Journal of Multidisciplinary Academic and Practice Studies
ISSN 2656-2359, Vol 1, No 4, 2023, 287-297 https://doi.org/10.35912/jomaps.v1i4.1787

Using copper-coated round rod electrodes at various depths in freshwater marshes

Dian Eka Putra[1*], Zainuddin Nawawi[2], M. Irfan Jambak[3]
Palembang University, Indonesia[1*]
Sriwijaya University, Indonesia[2&3]
dianekaputra90@gmail.com[1*], nawawi_z@yahoo.com[2], dianeka.putra@ymail.com[3]

Article History
Received on 15 November 2023
1st Revision on 20 November 2023
2nd Revision on 22 November 2023
Accepted on 27 November 2023

Abstract

Purpose: High-voltage electrical equipment requires grounding installation to protect lives in freshwater swamps with a hydrogen potential of 6.75. To build a grounding structure, it is necessary to know the resistance value and grounding materials, namely, copper-coated rod electrodes at different depths.

Research methodology: The research was conducted in a freshwater swamp close to the shampooing substation using field observations and direct measurements of soil resistance values, followed by a literature review and comparisons using COMSOL simulation and FEM Analysis.

Results: The results of direct research and simulations indicate that to accomplish a grounding resistance value < 5 Ω according to the PUIL 2011 standard for a single-rod system made of copper, it is necessary to optimize the depth of the grounding electrode within a range of 10 m, which differs from the simulation results of ground resistance measurement and the Comsol application. The percentage error was 1.05%.

Conclusion: The findings demonstrate that increasing electrode depth effectively reduces grounding resistance in freshwater swamp environments, though variations exist between field and simulated data.

Limitations: This study analyzed the results of measurements and grounding analysis using COMSOL Multiphysics at a depth of 1 m for a particular type of copper-coated round rod electrode at depths of 1, 1.5, and 2 m.

Contributions: The results of this study offer information on the usefulness of grounding resistance in freshwater wetlands with a pH greater than 6, where several rod electrode types can be utilized for comparison in future research.

Keywords: *Comsol Multiphysic, Freshwater Swamp Land (Marshes), Grounding Resistance, Rod Electrodes*

How to Cite: Putra, D. E., Nawawi, Z., & Jambak, M. I. (2023). Using copper-coated round rod electrodes at various depths in freshwater marshes. *Journal of Multidisciplinary Academic and Practice Studies*, 1(4), 287-297.

1. Introduction

The electrical energy distribution system is directly interconnected from substations to other substations (Lembang, Manjang, & Kitta, 2018), including using 150 kV High Voltage Air Lines by passing through various land conditions R Batista, Louro, and Paulino (2021), and types Some of them pass through wet soil (Salam, Rahman, Ang, & Wen, 2017), swamp land or wetlands (Salam et al., 2017); (Palembang, 2021). Owing to the length of the line employing an unprotected exposed wire, consumers regularly experience various types of external disturbances that halt the flow of electrical energy during distribution (Adnan et al., 2020). In the distribution of electrical energy, overcurrent relationships and lightning surges are among the most common disturbances (Adnan et al., 2020; Ali, Ahmad, & Nor, 2020).

A system or safety installation with a grounding system, usually known as a grounding system, specifically a safety system against devices that employ a grounding system (Camara, Atalar, & Yılmaz, 2020), can overcome the protection system needed for disturbances, short circuits, disturbances from lightning strikes, or ground disturbances. Electrical surges caused by lightning are the primary source of electricity as a power source (Łukaszewski & Nogal, 2021). In addition to covering metal or electrical equipment, the grounding system may shield people and other living things from the risk of coming into direct contact with electric current (Raphael Batista & Paulino, 2019); (Malanda, Davidson, Singh, & Buraimoh, 2018). To install a grounding system, electrode rods must be inserted parallel to the ground surface and several centimeters into the soil (Ghomi, Zhang, Bak, da Silva, & Yin, 2021). The ground surface was attached to each electrode rod. By connecting the electrode rods to one another, several networks are produced (Hu, Fang, Hu, Zeng, & Deng, 2021); (Yan et al., 2021).

