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Research Original Article

Comparison of Grounding Resistance Using Grounding Rod Electrodes with Different Fault Current Types in Podzolic Soil at *Prabumulih* Substation

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Abstract
For protection against electric shock in electrical equipment, particularly in control or instrument installations in substation equipment, a quality earthing system is required. The earthing system is also affected by soil resistivity with different soil types. In the equipment grounding system, knowledge of the types of electrodes and the type of soil is required. At the Prabumulih substation, Podzolic soil is required to evaluate the stress distribution that happens in the soil in order to reduce Ground Potential Rise (GPR). In addition to obtaining the economic value of the rod electrode type employed. In this study the resistivity value of the podzolic soil type is very decisive so that the resistivity value of the podzolic soil type at the pre-selection substation land is 150 Ωm.

Keywords: Ground Resistance, Bar Electrodes, Ground Potensial Rise (GPR)

Introduction
In the process of generating, distributing, and consuming electrical energy, it is inseparable from the grounding system, which protects humans and electrical equipment from electric shock (Ghomi et al. 2021)(Putra, Nawawi, and Jambak 2022a). The horizontal grounding construction system is planted in the ground and coupled to electrical equipment that utilizes electrical energy in order to quickly drain fault current into the ground (Adnan et al. 2020). Additionally, the kind of soil's resistivity dictates the low grounding resistance necessary to protect living beings and electrical equipment (Androvitsaneas et al. 2020), the type of grounding construction material is very decisive, including the use of the type of rod electrode material used for the grounding system (Hasibuan et al. 2021) (Ali et al. 2020). The type of grounding construction material, particularly the type of rod electrode material utilized for the grounding system, is of critical importance (Faudzi et al. 2020), especially on the control equipment at the substation. In the existing electricity regulations in Indonesia, the grounding resistance value is highly demanded to reach a low value below 5 ohms, this is stated in PUIL 2000 and PUIL 2011 (Putra et al. 2022). Multiple soil types make it extremely challenging to get a low resistance value (Elgayar et al. 2019). The area near the Prabumuli substation has a podzolic soil type with features of yellow clay and gravel, thus it would be quite interesting to perform research on the grounding system utilizing different types of rod electrodes. The types of rod electrodes utilized will influence crucial factors for calculating Ground Potential Rise (GPR) caused by fault currents (Adnan et al. 2020)(Salam et al. 2017).

Table 1. Soil type resistance based on PUIL 2000

Soil Type	Soil Type Resistance (Ω-m)
Marshland	30
Clay and Farmland	100
Wet Sand	200
Wet Gravel	500

When seen from table 1, the problems with podzolic types are very interesting, they can be a combination of wet clay and wet sand, meaning that they may have a soil resistivity value that exceeds the resistivity value of the soil type listed in PUIL 2000 and PUIL 2011, namely between 100 Ωm to 200 Ωm, while in the IEEE standard 80-2000 wet soil of 100 Ωm, in addition to the lack of research on the resistivity of podzolic soil types and it has not been listed in PUIL 2000 and PUIL 2011, the resistivity value of soil types is very important to study, because soil is a medium for the distribution of electric current when it occurs fault currents, both fault currents caused by lightning (Łukaszewski and Nogal 2021), or caused by insulation failure from the switching process, this fault current flows through metal equipment in the electrical installation and is channeled into the ground, with the smaller the resistivity value of the soil type, the safety of living things, especially humans, will be guaranteed from the dangers of touch voltage and step voltage, for electrical installation equipment reliability will be guaranteed (Azmi et al. 2019). The grounding system is used in power generation equipment systems by burying rod electrodes into the ground which are equipped with active conductors connected to electrical equipment made of metal, with an ideal grounding resistance value of below 5 ohms (PUIL 2000). The risk of the danger of direct contact with touch voltage and step voltage is getting bigger in the area around the generator and distribution of electricity, one of which is at the substation, besides that the equipment is powered by 150 kV, the equipment is made of metal and has a large capacity size and has the size of the equipment. high, it will be vulnerable to the risk of lightning strikes (de Araújo et al. 2021).

