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Simulation Study on Grounding Rod Using COMSOL Software

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Abstract. This paper presents a simulation-based study that focuses on three key factors: rod length, rod orientation, and soil resistivity, aiming to enhance knowledge of their impact on electrical parameters. Simulation works using COMSOL Multiphysics provide valuable insights into the relationship between these variables, aiding in the design and analysis of electrical systems and grounding installations. The simulation setup involves a conducting rod embedded in a heterogeneous soil model. The rod length is systematically varied at 1.5m, 3m, and 4.5m; while the rod diameter is maintained at 35mm; whereas soil resistivity and material properties are constant. By observing the potential voltage across the rod while changing its length, a nonlinear relationship is revealed. Additionally, the simulation explores the effect of rod orientation on current density distribution. Altering the angle of the rod concerning the ground surface allows for mapping the current density, demonstrating the influence of rod orientation on current flow. Moreover, the simulation incorporates variations in soil resistivity to analyze their impact on the electric field. Assigning different resistivity values to distinct soil regions enables the visualization of electric field distribution. Implementing this knowledge supports the design of efficient electrical systems, ensuring proper grounding and enhancing overall system performance. In conclusion, the selection of a 4.5m horizontal rod for the grounding system demonstrates careful consideration of safety and current distribution. This approach indicates an astute knowledge of the benefits of horizontal designs in limiting the dangers associated with localized hotspots and uneven current flows.

Keywords: Grounding Rods, COMSOL, Simulation

1. Introduction

The substation is a core part of the power system since it is through substations that electrical power is transferred from the generating station to the consumer load end [1]. Electricity distribution and transmission from one region to another would be difficult or impossible without substations. A fault at a substation could result from lightning, a short circuit on a transmission line, or even within the substation itself, in which case the fault current would flow to the Earth and isolate any exposed

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equipment [2]. Protection systems are required in substations to provide proper operation and protection against any faults. One of them is a grounding system. The purpose of a grounding system is to provide a way to carry electric currents into the Earth under normal and fault conditions without going over any operating and equipment limits or negatively affecting the continuity of service, as well as to ensure that a person nearby grounded facilities are not exposed to the risk of a fatal electric shock. [3]. Grounding systems, as a fundamental component of the electrical system, play an important role in power system network protection, particularly during abnormal conditions. The electrical system is made up of massive pieces of expensive equipment that require sophisticated protective mechanisms. Grounding's major goal is to provide a common reference point for electrical safety systems for both humans and equipment [4], as well as to reduce possible overvoltage.

As known, grounding systems are critical for protecting people because faulty grounding systems can cause major failures. Poor grounding adds not only to avoidable incidents but is also harmful, increasing the likelihood of equipment failure [5]. Grounding resistance is affected by the grounding material, soil resistivity, ground rod depth, soil type, and grounding system design. To develop a good grounding system, the stated aspects must be considered. Grounding resistance is affected by the grounding material, soil resistivity, ground rod depth, soil type, and grounding system design. To develop a good grounding system, the stated aspects must be considered. The standard driven rod is utilized as grounding at a variety of locations on Earth to discharge overvoltage, particularly during lightning strikes. It is considered that the existing grounding system can be enhanced by altering the grounding rod. Therefore, this paper investigates the effect of grounding rod length on voltage potential as well as the effect of vertical and horizontal rods on current density distribution.

2. Materials and Methods

2.1 Overall flowchart

The implementation of the simulation work process is illustrated in Figure 1. The simulation process was started by designing a grounding with different lengths using COMSOL Software. Cooper is selected as material to be tested with 1.5m, 3m, and 4.5 m for the rod length. Based on the result ground potential rise, the best length for the rod is used for the next stage. After the construction of the rod, the project proceeded by constructing a different type of rod configuration which is a single horizontal rod and a vertical rod. After that, the comparison and evaluation of the best configuration for the rod based on the current distribution is decided. Finally, the analysis of the grounding rod is conducted by placing the rod with different types of soil resistivity to obtain the electric potential and electric field. After that, the best grounding system configuration and place can be obtained.

2.2 Software

As mentioned before, the rod design was conducted using COMSOL Multiphysics Software. COMSOL Multiphysics is a software package that includes a finite element analysis, solver, and simulation for a variety of physics and engineering applications, particularly coupled phenomena, and Multiphysics. The software allows for traditional physics-based user interfaces as well as coupled systems of partial differential equations (PDEs). COMSOL offers an integrated development environment (IDE) and a single workflow for electrical, mechanical, hydrodynamic, acoustical, and chemical applications.