The more conductors are planted in this manner, the more consistently the stresses that emerge on the surface of the ground when a disturbance occurs will be spread. In addition to direct measurements of ground resistance analysis using rod electrodes on the land where the grounding is installed, direct measurements of ground resistance analysis using simulations with the COMSOL Multipysch program are required to establish the type of electrode used. Given the nature of the marshy and damp bog, the selection of rod electrodes has a considerable effect on the efficacy and reliability of grounding installations. In addition to mechanical strength, the rod electrode employed in this study was a copper-coated round rod electrode, which is more resistant to corrosion in wet environments. Zhang, Zhou, Chen, Song, and Shi (2017) research findings indicate that increasing soil salinity reduces the corrosion resistance of copper-clad steel, with the final stage showing lower corrosion levels compared to the mid-term stage. The resistance value increased with immersion time and then tended to stabilize. The corrosion resistance of copper-clad steel is better in non-salinized and lightly salinized soils. As the 150 kV transmission network matures, the grounding installation must be consistent and dependable so that maintenance can be performed repeatedly over an extended period of time (Nasir et al., 2021).

Due to the abundance of low-voltage and high-voltage electrical equipment in swamps, especially freshwater swamps, researchers are keenly interested in them, despite the scarcity of studies conducted on freshwater swamps. because the swampland is extremely difficult and muddy. In the swampland study, a true grounding resistance value will be determined, and it will be compared to research performed by other researchers on dry land or farmland, which has a grounding resistance and resistivity exceeding 100 m. Different soil types have different soil resistivity levels with different soil hydrogen potentials (pH) (Ishiwu, Nnanwube, Nkem, & Ezegbe, 2020); (Tiimub et al., 2020), and have different water hydrogen potentials (pH) (Ishiwu et al., 2020); (Ilomuanya, Nekahi, & Farokhi, 2018), which interest researchers in studying freshwater swamps, either by observation or by other methods (Andi, Kusumanto, & Yusi, 2022). Therefore, the results of research on swamps, particularly freshwater swamps, serve as a guide for the community to plan and build grounding installations in freshwater swamps, protecting living organisms from contact voltage and step voltage generated by leakage current. In addition to obtaining the value of the grounding resistance, copper-coated iron rods are used as an example of rod-electrode users for protection against touch voltages because galvanized-coated rods are easier to obtain at a lower cost, and installation is simpler than planting rods into the ground on dry land or farmland.

2. Literature Review

2.1 Grounding System

By creating a grounding installation, it is possible to mitigate the impacts of disturbances that occur when the electric power grid is in operation. In general, a grounding system is utilized in all elements of electric power, including generation, transmission, and distribution, as well as in residential and industrial settings. Two benefits of a grounding system are a decreased operating voltage and increased user and equipment safety. In addition, the grounding system can detect ground faults, decrease electromagnetic interference, reduce the risk of electrostatics, and lessen electromagnetic interference.

There are various ways to use the earthing system with 2000 IEEE Std 80, including:

1. Vertical rod grounding system (Driven rod)

To achieve the proper soil resistance value, this process requires planting electrode rods at a specified depth and perpendicular to the soil surface. Electricity from the rod electrodes of the earthing system flows through these cells in all directions. The ground cell with the smallest surface area and greatest resistance is closest to the grounding electrode rod. This distance, known as the effective resistance, is affected by both the diameter of the grounding rod electrode and the depth of implantation. Therefore, the resistance achieved improves when the electrode rod is buried deeper in the earth with 2000 IEEE Standard 80.

2. Grounding System using Horizontal Rod (Counterpoise)

This method is nearly identical to the vertical stem electrode method, except that the rod electrode is planted horizontally into the soil to the desired depth or until the desired soil resistance value is obtained.

3. Grid grounding system

Typically, grid grounding is employed to obtain a low-resistance value. The geometric form of the grounding grid may be square or rectangular.

2.2 Soil Structure

Soil structure consists of three main particles: solid, liquid, and gas. Solid particles in soil generally contain minerals and other organic matter. However, soil conductivity is largely determined by water content.

Based on previous research that has been done, soil conductivity decreases with decreasing temperature. When the temperature drops to 0 °C or lower, the water in the soil freezes slowly, and ice (with high resistivity) fills the space between the soil particles in a seed-like shape, so that the cross-conductivity of the soil decreases (Androvitsaneas, Damianaki, Christodoulou, & Gonos, 2020). Based on the general requirements for electrical installations, the value of soil resistivity is shown in Table 1.

Table 1. Soil resistivity based on PUIL

No	Type of soil	Soil Resistivity(Ω-m)
1	Marshland/ swamp land	30
2	Clay and Field soil	100
3	Wet Sand	200
4	Wet Gravel	500

Source : PUIL (2000); Mineral (2011)

2.3 Rod Electrodes

Rod electrodes are made of pipes or profiled steel bars driven into the ground. This type of electrode was the first to be used, and many grounding theories originated from it. Rod electrodes are widely used in residential buildings and office environments. They are technically easy to install, as they are simply driven into the ground. Moreover, installing this type of electrode does not require a large area of land, making it very practical to use (Zulhajji, Imran, & Haripuddin, 2022).