Materials & Methods

In a comparative study using a type of rod electrode planted vertically into the ground with a podzolic soil type in the Prebumulih substation area, appropriate materials and research methods were needed to obtain the expected results, while the materials needed are shown in table 1.

Table 1. Grounding Resistance Research Materials with Podzolic Soil Types

Information	Electrode type and size
Electrode Shape	Round rod
Electrode Material	- Galvanized plated iron (Zinc Coated Steel) - Steel (behel) - Copper plated iron
Electrode Length	200 cm (2 meter)
Electrode Diameter	- 16,56 mm - 15,37 mm - 15,14 mm
Rod electrode radius	- 0,00828 meter - 0,00768 meter - 0,00757 meter
Type of soil	Swamp Soil Resistivity: 30 Ω
Electrode embedding depth	- 1 meter - 1,5 meter - 1,75 meter - 2 meter
Resistance Earth Tester	Kyoritsu Digital 1450 A
Soil Resistivity Tester	ETCR 2000C

In this study, the grounding resistance measurement equipment, Kyoritsu 1450 A, has been calibrated by the appropriate institution in order to acquire the most accurate findings (Lai and Thuzar n.d.)(Faudzi et al. 2020). Using the three-point or three-pin method, measure the resistance of the ground on the driven rod electrode after conducting field observations and determining the kind of material and research aid equipment (Myint, Hla, and Tun 2020), this method was chosen because it is easier to do and very familiar to researchers in the field of grounding systems. First, the phases of the measurements are performed with one kind of ground rod electrode, and then this grounding resistance measurement is performed with another type of ground rod electrode to measuring ground rod electrodes of a different type which is carried out with different depths, as shown by the depth of the electrode in table 1.

After the grounding resistance data is obtained using the type of round iron (Hardi et al. 2019), galvanized iron and copper-coated grounding rod electrodes then by analyzing the resistivity of the soil type using the cymgrd application and simulated with fault currents to display the possibility of touch voltages and step voltages caused by currents or potential voltage on the ground, better known as Ground Potential Rise (GPR) (Putra, Nawawi, and Jambak 2022b).

To get the results of the comparison between the measurement and calculation results of the grounding resistance, use the driven rod grounding resistance formula (IEEE Std 81 2012) with the U. Dwight method

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

As for the calculation of soil type resistivity by converting from the U.Dwight method (Hu et al. 2021(IEEE Std 80 2000), which is presented in formula 2.

$$\rho = \frac{2\pi L.R}{[\left[in\frac{4L}{a}\right]-1]} \quad (2)$$

Figure 1. Location and Process of Testing and Measuring Grounding Resistance at *Prabumulih* Substation

Results and Discussion

From the results of field research, test data were acquired by measuring the grounding resistance of vertically-planted rod electrodes of various kinds and depths. The grounding resistance measurements given in the table below were collected on May 21, 2022.

Table 2. The average result of measuring the ground resistance in the Prabumulih substation area

Rod Depth	Rod Type (Ω)		
	Round Iron	Galvanized Coated Iron	Copper Plated Iron
1	81,6	76,9	90
1,25	74,9	69,8	89,5
1,5	73,2	69,4	80,8
1,75	73,1	64	80,6
2	70	60,9	80,4