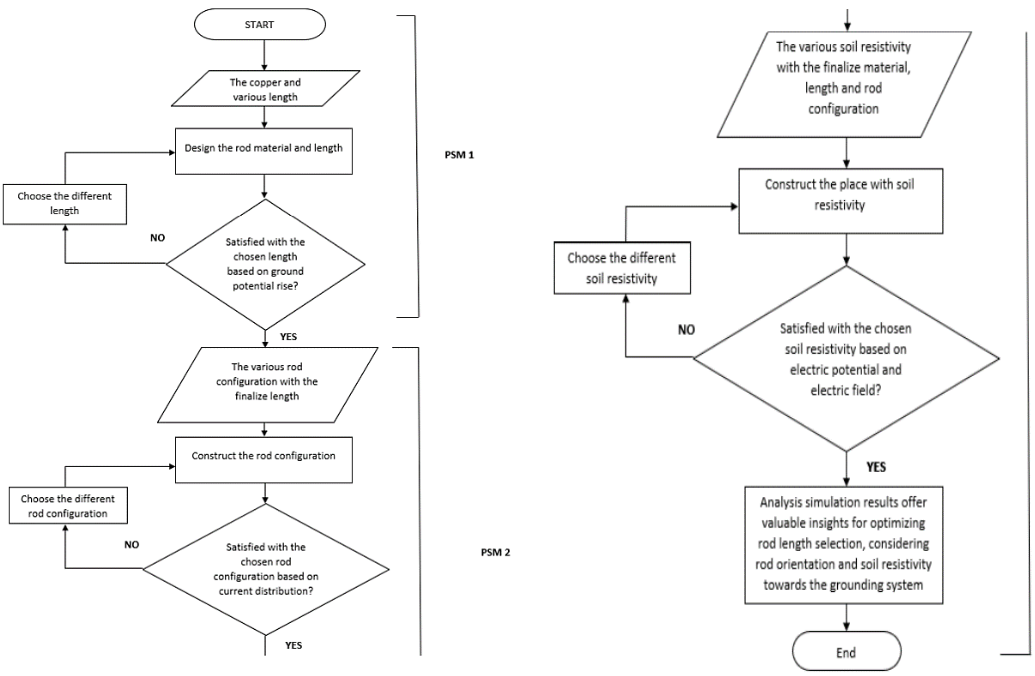

Figure 1: Overall Flowchart

3. Results and Discussion

3.1 Results of different rod lengths

The surface plots in Figure 2 depict the electric potential due to the grounding system inside the soil through slices at different distances in the x direction. It is observed that the highest potential is at the top of the center, where the rods are located. The color distribution illustrates a gradual reduction in potential as shown in the contour plots. This potential distribution is a result of injecting a 250-kA DC into the grounding system, with the vertical rods measuring 1.5 m. The same evaluation is repeated for other vertical electrode lengths such as 3.0 m and 4.5 m as depicted in Figures 3 and 4, respectively. Of course, there is an effect of increasing the vertical rod lengths as tabulated in Table 1.

