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

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Abstract
Purpose: High-voltage electrical equipment requires a grounding installation in order to protect lives in freshwater swamps with a hydrogen potential of 6.75. To build a grounding structure, it is required 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 measurement 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 in order to accomplish a grounding resistance value < 5 ohms 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 meters, which differs from the simulation results of ground resistance measurement and the Comsol application. The percentage error is 1.05%.
Limitations: This research analyzes the results of measurements and grounding analysis using Comsol Multiphysics at a depth of 1 meter for a particular type of copper-coated round rod electrode at depths of 1, 1.5, and 2 meters.
Contributions: The results of the study offer information on the usefulness of grounding resistance in freshwater wetlands with a pH greater than 6, where several rod electrode types are utilized to compare future research.
Keywords: *Grounding Resistance, Freshwater Swamp Land (Marshes), Comsol Multiphysic, Rod Electrodes*
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1. Introduction

The electrical energy distribution system is directly interconnected from substations to other substations (Lembang et al., 2018), including using 150 kV High Voltage Air Lines by passing through various land conditions (Batista et al., 2021), and types Some of them pass through wet soil (Salam et al., 2017), swamp land or wetlands (Salam et al., 2017; Sriwijaya & Palembang, 2021). Due to the length of the line employing an unprotected exposed wire, consumers regularly experience various sorts 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 (Ali et al., 2020; Adnan et al., 2020).

A system or safety installation with a grounding system or usually known as a grounding system, specifically a safety system against devices that employ a grounding system (Camara et al., 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 (Batista & Paulino, 2019; Malanda et al., 2018). In order to install a grounding system, electrode rods must be inserted parallel to the ground surface and several centimeters into the soil (Ghomi et al., 2021). Attached to each electrode rod is the ground surface. By connecting the electrode rods to one another, several networks are produced (Hu et al., 2021; Yan et al., 2021). The more conductors are planted using 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 kind 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 the grounding installation. In addition to mechanical strength, the rod electrode employed in this study is a copper-coated round rod electrode, which is more resistant to corrosion attacks in wet or watery environments. In addition to ensuring a high degree of security, the use of copper-coated round rod electrodes is clearly more cost-effective than the use of rod electrodes made of pure copper (PLN, 1993). As the 150 kV transmission network matures, the grounding installation must be consistent and dependable so that maintenance can be performed repeatedly for an extended period of time (Nasir et al., 2021).

Due to an abundance of electrical equipment, both low-voltage and high-voltage electrical equipment, on swamps, especially freshwater swamps, researchers are keenly interested, 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 certainly have different soil resistivity levels with different soil hydrogen potential (pH) (Ishiwu et al., 2020; Tiimub et al., 2020), and have different water hydrogen potential (pH)(Ishiwu et al., 2020; Ilomuanya et al., 2019), interest the researchers more in researching freshwater swamps, either by observation or by other methods (Andi et al., 2022). So that 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 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 a disturbance that occurs when the electric power grid is in operation. In general, the 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 decreased operating voltage and increased user and equipment safety. In addition, the grounding system may 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)

In order to achieve the proper soil resistance value, this process requires planting electrode rods at a specified depth and perpendicular to the surface of the soil. Electricity from the rod electrodes of the earthing system will flow through these cells in all directions. Closest to the grounding electrode rod is the ground cell with the smallest surface area and greatest resistance. This distance, known as the effective resistance, is affected by both the diameter of the grounding rod electrode utilized 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, with the exception 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 grounding resistance value. The grounding grid's geometric form might be square or rectangular.

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

Based on research that has been done, soil conductivity decreases with decreasing temperature. When the temperature drops to 0° 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 et al., 2020). Based on 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; Umum & Listrik, 2011)

2.3 Rod Electrodes
Rod electrodes are electrodes made from metal rods that are pushed into the ground, such as steel profiles, iron pipes, or other metal rods. All ideas concerning grounding that begin with this type of electrode use it as their initial electrode. Technically speaking, this rod electrode, which is installed by driving it into the ground, is commonly utilized in substations. Additionally, this electrode doesn't need a lot of space (PUIL, 2000).

2.4 Wenner Method
The Wenner configuration is one of the configurations in geophysical exploration where the electrode arrangement is located in a line that is symmetrical to the midpoint. The Wenner electrode configuration has a 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 et al., 2022). The electrode distance is the same when using the Wenner arrangement. The electrode spacing (a) in this design must be constant for each measurement to qualify as Wenner Alpha Method. This configuration is quite effective and suited for calculating the incoming voltage to current ratio. Determining the contact resistance between the electrode and the soil takes a while in 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 Std 80, 2000).

$$\rho = 2\pi \mathrm{aR} \qquad (1)$$

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

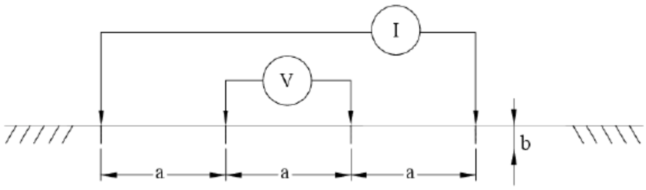


Figure 1. Wanner Method

The four electrodes for each test in the Wenner Method are 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 needs long wires, big electrodes, and one person for each electrode in order to do the study in the allotted time. Additionally, the four movable electrodes are simple to read and provide a variety of impacts.

