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The effectiveness of bentonite in reducing soil resistance in acidic water swampland

Dian Eka Putra[1], Muhammad Irfan Jambak[2], Zainuddin Nawawi[2]
[1]Department of Engineering Science Study Program Doctoral, Faculty of Engineering, Sriwijaya University, Palembang, Indonesia
[2]Department of Electrical Engineering, Faculty of Engineering, Sriwijaya University, Palembang, Indonesia

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ABSTRACT

This study aims to evaluate the effectiveness of bentonite mixtures in reducing grounding resistance in acidic swampy areas. The method used is an experiment comparing resistance before and after the addition of bentonite in various compositions (25%, 50%, 75%, and 100%), supplemented with linear regression analysis. The results showed that bentonite significantly reduced soil resistance in three types of electrodes: iron rebar, copper-coated iron, and galvanised iron. The highest reduction in resistance was achieved in iron rebar electrodes, from 35.93 Ω to 22.46 Ω (a 37% reduction) with the addition of 25% bentonite. Linear regression analysis showed a consistent negative relationship between the percentage of bentonite and grounding resistance, with a coefficient of determination (R^2) varying between 26.40% and 73.39%. These findings indicate that bentonite is effective as a natural grounding material in acidic swampy areas. This research makes an important contribution to the development of more efficient and safer electrical systems in swampy areas and challenging environments, while also supporting the use of natural materials to reduce dependence on synthetic chemicals.

Corresponding Author:

Zainuddin Nawawi
Department of Electrical Engineering, Faculty of Engineering, Sriwijaya University
St. Srijaya Negara, Bukit Besar, Palembang, Indonesia
Email: nawawi_z@unsri.ac.id

1. INTRODUCTION

Acidic swampland significantly impacts the management of electrical infrastructure, particularly in the grounding system. High grounding resistance may exacerbate safety risks and cause the electrical system to fail [1]. It can include the disruption of the electrical energy distribution system and damage to power installation equipment [2]–[4], as well as health risks to living organisms that are impacted by the failure [5]. In general, threats are derived from direct and indirect lightning strikes [6], [7], excessive electrical induction [8], insulation failure [9], unsafe installation construction, and other causes [10]. The performance of the grounding system can be significantly impacted by high soil resistivity [11], particularly in acidic swamp land [12], as evidenced by previous research. In this context, it is necessary to understand the characteristics of soil in swamp land, which frequently exhibits a low potential hydrogen (pH) and a high-water content. These factors can have an impact on the electrical conductivity of the soil. Acidic swamps, which are frequently observed in tropical regions, are characterized by a high organic matter content and the presence of heavy metals, all of which can contribute to a high level of resistance [13]. The mineral composition, water content, and other environmental conditions of soil can significantly affect its resistivity, as demonstrated by research [14]. Consequently, it is imperative to devise efficient strategies for decreasing ground resistance in acidic swamps. One promising approach is the utilization of bentonite, a material that possesses soil-stabilizing and absorbent properties [15].

Previous research on bentonite as a grounding material has primarily concentrated on dry or moist soils [16], [17], where bentonite has the potential to reduce grounding resistance [18]. However, research in acidic swampy areas with unique characteristics, such as high acidity and humidity fluctuations, is still scarce. Furthermore, there is no comprehensive guideline that specifies the optimal proportion of bentonite (25%, 50%, 75%, 100%) to achieve cost-effective resistance reduction in this environment. The absence of empirical data impedes the design of sustainable and efficient grounding systems in swampy areas. In the context of previous references, bentonite has been shown to enhance soil conductivity [19]. Additionally, research results have demonstrated that bentonite can significantly reduce resistivity or resistance values by up to 30% when combined with calcium carbonate soil [20]. Bentonite, a form of montmorillonite clay, has the capacity to absorb water and ions, thereby enhancing the electrical conductivity of the soil [21], [22].