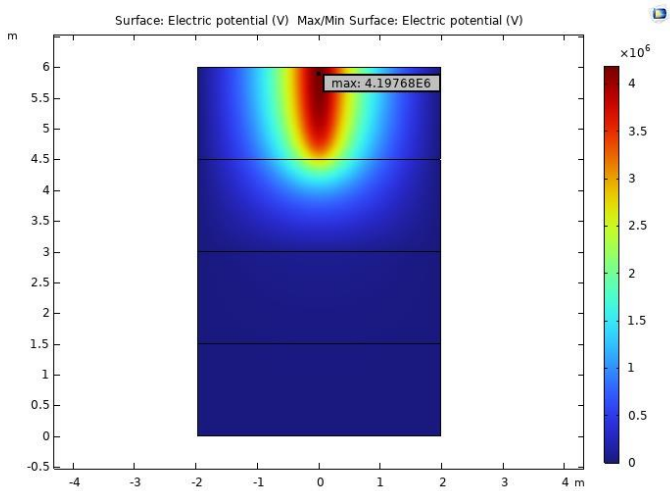

Figure 2: Surface of voltage potential for 1.5m

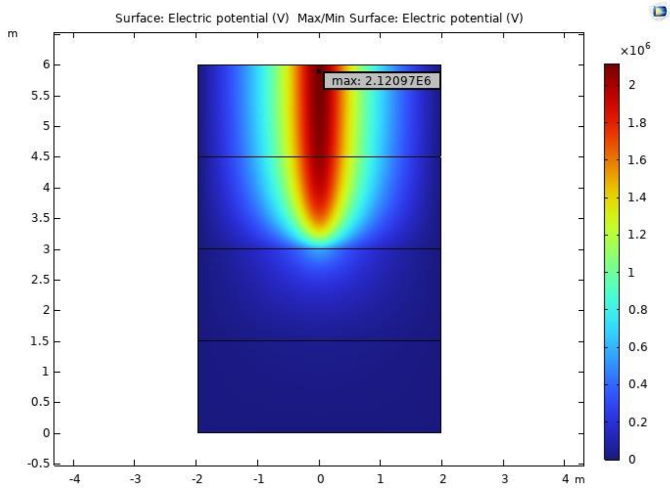

Figure 3: Surface of voltage potential for 3m

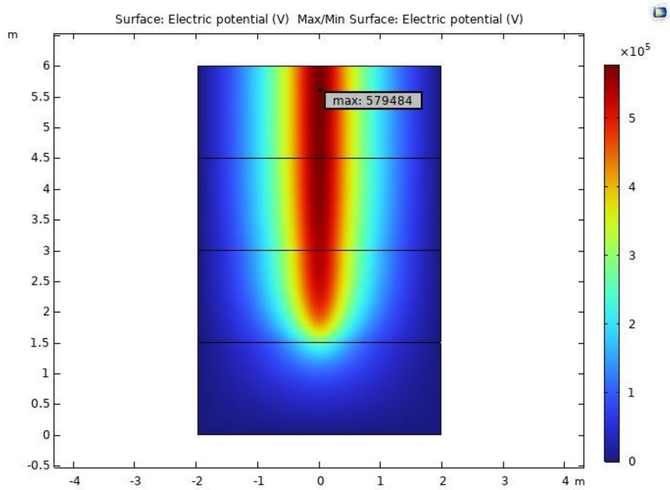

Figure 4: Surface of voltage potential for 4.5m

Table 1: Result of simulation

LENGTH (M)	1.5	3	4.5
Max Voltage Potential (V)	4.19768e6	2.12097e6	0.579484e6

Accordingly, Figure 5 shows the values of the maximum potential on the grounding system modified using different vertical electrode lengths. It can be summarized as the impact of electrode length on electric potential values, and it shows that the maximum voltage decreases when the rod length increases.

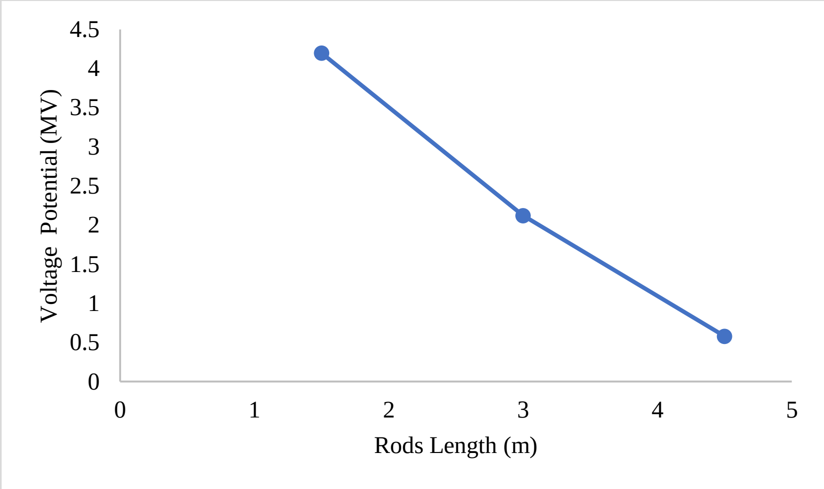

Figure 5: Graph voltage potential vs. rods length

In the case of a grounding system, the resistance (R) is influenced by factors such as the rod length, soil resistivity, and the geometry of the grounding system. By using Equation 1, the resistance of the rod can be determined by changing the value of the length of the rod and other values remain the same throughout the simulation process. Based on Equation 1, the resistivity of the material represents how much it resists the flow of electric current. The length of the rod affects the path length for the current to travel, while the cross-sectional area (A) represents the size of the conductor and influences the available conduction path.

$$R = p \times \frac{L}{A} \qquad \text{Eq. 1}$$

In a scenario where the soil resistivity and the material of the grounding system are the same, the length of the rod can affect the voltage potential. When a current flows through a grounding system, there is a voltage potential distribution in the soil. The longer the rod, the larger the surface area of contact between the rod and the soil. This increased contact area allows for a broader distribution of current into the soil, resulting in a more uniform voltage potential across the surrounding area. The electric potential tends to decrease with increasing distance from the grounding rod [6]. In other words, as you move away from the rod, the electric potential decreases. Voltage gradient can be affected by the overall resistance and impedance of the grounding system.