2.4 Wenner Method

The Wenner configuration is a configuration in geophysical exploration in which the electrode arrangement is located in a line symmetrical to the midpoint. The Wenner electrode configuration has good vertical resolution and high sensitivity to lethal changes, but weak current penetration with depth. The arrangement of the Wenner method can be shown as shown in Figure 1 (Putra, Sunawiri, Yansuri, Mutiar, & Sukarta, 2022). The electrode distance was the same when using the Wenner arrangement. The electrode spacing (a) in this design must be constant for each measurement to qualify as the Wenner Alpha Method. This configuration is effective and suited for calculating the incoming voltage-to-current ratio. Determining the contact resistance between the electrode and soil requires time under unfavorable circumstances, such as dry soil or solid dirt. The Wenner–Alfa method can be used to calculate soil resistivity, and the resulting equation is (IEEE, 2000).

$$\rho = 2\pi \text{aR} \quad (1)$$

Where R is the measured electrode resistance (Ω) and is the soil resistivity (Ω-m), a is the electrode length, depth (m)

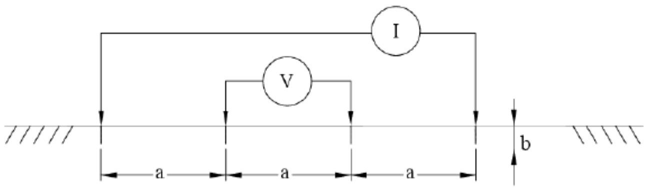


Figure 1. Wanner Method

The four electrodes for each test in the Wenner Method were stretched with each fitting of the same size placed closely together. There are two implementation viewpoints in Wenner's structure. The disadvantage of this method is that it requires long wires, large electrodes, and one person for each electrode to conduct the study in the allotted time. Additionally, the four movable electrodes were simple to read and provided a variety of impacts.

The advantage of this design is that it is very effective and ideal for calculating the ratio of the input voltage to the flowing current. In unfavorable circumstances, such as dry soil or solid dirt, it takes a long time to establish the contact resistance between the electrode and ground. The following equation can be used to determine the soil-type resistance using the Wenner method:

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

$$R = \frac{\rho}{2\pi C} \quad (3)$$

$$\frac{1}{C} = \frac{1}{L}\left(Ln\frac{4L}{a} - 1\right) \quad (4)$$

$$R_{d1} = \frac{\rho}{2\Pi.L} \text{In} \left(\frac{4L}{a} - 1\right) \quad (5)$$

For one electrode rod perpendicular to the soil and penetrating the second layer of soil, the following equation applies:

$$R_{d1} = R_a = \frac{\rho}{2\Pi.L} \text{In} \left(\frac{2L}{a} - 1\right) \quad (6)$$

R: Resistance for a single electrode rod positioned parallel to the ground (Ohm)
L: Electrode rod length (meters)
a: Electrode radius (meter)
ρ: the typical soil resistivity (Ohm-m)

2.5 Grounding of Equipment

By connecting the body of the protected equipment or installation with a grounded neutral conductor in such a way that, in the event of an insulation failure, there is no high touch voltage prior to the operation of the overcurrent safety device, grounding of the safety neutral grounding system (PNP) equipment is a security measure. What is meant by a part of this equipment is machine parts that, under normal circumstances, do not pass electric current but may do so under unusual circumstances. For instance, electrical panels, the housing and structure of electrical machines, and machine parts or tools are composed of metal (conductors of electricity). According to and, the Grounding Equipment should:

1. Prevent electric shock voltage from occurring, which is hazardous to nearby residents.
2. To permit the formation of a certain current of a given magnitude and duration in a ground disturbance condition without setting the structure or its contents on fire or causing an explosion.
3. This is done to enhance the visual appeal.

2.6 Lightning Protection Ground

A lightning protection system (SPP) is a device that shields the interior of a structure from lightning strikes. The SPP standard is crucial for ensuring the safety of both the structure and inhabitants. The two SPPs in the building are referred to as SPP External and SPP Internal. Using an air termination system to capture the lightning, a down conductor system to securely carry lightning current to the earth, and an earth termination system to disperse lightning current to the earth are the main objectives of the external SPP ("Chapter II," 2017). While using a potential equalization bond (IPP) between the External SPP components and other electrical regulating devices within the building structure, the Internal SPP is focused on preventing hazardous sparks in the building structure. Building lightning protection systems must be installed in accordance with the applicable regulations. This is crucial because if the lightning rod installation does not adhere to the requirements, it will not function as intended. The SNI 03-7015-2004, addressing lightning protection systems in buildings and IEC 622305-3 standard were utilized to describe this lightning protection system (ISO 20200:2004, 2003).

