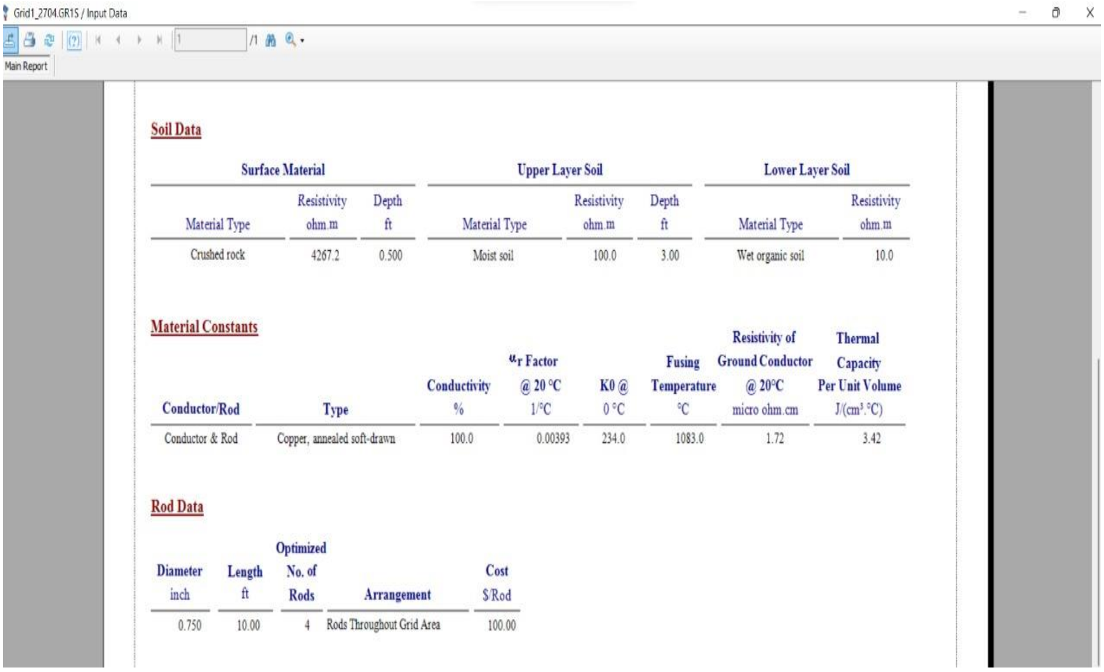
System Data

			Short-Circuit Current				Fault Duration (Seconds)		
Freq. Hz	**Weight** kg	**Ambient Temp.** °C	**Total Fault Current** kA	X/R	**Sf** Division Factor %	**Cp** Projection Factor %	**Tf** for Total Fault Duration	**Tc** for Sizing Ground Conductors	**Ts** for Available Body Current
60.0	50	40.00	9.393	11.41	100.0	100.0	0.50	0.50	0.50

Soil Data

Surface Material **Upper Layer Soil** **Lower Layer Soil**

Fig (2). Results of short circuit current using ETAP



Soil Data

Surface Material			Upper Layer Soil			Lower Layer Soil	
Material Type	Resistivity ohm.m	Depth ft	Material Type	Resistivity ohm.m	Depth ft	Material Type	Resistivity ohm.m
Crushed rock	4267.2	0.500	Moist soil	100.0	3.00	Wet organic soil	10.0