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

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

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

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

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

while for one electrode rod perpendicular to the soil and penetrates the second layer of soil, in this case, the 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 are 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 composed of metal (conductors of electricity). According to and, Grounding Equipment should:

1. Prevent electric shock voltage from occurring, which is hazardous for 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 exploding.
3. To enhance visual appeal.

2.6 Lightning Protection Ground

A lightning protection system (SPP) is a device that shields a structure's interior from the risk of lightning strikes. The SPP standard is crucial to ensuring the safety of both the structure and the inhabitants. The two SPPs in the building are called SPP External and SPP Internal, respectively. Using an air termination system to capture the lightning, a down conductor system to securely carry lightning current to earth, and an earth termination system to disperse lightning current to 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 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 are 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 there is no grounding. Of course, this puts those who use it or those around in danger. This condition will last 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 being grounded, 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. So that even if there is a shock to humans, this safety device will still not work because the electric current flowing into the body is not large enough for the safety to work due 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), then a very large fault current will flow so as to make the overcurrent safety work, namely by disconnecting the equipment from the power source. In a 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 that results from 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 back 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 said 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 will allow 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 a fire or explosion. Ground fault currents above 5 Ampere 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 the ground surface is uniform (uniform) thereby preventing an electric jump from the equipment to the ground. No less important is that when a ground fault occurs, the phase voltage that is experiencing the fault will decrease. This voltage drop greatly interferes with the performance of the equipment being operated. This incident can also disrupt the parallel work of the generators so that the overall performance of the power system will be disrupted.

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 of the 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, Unix). COMSOL Multiphysics can also incorporate systems of multiple partial differential equations. There are several reasons underlying the use of COMSOL in this study, namely that this program is a user-friendly program that makes it easy for users to enter their own mesh model and other coefficient parameters, boundary conditions, initial conditions and their relationship to other physical phenomena.

3. Research Methodology

An iron rod that has been coated with copper and pushed into the ground is utilized in grounding resistance research. The installation of this electrode, which is frequently used in substations or power plant installations, is technically quite 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:
For soil resistivity based on general requirements for electrical installations, the value of soil-type resistance is shown 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 (IEEE Std 81, 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 will be obtained from the measurement data, and these values will be compared to the grounding resistance values. by using multi-physics simulation in Comsol.

Data on alkaline sand soils were derived from field observations made 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 we 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 do the calculation results by referring to the 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 meter, 1.5 meters to 2 meters.

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

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

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

$$R_a = \frac{30}{2 * 3{,}14 * 2} \text{In} \left(\frac{2*2}{0{,}00757} - 1 \right) = 12{,}59\ \Omega$$: 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 grounding resistance in freshwater swamps, with a swamp soil resistivity of 30 Ωm at different depths, then based on table 5 the deeper the copper-coated iron rod electrode is planted, the smaller the grounding resistance is obtained, this is evidenced by calculations in 1 meter of grounding resistance obtained of 25.2 Ω while at a depth of 2 meters the ground resistance value is smaller than the grounding resistance at a depth of 1 meter, which is 12.59 Ω, meaning that there is a difference in ground resistance in freshwater swamps of 12.61 Ω.

As for the results of direct measurements in the field at a depth of 1 meter, the resistance value is greater than the calculation, namely 25.2 Ω where this is due to the condition of the swamp soil with muddy conditions soft soil texture, and soft watery. But when the measurement is 2 meters deep, the soil texture is soft and dense so the measurement results are 11.8 Ω smaller than the calculation, the smaller the resistance is, the better the rod electrode implantation is. With a small resistance, it makes it easier for electric current to flow to earth so that living things are protected from the dangers of touch voltage or step voltage.

