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Enhancing grounding system efficiency through biopore technique in seasonal soil conditions

Dian Eka Putra[1*], Yos Randika[2], Ifan Randika[2], Hafiz Inamullah[2], Widarianto[2], Aang Rusdiansyah[2], Wahyu Raharjo[2]
Electrical Engineering Department, Faculty of Engineering, Palembang University, Indonesia[1]
Student of Electrical Engineering Department, Faculty of Engineering, Palembang University, Indonesia[2]

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Abstract
Resistance values in grounding systems are prone to variation due to weather changes. Specifically, soil condition fluctuations, transitioning from moist to dry, cause an increase in the resistance of prolonged grounding installations. This rise in grounding resistance is further influenced by seasonal shifts, such as the transition from wet to dry seasons. During the dry season, arid conditions dominate the research site, particularly affecting field and organic soils known for their rapid drying. To mitigate surface soil dryness, it is crucial to enhance the moisture content of the surface soil. The biopore technique was implemented at Bukit Asam Company in Tanjung Enim, Indonesia, to augment soil moisture around the grounding rod electrodes embedded in the soil. This study explored the biopore technique, which involved creating holes of various depths and filling them with a mixture of rice husks and salt (NaCl). This mixture serves as a water reservoir, utilizing water collected from the exhaust of air conditioning units. The primary goal of this method is to lower grounding resistance in dry conditions with dry surface soil. The result of modifying the depths of the biopore holes was a decrease in grounding resistance. Resistance diminished following the application of the biopore technique, combined with rice husks and NaCl. The findings suggest that enhancing soil moisture content can significantly reduce grounding resistance, with the reduction being directly proportional to the depth of the biopores.

Keywords
Grounding resistance, Biopore technique, Soil moisture enhancement, Seasonal variability, Electrical grounding systems.

1.Introduction
The grounding system is a critical component in the operation of electrical installations, according to the field of electricity [1, 2]. Grounding, or earthing, aims to protect and prevent humans from the risk of direct contact with electricity [3]. Moreover, the grounding system's purpose is to conduct or transfer electric current to the earth via a grounding rod electrode [4]. Static electrical charges, generated by active conductors, create the potential for leakage currents, either from insulation failure or from induction by metal electrical equipment [5], by flowing electric current to the earth at low resistance [6]. In Indonesia, grounding systems are regulated by the General Requirements for Electrical Installation of 2000(PUIL 2000) and the updated 2011 standards, which state that although an ideal resistance is 0 Ω, a maximum grounding value of 5 Ω is considered acceptable [7].

Grounding resistance values below 5 Ω also align with Institute of Electrical and Electronics Engineers (IEEE) standards [8], essential for safeguarding against hazards resulting from touch voltage [9]. It is important to regulate and monitor the resistance value of grounding rods in electrical installations to ensure it remains within acceptable limits. Factors that can affect grounding resistance and the resistivity of soil types include moisture content [10], soil chemical content or soil type [11,12], geography, and temperature [13].

At the research location, characterized by frequent changes between the rainy and dry seasons, the dry season poses two main issues. Firstly, the water content in the soil decreases, leading to an increase in surface soil temperature where the grounding rod electrode is inserted. Secondly, the dry conditions or reduced water concentration negatively impact the grounding resistance or soil resistivity. As a result, when the soil becomes dry, the soil resistivity value becomes high [14]. During the dry season,

*Author for correspondence

researchers face the challenge of increasing the water content on the soil surface as the water content decreases. This effort aims to maintain the grounding resistance value and hopefully achieve a decrease in grounding resistance.

This research focuses on minimizing grounding resistance. Previous researchers have identified numerous methods for achieving this, including the use of chemical and natural mixtures such as bentonite [15, 16], charcoal [17], salt (NaCl) [18], and others. In addition to using these mixed materials, one can reduce grounding resistance by choosing the type of construction material or the grounding system construction model [19, 20]. Researchers have conducted extensive research on grounding systems to minimize grounding resistance by utilizing diverse combinations of materials. These materials are blended and positioned in close proximity to the grounding rod electrode to establish direct contact [21].

In this study, novel methods for reducing grounding resistance in field or clay soil were explored by employing the biopore technique. This technique involves increasing the humidity or water concentration around the grounding rod electrode without direct contact. The biopore hole is positioned at a distance from the grounding rod electrode. The objective of the study is to decrease grounding resistance by employing the biopore technique to enhance soil moisture, comparing the depths of various biopore holes, ranging from 0.5 meters to 1.25 meters [22].

This research is unique, as there are no existing studies on increasing humidity using this approach. The focus is on utilizing cost-effective organic materials in the vicinity of the grounding rod electrode to mitigate the potential for environmental harm. This research aims to contribute to the field of engineering by reducing grounding resistance and exploring new methods to enhance groundwater concentration or soil moisture using the biopore technique. As the level of humidity rises, the task of decreasing the grounding resistance simplifies. In addition, NaCl water has the ability to decrease grounding resistance through the process of electrolysis [23], as well as serving as a preservative medium. The water source for this research is the waste water from an air conditioner (AC). During the research process, either a conventional or driven rod serves as the grounding system in the field [24].

The research site is in close proximity to a coal mining area characterized by hot and arid weather, typically reaching temperatures of 37°C to 40°C. This circumstance poses a significant challenge when conducting research. There is an expectation that water produced from AC exhaust can help decrease grounding resistance. Additionally, this study has shown that higher humidity levels can lower soil resistivity by increasing water content. However, it is important to note that a high-water content does not necessarily mean there will be a high level of corrosion [25].

This study demonstrates the potential of using this reference as research material to enhance humidity around grounding electrodes. This is achieved by inserting the electrodes into soil pores and subsequently filling them with a combination of rice husks and NaCl. The biopore method involves utilizing water from the AC to achieve a resistance value below 1 Ω.

This technique is further explored in future research involving experiments with various mediums. This contributes to advancing scientific knowledge in the field of grounding systems. The study systematically examined the relationship between soil moisture and grounding resistance by increasing soil moisture through biopore holes. It aimed to determine standard grounding resistance values based on different pore hole depth level parameters for field soil or clay soil types.

This paper is organized as follows: Section 2 discusses related work. Materials and methods are presented in Section 3. Results are explored in Section 4. The discussion of the results is in Section 5. Finally, conclusions and summaries are provided in Section 6.

2.Literature review

As per the IEEE standard 80 of 2000, [9] soil moisture has the ability to alter soil resistivity values. Specifically, a decrease in soil surface moisture can lead to a reduction in the resistivity of soil types by a range of 10% to 80%. This includes the utilization of NaCl material to lower soil resistivity and subsequently decrease grounding resistance.