The objective of this study is to address those revived above gaps by conducting a comprehensive experimental investigation into the effectiveness of bentonite mixtures in reducing grounding resistance in acidic swamp land. Specifically, the study evaluates the effectiveness of bentonite mixtures in varying proportions (25%, 50%, 75%, and 100%) in reducing grounding resistance in acidic water swamp land. The novelty of this research is that it is the first to specifically evaluate the effectiveness of bentonite in a variety of mixture proportions for swamp land with acidic water. The results of this research are expected to provide recommendations for the optimal bentonite mixture proportions based on field data, which can be directly applied to the design of grounding systems in swamp areas.

The experimental approach employed in this study involved the mixing of various bentonite and swamp soil mixtures, which were subsequently inserted into grounding electrode planting holes of varying types. The impact of these mixtures on grounding resistance was subsequently evaluated. The resistance testing was implemented by employing suitable soil resistivity measurement methodologies [23], [24]. The grounding resistance was measured by utilizing a variety of grounding rod electrodes that were embedded in the soil. Furthermore, the statistical analysis was implemented to ascertain the significance of the results obtained, thereby enabling a more profound understanding of the effectiveness of different electrode types and material combinations in reducing grounding resistance. It is anticipated that the study’s findings are expected to offer a more precise understanding of the effectiveness of bentonite mixtures in the context of acidic water swamp land as a result of an understanding of these factors. It is expected that the findings of this investigation will offer engineers and practitioners valuable empirical data to aid in the development of more effective and efficient grounding systems in regions with difficult soil conditions.

2. METHOD

This research method was conducted using an experimental approach, in which a bentonite mixture was combined with soil from an acidic swamp area. The initial step involved the collection of water samples from the research location, which was analyzed to ascertain its initial characteristics, including soil resistivity. Subsequently, the bentonite mixtures with varying proportions were prepared to investigate their impact on the grounding resistance. The grounding resistance testing was carried out using the three-point soil resistivity measurement method [25], [26], with a grounding resistance measuring tool, namely the Kyoritsu R1405 A digital [27]. This test was conducted for 6 months in an acidic swamp area in Karang Anyar Village, Muara Padang District, Banyuasin Regency, South Sumatra Province. The test involved holes’ construction for the planting of a specific type of grounding rod electrode, which was subsequently filled with soil that had been mixed with the bentonite. The resulting grounding resistance was determined by testing each variation of the mixture. The descriptive statistics were employed to analyze the data obtained from the measurement results to ascertain the bentonite mixture’s substantial impact on grounding resistance. In this investigation, the observations were conducted regarding additional variables that could potentially influence the outcomes, including environmental conditions and soil water content. Furthermore, an assessment of the swamp water level was completed to verify that the addition of bentonite could account for any modifications in soil resistivity.

It is expected that this investigation will offer a more profound understanding of the correlation between grounding resistance and bentonite mixtures in low-pH acidic swamps (3.95 pH). It is anticipated that the results of this analysis will offer a comprehensive understanding of the effectiveness of bentonite mixtures in reducing grounding resistance, where initial investigations found that the grounding resistance value in acidic swamp land was high, reaching almost 38 Ω at a depth of 1 meter, and the sulphate content was 4 mg/l. The soil characteristics of this swamp are clayey on the surface and loamy underneath. This research can be considered the first of its kind. for which a mixed system of bentonite and swamp soil was used, starting with a bentonite proportion of 25%, 50%, 75% up to 100% bentonite. This research not only aims to prove that bentonite is good for reducing the resistance of acidic swamp soil, but also to produce the best data on the use of bentonite and find the optimum proportion for its use. Consequently, this investigation emphasizes the processes and methodologies implemented to accomplish the research objectives, in addition to the outcomes.

To support the related field research, it is necessary to prepare the materials and ingredients shown in Table 1. In the context of testing in acidic swamp water, the materials consisted of the types of grounding rod electrodes used, grounding resistance measuring instruments, and types of mixed materials to reduce grounding resistance.

