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Analysis of the Influence of Soil Resistance on the Substation Grid Grounding System

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Abstract – *The grounding system is one of the security systems in substations to channel excess voltage caused by lightning strikes that occur at substations, as well as electrical equipment. To design a grounding system, several factors must be considered, including the type of soil, the configuration of the grounding system, the resistivity of the soil, and the condition of the surrounding environment. This research aims to determine the safe limit in the substation grounding system which is influenced by the type of soil in the emergence of touch voltage and step voltage which can be dangerous to humans. The method used is simulation with the Finite Element Method (FEM). The overall result is that with variations in area and soil type, the highest resistance values and touch and step stress values are found in rocky soil types. The touch and step voltage values are within safe limits and do not harm humans, namely in swampy soil where the actual touch voltage value is smaller than the permitted touch voltage value. For the actual touch voltage on rocky soil and wet soil, the actual touch voltage value is greater than the actual touch voltage value, this is within the unsafe limit and can be dangerous to humans. The actual step stress value also results in the actual step stress value being smaller than the permitted step stress value, this is included in safe conditions, and for rocky and wet soil types the actual step stress value is greater than the permitted step stress value, this is included in the condition unsafe and can harm humans.*

Keywords – *Substation; Touch Voltage; Step Voltage; Soil type; the Finite Element Method (FEM).*

I. Introduction

When there is a phase-to-ground disturbance, the fault current flows through the equipment to the ground, which could pose serious risks to human safety around the substation. To mitigate these dangers, the substation must have a system in place to address such disturbances effectively [1]. A reliable grounding system is required at the substation to prevent harm in these scenarios. This will cause a voltage gradient, namely: equipment with equipment, equipment with the ground and on the ground surface [2]. This incident is certainly dangerous for humans and equipment in the substation area. Therefore, a good and effective grounding system is needed to level the voltage gradient that appears [3]. The grounding system for substation equipment that is often used today is the driven rod grounding system, counterpoise, using a grid and a combination of grid and rod grounding systems [4].

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The grounding system is one of the security systems in the substation. Its purpose is to drain excess voltage caused by lightning strikes that occur at the substation, or on electrical equipment [5]. To design a grounding system, there are several factors that must be considered, including soil type, grounding system configuration, soil resistivity, and environmental conditions [6]. This study examines the effects of soil type and resistivity on grid grounding systems in substations. Soil resistivity significantly influences grounding resistance, ground potential rise, and touch and step voltages [7, 8]. Various soil models, including uniform, two-layer, and multi-layer, affect these parameters differently [7, 9]. Proper soil resistivity measurement is crucial for designing safe grounding systems, especially in anisotropic ground [10]. Factors such as fault current magnitude, soil layer height, and grid configuration also impact grounding system performance [8, 11]. Additionally, concrete properties and grid burial depth influence touch and step voltages in foundation grounding systems [12]. Simulation tools like ETAP and CDEGS are used to analyze these complex relationships [7, 13]. Understanding these factors is essential for designing effective and safe grounding systems in various soil environments [9, 14].

Grounding systems in substations are crucial for safety and equipment protection. Recent research has focused on optimizing grid designs for various soil conditions using methods like Simulated Annealing [15] and unequal spacing arrangements [16]. Studies have examined the effects of high-frequency faults [17] and lightning impulses [18] on grounding system performance. Novel approaches for grid configuration detection using static electric fields [19] and fault diagnosis considering electromagnetic interference [20] have been developed. Researchers have also investigated the coupling between multiple grounding electrodes in two-layer soil [21] and analyzed grounding systems in underground compact substations using the Boundary Element Method [22]. These advancements contribute to improving the design, analysis, and maintenance of substation grounding systems, ensuring better safety and performance under various conditions. This grid system is at a depth of 0.5 m to 1.5 m. The grid grounding system is carried out by planting electrode rods at a certain depth. The electrode rods are connected to each other using conductors, forming several meshes.