Ya'acob et al. [18] used an agrivoltaic approach on herbal plantations under a solar power generator or photovoltaic (PV) array to increase soil conductivity in a PV grounding system. Fertilization systems distribute fertilizer evenly in irrigation, increasing nutrient availability and soil water content. This study focused on a specific location (Puchong Solar Farm, Selangor, Malaysia) that may not be generalizable to other regions and does not broadly address the potential challenges or drawbacks of implementing agrivoltaic systems in solar power plants.

Hassan and Nadhum [22] characterized and classified the soil using the unified soil classification system (USCS) through laboratory tests that involve sieve analysis, liquid limit, and plastic limit. These tests were conducted on soil specimens with varying water content, dry density, and compaction effort. Electrical resistivity is measured during the tests to establish geotechnical-electrical relationships that help evaluate compaction parameters. The resistivity method is also used as a complementary tool in the initial site investigation, as it has a high correlation coefficient with degree of saturation and volumetric water content. However, it is recommended to investigate the influence of other physical and geotechnical properties, such as fines content, shear stress, and compressibility, on soil resistivity.

Azmi et al. [25] analyzed the corrosion behavior of copper on bentonite under different relative humidity conditions using vapor equilibrium techniques for approximately 66 days. The copper corrosion rate in Andrassy bentonite ranged from 2.2 to 2.8 × 10-3 mm/year, with the highest corrosion rate observed at a relative humidity of 75%. Microbiological analysis identified eight microbes in Andrassy bentonite, including bacterial and fungal species that contribute to erosion-corrosion on grounding electrodes such as copper. On visual inspection, there was a visible change in the color of the copper disc after testing, with a greenish and blackish surface indicating the corrosion process. However, this study does not examine the specific chemical species in bentonite that may contribute to copper corrosion, thus providing a more comprehensive understanding of the corrosion mechanisms.

Noordin and Othman [26] described a project that involved designing earthing rods, installing them at varying depths, and using model 4105A earthing resistance meters to measure soil resistance. The installation techniques included both single-rod and parallel-rod electrode mounting methods. The results indicated that soil resistance decreased as more electrodes were installed in parallel. However, it should be noted that this study was limited to the use of grounding rod electrodes with single and parallel rod configurations.

Pratama and Saputra [27] used a qualitative approach with a case study method, aiming to improve the grounding system by adding additives in bentonite and NaCl to reduce grounding resistance, including the depth of the grounding rod electrode. This study highlighted that the depth and type of soil can also influence the grounding resistance value. Based on the results of research and measurements, the addition of Bentonite and NaCl or additives can increase the soil resistance value. Apart from adding additives, the depth and type of soil can also influence the grounding resistance value. The limitation of this research is that it does not yet determine the long-term effects of the electrode rods used.

Haque et al. [28] experimented in a laboratory where they added a mix of organic materials to paddy field soil. The organic materials included rice husk biochar, empty oil palm fruit bunch biochar, compost, rice husk ash, and palm oil bunch ash. The soil was then incubated for 60 days, with samples taken at 15-day intervals to analyze soil moisture retention and chemical properties. The combination of rice husk biochar, empty oil palm fruit bunch biochar, and compost significantly increased the soil's moisture storage capacity and nutrient enrichment in the paddy field soil. This resulted in high gravimetric water content and improved soil chemical properties. However, this research was conducted through an incubation study, which may not fully represent field conditions.

Tresmin [29] presented a method for measuring the relative moisture content of soil in three dimensions using electrical resistivity. The system uses multiple pairs of electrodes to measure resistance and reconstructs the humidity distribution in real-time. Computer simulations have validated the system's ability to accurately visualize areas with higher water content that result in a decrease in resistance. However, the system's accuracy can be affected by factors such as soil salinity, temperature, and porosity, which can cause inaccuracies in resistance-based measurements. Therefore, environmental factors and soil composition should be taken into account to ensure the accuracy of the measurements.

Kouchaki et al. [30] conducted laboratory geophysical investigations to understand the factors influencing soil resistivity across different soil types representing the main soil groups. Box soil resistivity tests were performed on commercially available sand, Kaolin clay, Bentonite clay, and red art clay, focusing on variations in density and water content. The study found that bulk density and the degree of saturation are the most significant parameters in determining how soil types influence resistivity. Additionally, the research indicated that water mineralization significantly affects resistivity at low degrees of saturation but has minimal impact on saturated sand. The study also highlighted limitations in the equipment used for measuring electrical resistivity in certain soil types due to specific water content requirements. The limited variety of natural soil samples tested could potentially affect the generalizability of the findings. Furthermore, the inability to replicate field conditions in the laboratory limits the direct applicability of the results to real-world scenarios.

Onyedikachi et al.[31] aimed to predict changes in soil resistivity around earth electrodes using the water content dependent resistivity (WCDR) simulation model, which estimates changes in resistance at earth electrodes. The study included laboratory and field experiments, empirical modeling, regression modeling, and simulation modeling. The WCDR model estimates electrical conductivity or resistivity at different soil suctions, using the Archie equation. The resistance of the earth electrode of the driving rod in varying saturated homogeneous soils shows a value within 10% accuracy compared to the simulation results. Seasonal changes in soil resistivity occur due to factors such as water retention and permeability based on soil texture.

Umasugi et al. [32] Research on the effect of biopores and organic litter on soil moisture storage. The experiment involved the use of plant litter, specifically clove leaf litter, nutmeg, and Guinea grass as organic materials in biopore technology. This study found that evaporation and percolation are climatic factors that influence water loss, with increased soil water storage at a depth of 20-40 cm due to special treatment involving biopores and organic litter. Soil texture, porosity, and pore size distribution were identified as important factors influencing water movement in the soil, with silt and sand particles contributing to low water retention and increased water loss in clove plantations. With a biopore depth of 20-40 cm and organic litter on soil moisture storage, it was not found to be statistically significant in several aspects of the research. This study does not address the long-term implications of treatments on soil moisture retention and does not explore potential interactions between different types of litter organic matter and biopores on soil moisture dynamics.

Ashabie and Masjud [33] conducted experimental field tests on biopore infiltration holes at several locations, which involved vertically immersing a ring into the ground, measuring the water infiltration rate, and ensuring the flow was stable. The results indicated that 1,711.8 Biopori Absorption Holes could be implemented in the President University campus area, significantly reducing waterlogging. The use of Biopore Absorption Holes with specific dimensions and spacing has proven effective in increasing groundwater reserves and reducing surface water. However, this study does not address the long-term maintenance and sustainability of the Biopori Absorption Holes implemented at the President University campus. Additionally, as this research is focused on a specific geographic location, the Bekasi Regency, it may limit the generalizability of the findings to other regions.

