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The grounding resistance improvement of the distribution substation using multiple rods and wood charcoal as soil treatment

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Abstract: The grounding system plays the important role in securing the electric power system. Low grounding resistance ensures the proper operation of the grounding system. The lower the grounding resistance value, the easier current flow through the earth without any obstacles then prevents equipment from being damaged or causing the injury of personnel. According to the PUIL 2000 standard, grounding resistance should be less than 5Ω. Methods that can be performed to reduce grounding resistance are increasing the length and diameter of the grounding rod, using multiple rods, and treating the soil to reduce its resistivity. In this study, we would like to improve the grounding system of the KA2317 distribution substation located at Mertasari, Jimbaran in South Kuta, Bali which has a grounding resistance of 8.1Ω (more than 5Ω). The method that was applied in this study was grounding improvement by adding an electrode rod and adding wood charcoal to reduce soil resistivity. At the end of the study, grounding resistance can be reduced from 8.1Ω to 1.9 Ω or improved by 76.6%.

Keywords: charcoal, electrode rod, grounding resistance

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Introduction

The grounding system plays the important role in securing the electric power system. Low grounding resistance ensures the proper operation of the grounding system. The lower the grounding resistance value the easier the current flows through the earth without any obstacles, then prevent equipment from being damaged or causing the injury of personnel. According to the PUIL 2000 standard, grounding resistance should be less than 5Ω [1].

The value of grounding resistance is influenced by several factors, namely soil resistivity, size and the type of electrode used, and depth electrode implantation. While Soil type resistivity is influenced by soil composition, temperature, water content (moisture), and chemical content in the soil [2]. One method to get a lower grounding resistance and soil resistivity are by chemical soil treatment in the form of adding additives to the soil. Some additives that are often used are bentonite, gypsum, salt, and charcoal [3]. Wood charcoal has the highest percentage of carbon at 25.04%, and the least is hydrogen at 4.77% based on laboratory test results. The large active carbon content in wood charcoal acts as an additive that can increase water absorption due to its hygroscopic so that it can increase the electrical conductivity of soil [4].

Based on pre-research conducted on the K2317 distribution substation of PLN located at at Mertasari, Jimbaran in South Kuta, Bali, it was found that the grounding system at this substation has a resistance quite high of 8.1Ω (greater than the PUIL 2000 requirement). This situation could potentially endanger the electrical network system in that area from the possibility of overcurrent or lightning disturbances. In order to prevent the possibility of electrical interference, it is very urgent to improve the grounding system.