3.2 Result of different configuration

Figure 6 and 7 shows the current density distribution for vertical and horizontal rod, respectively. It is observed that the current density distribution for the vertical rod seems stronger towards the rod's surface and decreases towards the middle. In general, the current density at the vertical rod's surface is higher than the current density at its middle. This is due to eddy currents being formed in the surrounding medium by the self-induced magnetic field produced by the current flowing through the rod. Near the surface, as these eddy currents are stronger, there is a higher level of current density.

In contrast, the current density distribution in the horizontal rod is more evenly distributed across the cross-section than it would be across a vertical rod [7]. In this instance, the induced eddy currents flow in a plane that is perpendicular to the direction of the current. The horizontal rod's surface has the maximum current density, and its middle has a lower current density. However, the current density tends to be more uniformly distributed over the cross-section because the current spreads across a broader surface area than a vertical rod. Therefore, based on the two results, a horizontal rod distributes the current over a larger surface area, lowering the risk of localized heating and potential ground potential rise, whereas a vertical rod concentrates current flow near the surface, which may cause a slightly higher ground potential rise in that area.

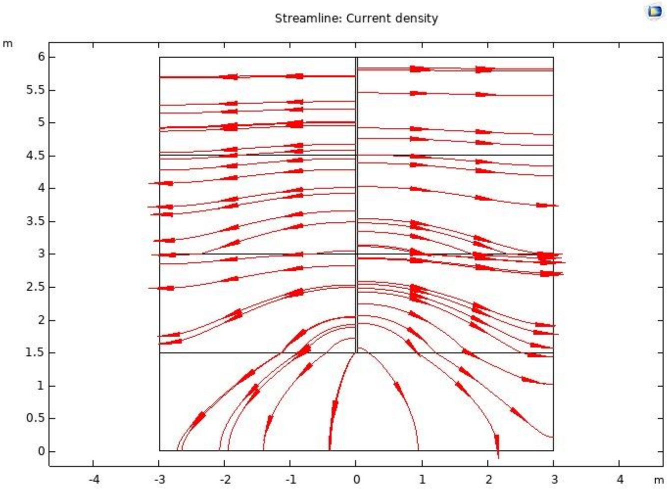

Figure 6: Current density of vertical rod

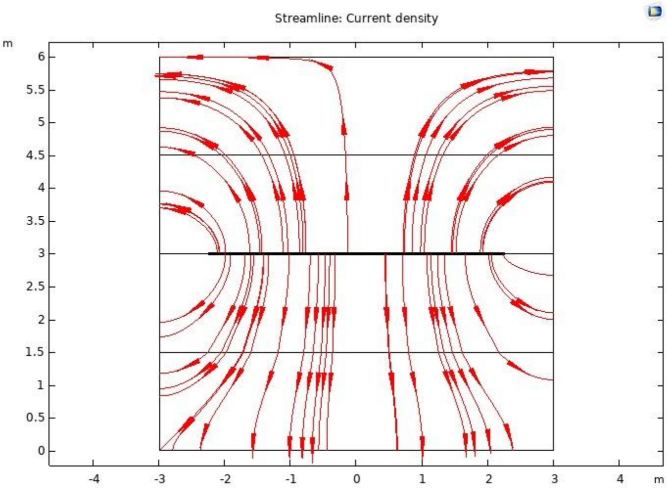

Figure 7: Current density of horizontal rod

3.3 Result of different cases of soil resistivity in each layer

This section requires data from [8] to analyze the difference in soil resistivity of each layer affecting the electric field in the grounding system as shown in Table 2. Figure 8, 9, and 10 shows how the surface's electric field is modified by changing the soil resistivity for each layer. By injecting 25 kA current into the grounding system, charges accumulate on the surface of the ground rod. These charges tend to spread out in a radial pattern, with the highest concentration near the bottom of the rod. The reason for this is that the rod's tip offers the smallest surface area for charges to reside on, so they become more densely packed. The accumulation of charges near the bottom of the rod results in an increased electric field strength in that region. Electric field strength is the force experienced by an electric charge per unit charge. The electric field is strongest where the charge density is highest, which is typically near the bottom of the grounding rod. In summary, the maximum electric field occurs near the bottom of a grounding rod because charges tend to accumulate more densely in that region, resulting in a higher charge density and, consequently, a stronger electric field.