Karmiathi and Yoga [34] reduced, the grounding resistance by adding copper-coated electrode rods and wood charcoal as a soil processing additive. As a result, the grounding resistance decreased from 8.1Ω to 1.9Ω, which is a 76.6% increase. After the addition of wood charcoal to the soil, the measured grounding resistance reached 1.3Ω, which meets the requirement of being less than 5Ω. However, chemical soil treatments such as bentonite and NaCl may not provide long-term resistance to small soils, especially in dry clay and sandy soils.

Pavlovich and Baraishuk [35] studied the factors that influence electrical resistance in grounding systems based on soil electrophysical parameters. Control samples were placed in non-conductive containers to measure resistivity based on moisture, temperature, graphite, and hydrogel content. The study established a relationship between moisture retention, seasonal fluctuations in electrical resistance, and environmental conditions, and proposed a method for reducing resistance by replacing the soil with a conductive mixture.

Pavlovich and Baraishuk [36] discussed humidity, and temperature using a series of four electrodes with direct current. Using a mixture based on hydrogel and graphite reduces resistance coefficient fluctuations by up to 25% and reduces the resistance of grounding devices by 3 times. This study focused on reducing resistance in high-resistance soils using hydrogel mixtures, but the long-term durability and effectiveness of these mixtures in various environmental conditions may require further investigation. This research primarily addresses the impact of mixtures on soil resistivity, seasonal factors, and ground loop resistance. Still, specific effects on other soil properties or corrosion of grounding device elements are not extensively explored.

Barbosa et al. [37] explored quantitative experiment to measure the distribution of water content in biopores in clay and organic materials with Bt samples and C samples in biopores. The flow of water exchange is smaller for the coated biopore surface in the clayier Bt horizon compared to the carbon C horizon, where higher absorption capacity intensifies mass exchange. The results suggest further analysis of the contrasting properties and structure of lining materials on burrow walls in the Bt and C horizons. Differences in soil water repellency were found between layers from the Bt and C horizons, but small infiltration experiments did not show significant differences in absorption capacity.

Nugraha et al. [38] discussed the use of the biopore infiltration technique in the field by creating holes around coastal Casuarina plants. This technique significantly increased the nitrogen, phosphorus, and potassium content in the soil. The organic components involved in biopore processing influenced the formation of metal bonds, leading to a decrease in lead content. Although the nitrogen content observed in biopore processing was still low, indicating a deficiency of macroelements in the soil, the causes of reduced nitrogen levels were not addressed in this study.

Yaseen et al. [39] aimed to assess the impact of the grounding system on short-circuit currents in the Iraqi power system using Power System Simulation for Engineering (PSS/E) simulations. The findings from the PSS/E simulations showed that single-phase current disturbances to the ground were greater than those in three-phase currents. These disturbances occurred primarily in the transformer, affecting the neutral grounding system's ability to transmit current to the earth. However, it is important to note that this study did not address specific challenges or limitations encountered during the PSS/E analysis. Furthermore, the research did not investigate potential obstacles or weaknesses in the analysis of the grounding system within the Iraqi electric power system.

Some literature suggests that the primary purpose of a grounding system is to redirect fault currents to the earth with minimal resistance. To achieve low resistance, enhancing soil moisture and adding NaCl are beneficial. Organic mixtures also play a key role in absorbing and retaining moisture, while the biopore method serves as a water reservoir. Rainfall effectively increases soil moisture content. Utilizing organic materials such as rice husks in biopore holes can improve soil functionality and retain moisture, depending on the depth of the holes. Therefore, experiments can be conducted using wastewater from air conditioning systems to reduce grounding resistance in grounding system installations. This involves utilizing the benefits of biopore holes, set at specific depths, to act as reservoirs and water absorbers around embedded grounding rod electrodes.

3.Materials and methods

3.1Research design and tools

For research aimed at reducing grounding resistance by increasing soil moisture, the appropriate research method is experimental. This research involved adding rice husks or rice husks to increase soil moisture from AC wastewater. The method for measuring ground resistance uses the three-pole or pin method to measure the resistance of the ground electrode. The Krisbow Digital Earth Tester type KW06-768 served as the measuring instrument in the research to collect ground electrode resistance values. The installed grounding installation was measured again to obtain initial data on the resistance of the grounding electrode, and then an evaluation was carried out. To obtain a decrease, additional humidity was used by AC waste as a medium. The three-point measurement method was used, which is both highly suitable and practical for determining the resistance of the ground electrode [40].

In order to facilitate research on reducing grounding resistance, a research construction drawing is demonstrated as shown in *Figure 1.*

As a calculation material, researchers used the grounding resistance formula from the U.Dwight method, or IEEE Standard 81-2012 [8] (Equation 1to 3).

$$R = \frac{\rho}{2\pi C} \quad (1)$$

$$\frac{1}{C} = \frac{1}{L}\left(ln\frac{4L}{r} - 1\right) \quad (2)$$

$$R = \frac{\rho}{2\Pi.L} \ln\left(\frac{4L}{r} - 1\right) \quad (3)$$

Where

R: Resistance for one electrode rod planted perpendicular to the ground surface (Ohm).

L: Rod electrode length (meter).

r: Electrode radius (meter).

ρ: Average soil resistivity (Ohm-m).

(index 1 or 2 shows the soil layer).

Hb: Depth of electrode implantation (meter).

To reduce grounding resistance, waste water was used from the room AC process and filled the hole biopore technique with a mixture of rice husks and NaCl. As shown in *Table 1*, the weight of rice husks and NaCl was calibrated to meet the specific requirements of the prepared hole biopore technique. In the initial research, rice husks with a small amount of NaCl was combined. The NaCl constituted 25% of the volume of the pore holes. The purpose of adding NaCl was to enable it to absorb water from the AC exhaust without compromising the reliability of the grounding installation, specifically by preventing corrosion.