Table 1. Research materials and tools

Information	Electrode type and size
Electrode shape	Round rod electrode
Electrode material	Galvanized plated iron (zinc coated steel) Iron (begel) Copper (Cu) plated iron
Electrode length	100 cm
Electrode diameter	Galvanis plated iron 16.56 mm Iron (begel) 15.37 mm Cu plated iron 15.15 mm
Electrode embedding depth	1 meter
Earth teste grounding resistance reduction material	Kyoritsu R 1450 a digital Bentonite

When planting the grounding electrode and the mixed material in the form of bentonite, the use of the image model or image design illustrated in Figure 1 was essential for the purpose of reducing grounding resistance, which in turn enhanced the accuracy and efficiency of field measurements. The schematic image of the grounding system assisted researchers in visualizing the electrode configuration and installation depth. Additionally, the image design in Figure 1 enabled simulation prior to implementation, thereby minimizing practical errors during field research.

As real evidence or documentation, Figure 2 shows the research location where the grounding electrodes were embedded along with the bentonite mixture according to the design of the drawing used, where on the land the testing and measurements were carried out for six months with a measurement duration of once a week. Figure 2 shows the acidic water swamp land which is flooded with water.

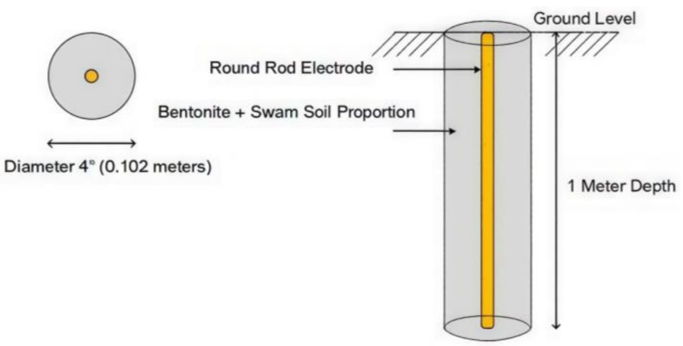

Figure 1. Design of electrode planting and bentonite mixture material

Figure 2. Research location for reducing grounding resistance using a mixture of bentonite materials

3. RESULTS AND DISCUSSION

The results of this study demonstrated that the bentonite mixture has the potential to significantly reduce grounding resistance in acidic water swamps. This section describes the comparison of data obtained from the grounding resistance test in acidic water swamps, contrasting the grounding resistance without bentonite to that with various compositions of bentonite. The average results of measurements of both water pH and soil pH, as well as the average water height of the swamp water, are presented in Table 2, where the results of the 6-month study in the acidic water swamp land were obtained. The study of measuring the decrease in grounding resistance was conducted concurrently with the acquisition of the average data, which indicated a water pH of 3.95, a soil pH of 3.90, a swamp water height of 8.11 cm, and a swamp soil resistance of 26.64 Ω. The effectiveness of the grounding system and the characteristics of the soil can be influenced by an acidic environment, as evidenced by low pH values in water and soil. The capacity of electrodes to absorb electric current during lightning strikes or leakage currents can be impacted by an increase in soil resistivity in acidic soil conditions. The recorded water level indicates a stable water pool, a crucial factor in the grounding resistance measurement process. This suggests that the interaction between hydrogeological and chemical conditions in the soil influences the resistance values, with acidic pH levels playing a significant role.

Table 2. Hydrological conditions, soil resistance

Water pH	Soil pH	Water level (cm)	Resistance (Ω)
3.95	3.90	8.11	26.64

The selection of bentonite proportion variations of 25%, 50%, 75%, and 100% is made to encompass the spectrum from a minimal mixture (25% bentonite + 75% native soil) to the full use of pure bentonite (100%). The purpose of the experiment is to effectively evaluate the influence of bentonite in stages where acidic swamp water exhibits high resistivity and grounding resistance. The results of this study demonstrate a substantial impact of the bentonite mixture on grounding resistance on various electrodes, including stirrup iron, copper-coated iron, and galvanized iron, as the study is dedicated to reducing the value of grounding resistance in acidic water swamp land. The use of bentonite in various concentrations (25%, 50%, 75%, and 100%) can effectively reduce the grounding resistance, as illustrated in Figure 3. In this investigation, the effectiveness of reducing grounding resistance through the incorporation of a bentonite mixture is assessed by evaluating three types of grounding electrodes: stirrup iron, copper-coated iron, and galvanized iron.