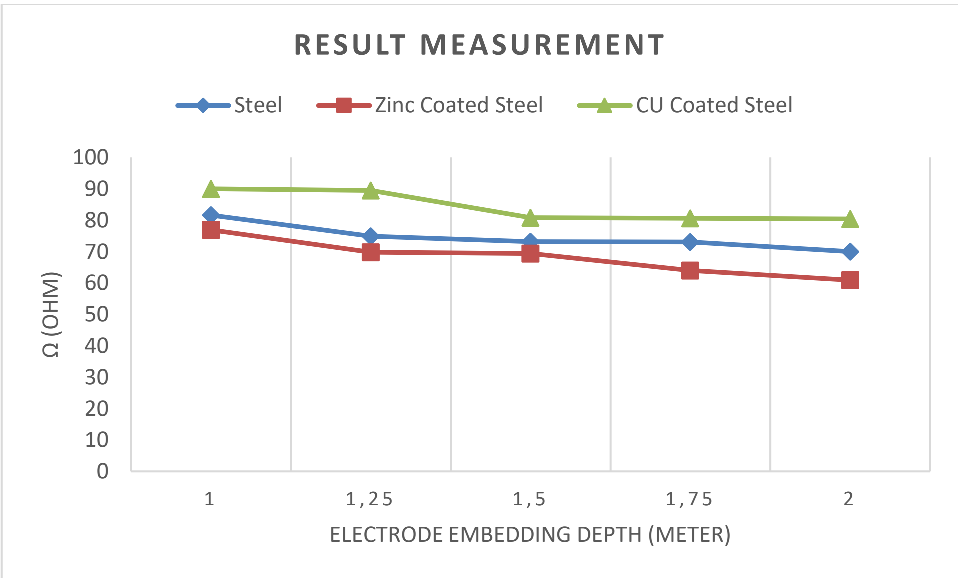


Figure 2. Measurement results of grounding resistance of rod electrodes on podzolic soil types

According to the results of testing and measuring grounding resistance using the three-point approach, galvanized coated iron rod electrodes performed better on podzolic soil types than iron type grounding rod electrodes and copper plated grounding rod electrodes. The copper-plated iron rod electrode demonstrates the smallest value of all tests conducted at different depths; the grounding resistance value declines with the depth of the rod electrode; the deeper the rod electrode, the lower the grounding resistance value determined by the three-point method.

Using formula 1, the calculation of the driven rod grounding resistance with podzolic soil types assumes that the soil type is a mixture of wet clay and sand (table 1). In this study, the resistivity value for podzolic soil types was 150 Ωm. can be compared with the measurement results with the 3-point method.

Table 3. Results of Measurement and Calculation of Grounding Resistance

Rod Electrode Depth (meters)	Calculation Electrode Rod (Ω)	Average Earthing Resistance Measurement (Ω)
1	109,32	82,83
1,5	91,72	78,07
1,75	79,33	74,47
2	70,10	72,57

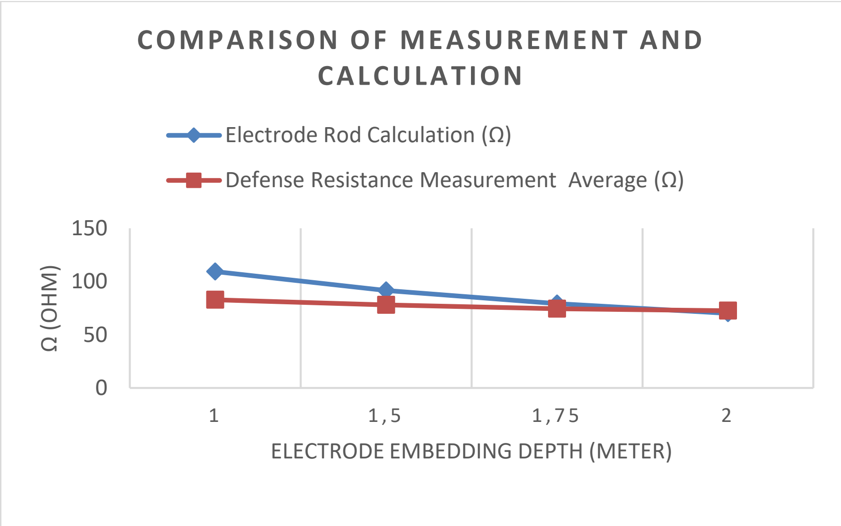


Figure 3. Comparison of Measurement and Calculation on podzolic soil types

In Figure 2, a comparison graph between the calculated results and the average measurement results reveals that at the same depth of the rod electrode, the grounding resistance value of the rod electrode in the podzolic soil type is relatively close to the same results, particularly at a depth of two meters for the rod electrode. The researchers assume that podzolic soils have an average resistivity of 150 Ωm.