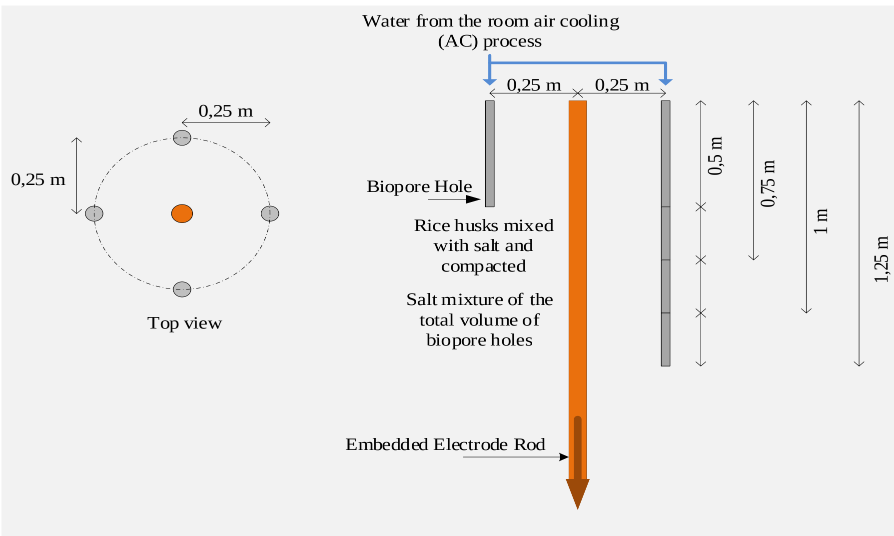

Figure 1 Construction plan for research on reducing grounding resistance using the biopore technique

Table 1 Biopore technique research materials

Description	Information
Embedded electrodes	Round rod (Diameter 14.6 mm : 0.0146 meters)
Electrode Depth	17 meters
Type of soil	Farm Land
Soil Drill	1 set
Rice Husk	4 kg
Salt	3 kg
Water hose	7 meters
Earth Tester	Krisbow KW06-768

3.2Rice husk

Rice husk, a byproduct of agricultural activities during grain harvesting, can be used as an adsorbent by attaching molecules to its surface [41]. Apart from that, rice husks can be used as agricultural fertilizer and also to absorb and store groundwater [42]. In this study, rice husks were used to increase and maintain soil moisture in grounding installations.

3.3Salt (NaCl)

NaCl was combined with rice husks and a small amount of water was added to act as a binder. In this research, rice husks that were mixed with NaCl will be inserted into the pore holes. Consequently, the NaCl used was 25% of the biopore volume. This type of NaCl had a density of 0.8 to 0.9, a melting point of 80oC, and hydroscopic properties, so it is easy to use to absorb water.

Apart from that, to increase the conductivity or electrical conductivity of the soil, a NaCl solution was added, which is an electrolyte so it can conduct electric current. Apart from its ability to bind soil, NaCl also has properties that can change the composition of the soil, thereby increasing its electrical conductivity [43].

3.4Soil Types in research area

At the research site, two distinct soil layers with different characteristics were identified [44]. The upper layer consisted of humus soil, which is like agricultural soil in its blackish color and fine sand texture. This soil exhibits high permeability, allowing for rapid water absorption [45]. During periods of low humidity, it became arid and powdery. The acidity of the surface soil was measured, revealing a potential of hydrogen (pH) of 5.16, indicating that this soil is conducive to creating pores due to its high-water absorption capacity. The soil in the second layer has a slight clayey texture and appears grayish-white in color.

3.5 Measurements using an earth tester

To obtain the grounding resistance value, a method involves conducting measurements using an earth tester [46, 47]. In this research, measuring grounding resistance using the Krisbow KW06-798 digital earth tester is the same as using the Kyoritsu earth tester, measuring grounding resistance using the 3-point or 3-pole method [48, 49]. The measurement procedure consisted of three distinct cable types incorporated into the earth tester measuring instrument: the green cable was linked to the electrode to be measured subsequent to its connection to the earth tester; the red and yellow cables were utilized to connect to the auxiliary electrodes, with a minimum distance of 5 meters between the auxiliary electrodes. Once all components were connected, it proceeded to configure the range button or measurement scale to begin at 20 Ω. Subsequently, the ground resistance value was determined by pressing the test button on the measuring instrument. After a brief delay, the measured ground resistance value was displayed. In the interim, it pressed the hold button to obtain a temporary patent measurement result, which facilitated the documentation and recording of the measurement.

4.Results

In a driven rod earthing system, the electrode is embedded straight into the ground [50]. After carrying out calculations using the U.Dwight method in a grounding installation installed in the ground using Equation 3, a grounding resistance (R) value of 6.89 Ω was obtained. To obtain maximum results, testing for reducing grounding resistance by increasing groundwater concentration using the biopore technique was carried out at 4 points in different locations in the embedded grounding installation using soil pore holes at different depths. Grounding resistance measurements were carried out 13 times, where the first measurement used the biopore technique but water from the AC exhaust had not yet flowed, while the second to the thirteenth measurements used the soil biopore hole technique, which had been flowed by wastewater from the air-cooling process. The graph demonstrating the reduction in grounding resistance using the biopore technique is shown in *Figure 2*. In this experimental process of reducing grounding resistance, to avoid measurement errors from field testing using the 3-pole method using an earth tester, where errors often occur in the measurement process, especially in the connectivity of the grounding measuring instrument to the auxiliary electrode, it is necessary to pay attention to the cleanliness of the measuring instrument's connectivity and repeated measurements are carried out at least 2 or 3 times to obtain the grounding resistance value.

4.1Testing for earthing resistance with a soil hole biopore technique at 0.5 meter

For initial research in the subsidence research process, a grounding system was installed at the first location with biopore engineering construction starting at a depth of 0.5 meters as shown in *Figure 1* with 4 holes, where the biopore holes were filled with 26 grams of rice husks mixed with 6.5 grams of NaCl, then the hole was drained by water from the AC exhaust. The mixture composition in the pore hole is 0.5 meters deep with a hole diameter of 0.0158 meters. During the first measurement without air conditioning waste water flowing, the grounding resistance value was found to be 5.23 Ω, exceeding the Requirements For Electrical Installation of standard limit, and after flowing water into the biopore hole at a depth of 0.5 meters, the second measurement showed a decrease in the grounding resistance value, although not yet significant, namely 4.61 Ω, the decrease in grounding resistance continued to occur from the third measurement to the thirteenth measurement or the twelfth day of the experiment, marked by a grounding resistance value of 2.07 Ω, the decrease can be seen in *Figure 2* of the blue measurement graph, where this event occurs as the concentration of groundwater at the surface increases, reaching 50% humidity at the grounding location being tested or measured. Humidity occurs due to the continuous flow of AC wastewater and the use of rice husks which can absorb water and retain humidity.