2.7 Indirect Touch Voltage

The term "indirect touch voltage" refers to the voltage on equipment or installation elements that ordinarily do not pass current but do so because the insulation surrounding that equipment or installation has failed. The contact voltage is equal to the working voltage of the tool or installation if no grounding is present. Of course, this puts those who use it or those around them in danger. This condition persists as long as the overcurrent protection mechanism does not shut off the circuit. The potential touch voltage during a failure is nevertheless constrained to a safe level or a maximum of 50 V for AC with correct grounding. In the state before grounding, if there is a fault current (leakage current), then the tool enclosure has a voltage to the ground equal to the source voltage (voltage between L-N). This voltage is of course very dangerous for the operator or people who touch the enclosure of the tool, and the overload current safety does not work to cut off the flow if it does not exceed its working limit. Therefore, even if there is a shock to humans, this safety device will not work because the electric current flowing into the body is not large enough for the safety device to work owing to the relatively large body resistance. Meanwhile, in the situation after grounding, if there is a fault current, because the grounding resistance is very small (requirement), a very large fault current will flow to ensure the overcurrent safety work, namely by disconnecting the equipment from the power source. At the time of occurrence of this fault current and with very low ground resistance, the touch voltage can be limited to a safe limit.

2.8 Step voltage

The voltage resulting from the fault current flowing through the ground is known as the step voltage. The voltage at the ground surface will be high if the fault current, which is relatively significant, passes through the ground, which has a relatively high resistance, from the location where the disturbance occurs to the source (neutral point). 2000 IEEE Std 80.

Table 2. Touch Voltage and Maximum Breakout Time (IEC)

Maximum RMS Touch Voltage (Volt)	Maximum Disconnection Time (Second)
< 50	~
50	5,0
75	1,0
90	0,5
110	0,2
150	0,1

220	0,05
280	0,03

Based on this table, it can be concluded that the higher the touch voltage, the shorter the disconnection time required for the protective device. For touch voltages less than 50 V AC, there is no cut-off time requirement, which means that the voltage is allowed as a permanent voltage.

2.9 Explosion Voltage

When there is a ground fault with a large current, it allows a potential difference between the parts through which the current passes and between parts that do not pass the current to the ground, which is called the exposure voltage. This voltage can create a grounding arc that can cause fires or explosions. Ground fault currents above 5 A tend not to be self-extinguishing, causing potential fires and explosions. With this grounding system, the potential of all parts of the structure, equipment, and ground surface is uniform (uniform), thereby preventing an electric jump from the equipment to the ground. Equally important is that when a ground fault occurs, the phase voltage experiencing the fault decreases. This voltage drop significantly interferes with the performance of the equipment being operated. This incident can also disrupt the parallel operation of the generators, thereby disrupting the overall performance of the power system.

Table 3. Voltage Steps and Maximum Allowable Disconnection Time

Duration of Disturbance T (second)	**Allowable Step Voltage (V)**
0,1	7.000
0,2	4.950
0,3	4.040
0,4	3.500
0,5	3.140
1,0	2.216
2,0	1.560
3,0	1.280

Source: 2000 IEEE Std 80

2.10 COMSOL Multiphysic

One software that uses the finite element method as the basis for calculations is COMSOL Multiphysics. COMSOL Multiphysics is software that can analyze and solve various physics and engineering applications, especially those with multiple phenomena, known as multiphysics. COMSOL can run on various operating systems (Windows, Mac, Linux, and Unix). COMSOL Multiphysics can also incorporate systems of multiple partial differential equations. There are several reasons for using COMSOL in this study. This program is user-friendly and allows users to easily enter their own mesh model and other coefficient parameters, boundary conditions, initial conditions, and their relationship to other physical phenomena.

4. Research Methodology

An iron rod coated with copper and pushed into the ground is used in grounding resistance research. The installation of this electrode, which is frequently used in substations or power plant installations, is technically simple and only requires driving a rod into the ground. Formula (Equation) 6 is used to calculate the ground resistance in Figure 1 using a single rod electrode:

The soil-type resistance values based on the general requirements for electrical installations are listed in Table 1.

Using direct observation and experimental methods, the study of grounding resistance and soil resistivity in freshwater swamp land with a water pH of 6.75 was conducted. Grounding resistance was measured using the 3-point method (Association, 2012), with an Earth Tester Kyioritsu Digital R 1405 A with serial number W8205886, as for the swamp land with the freshwater swamp type. The soil resistivity was measured directly using a soil resistivity ECTR 2000 C measuring device and the 4-point method. The grounding resistance and soil resistivity values were obtained from the measurement data, and these values were compared with the grounding resistance values. by using multiphysics simulations in COMSOL.