The data from field measurements will be analyzed for soil type resistivity using the cymgrd application, here in this study to see the magnitude of the GPR with potential touch voltage and potential step voltage, the variables in table 2 are needed, as follows:

Table 4. Variable input simulation cymgrd

Earth resistance Measurement, potential step and touch (Body Weight 50 kg) Swampland	
Bus ID	150 kV
Nominal frequency	50 herzt
LG Fault Current	100 A
Remote contribution	100%
Upper Layer Thickness	0.5 m
Electrode :	
Rod	- Steel Rod - Zinc Coated Steel - Copper plated steel
Conductor	Copper commercial hard-drawn – 16 mm
Lengt Rod	2 meter
Length Conductor Total	16 meter
Primary Rod Length Total	8 meter

From the simulation results by inputting the resistivity value of the soil type according to the resistance measurement at the grounding rod electrode, the soil resistivity value is shown in table 5 below:

Table 5. Resistivity Value of Podzolic Soil Type at the *Prabumulih* Substation

Rod Depth	Podzolic Soil Resistivity Value (Ωm)		
	Steel	Zinc Coated Steel	CU Coated Steel
1	114,21	105,87	123,49
1,25	124,83	114,52	146,37

1,5	140,94	131,62	152,77
1,75	159,19	137,34	172,46
2	169,72	145,56	191,62

After inputting the parameters listed in table 4 into the cymgrd application, the value of the potential for the occurrence of Ground Potential Rise (GPR) is obtained for each use of the types of grounding rod electrodes that are planted vertically in the ground. Additionally, the value of the potential for the occurrence of touch voltage and step voltage varies as shown in the table below.

Table 6. Touch Voltage, Step Voltage and Ground Rise Potential

Description	Voltage (volt)		
	Steel	Zinc Coated Steel	CU Coated Steel
Max Permissible Touch	209,39	209,01	209,81
Max Permissible Step	345,4	343,89	347,88
Ground Potensial Rise (GPR)	1520,4	1324,31	1686,51

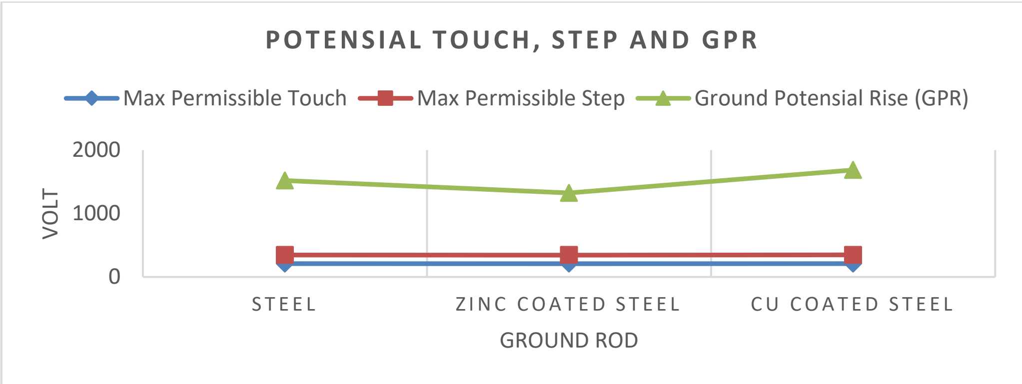
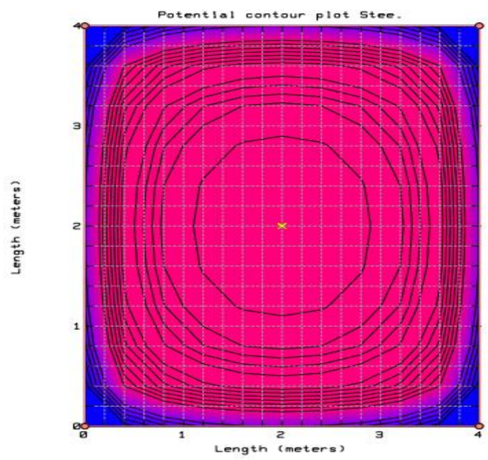
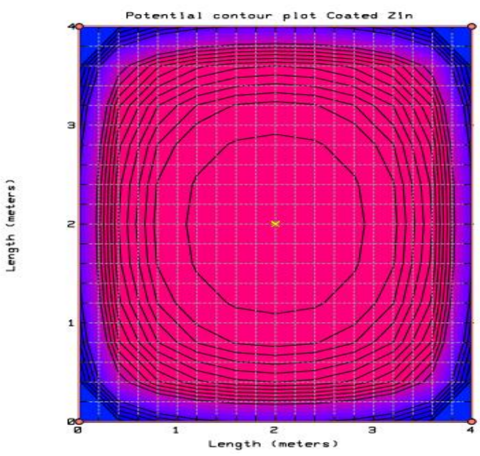