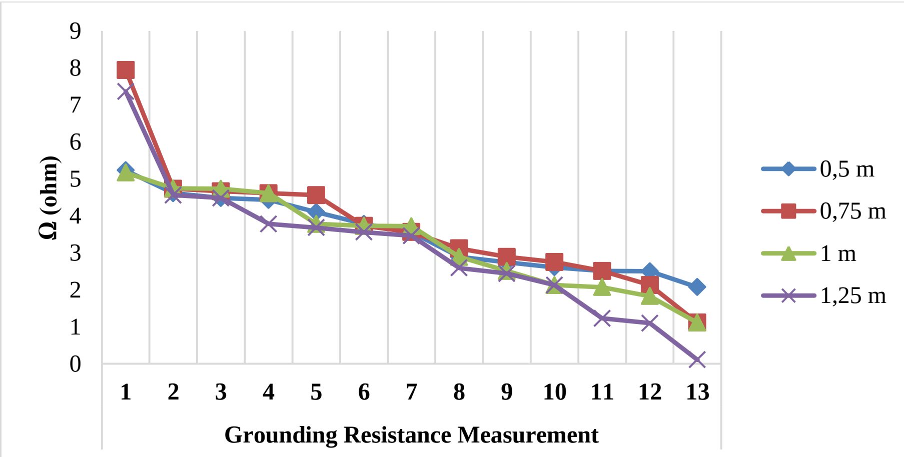

Figure 2 Measurement graph of reducing grounding resistance using the biopore technique

4.2Testing for earthing resistance with a soil hole biopore technique at 0.75 meter

In the next process, research was conducted at a second location using the same technical method, where each biopore hole at a depth of 0.75 meters was filled with 39 grams of rice husks mixed with 9.75 grams of NaCl, then the holes were filled with water from the exhaust air cooling process. For the second location, initial measurements were taken to obtain comparative values before and after water flowed into the biopore holes. Initially, 13 measurements were conducted, yielding a grounding resistance value of 7.94 Ω, which did not meet the standards of PUIL 2011. After employing the biopore technique at a depth of 0.75 meters in the installed grounding system and introducing water from the AC exhaust, the second measurement recorded a decreased grounding resistance value of 4.73 Ω. To document the decrease in grounding resistance, the test is intended to be conducted over 12 days with 13 measurements. As shown in *Figure 2*, the red line graph illustrates the daily decrease in grounding resistance, culminating on the twelfth day with a value of 1.11 Ω. From testing the biopore method, the humidity reached 50%, and maintaining this level of humidity is crucial for reducing grounding resistance.

4.3Testing for earthing resistance with a soil hole biopore technique at 1.0 meter

After conducting the first and second tests at different locations, the research process for reducing grounding resistance continued at a third location using the same technical method. Here, each biopore hole, 1 meter deep, was filled with 52 grams of rice husks, mixed with 13 grams of NaCl, and then hydrated with water from the waste air cooling process, specifically water from the AC. Where the test is carried out by taking initial data on the installed grounding installation before testing the biopore technique or without running water from the AC exhaust, from the initial data marked by the first measurement of the grounding resistance value of 5.17 Ω. Assuming the initial data before the bio pore technique was carried out or before the water flowed, the research continued with the biopore technique around the location where the grounding electrode was planted at a depth of 1 meter, from the test results on the second measurement or the first day the resistance value was found to have decreased compared to before using the biopore technique. The value obtained is 4.74 Ω. The decrease in resistance occurred at each measurement and continued up to the thirteenth measurement, where it was in line with the increasing humidity at the test location, which reached 50%. The decrease can be observed in *Figure 2*, marked by the green graph line. A significant decrease occurred on the twelfth day, where the resistance value obtained was 1.1 Ω, matching the measurement results at a depth of 0.75 meters.

4.4Testing for earthing resistance with a soil hole biopore technique at 1.25 meter

In the fourth location, where the research process for reducing grounding resistance was carried out, a grounding system was installed, using the same method, where each biopore hole at a depth of 1.25 meters was filled with rice husks weighing 65 grams and mixed with NaCl weighing 16.25 grams, then the holes were drained by water from the exhaust air cooling process. In the initial measurement, the ground resistance obtained was 7.36 Ω. Looking at the initial data before implementing the biopore technique, the value of 7.36 Ω does not meet the safe limit or standard set by the Requirements for Electrical Installation of 2011(PUIL 2011). This was evident from a series of tests to reduce grounding resistance using the biopore technique, which involved flowing water during the second measurement on the first day. The decrease in resistance was 4.56 Ω. The decrease in grounding resistance occurred in the following days until the thirteenth measurement or the fall on the twelfth day. It can be seen in *Figure 2*. The purple line graph shows the decrease in grounding resistance. In testing inside the 125 cm biopore, the value of grounding resistance reached the expected value of 0.11 Ω. The value 0 Ω is the value expected by both users of grounding installations and researchers, especially in grounding systems.

5.Discussion

This research aims to decrease grounding resistance by raising the groundwater humidity at the site where grounding rod electrodes are installed, using wastewater from the air cooling process. This research examined the use of the biopore technique, which involves creating four holes in field or clay soil. The goal is to increase the concentration of groundwater by varying the depth of the pores. Through observations and measurements conducted over a period of 12 days in the field, using the biopore technique resulted in a significant increase in humidity or water concentration, reaching levels of 50% and above. The soil surrounding the rod electrodes became soft and clayey as a result. This technique also has the potential to reduce the cost of grounding resistance by 60% to 90%, as shown in *Figure 2,* where the graph illustrates the daily decrease in resistance.

Additionally, the rate at which water absorbs into the soil directly depends on the depth of the biopores. The deeper the biopores, the greater the water absorption capacity, facilitating the occurrence of the electrolysis process. The moisture content of the soil primarily affects the electrolysis process, which is the phenomenon of electric current flowing through the soil. Increasing the water concentration in the ground enhances the conductivity of electricity in land areas with high humidity or water concentration.