The studies of grounding system improvement have been developed in several scientific research works as described in the following summary. As published in [5] grounding improvement by implementing soil treatment biochar instead of chemicals. The method contributes to reducing the earth's resistance over long periods to avoid the expensive cost of these elements and their secondary effects. The use of this method significantly reduced the earth resistance with one electrode from 242.0Ω to an average of 26.27 Ω with the Clay sandy soils of the Sahelian zone of Cameroon during the dry season and 2.1 Ω during the rainy season. While as published in [6] The effect of bentonite to reduce soil resistance was analyzed. The grounding resistance is observed with and without bentonite. The earthing system with bentonite as addictive has a smaller grounding resistance than that without bentonite. The biggest percentage of reduction in grounding resistance is 74% due to bentonite which is activated at a temperature of 2000C. Non-activated bentonite can achieve a 68% reduction in grounding resistance. In contrast, the composition of 50% non-activated bentonite and 25% soil can reduce the grounding resistance by 69%. The results obtained from the comparison using dry coconut shell charcoal and wet coconut shell charcoal show that measurements using wet coconut shell charcoal are better (less resistant) than using dry coconut shell charcoal. Soil resistivity measurements will be much better at the maximum depth than the usual depth (110 cm), better than 10cm [7]. The application of bentonite to improve the value of grounding resistance was found in the study [8]; bentonite was chosen because has various good properties including very low and stable resistivity; abilities to absorb and retain large quantities of water; can swell up to 13 times its dry volume; low cost; it will not gradually leach out because it is part of the clay itself. The result shows that the decrement of grounding resistance is around 16% - 48% (average 32%) with a deviation standard is 8%. The research on grounding system improvement that was conducted in the Laboratory of Electrical Engineering, University of Lampung shows that the lowest grounding resistance values were 45.896 Ω on the concrete with bentonite: cement: sand: gravel = 0.3: 0.7: 2: 4. By adding 1.5% coconut fiber, the grounding resistance value is 3.5 times smaller than the grounding resistance values of the soil (161.2 Ω). Adding bentonite and coconut fiber can decrease the grounding resistance values [9]. The research on Specific locations within the Niger Delta region of Nigeria shows that the deeper-driven single vertical electrode was observed to have decreased after the deeper-driven exercise. The resistance values of the deeper-driven electrodes showed resistance of up to 98% resistance reduction [10]. The research grounding improvement published in [11] shows that the best composition is 90% Zeolite, 5% NaCl, and 5% charcoal for the rod depth of 1.2m, resulting in a resistance decrease from 94.3Ω down to 5.3Ω (94.4%). In the research published in [12] the utilization of coconut charcoal as alternative media of grounding was investigated. The mesh-electrode was made of stainless steel of 8-mm diameter, whereas its lattice dimension was 50cmx50cm. Three variations of lattice number were considered, i.e. 1-, 2-, and 4-lattice structures. Dry and wet charcoal media were considered. Mesh location was fixed at the depth of 80cm under the ground, while the 10cm of medium thickness variation was chosen. The resistance obtained using a 10-cm thickness of the charcoal layer in a mesh consisting of 1-, 2-, and 4-lattices were 268, 131, and 78 ohms consecutively. The addition of layers up to 80 cm resulted in a resistance decrease of 48%, 33%, and 44%. Using wet charcoal, the 10-cm layer produced 26.5, 17.5, and 14.8 ohms of grounding resistance and a reduction of 25%, 10%, and 3.6% subsequently for 1-, 2-, and 4-lattice mesh structure if the layer thickness was 80cm. Meanwhile as reported in [13] there was a decrease in the value of grounding resistance which originally used a single-circuit electrode grounding system to a parallel-connected electrode grounding system of 52.307% and a parallel-connected electrode grounding system with charcoal media mixed with the soil by 60%. An almost similar finding was also reported in [14], the addition of wood charcoal and salt (NaCl) as a soil treatment to the electrode with a depth of 0.8 m resulted in a decrease in grounding resistance from 16.70Ω to 5.31Ω or an improvement of 68.2%.

All these above studies confirmed that additional electrodes and additives as soil treatment can reduce grounding resistance and improve the grounding system effectively. However, the weakness of using chemicals (i.e.: bentonite, NaCl) as soil treatment cannot achieve very small earth resistance for a long time, especially in the case of dry clay and dry sandy soils. Secondly, they are not only expensive but also not available everywhere and all the time. Some are corrosive and some are easily leached [5]. Meanwhile using bio charcoal like wood and coconut as soil treatment can provide small grounding at a low cost without causing corrosion issues against the grounding rods.

As previously described, in this research, we will carry out an improvement of the grounding system of the distribution substation located in limestone soil. Considering that the ground condition is limestone soil which is alkaline in nature and has low conductivity-high resistivity on one hand. On the other hand, limestone soil in nature has a very hard surface which is become a constraint in implementing deep electrode rods to get lower resistance. So that to overcome this situation, we will carry out this grounding improvement by applying the addition of electrode rods in parallel combined with soil treatment. Considering that wood charcoal is a good soil treatment, does not cause corrosion and is easy to find, and has a low price, wood charcoal was chosen as an additive as a soil treatment in this study. By implementing these methods at the end of the study, it is expected that the grounding resistance will be improved and comply with the requirement according to PUIL 2000 Standard.

Methodology

This research was conducted at Distribution Substation KA 2317 located at Mertasari, Jimbaran in South Kuta, Bali in the period from Jul to Aug 2022. The supporting data was obtained from a). Field Observation b). Literature review from various relevant sources such as books, journals, and regulations related to grounding improvement.

The stage of work carried out in this study is shown in Figure 1, which includes:

First Stage, collecting existing grounding resistance data and references related to grounding system improvement;

Second Stage, compose a plan to improve the grounding system of the distribution substation by applying additional rods in combination with soil treatment;

Third Stage, implementing the grounding system improvement in three steps: (i) add new electrode rods, (ii) add wood charcoal as a soil treatment into the hole of additional Electrode gradually in 10% steps from 50% of hole volume until 100% then measure the grounding resistance at the end of every step, until getting resistance value lower then 5Ω, (iii) connecting additional new electrode rods to the existing electrode in parallel then we get the final grounding resistance value.