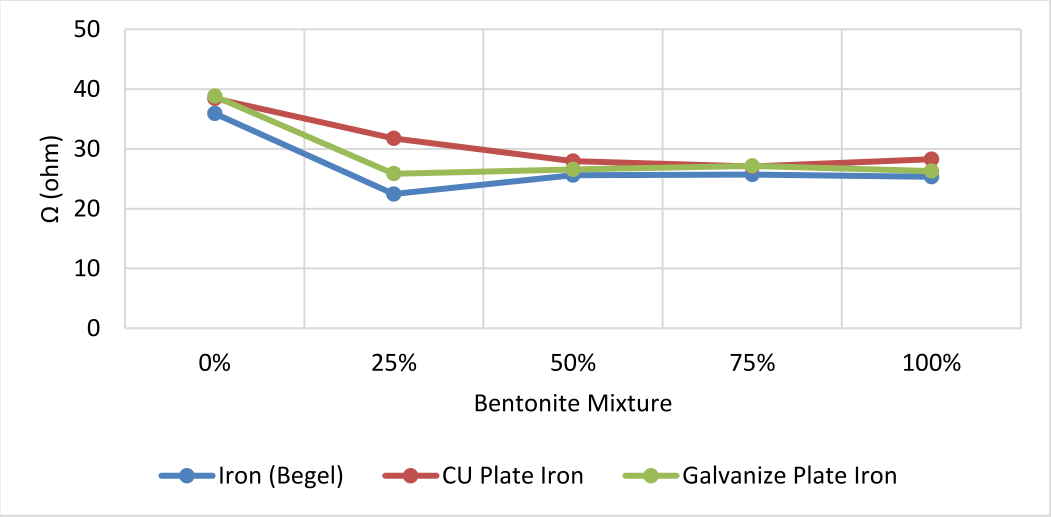

Figure 3. Comparison of grounding resistance using rod electrodes against the proportion of bentonite

When viewed from the initial data on average grounding resistance at a depth of 1 metre before the decline from several test points using grounding electrodes, as shown in Table 3, the grounding resistance value of swamp soil is quite high.

Table 3. Initial grounding resistance values in acidic swamps

Electrode	Soil ristance (Ω)
Galvanized plated iron	38.80
Iron (begel)	35.93
Cu plated iron	38.84

The results indicate that the use of bentonite significantly reduces the resistance of all electrode types. The use of 25% bentonite results in a decrease in the initial resistance of the stirrup iron electrode from 35.93 Ω to 22.46 Ω, which indicates exceptional performance. In the interim, the copper-coated and galvanized electrodes also demonstrate improvements, with their resistances decreasing from 38.44 Ω to 27.06 Ω and from 38.80 Ω to 26.30 Ω with 75% bentonite, respectively. The electrode conductivity is not only enhanced by the addition of bentonite, but it is also demonstrated that the correct mixture composition is essential for achieving optimal performance in grounding systems. These discoveries offer novel perspectives on the development of grounding systems that are both safer and more efficient.

This study shows that the bentonite mixture effectively reduces grounding resistance across all tested electrode types. Specifically, the reduction in grounding resistance in acidic swamp land combined with iron stirrup-type grounding electrodes reached 37%, which is a greater reduction than previous studies that used bentonite in land with low water content, where the reduction in grounding resistance only reached 30%. The effectiveness of the grounding electrodes is significantly influenced by the use of bentonite mixtures, although resistance values fluctuate at higher bentonite concentrations. Future researchers can use these results as a benchmark to develop more effective grounding systems.