5.1Biopore technique

From the ground resistance measurement data before using the biopore technique at four different locations, the average ground resistance value was above 5 Ω. This value is certainly outside the safe standard limits permitted by the PUIL 2000 and 2011, as well as IEEE standards. When seen during measurements, the condition of the ground surface around the construction site where the grounding rod electrodes are planted has low humidity. In this research, biopore technique was employed to enhance soil moisture, particularly in areas where driven rod electrodes were planted. Where the function of the biopore is to accommodate wastewater from the AC, to facilitate the occurrence of even moisture on the surface of the soil around the location where the grounding rod electrode is planted, four biopore holes are made whose construction design as shown in *Figure 1*. With this biopore technique, the AC waste water is easily collected, absorbed, and spread both into the soil and on the surface of the soil. The pores filled with rice husks mixed with NaCl turned out to be effective in reducing grounding resistance. This event means that the rice husks, which have adsorbent properties, can absorb water and retain moisture in the location around the place where the grounding rod electrode is embedded. Apart from that, the process of adding soil moisture was carried out. The soil condition was initially dry and dusty due to hot weather, with temperatures initially averaging 35.5 °C. After adding moisture, there was a decrease in soil temperature, which then averaged 30.4 °C. This indicates that an increase in humidity leads to a decrease in soil temperature around the test location. Testing for reducing grounding resistance using the biopore method is only carried out at four different types of biopore depth, starting from a depth of 0.5 m, 0.75 m, 1.0 m, and the deepest 1.25 m, using wastewater from the room cooling process from an AC machine for 12 days. Field research by measuring the grounding resistance of the research object obtained the lowest value both for the grounding resistance value before the grounding resistance reduction process using the biopore technique and the lowest value for grounding resistance using the biopore method using AC waste water. A decrease in grounding resistance was obtained. The value of the decrease in grounding resistance occurs in direct proportion to the depth of the biopore hole, which is moistened with wastewater from the AC device. This means that the soil moisture deepens, thereby reducing grounding resistance, which reached 97.81% at a depth of 1.25 m from the initial value of grounding resistance before using the biopore method. After obtaining a significant reduction in grounding resistance from this research, it is evident that there are substantial benefits to using wastewater from air conditioning and rice husk waste to reduce grounding resistance.

High humidity is located in the soil, so the deeper the soil, the higher the humidity. Based on the resistivity theory of soil types, the largest resistivity values are at the surface of the soil, and the resistivity will decrease with soil depth. In measuring the resistivity of soil types, the grounding resistance is obtained or the grounding resistance is getting smaller. This is proven in each measurement of the grounding resistance of the biopore method at each depth, where humidity occurs at a certain depth and will produce a certain value. At a depth of 1.25 m, there is high humidity caused by AC. Wastewater mixed with groundwater will cause high humidity, resulting in low soil resistivity.

5.2Function of rice husk

Short-term testing reveals that rice husks effectively reduce grounding resistance due to their adsorbent properties, which enable them to absorb water molecules and other substances. As a result, water does not evaporate rapidly from the soil surface, making rice husks highly effective in maintaining humidity. Soil or rice husks had not been used to reduce grounding resistance until now. Nevertheless, prolonged utilization of rice husks necessitates regular upkeep due to their inherent tendency to decompose. It is imperative to periodically replace the used rice husks as well as address the issue of NaCl, which gradually dissolves in groundwater over an extended period. Based on the research, to ensure the stability of grounding resistance, it is imperative to periodically replace rice husks, preferably monthly.

5.3Utilization of AC waste water

The utilization of water derived from AC exhaust in research is typically highly advantageous for the environment, as it serves to effectively hydrate the soil in the surrounding area, particularly during dry seasons. AC waste water is collected using the biopore technique. From this hole, the water easily absorbs both into the soil and around the surface of the hole using the using the biopore technique. The biopore technique is made around the planting location of the grounding rod electrode, which is filled with rice husks that have been mixed with NaCl and then flowed with the AC waste water. Increasing soil moisture evenly according to depth may reduce grounding resistance. From a series of experimental tests carried out to reduce grounding resistance using the biopore technique by utilizing wastewater from AC, the results of the data obtained in the field stated that there was a correlation with the influence of the depth of the pore holes (0.5, 0.75, 1.0, and 1.25 meters) on the grounding resistance value. As humidity increases at each depth in the pore hole, the grounding resistance value experiences a greater decrease in the deepest biopore hole. This event explains that the decrease in grounding resistance is directly proportional to the depth of the biopore hole. This can be seen in *Figure 2*, where there is a decrease in grounding resistance using the biopore technique every day. This result is also caused by increasing humidity or groundwater concentration, where the more humid and deeper the area, the greater thearea, the greater the area, the greater the decrease in grounding resistance.

The limitations of this study are as under:

- This research does not address the effect of humidity on grounding rod electrode durability or corrosion due to the use of AC wastewater or the capacity of water flowing into biopore holes.
- Additionally, this research does not address the impact of humidity on the longevity of metal grounding electrodes, nor the ability of water to flow through biopore holes.

A complete list of abbreviations is summarized in *Appendix I.*

6.Conclusion

After conducting a series of studies, the effectiveness of the biopori technique in reducing grounding resistance has been demonstrated. This technique increases humidity or groundwater concentration by up to 50%, making the soil around the grounding rod electrodes in the installed grounding systems soft and pliable. The biopori technique, utilizing varying depths and adding rice husks mixed with NaCl and water from the room cooling process, significantly reduced the grounding resistance value by up to 90% of the original value.

The results indicate that the depth of the biopore hole affects the grounding resistance; as the depth increases, the resistance decreases. The combination of rice husks and NaCl serves effectively as a binder for water molecules and as an absorber, helping to maintain moisture and directly correlating with a decrease in grounding resistance. Moreover, the use of rice husks and AC water has proven highly effective in reducing grounding resistance. However, since rice husks are organic and tend to decompose over time, it is recommended to explore alternative organic materials that can maintain their functionality for longer periods.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

The research data can be obtained from the design and measurement of grounding resistance conducted in the field at the Bukit Asam coal mining office complex. Although unpublished data is available, the author or corresponding party can provide the necessary data and documents upon appropriate and realistic requests.

Author's contribution statement

Dian Eka Putra is responsible for various tasks, such as choosing the Biopori Method, creating the production framework, performing experiments, analyzing the results and necessary revisions. **Yos Randika** conducts supervision and measurements at location 1, specifically to a depth of 50 cm and final revisions. **Ifan Randika** conducts supervision and measurements at location 2, specifically to a depth of 75 cm and final revisions. **Hafiz Inamullah** conducts supervision and measurements at location 3, reaching a depth of 100 cm and final revisions. **Widarianto** conducts supervision and measurement at location 4 up to a depth of 125 cm and final revision. **Aang Rusdiansyah** and **Wahyu Raharjo** are responsible for conducting field experiments, overseeing measurement results, supervising, evaluating manuscripts, and feedback.

References

[1] Putra DE, Nawawi Z, Jambak MI. Earth resistance and earth construction to interference currents on swamp land. In international conference on sciences development and technology 2022 (pp. 20-7).

[2] Permal N, Osman M, Ariffin AM, Zainal M, Ab KA. Assessment of the grid safety values for substation grounding grid design parameters in vertical two-layer soil structure. Pertanika Journal of Science & Technology. 2022; 30(3):1789-1814.