Fourth Stage, conducting technical analysis and discussion. And finally, compose the conclusion.

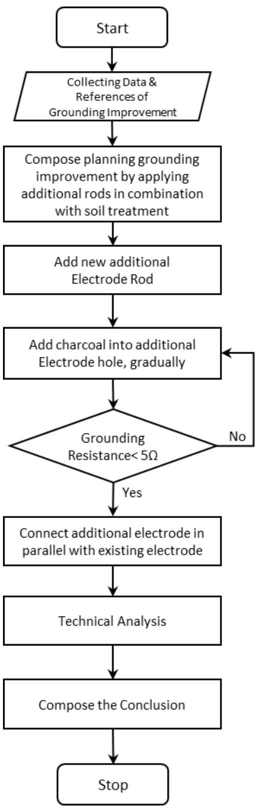

Figure 1. Grounding improvement flowchart

Results and Discussions

Results

General Information of Object of Study

KA2317 Distribution Substation located at Mertasari, Jimbaran in South Kuta, Bali is one of the distribution substations of the Citraland Jimbaran feeder. This substation is a portal-type substation, with a capacity of 160KVA, in 2 directions, which serves residential housing. In this substation, valve-type arresters are installed, grounded in limestone-type soil. This substation is using single electrode rod grounding with resistance that does not meet the PUIL 2000 requirements, which is greater than 5Ω.

Existing Grounding System Measurement of KA2317 Substation

The measurement results of the existing grounding system KA2317 Substation (initially using an existing single electrode) are shown in Table 1.

Table 1. Grounding resistance measurement of existing electrode

Time	Grounding Resistance (Ω)	Soil Humidity (%)	Ambient Temperature (°C)
9:00	8.0	60	34.7
13:00	8.3	60	36.1
17:00	8.1	60	35.3
Average	8.1		

Measurements were taken 3 times (at 9 AM, at 1 PM, and 5 PM) with an average value of 8.1Ω which still does not meet the PUIL 2000 standard, namely <5Ω.

KA2317 Substation Grounding Improvement

According to the formulas developed by Herbert Bristol Dwight, an American-Canadian Electrical Engineer, and published in AIEE Transactions in December 1936, the grounding resistance can be calculated as follow [15]:

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

Where,

R = Resistance to the ground (Ω)
ρ = Soil resistivity (Ωm)
L = Rod length (m)
a = Rod radius (m)

Refer to formula (1), several methods can be applied to reduce the resistance and improve the grounding system, i.e.:

- Increase the rod diameter
- Increase the length of the rod
- Use multiple rods in parallel
- Treat the soil to reduce its resistivity

Additional New Grounding Electrode

As a part of grounding improvement, in this research, we add a new grounding electrode made of copper-coated steel, with dimensions of 200cm in length and 1.5cm in diameter. This new electrode is installed around 300cm away from the existing electrode as shown in Figure 2.

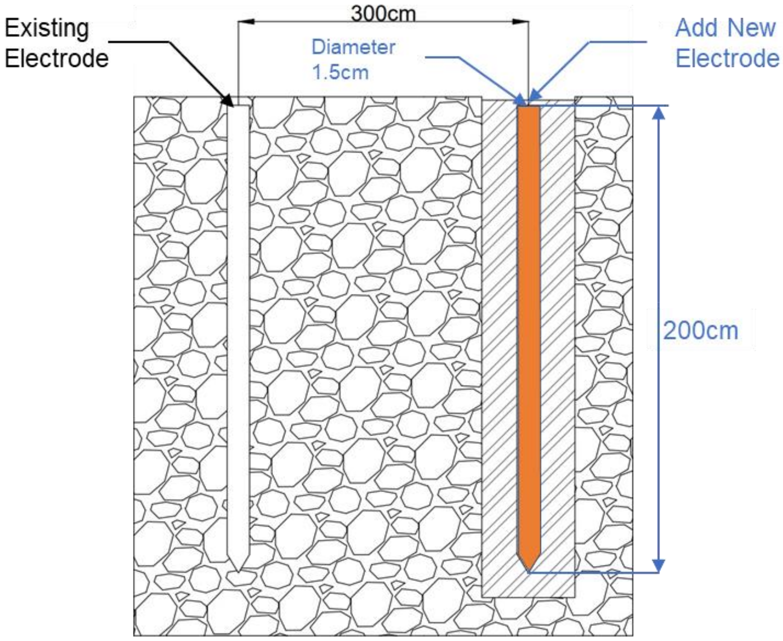

Figure 2. Existing and additional new grounding electrode

The same as for the existing grounding electrode, we did measurements of resistance of adding new grounding electrode, which was also taken 3 times (at 9 AM, at 1 PM, and at 5 PM) as tabulated in Table 2.