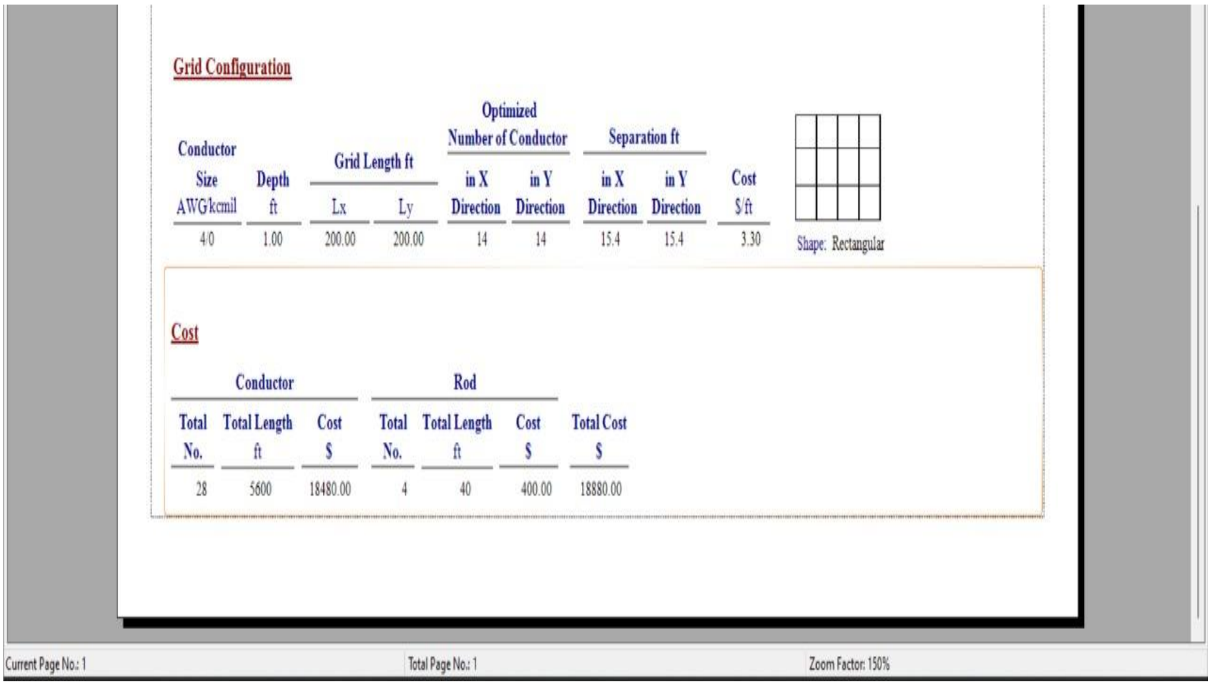
Material Constants

Conductor/Rod	Type	Conductivity %	α_r Factor @ 20 °C 1/°C	K0 @ 0 °C	Fusing Temperature °C	Resistivity of Ground Conductor @ 20°C micro ohm.cm	Thermal Capacity Per Unit Volume J/(cm³.°C)
Conductor & Rod	Copper, annealed soft-drawn	100.0	0.00393	234.0	1083.0	1.72	3.42

Rod Data

Diameter inch	Length ft	Optimized No. of Rods	Arrangement	Cost $/Rod
0.750	10.00	4	Rods Throughout Grid Area	100.00

Fig(3). Results of Soil data, Material constants and Rod data



Grid Configuration

Conductor Size AWG/kcmil	Depth ft	Grid Length ft Lx	Grid Length ft Ly	Optimized Number of Conductor in X Direction	Optimized Number of Conductor in Y Direction	Separation ft in X Direction	Separation ft in Y Direction	Cost $/ft
4/0	1.00	200.00	200.00	14	14	15.4	15.4	3.30

Shape: Rectangular

Cost

Conductor			Rod			
Total No.	Total Length ft	Cost $	Total No.	Total Length ft	Cost $	Total Cost $
28	5600	18480.00	4	40	400.00	18880.00