[3] Adnan M, Abdul-malek Z, Din NS, Jambak MI, Nawawi Z, Sidik MA. Effects of lightning impulse front time on substation grounding system performance. Indonesian Journal of Electrical Engineering and Computer Science. 2020; 20(2):569-74.

[4] Sakar C, Toz AC, Buber M, Koseoglu B. Risk analysis of grounding accidents by mapping a fault tree into a Bayesian network. Applied Ocean Research. 2021; 113:102764.

[5] Nnamdi OS, Chandima G. New method for modelling seasonal variation in resistance and performance of earthing systems. Energies. 2023; 16(19):1-21.

[6] Win LL, Soe KT. Design consideration of electrical earthing system for high-rise building. American Scientific Research Journal for Engineering, Technology, and Sciences. 2016; 26(2):270-82.

[7] https://www.scribd.com/document/638832057/SNI-04-0225-2000-General-req-for-Electrical-Installations. Accessed 24 March 2024.

[8] IEEE Std 81, IEEE guide for measuring earth resistivity, ground impedance, and earth surface potentials of a grounding system. 2012.

[9] Standard ZB. Guide for safety in AC substation grounding. IEEE Standards Association: Piscataway, NJ, USA. 2006:80-2000.

[10] Golovko L, Pozdnyakov AI. Electrical geophysical methods in agriculture. In proceeding of the 4th international symposium on intelligent technology in agriculture, Beijing, China 2007 (pp. 457-71).

[11] Duarte TF, Silva TJ, Bonfim-silva EM, Fenner W. Resistance of a red latosol to penetration: comparison of penetrometers, model adjustment, and soil water content correction. Engenharia Agrícola. 2020; 40(4):462-72.

[12] Wu X, Xu J, Ke W, Xu S, Feng B, Hu B. Effects of PH value on corrosion behavior of thermal-sprayed Al-Si coated Q235 steel in simulated soil solutions. Journal of Materials Engineering and Performance. 2014; 23:2265-73.

[13] Hossain MS, Ahmed R, Hossain S. Design and optimization of substation grounding grid for ensuring the safety of personnel and equipment. Journal of Electrical Power & Energy Systems. 2021; 5(1):71-80.

[14] Qiu L, Yang Y, Ma L, Qiao J. Research on the electrical resistivity characteristics of statue remolded soil. In IOP conference series: earth and environmental science 2021 (pp. 1-15). IOP Publishing.

[15] Martin Y, Permata D. Decreasing the value of grounding resistance in tropical soil through the addition of bentonite additives are activated physically. In proceeding of international conference: 3rd SHIELD 2018 (pp. 169-77).

[16] Tadza MY, Mohamad D, Tripathy S, Rahman RA, Ismail MA. Bentonite and marconite for electrical grounding applications from geotechnical engineering perspective. In AIP conference proceedings 2019. AIP Publishing.

[17] Harahap PH, Al-ani WK. The effect of charcoal on the improvement of grounding resistance as a soil treatment in reducing grounding resistance. Journal of Renewable Energy, Electrical, and Computer Engineering. 2021; 1(1):12-5.

[18] Ya'acob ME, Lu L, Zulkifli SA, Roslan N, Ahmad WW. Agrivoltaic approach in improving soil resistivity in large scale solar farms for energy sustainability. Applied Energy. 2023; 352:121943.

[19] Ayodele TR, Ogunjuyigbe AS, Oyewole OE. Comparative assessment of the effect of earthing grid configurations on the earthing system using IEEE and finite element methods. Engineering Science and Technology, an International Journal. 2018; 21(5):970-83.
[20] Abdul AAW, Ahmad NN, Mohamad NN, Idris NF, Hanaffi F. Investigations on the performance of grounding device with spike rods (GDSR) with the effects of soil resistivity and configurations. Energies. 2020; 13(14):1-31.
[21] Ahmad R, Kassas M, Ahmed CB, Khan F, Khan S, Jamal A, et al. Application of mineral compounds for a high-voltage portable grounding system: an experimental study. Electronics. 2021; 10(16):1-22.
[22] Hassan AA, Nadhum GU. Geotechnical-electrical evaluation of soil compaction parameters, south of Baqubah city. The Iraqi Geological Journal. 2023: 144-55.
[23] Hernanda IG, Negara IM, Asfani DA, Ksatria AB, Pratama PD, Ramadhan SF. The effects of sulfuric acid and salt on the resistance value of bentonite grounding in the limestone soil. In international seminar on intelligent technology and its applications 2022 (pp. 365-70). IEEE.
[24] Gouda OE, Amer GM, EL-saied TM. Design of charts for ground resistance calculations of driven rods system in uniform and non-uniform soils. In proceedings of the xivth international symposium on high voltage engineering, Tsinghua University 2005 (pp. 1-5).
[25] Azmi NS, Mohamed D, Tadza MY. Effects of various relative humidity conditions on copper corrosion behavior in bentonite. Materials Today: Proceedings. 2022; 48:801-6.
[26] Noordin MI, Othman NA. The experimental analysis for different rod configurations of grounding system. Evolution in Electrical and Electronic Engineering. 2023; 4(2):215-24.
[27] Pratama R, Saputra WS. Analysis of additional bentonit and salt for improving the resistance of electrode rods. In IOP conference series: materials science and engineering 2018 (pp. 1-10). IOP Publishing.
[28] Haque AN, Uddin MK, Sulaiman MF, Amin AM, Hossain M, Zaibon S, et al. Assessing the increase in soil moisture storage capacity and nutrient enhancement of different organic amendments in paddy soil. Agriculture. 2021; 11(1):1-15.
[29] Tremsin VA. Real-time three-dimensional imaging of soil resistivity for assessment of moisture distribution for intelligent irrigation. Hydrology. 2017; 4(4):1-14.
[30] Kouchaki BM, Bernhardt-barry ML, Wood CM, Moody T. A laboratory investigation of factors influencing the electrical resistivity of different soil types. Geotechnical Testing Journal. 2019; 42(4):829-53.
[31] Onyedikachi SN, Gomes C, Van CJ. Equations for predicting the volumetric water content affecting the resistivity of soil in the vicinity of a driven earth electrode in variably saturated homogeneous soil. In 36th international conference on lightning protection 2022 (pp. 1-6). IEEE.
[32] Umasugi B, Prijono S, Soemarno, Ariffin. Improvement of soil moisture storage in clove plantation land using biopore technology and organic material litters. Journal of Degraded and Mining Lands Management, 2021; 8(2):2601-10.
[33] Ashabie AS, Masjud YI. The study of biopore infiltration holes (BIH) implementation to reduce waterlogging in president university campus Area. In IOP conference series: earth and environmental science 2022 (pp. 1-10). IOP Publishing.
[34] Karmiathi NM, Yoga PM. The grounding resistance improvement of distribution substation using multiple rods and wood charcoal as soil treatment. Matrix: Jurnal Manajemen Teknologi dan Informatika. 2023; 13(1):33-41.
[35] Pavlovich IA, Baraishuk SM. Reducing the electrical resistance of grounding devices by using a soil-substituting mixture based on graphite and hydrogel to stabilize the electrophysical parameters of the soil. Energy. News of Higher Educational Institutions and Energy Associations of the CIS. 2023; 66(4):322-32.
[36] Pavlovich IA, Baraishuk SM. The use of hydrogels in mixtures to reduce the transient resistance of the soil-grounding device. In international summer school: collection of the international scientific and practical conference of young scientists, Almaty 2022 (pp. 31-8).
[37] Barbosa LA, Lima FV, Gerke HH. Neutron imaging of exchange flow between biopore and matrix for BT versus C horizons. Vadose Zone Journal. 2024:e20320.
[38] Nugraha F, Akbar AA, Jumiati J. The use of the biopore technique to improve soil quality and the growth of beach Casuarina plants on the reclaimed former tin mine land in Bangka Belitung islands. Journal of Degraded and Mining Lands Management. 2024; 11(3):5849-63.
[39] Yaseen AY, Kshash FJ, Sahood YA. Impact of neutral grounding system on short circuit current in Iraqi power system. In AIP conference proceedings 2024. AIP Publishing.
[40] Andrade AF, Da CEG, Lira GR. Methods for field measurement of electrical parameters of soil as functions of frequency. Electric Power Systems Research. 2021; 199:107447.
[41] Garba J, Samsuri AW, Hamdani MS, Sadiq TF, Nabayi A. Glyphosate degradation in Malaysian sandy loam soil amended with cow dung or rice husk ash as influenced by soil moisture content. Malaysian Journal of Soil Science. 2022; 26:44-54.
[42] Aziz NI, Othman N, Altowayti WA, Yunus ZM, Fitriani N, Din MF, et al. Hardness removal of groundwater through sand, zeolite and rice husk activated carbon. Malaysian Journal of Analytical Sciences. 2021; 25:605-21.