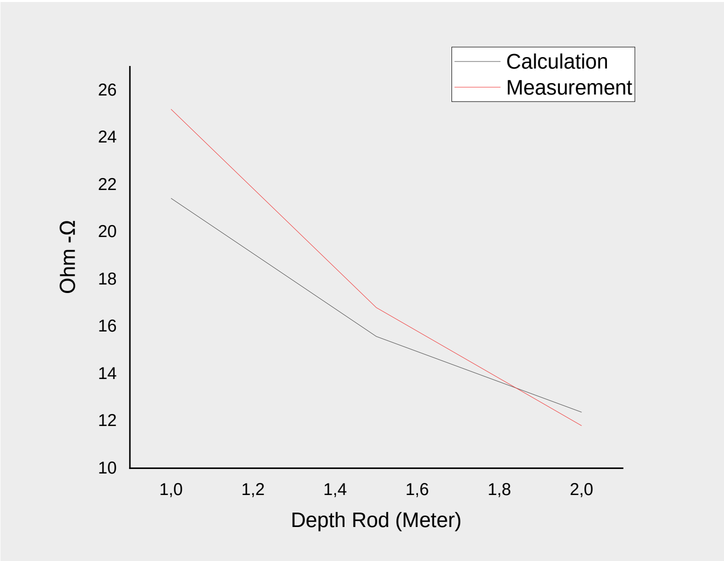


Figure 3. Graph of Measurement and Calculation of Grounding Resistance

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 meters, according to Dwight. When viewed from the results of calculations using the equation from UB. Dwight, then the ground resistance value for 1 electrode rod still gets a high resistance value from a depth of 1 meter to a depth of 2 meters 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 meters 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 meters, the results of grounding resistance in freshwater swamp land are better than dry land or farmland, whereas in field soil at a depth of 2 meters with a soil resistivity of 100 mΩ the value of grounding resistance will be obtained at 41.96 Ωmeans 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 Calculating Rod Resistance using Comsol Multiphysics 5.6 tools. By designing the electrodes, specify the material properties. The simulation will produce an Electrical Current profile. From this Electrical Curren profile, the resistance of the Rod can be calculated. Where 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

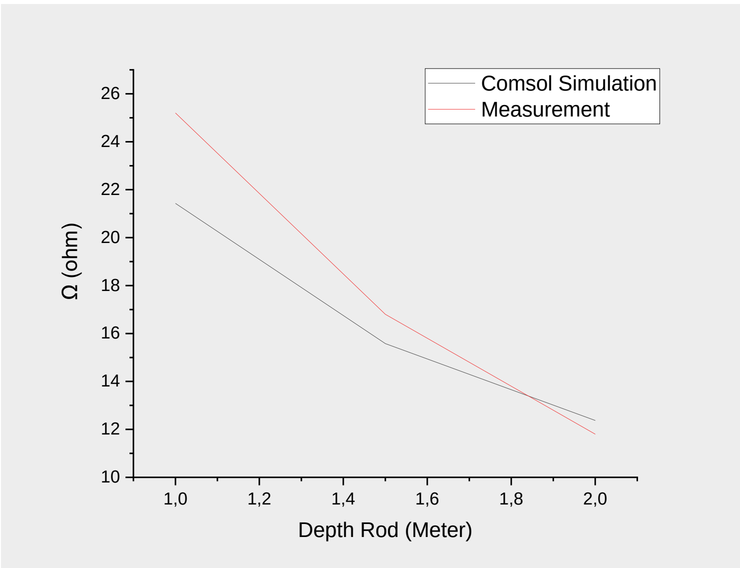
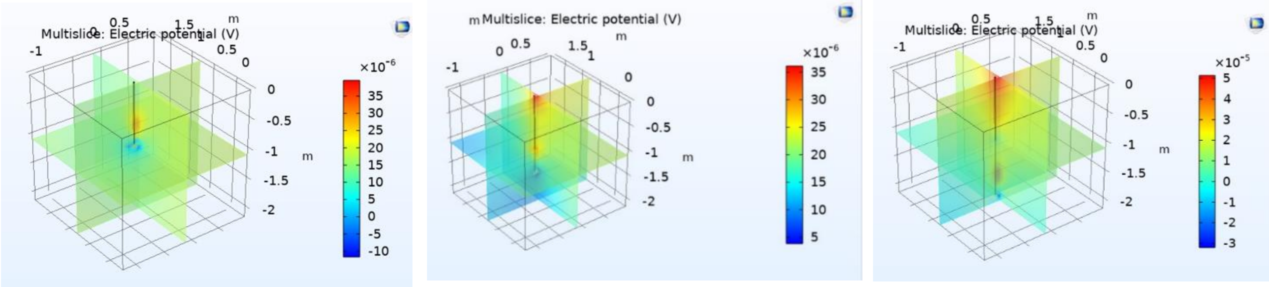


Figure 4. Resistance Graph of Measurement Results and Simulation Results



(a) (b) (c)

Figure 5. Rod Electrodes at a depth of (a) 1 m, (b) 1.5 m, (c) 2 m, Comsol Simulation

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 meter, the resistance value obtained is 25.2 **Ω** while at a depth of 2 meters, 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 meter, the resistivity value is 226.80 **Ω**m and at a depth of 2 meters, the soil resistivity is 122.50 **Ω**m. In the simulation using Comsol Multiphysics software analysis, there is a difference between the Comsol Multiphysics application and direct measurements where the average difference is 1.05% as shown in table 4. To get maximum results, it is necessary to research grounding resistance using other types of rod electrodes such as galvanized iron rod electrodes, so as to get 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 research and analysis findings, the rod material utilized in field study must be made of pure materials to yield the best results.
2. Material examination in the lab is required before using rods, and the results from this study will be used as every last calculation detail in the Comsol Multiphysics application.
3. Additional investigation into soil types other than freshwater swamp soil is required.
4. A comparison 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.

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