Table 2. Grounding resistance measurement of additional new electrode

Time	Grounding Resistance (Ω)	Soil Humidity (%)	Ambient Temperature (°C)
9:00	7.6	60	35
13:00	8.2	60	38
17:00	7.8	60	36
Average	7.9		

As shown in the above table, with an average value of 7.9Ω which still does not meet the PUIL 2000 standard, namely <5Ω. So that needs additional effort to reduce the grounding resistance.

Add Wood Charcoal as Soil Treatment

Considering the properties of wood charcoal i.e.: (i) it has a high active carbon content (25.4%) and is hygroscopic- so that it has a high water absorption capacity which can increase soil conductivity [4], (ii) it is easy to obtain and (iii) it is valuable cheap, in this research we choose wood charcoal as soil treatment additive as shown by Figure 3.

The step-by-step process of adding wood charcoal as a soil treatment is as follows:

- First, prepare a hole with a depth of 205cm and a diameter of 15cm for placing additional electrodes and additional wood charcoal additives.
- Second, preparation of wood charcoal powder of as much as ± 8 kg mixed with a little water.

- Third, installation of the electrode into the hole.
- Fourth: add wood charcoal powder which has been mixed with water using a measuring cup gradually starting from 50%, 60%, 70%, 80%, 90%, and 100% of the volume of the hole.
- Fifth: measuring the resistance of the grounding electrode at the end of each stage of filling the additive.

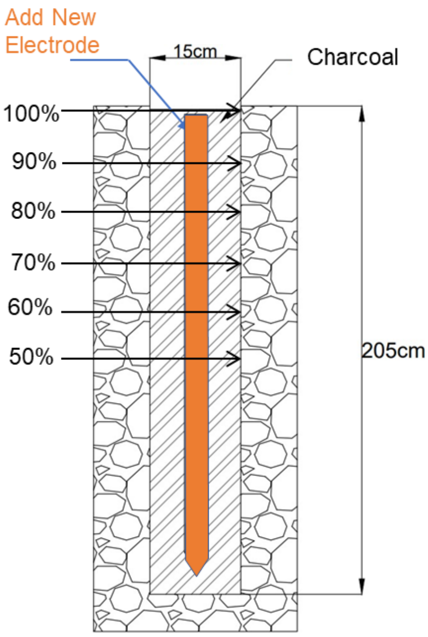

Figure 3. Additional charcoal stage as soil treatment

The results of grounding resistance measurements are recorded in Table 3.

Table 3. Grounding resistance variation after gradual addition of charcoal soil treatment

No	Charcoal filled Composition	Grounding Resistance (Ω)
1	50%	6.6
2	60%	5.2
3	70%	3.7
4	80%	2.2
5	90%	1.7
6	100%	1.3

As shown in Table 3, after 100% charcoal-filled composition is reached, measured grounding resistance achieves 1.3Ω which has met the PUIL 2000 requirement, namely <5Ω.

Parallel Connection Existing and Additional Electrode with Wood Charcoal as Soil Treatment

Referring to the results of grounding resistance measurements in tables 1 and 3, it is known that the resistance of the existing grounding electrode and the additional electrode with wood charcoal soil treatment is 8.1Ω and 1.3Ω respectively. To obtain a lower grounding resistance and meet PUIL 2000 requirements, the two grounding electrodes will be connected in parallel as shown in Figure 4.