Data on alkaline sand soils were derived from field observations in freshwater wetlands near the Keramasan Substation in Palembang City. Formula 4 can be used to determine the grounding resistance with one electrode rod implanted perpendicularly in the swamp soil at a depth of 1 meter with a grounding resistance of 21.3 Ω and a swamp soil resistivity of 30 Ωm in accordance with.

Figure 2. Field Measurement Process

The following data were obtained in conducting this research:

Table 4. Types of soil and specifications of electrode rods

Information	Electrode type and size
Electrode Shape	Round rod
Electrode Material	Copper Plated Iron (Visalux)
Electrode Length	200 cm : 2 meters
Electrode Diameter	15.14 mm : 0.01514 meters
Rod electro spokes	0.00757 meters
Type of soil	Swamp Soil Resistivity = 30 Ωm
Electrode spacing	1 meter
Earth Tester	Kyoritsu R 1450 A Digital
Resistivity Soil Tester	ETCR 2000C

4. Results and Discussions

To analyze the measurement results, it is necessary to perform the calculation results by referring to formula no. 6 for the calculation of one electrode rod perpendicular to the soil and penetrating the second layer of soil, the calculation is from a depth of 1 m, 1.5 m to 2 m.

$$R_{d1} = R_a = \frac{\rho}{2\Pi.L} \text{In} \left(\frac{2L}{a} - 1 \right)$$

$$R_a = \frac{30}{2*3{,}14*1} \text{In} \left(\frac{2*1}{0{,}00757} - 1 \right) = 21{,}86\ \Omega \text{ : for a depth of 1 meter}$$

$$R_a = \frac{30}{2*3{,}14*1.5} \text{In} \left(\frac{2*1.5}{0{,}00757} - 1 \right) = 15{,}87\ \Omega \text{ : for a depth of 1.5 meter}$$

$$R_a = \frac{30}{2*3{,}14*2} \text{In} \left(\frac{2*2}{0{,}00757} - 1 \right) = 12{,}59\ \Omega \text{ : for a depth of 2 meter}$$

From the results of the calculation of resistance and based on the results of measurements and observations directly in the field carried out with a rod electrode depth starting from 1 m, the results obtained are as follows:

Table 5. Calculation and Measurement Results

No	Depth Rod (m)	Resistivitas Soil (Ω-m)	Diameter Rod (m)	Calculation (Ω)	Measurement (Ω)
1	1	30	0.01514	21.86	25.2
2	1.5	30	0.01514	15.87	16.8
3	2	30	0.01514	12.59	11.8

Source: Calculation and Measurement 2022

From the results of the calculation of the grounding resistance in freshwater swamps, with a swamp soil resistivity of 30 Ωm at different depths, based on Table 5, the deeper the copper-coated iron rod electrode is planted, the smaller the grounding resistance obtained. This is evidenced by calculations in 1 m of grounding resistance obtained of 25.2 Ω, while at a depth of 2 m, the ground resistance value is smaller than the grounding resistance at a depth of 1 m, which is 12.59 Ω, indicating that there is a difference in ground resistance in freshwater swamps of 12.61 Ω.

The results of direct measurements in the field at a depth of 1 m showed that the resistance value was greater than the calculation, namely 25.2 Ω, which was due to the condition of the swamp soil with muddy conditions, soft soil texture, and soft water. However, when the measurement was 2 m deep, the soil texture was soft and dense, so the measurement results were 11.8 Ω smaller than the calculation; the smaller the resistance, the better the rod electrode implantation. With a small resistance, it is easier for the electric current to flow to the earth so that living things are protected from the dangers of touch voltage or step voltage.