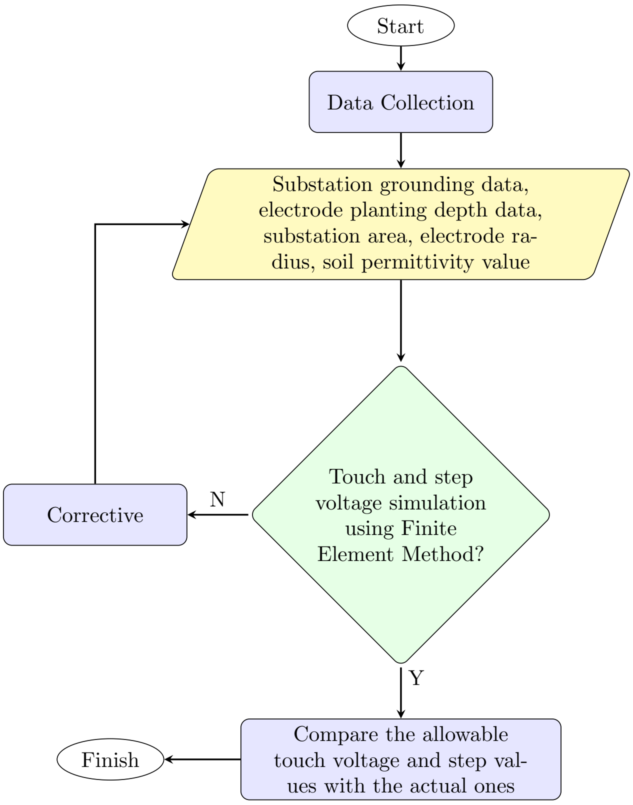

Figure 1: Research flow diagram

II. Research Methods

This study was conducted using data from the IEEE case study, which is a substation with a grid grounding system designed to meet the required parameters. The study employs software assistance, specifically the ETAP (Electrical Transient Analyzer Program) using the FEM (Finite Element Method). The study involves substation grounding data, electrode planting depth data, substation area, electrodes used, electrode radius, and soil permittivity values. The research flow is depicted in the figure 1.

According to Sverak, the grounding resistance value of the substation grid at a certain depth is based on the following equation [23]:

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

with R_g is the grid grounding resistance (Ω), ρ is the soil resistivity ($\Omega - m$), A is the grid grounding area (m^2), h is the grid conductor embedment depth (m), and L_T is the total length of embedded conductors (m).

Step voltage is the difference in potential of the ground surface through a part of the human body (feet) without any direct contact with grounded equipment. Touch voltage is the difference in potential of the ground surface at the point where a person stands and at the same time his body part is in direct contact with grounded equipment.

Assuming a human body weight of 50 kg and 70 kg, the amount of allowable step voltage can be determined through the following equations [24]:

$$\begin{aligned} E_{\text{Step50}} &= (1000 + 6C_s\rho_s)\sqrt{\frac{E_{50}}{R_h \times t_s}} \\ E_{\text{Step70}} &= (1000 + 6C_s\rho_s)\sqrt{\frac{E_{70}}{R_h \times t_s}} \end{aligned} \tag{2}$$

Touch voltage:

$$\begin{aligned} E_{\text{touch50}} &= (1000 + 1.5C_s\rho_s)\sqrt{\frac{E_{50}}{R_h \times t_s}} \\ E_{\text{touch70}} &= (1000 + 1.5C_s\rho_s)\sqrt{\frac{E_{70}}{R_h \times t_s}} \end{aligned} \tag{3}$$

Step voltage is the voltage that occurs between two human feet standing on the ground that is being passed by ground fault current [25]. Touch voltage is the voltage that exists between an object that is touched and a point 1 meter away, assuming that the object that is touched is connected to the grounding grid below it. Then the actual step voltage value can be calculated by [26]:

$$E_s = \frac{\rho \times K_s \times K_i \times I_{(t)}}{L_s} \tag{4}$$

Step voltage:

$$E_m = \frac{\rho \times K_m \times K_i \times I_{(t)}}{L_M} \tag{5}$$

III. Results and Discussion

This study used a case study of the IEEE grid grounding system with varying substation area sizes, with a grounding depth of 0.5 m, an electrode radius of 0.006 m, and a soil permittivity value (ε) of 15. The soil resistivity used is based on the General Requirements for Electrical Installations (PUIL) 2011 standard, namely [27]:

Table 1: Actual touch voltage value with the influence of area and type of soil with E_T is E (Tauch)

Soil Type	Resistance (Ω)	E_T (Actual)	E_T (Allowed)
Marshland	0.73	468.8	640.7
Rocky Land	57.69	38270.9	807.3
Wet Land	8.77	5979.1	667

The actual touch voltage simulation results using the Finite Element Method:

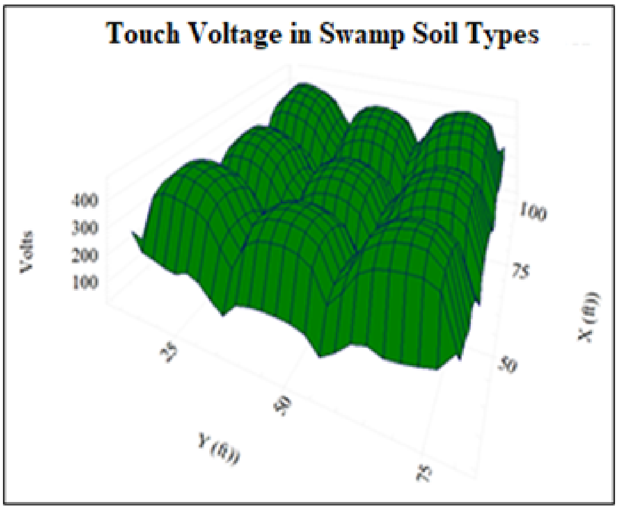

Figure 2: Simulation of touch voltage on swampy soil

Figure 2 shows the actual touch voltage with a swampy soil type of 468.8 volts, with a resistance value of 0.73 Ω, and an area of 70m x 70m. This condition is still within the safe limit.

Figure 3 shows the actual touch voltage with a rocky soil type of 38270.9 volts, with a resistance value of 57.69 Ω, and an area of 90m x 90m. This condition is unsafe and can endanger humans.

Figure 4 shows the actual touch voltage with a wet soil type of 5979.1 volts, with a resistance value of 8.77 Ω, and an area of 100m x 100m. This condition is also unsafe and can endanger humans.

The actual step voltage simulation results using the Finite Element Method:

Figure 5 shows the actual step voltage with a swampy soil type of 391.4 volts, with a resistance value of 0.73 Ω, and an area of 70m x 70m. This condition is still within the safe limit.

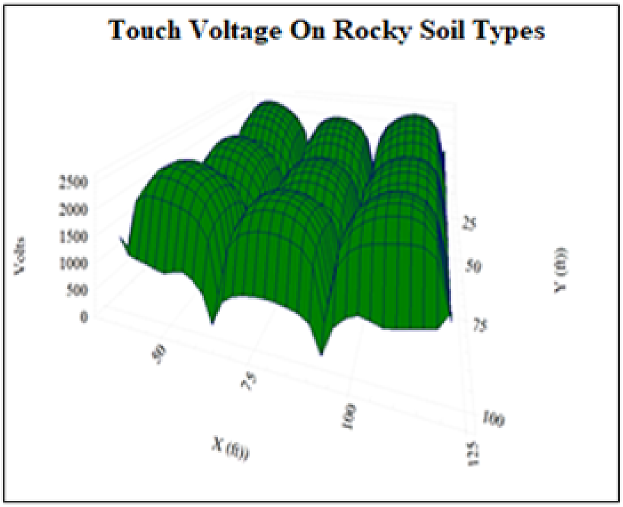

Figure 3: Simulation of touch voltage on rocky soil.

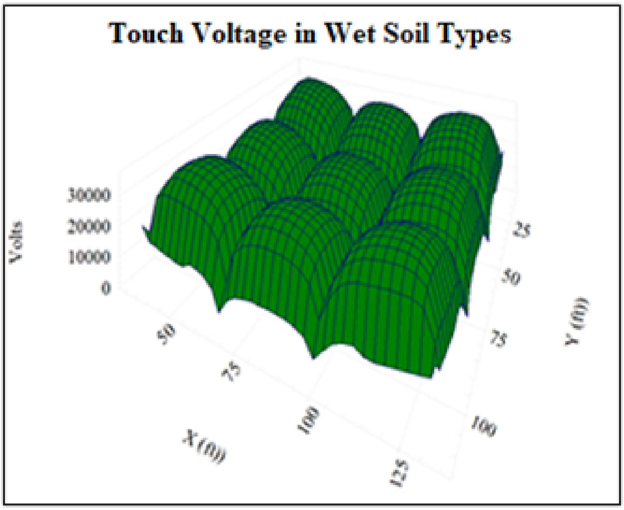

Figure 4: Simulation of touch voltage on wet soil.

Table 2: Actual step voltage value with the influence of area and type of soil with E_T is E (Tauch)

Soil Type	Resistance (Ω)	E_T (Actual)	E_T (Allowed)
Marshland	0.73	391.4	2070.6
Rocky Land	57.69	29925.2	2708.7
Wet Land	8.77	4454.7	2176

Figure 6 shows the actual step voltage with a rocky soil type of 29925.2 volts, with a resistance value of 57.69 Ω, and an area of 90m x 90m. This condition is unsafe and can endanger humans.