Table 2: Data of the case for simulation [8]

Case	Level of Soil (m)	Soil Description	Soil Resistivity (Ω-m)	Permittivity
1	1.5	Sandy Clay	995	10-30
	3.0	Sandy Clay	1073	10-30
	4.5	Sandy Clay	183	10-30

	6.0	Sandy Clay	87	10-30
2	1.5	Slightly Sandy Slit	1436	5-20
	3.0	Slightly Sandy Clay	137	10-30
	4.5	Slightly Sandy Clay	242	10-30
	6.0	Gravely Sandy Clay	924	15-30
3	1.5	Slightly Sandy Clay	588	10-30
	3.0	Sandy Slit	646	5-20
	4.5	Clay	36	5-30
	6.0	Slightly Sandy Clay	167	10-30

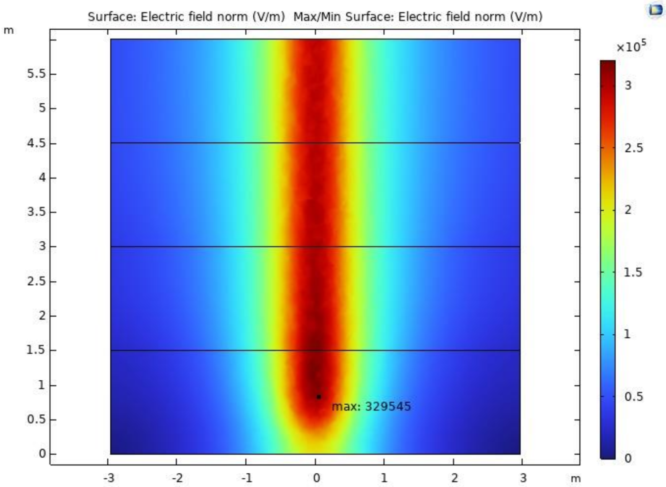

Figure 8: Surface Electric Field for Case 1

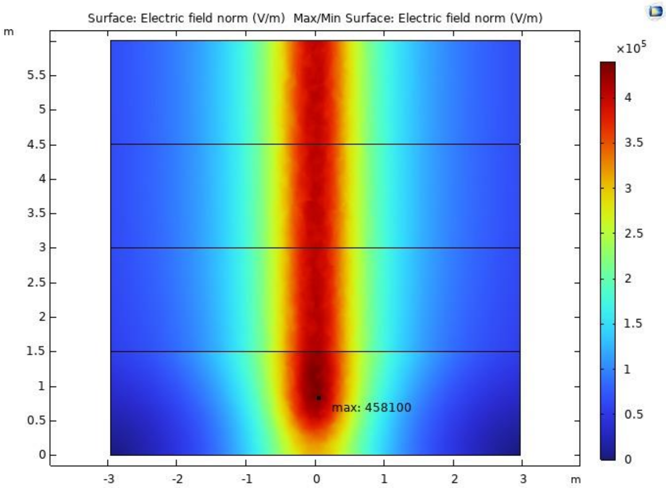

Figure 9: Surface Electric Field for Case 2

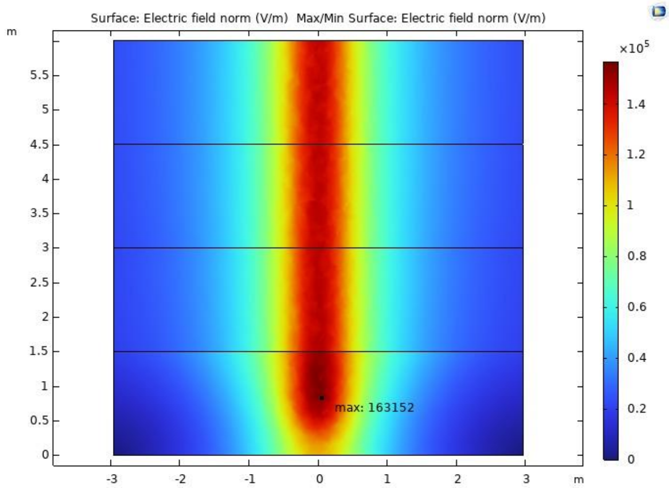

Figure 10: Surface Electric Field for Case 3

Table 3 tabulates the comparison of total soil resistivity and maximum electric field. The effect of soil resistivity on the electric field in the grounding system can also be seen in Figure 11. It is observed that the greater value of total soil resistivity gives the maximum value of the electric field. If the grounding system remains the same but the soil resistivity changes, it can have significant effects on the performance and effectiveness of the grounding system.