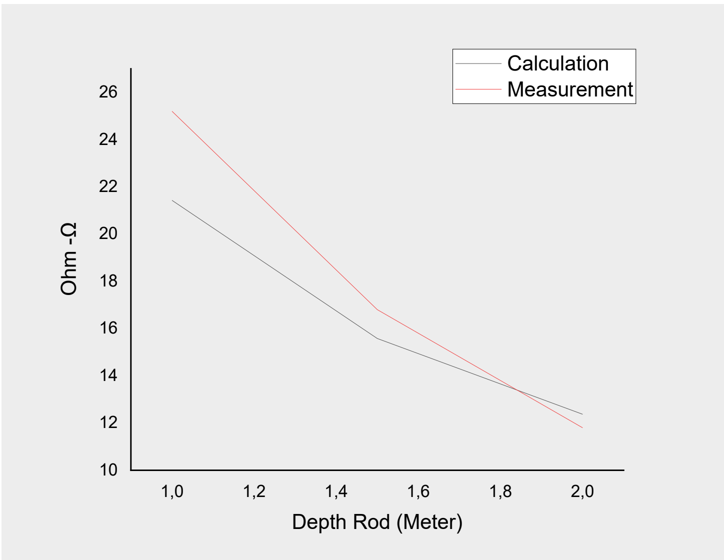


Figure 3. Graph of Measurement and Calculation of Grounding Resistance

Use the UB approach. The findings of testing on freshwater swamp land have a grounding value that surpasses the requirement, namely 5, where the rod electrode has a grounding resistance value of 11.8 Ω at a depth of 2 m, according to Dwight. When viewed from the results of the calculations using the equation from UB. Dwight, then the ground resistance value for one electrode rod still gets a high resistance value from a depth of 1 m to a depth of 2 m in freshwater swamp land at the Keramasan Substation location, with calculation data, on swamp land in conditions of clay that the value of the grounding resistance exceeds the maximum allowable standard of 5Ω where at a depth of 2 m copper-coated rod electrodes obtained a grounding resistance value of 12.59 Ω meaning that there is a different value of 0.79 Ω greater than the calculated value of grounding resistance in freshwater swamp land.

When viewed from the results of calculations and direct measurements in the field at a depth of 2 m, the results of grounding resistance in freshwater swamp land are better than those in dry land or farmland, whereas in field soil at a depth of 2 m with a soil resistivity of 100 mΩ, the value of grounding resistance will be obtained at 41.96 Ω, which means that the planting of rod electrodes in swamp land is more effective than planting on dry land or field soil, so that living things are protected from the danger of touch voltage.

After the results of the research are analyzed and calculated, the next step is to make comparisons using the calculation of rod resistance using COMSOL Multiphysics 5.6 tools. The material properties were specified by designing the electrodes. The simulation produced an Electrical Current profile. From this electrical current profile, the resistance of the rod can be calculated. In the COMSOL Multiphysics 5.6 simulation process, the researchers limited the data from the direct measurement of the smallest resistance, the Kyoritsu R 1405 A digital Earth tester on the copper-coated iron rod electrode material, to perform a comparison value.

Table 6. Measurement Results and Simulation

Copper Plated Rod				
L (m)	**Water pH**	**Earth Resistance (Ω)**	**Resistivity Soil (Ωm)**	**Comsol Multiphysics (Ω)**
1	6,75	25.2	226,80	23,05
1,5	6,75	16,8	170,80	17,36
2	6,75	11,8	122,50	12,45

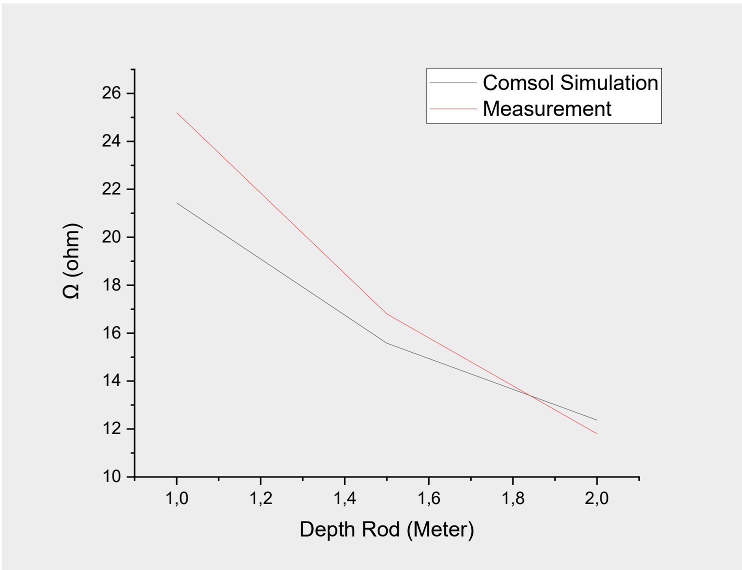
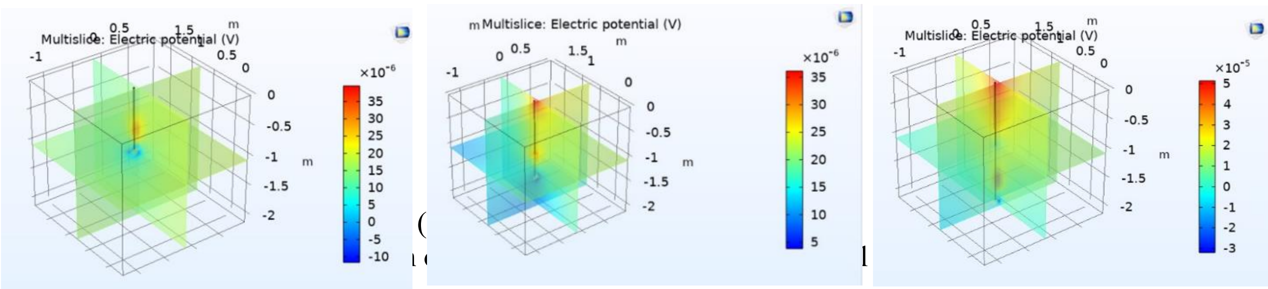