Figure 7 shows the actual step voltage with a wet soil type of 4454.7 volts, with a resistance value of 8.77 Ω, and an area of 100m x 100m. This condition is also unsafe and can endanger humans.

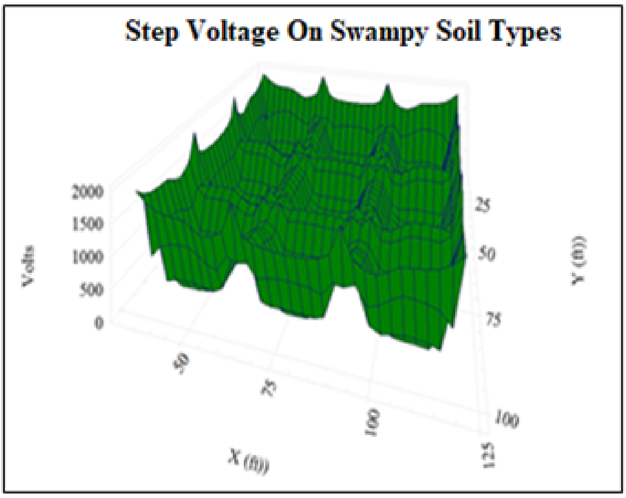

Figure 5: Simulation of step voltage on swampy soil.

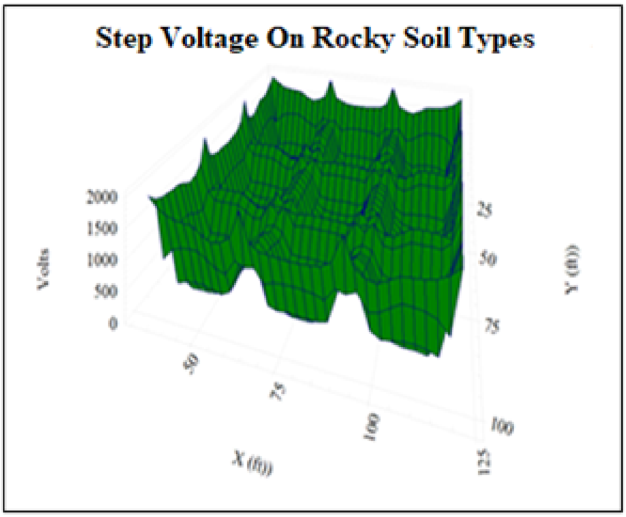

Figure 6: Simulation of step voltage in rocky soil.

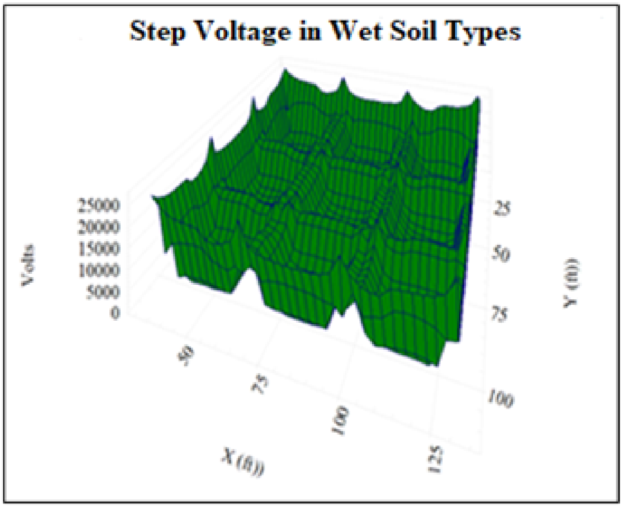

Figure 7: Simulation of step voltage on wet soil.

IV. Conclusion

From this study, it can be concluded that with variations in soil types and substation area, the value of touch and step voltages is within safe limits and does not endanger humans, namely in swampy soil types where the actual touch voltage value is smaller than the permitted touch voltage value. For the actual touch voltage on rocky and wet soil types, the actual touch voltage value is greater than the actual touch voltage value, this is included in the unsafe limit and can endanger humans. The actual step voltage value also produces an actual step voltage value smaller than the permitted step voltage value, this is included in safe conditions, and for rocky and wet soil types, the actual step voltage value is greater than the permitted step voltage value, this is included in unsafe conditions and can endanger humans. The overall result is that with variations in the area and type of soil, the highest resistance value and touch and step voltage values are found in rocky soil types.

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