We aim to investigate the impact of bentonite and dolomite ratios on grounding resistance through a range of rod electrode types, including stirrup iron rod electrodes, Cu coated iron rod electrodes, and galvanized (zinc) coated iron rod electrodes. By applying linear regression analysis, this study will analyze the relationship between material composition and grounding resistance produced by each type of electrode.

From the field data, Figure 4 shows the regression equation obtained, $Y = -0.05832X + 30.298$, where Y is the grounding resistance (Ω) and X is the percentage of bentonite proportion. This equation shows that, for every 1% increase in the percentage of bentonite, the grounding resistance tends to decrease by 0.05832 Ω. This result indicates a negative relationship between the percentage of bentonite and the grounding resistance using iron electrodes, meaning that the higher the percentage of bentonite, the lower the resulting grounding resistance. However, the coefficient of determination R^2 obtained of 0.2640 indicates that only about 26.40% of the variation in grounding resistance can be explained by variations in the percentage of bentonite. The remaining 73.60% is likely influenced by other factors, namely environmental factors where corrosion occurs on the surface of the iron rod electrode caused by the ebb and flow of acidic swamp water.

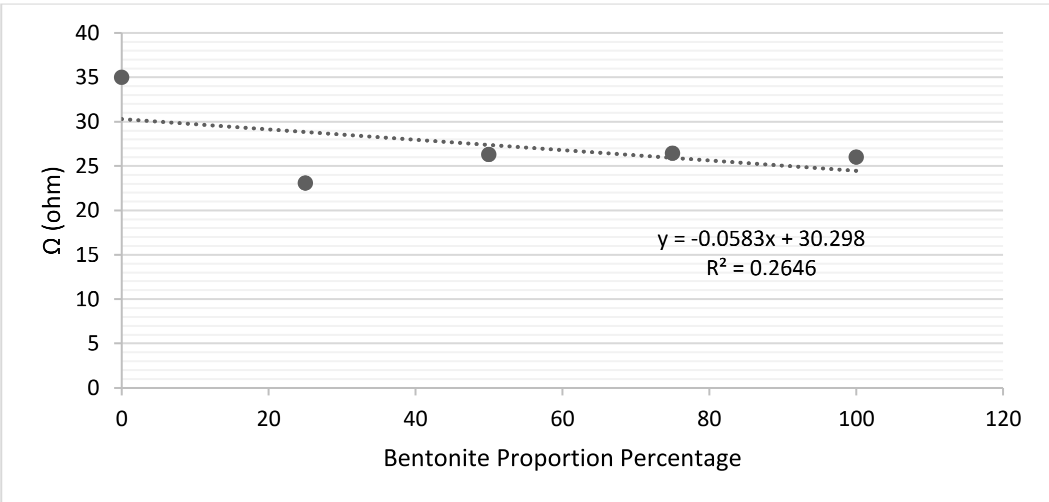

Figure 4. Linear regression line of the relationship between the proportion of bentonite percentage and grounding resistance using iron rod electrodes in acidic water swamps

Based on the analysis in Figure 5, the regression equation $Y = -0.08604X + 35.45$ is obtained, where Y is the grounding resistance (Ω) and X is the percentage of the bentonite proportion. This result shows that, for every 1% increase in the percentage of bentonite, the grounding resistance tends to decrease by 0.08604 Ω. It indicates a significant negative relationship between the percentage of bentonite and grounding resistance, meaning that the higher the percentage of bentonite, the lower the resulting grounding resistance. The coefficient of determination R^2 obtained is 0.7339, indicating that approximately 73.39% of the variation in grounding resistance can be explained by variations in the percentage of bentonite. The remaining 26.61% is likely influenced by other factors, such as corrosion, that are not included in this model. Thus, it can be concluded that the percentage of bentonite has a significant influence on grounding resistance.