Figure 4. Resistance Graph of Measurement Results and Simulation Results



5. Conclusion

From the results of measurements of grounding resistance and soil resistivity in freshwater swamp land with a pH of 6.75, the deeper the rod electrode, the smaller the value of grounding resistance and soil resistivity, as evidenced by the difference in values at a depth of 1 m, the resistance value obtained is 25.2 Ω while at a depth of 2 m, the rod electrode is planted, the ground resistance value is 11.8 Ω in direct proportion to the soil resistivity at a depth of 1 m, the resistivity value is 226.80 Ωm and at a depth of 2 m, the soil resistivity is 122.50 Ωm. In the simulation using COMSOL Multiphysics software analysis, there was a difference between the COMSOL Multiphysics application and direct measurements, where the average difference was 1.05%, as shown in Table 4. To obtain maximum results, it is necessary to research the grounding resistance using other types of rod electrodes, such as galvanized iron rod electrodes, to obtain the value of the ideal ground resistance and soil resistivity ratio.

5.1 Limitations

The authors offer a number of recommendations for more research based on the limitations of the study, which are as follows:

1. According to the research and analysis findings, the rod material utilized in the field study must be made of pure materials to yield the best results.
2. Material examination in the laboratory is required before using the rods, and the results from this study will be used as the last calculation detail in the COMSOL Multiphysics application.
3. Further investigation into soil types other than freshwater swamp soil is required.
4. A comparative study using the CYMGRD program for large soil resistance and a construction analysis system utilizing a grid system is required to determine the contour of the soil in the event of a fault current.

References

Adnan, M., Abdul-Malek, Z., Din, N. S. M., Jambak, M. I., Nawawi, Z., & Sidik, M. A. B. (2020). Effects of lightning impulse front time on substation grounding system performance. *Indonesian Journal of Electrical Engineering and Computer Science, 20*(2), 569-574. doi:https://doi.org/10.11591/ijeecs.v20.i2.pp569-574

Ali, A. W. A., Ahmad, N. N., & Nor, N. M. (2020). *Effects of impulse polarity on grounding systems.* Paper presented at the 2020 IEEE International Conference on High Voltage Engineering and Application (ICHVE).

Andi, K., Kusumanto, R., & Yusi, S. (2022). IoT monitoring for PV system optimization in hospital environment application. *Stud. Inform., Technol. Syst., 1*(1), 1-8. doi:https://doi.org/10.35912/jomaps.v1i4.1792

Androvitsaneas, V. P., Damianaki, K. D., Christodoulou, C. A., & Gonos, I. F. (2020). Effect of soil resistivity measurement on the safe design of grounding systems. *Energies, 13*(12), 3170. doi:https://doi.org/10.3390/en13123170

Association, I. S. (2012). IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System (IEEE Std 81-2012).

Batista, R., Louro, P., & Paulino, J. (2021). Lightning performance of a critical path from a 230-kV transmission line with grounding composed by deep vertical electrodes. *Electric Power Systems Research, 195*, 107165. doi:https://doi.org/10.1016/j.epsr.2021.107165

Batista, R., & Paulino, J. O. S. (2019). A practical approach to estimate grounding impedance of a vertical rod in a two-layer soil. *Electric Power Systems Research, 177*, 105973. doi:https://doi.org/10.1016/j.epsr.2019.105973

Camara, M., Atalar, F., & Yılmaz, A. E. (2020). A new grounding cake to improve the safety performance of grounding systems. *Journal of Electrostatics, 108*, 103521.