Figure 3. Potensial Touch, Step and Ground Potesial Rise (GPR)

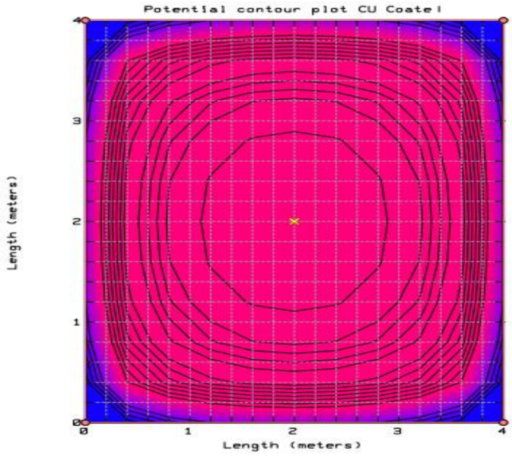
The Ground Potential Rise in each grounding rod electrode test is replicated using a grid structure that may be observed by the contour or color of the voltage distribution on the ground surface, as shown in the image below.



(a). Iron Type Rod Electrodes



(b). Galvanized Coated Iron Type Rod Electrodes



(c). Copper Coated Iron Type Rod Electrodes

Figure 4. Spread of GPR on the surface of podzolic soils using different types of ground rod electrodes.

This event indicates that there is still a large potential for voltage spreading on the ground surface, so it still has a dangerous impact on the operator or living things in the vicinity if there is a fault current caused by lightning or a failure in the switching process of electric power installations.

Conclusions

Based on the results of a series of field tests conducted by measuring ground rod electrodes in different types of soil at low soil depths on podzolic soil types with yellowish clay soil characteristics and red pebbles having a relatively high soil resistivity, podzolic soil resistivity values are a combination of wet clay and sand. Hence, it assumes 150 Ωm. This is consistent with the significant grounding resistance seen when utilizing rod electrodes. The best grounding resistance is shown when using a galvanized iron type grounding rod electrode, particularly at a depth of 2 meters in the ground, where the resistance value using a galvanized type rod electrode is 10% to 20% lower than when using an iron type rod electrode or a copper-coated iron type, indicating that the grounding resistance is not as good when using an iron type rod electrode or a copper-coated iron type. However, it is impacted not only by the resistivity of the soil type, but also by the type of ground rod electrode material that is vertically planted in the soil. In the simulation utilizing the cymgrd application, the greatest Ground Potential Rise (GPR) value is 1686.51 volts for a copper-coated grounding rod electrode with a potential touch voltage of 209.81 volts and a step voltage of 347.08 volts with a fault current of 100 amperes. In order to obtain a low resistance value and decrease the GPR potential value, it is necessary to embed the ground rod electrode deeper than the results of the above experiments.

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