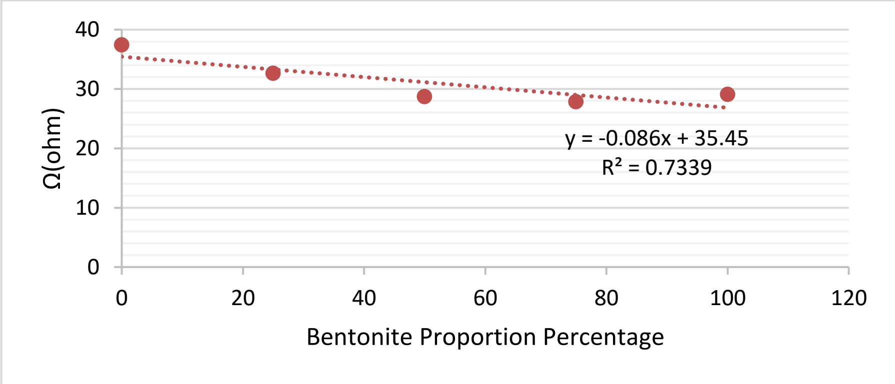

Figure 5. Linear regression line of the relationship between the proportion of bentonite percentage and grounding resistance using copper-coated iron rod electrodes in acidic water swamps

Based on Figure 6, the regression equation Y = −0.0807X + 33.362 is obtained, where Y is the grounding resistance (Ω) and X is the percentage of the bentonite proportion. This equation shows that, for every 1% increase in the percentage of bentonite, the grounding resistance tends to decrease by 0.0807 Ω. This result indicates a negative relationship between the percentage of bentonite and grounding resistance, meaning that the higher the percentage of bentonite, the lower the resulting grounding resistance. The coefficient of determination R^2 obtained from the application of 0.4487 indicates that approximately 44.87% of the variation in grounding resistance can be explained by variations in the percentage of bentonite. The remaining 55.13% is likely influenced by factors such as other corrosion that are not included in this model. Thus, it can be concluded that the percentage of bentonite has a significant influence on grounding resistance.

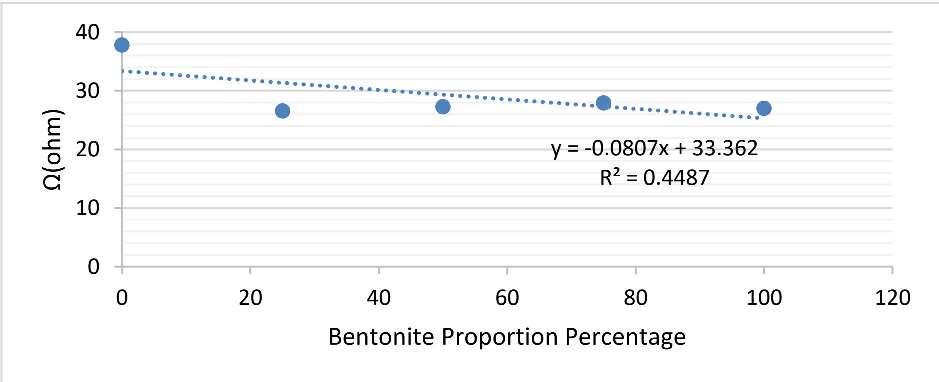

Figure 6. Linear regression line of the relationship between the proportion of bentonite percentage and grounding resistance using galvanized iron rod electrod, Selangor in acidic water swamps