Ghomi, M., Zhang, H., Bak, C. L., da Silva, F. F., & Yin, K. (2021). Integrated model of transmission tower surge impedance and multilayer grounding system based on full-wave approach. *Electric Power Systems Research, 198*, 107355. doi:https://doi.org/10.1016/j.epsr.2021.107355

Hu, H., Fang, M., Hu, F., Zeng, S., & Deng, X. (2021). A new design of substation grounding based on electrolytic cathodic protection and on transfer corrosion current. *Electric Power Systems Research, 195*, 107174. doi:https://doi.org/10.1016/j.epsr.2021.107174

IEEE. (2000). 80-2000 - IEEE Guide for Safety in AC Substation Grounding. doi:https://doi.org/10.1109/IEEESTD.2000.91902
Ilomuanya, C., Nekahi, A., & Farokhi, S. (2018). *Acid rain pollution effect on the electric field distribution of a glass insulator.* Paper presented at the 2018 IEEE International Conference on High Voltage Engineering and Application (ICHVE).
Ishiwu, C., Nnanwube, I., Nkem, J., & Ezegbe, C. (2020). Investigation of Functional and Sensory Properties of Plantain Flour in Citric Acid. *Annals of Science and Engineering Research, 1*(1), 27-47. doi:https://doi.org/10.35912/jomaps.v1i4.1789
Lembang, N., Manjang, S., & Kitta, I. (2018). *The Effect of Grounding Resistance about Back Flashover on 150 KV Tranmission Network in Main Station of Sungguminasa-Tallasa (Makassar).* Paper presented at the Journal of Physics: Conference Series.
Łukaszewski, A., & Nogal, Ł. (2021). Influence of lightning current surge shape and peak value on grounding parameters. *Bulletin of the Polish Academy of Sciences. Technical Sciences, 69*(2). doi:http://dx.doi.org/10.24425/bpasts.2021.136730
Malanda, S. C., Davidson, I. E., Singh, E., & Buraimoh, E. (2018). *Analysis of soil resistivity and its impact on grounding systems design.* Paper presented at the 2018 IEEE PES/IAS PowerAfrica.
Mineral, K. E. d. S. D. (2011). Peraturan Umum Instalasi Listrik (PUIL 2011).
Nasir, N. A. F. M., Kadir, M. Z. A. A., Osman, M., Abd Rahman, M. S., Ungku Amirulddin, U. A., Mohd Nasir, M. S., . . . Nik Ali, N. H. (2021). Effect of earthing enhancing compound (EEC) on improving tower footing resistance of a 500 kV tower in a rocky area. *Applied Sciences, 11*(12), 5623. doi:https://doi.org/10.3390/app11125623
Palembang, U. (2021). INVESTIGASI KINERJA RESISTANSI PENTAHANAN (GROUNDING) PADA LAHAN RAWA TIMBUN Dian Eka Putra 1, Raden Ahmad Yani 2. *vol, 5*, 1-6. doi:https://doi.org/10.31539/spej.v5i1.2908
PUIL. (2000). Standard 80-2000 Guide for Safety in AC substation gorunding.
Putra, D. E., Sunawiri, S., Yansuri, D. S., Mutiar, M., & Sukarta, E. (2022). Evaluasi Resistivitas Tanah dan Resistansi Pentanahan pada Lahan Tanah Pasir Basah. *Jurnal Ampere, 7*(1), 9-14. doi:https://doi.org/10.31851/ampere.v7i1.7807
Salam, M. A., Rahman, Q. M., Ang, S. P., & Wen, F. (2017). Soil resistivity and ground resistance for dry and wet soil. *Journal of Modern Power Systems and Clean Energy, 5*(2), 290-297. doi:https://doi.org/10.1007/s40565-015-0153-8
Tiimub, B. M., Christophé, N., Atepre, B. A., Tiimob, R. W., Tiimob, G. L., Tiimob, E. N., . . . Agyenta, J. J. (2020). Crop production potential of reclaimed mine sites for sustainable livelihoods. *Journal of Applied Research Technology (JART), 1*(1), 1-15. doi:https://doi.org/10.35912/jomaps.v1i1.1785
Yan, W., An, Y., Hu, Y., Jiang, Z., Gao, X., & Zhou, L. (2021). Research on cylinder Flexible Graphite Earth Electrode (FGEE) used to reduce tower earth resistance☆. *Electric Power Systems Research, 196*, 107268. doi:https://doi.org/10.1016/j.epsr.2021.107268
Zhang, X., Zhou, Z., Chen, X., Song, J., & Shi, M. (2017). *Study on corrosion behavior of copper-clad steel for grounding grids.* Paper presented at the Advances in Materials, Machinery, Electrical Engineering (AMMEE 2017).
Zulhajji, Z., Imran, A., & Haripuddin, H. (2022). Analisis Resistansi Sistem Pembumian Elektroda Batang Berdasarkan Jenis Tanah.