Fig (4). Results of Grid configuration and Cost using ETAP

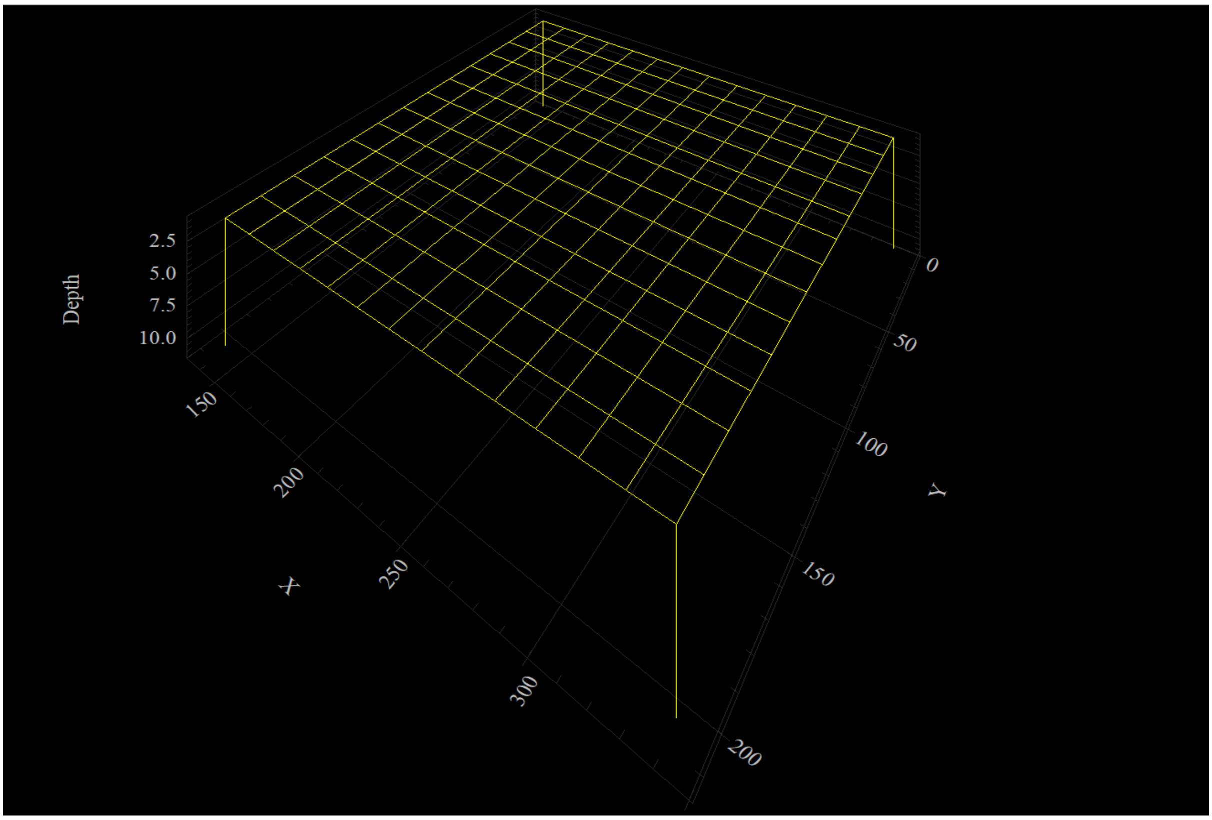


Fig (5). Final Optimized grid design using ETAP

Table1. Validation of ETAP results with Theoretical values

	By ETAP	Theoretical	Error
GPR(in V)	**4780**	**4743**	**0.7%**
TOUCH POTENTIAL (in V)	**974**	**920**	**5.5%**
STEP POTENTIAL (in V)	**3429**	**3188**	**7%**

IV.CONCLUSIONS

The main focus of this work was to identify potential issues in the ground grid mesh of an 11KV substation. To achieve this, we collected comprehensive data from the substation following the latest IEEE 80-2000 standard. Using this data, we conducted a thorough simulation in ETAP to analyze the performance of the ground grid mesh. The results obtained from the ETAP simulation were then compared against the limits specified in the IEEE standard. By identifying any deviations from these limits, we were able to pinpoint deficiencies in the existing ground grid mesh. To address these deficiencies and ensure that all safety parameters are within the prescribed limits, we proposed a potential solution. This solution consisted of a series of amendments that needed to be implemented in the ground grid mesh. These amendments aimed to rectify the identified issues and improve the overall performance and safety of the ground grid system. By implementing these recommended amendments, we aimed to bring the ground grid mesh into compliance with the required safety standards and mitigate any potential risks or hazards.

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