Table 3: Comparison of Total Soil Resistivity and Max Electric Field

Case	Total Soil Resistivity (ohm meter)	Maximum Electric Field (V/m)
1	2338	3.295e5
2	2739	4.581e5
3	1473	1.632e5

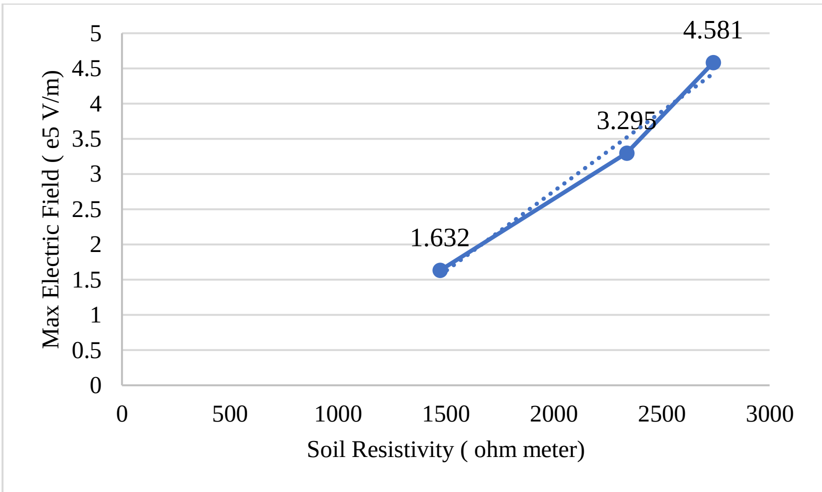

Figure 11: Graph for Total Soil Resistivity and Max Electric Field

Soil resistivity plays a crucial role in determining the resistance to the flow of electric current in the grounding system and, consequently, the distribution of charges and the electric field. When the soil resistivity is low, it means that the soil has good conductivity and allows for efficient dissipation of electric charges. In such cases, the grounding system can effectively disperse the charges into the surrounding soil, resulting in a lower accumulation of charges and a relatively lower electric field. On the other hand, when the soil resistivity is high, it means that the soil has poor conductivity and restricts the flow of electric current [9]. This can impede the dissipation of charges and lead to a higher accumulation of charges near the grounding system. As a result, the electric field in the vicinity of the grounding system can be stronger. This can be proven by using Equation 2.

$$\rho = \frac{E}{J} \qquad \text{Eq. 2}$$

4. Conclusion

In a nutshell, the voltage potential tends to decrease as the length of the rod increases. This is because a longer rod allows for better dissipation of electrical energy into the surrounding soil. As a result, a larger portion of the electrical current flows through the rod and into the ground, reducing the voltage potential at the grounding point. So, the 4.5m rod is the best length for the grounding system. In terms of current density, vertical rods tend to distribute current radially around the rod, with higher density near the surface of the ground. Horizontal rods distribute current more uniformly along their length, resulting in a more consistent current density distribution. Ultimately, the selection of vertical or horizontal rods should be based on a comprehensive evaluation of the specific circumstances, including soil resistivity, available space, installation feasibility, maintenance requirements, and grounding system objectives. But in terms of safety, horizontal can minimize the risk of localized hotspots or uneven current flow.

Finally, it can be concluded that different soil resistivity levels can have a significant impact on the performance of a grounding system. Low soil resistivity promotes effective charge dissipation, while high soil resistivity can hinder dissipation, leading to higher charge accumulation and potentially stronger electric fields. It is crucial to consider the soil resistivity and employ appropriate measures to ensure the effectiveness and safety of the grounding system in different soil conditions. A high electric field in the vicinity of a grounding system can increase the risk of electrical shock hazards. Touch potential and step potential, which refer to the potential difference between different points on the ground, can become elevated when there is a high electric field. This can pose a danger to people and animals in the area. So, case 3 is the better area for the grounding system because this area has a low resistivity and low electric field.

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