[43] El-tous Y, Alkhawaldeh SA. An efficient method for earth resistance reduction using the Dead sea water. Energy and Power Engineering. 2014; 6(4):47–53.
[44] Shawver S, Ishii S, Strickland MS, Badgley B. Soil type and moisture content alter soil microbial responses to manure from cattle administered antibiotics. Environmental Science and Pollution Research. 2024:1-4.
[45] Wang W, Zhang Q, Xu J, Zheng D, Liu L, Su Y. Hydrodynamic resistance of pore–throat structures and its effect on shale oil apparent permeability. International Journal of Coal Science & Technology. 2024; 11(1):1-10.
[46] Illias HA, Su CS, Bakar AH. Investigation on soil resistivity of two-layer soil structures using finite element analysis method. IET Science, Measurement & Technology. 2021; 15(2):120-9.
[47] Leal AG, López-salamanca HL, Lazzaretti AE, Marcilio DC. A new approach for ground resistance measurements in onshore wind farms based on clamp-on meters and artificial neural network. Electric Power Systems Research. 2022; 210:108161.
[48] Bilal M, Khattak A, Ahmed N, Qureshi SA. Earthing analysis of high voltage laboratory at USPCAS-E, NUST. Engineering Proceedings. 2022; 20(1):1-6.
[49] Halim NH, Hairuddin MF, Arshad SN, Isa M, Adzis Z, Khang AW. Analysis on topology of grounding system using bentonite and coconut husk as additive material. Universal Journal of Electrical and Electronic Engineering. 2019; 6(5):50-8.
[50] Wang B, Wang H, Zhang L, Zhu D, Lin D, Wan S. A data-driven method to detect and localize the single-phase grounding fault in distribution network based on synchronized phasor measurement. EURASIP Journal on Wireless Communications and Networking. 2019; 2019:1-3.

Dian Eka Putra is currently a Lecturer in Electrical Engineering at the Faculty of Engineering, Palembang University. He earned his bachelor's degree in Electrical Engineering from Palembang University in 2005 and a Master of Electrical Engineering with a specialization in Electrical Power Engineering from the Institute of Science and Technology National (ISTN) in 2013. His research interests have focused on Grounding Resistance and Grounding Systems since 2017. He is also pursuing a doctoral degree in the Engineering Sciences study program, specializing in Electrical Engineering, at Sriwijaya University.
Email:dianekaputra90@gmail.com

Yos Randika is currently a student in the Electrical Engineering Department at Palembang University, where he has been studying since 2019. He also works as an Electric Technician at PT. Bukit Asam, Tbk.

Email:yosrandika91@gmail.com

Ifan Randika is currently a student in the Electrical Engineering Department at Palembang University, where he has been studying since 2019. He also works as an Electric Technician at PT. Bukit Asam, Tbk
Email:i_randika@yahoo.com

Hafiz Inamullah is currently a student in the Electrical Engineering Department at Palembang University, where he has been studying since 2019. He also works as an Electric Technician at PT. Bukit Asam, Tbk.
Email:Hafiz.inamullah88@gmail.com

Widarianto is currently a student in the Electrical Engineering Department at Palembang University, where he has been studying since 2019. He also works as an Electric Technician at PT. Bukit Asam, Tbk.
Email:widarianto.watrik@gmail.com

Aang Rusdiansyah is currently a student in the Electrical Engineering Department at Palembang University, where he has been studying since 2019. He also works as an Electric Technician at PT. Bukit Asam, Tbk.
Email:aangrudiansyah2@gmail.com

Wahyu Raharjo is currently a student in the Electrical Engineering Department at Palembang University, where he has been studying since 2019. He also works as an Electric Technician at PT. Bukit Asam, Tbk.
Email:wahyuraharjo95@gmail.com

Appendix I

S. No.	Abbreviation	Description
1	AC	Air Conditioner
2	H_2SO_4	Sulfuric Acid
3	IEEE	Institute of Electrical and Electronics Engineers
4	NaCl	Natrium chloride (salt)
5	PUIL 2000	Requirements For Electrical Installation of 2000
6	PUIL 2011	Requirements For Electrical Installation of 2011
7	PH	Potential of Hydrogen
8	PSS/E	Power System Simulation for Engineering
9	PV	Photovoltaic
10	USCS	Unified Soil Classification System
11	WCDR	Water Content Dependent Resistivity