This research provides significant benefits in the effective management of grounding systems, particularly in acidic wetlands, which are known for their unique challenges in terms of grounding resistance. By demonstrating that the use of bentonite mixtures can effectively lower grounding resistance, the immediate benefit of this finding is increased soil conductivity, which has the potential to reduce energy losses due to high resistance, ensuring electrical current can flow more smoothly and safely [28]. This research has important implications, especially in improving the efficiency and safety of electrical systems by reducing grounding resistance. By minimizing the risk of leakage currents in vulnerable areas such as acidic soils and standing water, this research has the potential to reduce electrical accidents and infrastructure damage. The results of this study also strengthen engineering standards for electrical system design in wetlands, offering better guidance for challenging environments. The novelty of this research lies in the experimental approach that incorporates the use of bentonite in the context of acidic wetlands, which have previously been under-researched. This research demonstrates that the addition of bentonite can improve soil conductivity and grounding system performance, with the right mixture proportions being able to effectively suppress grounding resistance. These findings are relevant to electrical engineering and support the use of natural materials, such as bentonite, reducing reliance on synthetic chemicals that can potentially damage the environment. Overall, this research is expected to serve as a reference for engineers, academics, and practitioners in designing safer and more efficient grounding systems, as well as stimulate further research to improve the quality of electrical infrastructure in remote and disaster-prone areas.

4. CONCLUSION

This study proves that the use of bentonite mixture significantly reduces the grounding resistance of various types of electrodes, namely iron rods, copper-coated iron, and galvanized iron. Iron rod electrodes showed the most drastic resistance reduction, from 35.93 Ω to 22.46 Ω at a concentration of 25% bentonite. Meanwhile, copper-coated and galvanized electrodes achieved the lowest resistance of 27.06 Ω and 26.30 Ω, respectively, at a concentration of 75% bentonite. In addition, the combination of galvanized rod electrodes with bentonite provided more consistent results in reducing grounding resistance in acidic swampy areas. These findings confirm that optimal mixture composition plays an important role in increasing the effectiveness of the grounding system, reducing the risk of leakage currents, and improving the safety of electrical installations.

Statistical analysis confirmed a significant negative correlation between increased bentonite concentration and decreased resistance. The strength of this study lies in its approach to examining the interaction between bentonite and acidic peat soil. The limitations of the study include limited concentration variations and locations. For further research, it is recommended to test more mixture variations, different soil locations, and combinations of bentonite with other materials. These findings provide valuable contributions to the development of more effective and safer grounding systems.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Dian Eka Putra	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓
Muhammad Irfan Jambak		✓				✓			✓	✓	✓	✓		
Zainuddin Nawawi	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

In this study, we are not related to using animal or human media to be used as research material. Where this research is in the form of research using swamp land, grounding rod electrodes and bentonite and measuring instruments to conduct research on reducing grounding resistance in acidic water swamp land.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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BIOGRAPHIES OF AUTHORS

Dian Eka Putra received the B.S. degree in Electrical Engineering from the University of Palembang, Palembang Indonesia, in 2005, and Master in Electrical Engineering from the Institut Sains and Teknology Nasional (ISTN), Indonesia in 2013. He is currently as Lecturer in Electrical Department at University of Palembang. His research interested are Soil resistivity and earth resistence, and grounding system. He can be contacted at email: dianekaputra90@gmail.com.

Muhammad Irfan Jambak received the B.S. degree in Electrical Engineering from University of Sriwijaya, Indonesia in 1996, Master degree in Electrical Engineering from the Universiti Teknologi Malaysia in 2022 and Ph.D. in Electrical Engineering from the Universiti Teknologi Malaysia (UTM), Malaysia in 2010. He is currently lecturer in Electrical Department of University of Sriwijaya. His research interests are high voltage phenomenon and materials insulation, and high voltage and protection systems. He can be contacted at email: irfanjambak@unsri.ac.id.

Zainuddin Nawawi received the B.S. degree in Electrical Engineering from University of Sriwijaya, Indonesia in 1984 and Ph.D. in Electrical Engineering from the Universiti Teknologi Malaysia (UTM), Malaysia in 2011. He is currently Professor in Electrical Department of University of Sriwijaya. His research interests are High voltage phenomenon and materials insulation, and high voltage and protection systems and grounding system. He can be contacted at email: nawawi_z@yahoo.com and nawawi_z@unsri.ac.id.