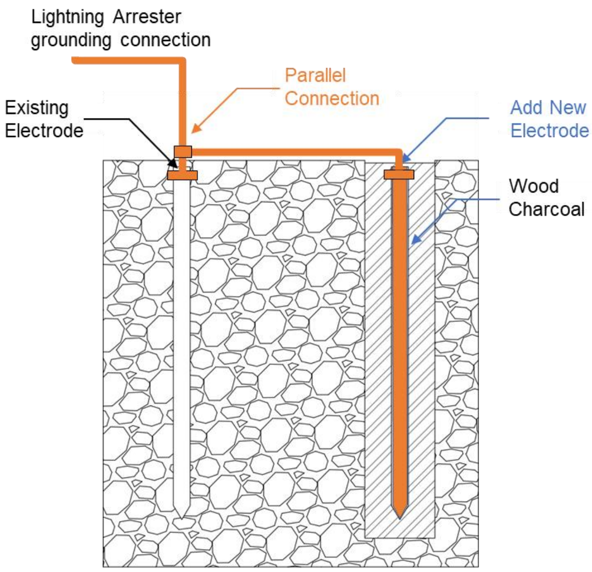

Figure 4. Parallel connection existing and additional electrode with charcoal soil treatment

In order to get a more accurate result, we did resistance measurements taken 3 times (in the morning at 9 AM, in the afternoon at 1 PM, and in the evening at 5 PM) as tabulated in Table 4.

Table 4. Grounding resistance measurement after parallel connection of existing and additional electrodes with wood charcoal soil treatment

Time	Grounding Resistance (Ω)	Soil Humidity (%)	Ambient Temperature (°C)
9:00	1.8	70	34
13:00	1.9	70	36
17:00	2.0	70	35
Average	1.9		

As shown by Table 4, the average resistance value of grounding after the parallel connection of Existing and Additional Electrode rods with Wood Charcoal Soil Treatment is 1.9Ω which has met to PUIL 2000 requirement. This grounding resistance value (1.9Ω) improves significantly compare with the grounding resistance of the existing electrode rod (8.1Ω). The percentage of improvement is around 76.6%.

Discussions

As shown in the previous section (Table 1), the grounding resistance of the K2317 distribution substation is quite high (8.1Ω). This high grounding resistance is caused by the following condition i.e.: first, the type of soil where the grounding is installed is limestone-type soil which is alkaline so it has low conductivity and high resistivity. Second, the hard limestone soil conditions also make it difficult to install deep electrodes.

In order to improve the grounding resistance, firstly we add a new electrode rod, which is installed at the same depth as the existing electrode rod without any soil treatment. With this condition produces a grounding resistance that is almost the same, i.e.: 7.8Ω (table 2). It shows that the high resistivity of the soil (limestone) has a significant effect on the high value of the grounding resistance.

The gradual addition of wood charcoal as a soil treatment to the new electrode hole resulted in a decreased value of the grounding resistance. Filling wood charcoal 50% of the new electrode hole, getting a resistance value of 6.6Ω. Adding more wood charcoal, getting more decreased in grounding resistance, and finally adding wood charcoal into 100% of the hole volume resulting the grounding resistance reduction to 1.3Ω, which met the PUIL 2000 requirement. This finding is in accordance with the results of previous research published in [3], [7], [9], [12], and [13]. Charcoal is effectively able to reduce soil resistivity because charcoal has a high percentage of active carbon at 25.04% which is hygroscopic and acts as an additive that can increase water absorption so that it can increase the electrical conductivity of the soil.

In the end, by making a parallel connection between the existing electrode rod and the new electrode rod which has been equipped with wood charcoal soil treatment, the final grounding resistance of the K2317 substation reaches 1.9Ω (Table 4) which meets the requirements of PUIL 2000. This grounding resistance significantly improve by 76.6% compared to the previous grounding resistance. The result of this study almost similar to the conclusion of studies that were published in [13] and [14], which was indicated that the use of wood charcoal as a soil treatment is very effective in improving the resistance value of the grounding system.

Conclusion

The distribution substation K2317 at Mertasari, Jimbaran in South Kuta, Bali initially has a high grounding resistance value (8.1Ω), which was not met the PUIL 2000 requirements (should be less than 5Ω). By applying the method of reducing grounding resistance through the addition of electrode rods (multiple rods) combined with applying wood charcoal as a soil treatment, the grounding resistance is reduced to 1.9Ω which meets the PUIL 2000 standard requirements. The percentage of grounding improvement through this method reaches 76.6%. Studies in this research only focus on aspects of planning and implementation. Further studies are needed from a maintenance aspect point of view, namely, to determine the effect of aging soil treatment with wood charcoal on the stability of grounding resistance.

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