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Analysis of Grounding Resistance Performance with Effect of Conductive Compound Medium

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Abstract

Grouding system is the most crucial area in power system network. Poor grounding system can be dangerous to the users and wire of the electrical distribution system in the event of electrical fault. To prevent this accident, it is very important to have a good grounding system to protect the systems well as to the user. Therefore, this paper measures the grounding resistance with two planted electrode designs with two different conductive compound using Driven Rod method with the help of equipment earth testers. The experimental works was conducted in two medium of conductive compound which is graphite and bentonite using standard and three branches copper rod. The experimental results show that the copper rod with conductive compound suitable to replace the standard copper rod since the measured grounding resistance is the lowest. It is also proven that the three branches copper rod exhibits better value of soil resistaivity which can be used for the grounding system.

1. Introduction

Grounding systems are crucial for electrical safety, providing a low-resistance path for leakage currents to discharge into the earth. According to the IEEE Standard 142™ 2007, the primary purpose of a grounding system is to facilitate the detection of undesired connections between the system conductor and the earth, triggering automatic equipment to cut off the voltage supply [1]. This system ensures that electrical faults are managed efficiently, preventing hazards and maintaining system integrity.

The performance of a grounding system heavily depends on soil resistivity, as it dictates the ease with which electrical currents can pass through the earth. Because soil resistivity governs the electrical conductivity of the ground, it plays a critical role in determining the effectiveness of grounding solutions [2]. Low soil resistivity is advantageous for grounding as it allows the current to flow more freely into the earth, improving system performance [3]. However, changes in soil resistivity due to seasonal moisture and temperature variations can alter grounding reliability over time [4]. For instance, soil that is conductive during humid seasons might become resistive during dry periods. Understanding soil composition helps predict its resistivity and consequently the grounding system's performance.

Applying chemicals such as magnesium sulfate, copper sulfate, or rock salt around a grounding rod enhances soil conductivity and lowers resistivity, improving grounding performance [5]. By lowering soil resistivity, these chemicals help bring the grounding system's resistance within desired specifications, improving overall safety and performance. This approach ensures that the grounding system remains effective despite varying environmental conditions.

2. Materials and Methods

2.1 Grounding rod material selection

The most common form of grounding electrode is a copper rod that is hammered into the ground so that its entire length is submerged. As we know, the ability of a material to resist the flow of electric energy is called the electrical resistivity of the material. Table 1 shows the resistivity and conductivity of copper material [6]. Apart from that, copper and galvanized iron material was utilized in the Telekom Malaysia research for good grounding system yet to be economical [7].

Table 1: *The resistivity and conductivity of copper material*

Material	Resistivity at 20°C	Conductivity at 20°C
Copper	1.68×10^{-8}	5.96×10^{7}

2.2 Designing of Ground Rod

The types of electrodes used in this project are standard copper rod and three branches copper rod. Next, the mixture of soil and conductive compound has been used as a grounding material in the development of the grounding system. First, the reason roots electrode used in this project is because based on previous research when there is more arms produce leakage current that can go through the area, so the roots electrodes is suitable for this project where it has been provided high distribution of current density due to the numbers of arms on the electrodes. The prototype of standard and three branches rod for copper materials must be drawn before developed by cutting and welding the combination of branches on the size as shown in Fig.1.

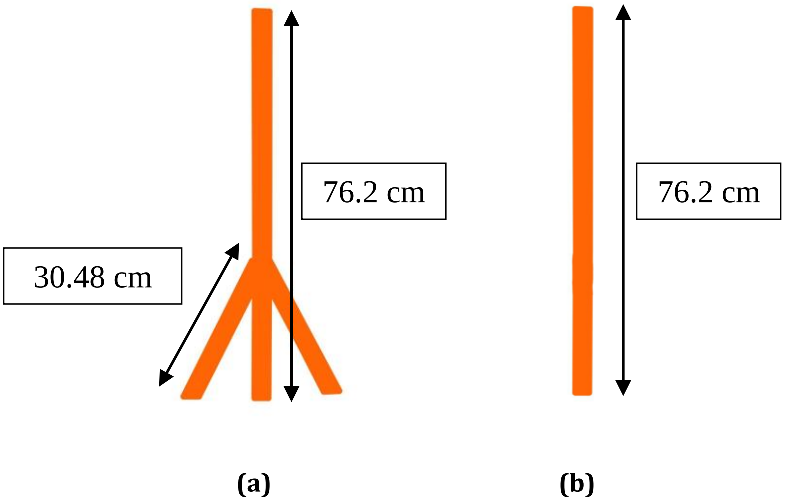

Fig. 1 *(a) Three branches copper rod (b) Standard copper rod*

2.3 Enhancement Material

Generally, the natural material does not alter the original properties of the soil [8]. Hence, the soil condition can be maintained. On the other hand, the chemical enhancement material could alter the soil properties. Therefore, the soil properties such as pH level, fertility, and mineral are significantly affected. Several studies on natural material have been conducted to find the most suitable material which can efficiently reduce grounding resistance [9].

The best material is chosen based on the lowest impedance and durability. Bentonite is a natural clay where it is widely used as a ground enhancement material (GEM). This material is preferred due to its ability to absorb moisture while maintaining humidity in the soil. Hence, it is the best solution to be applied in the grounding system in areas with high soil resistivity, like rocky soil. Bentonite can absorb up to five times its own weight in water and expand to thirteen times its dry volume, significantly reducing the impedance of grounding systems. [10].

Other than that, using graphite as a conductive compound in grounding systems is a recognized practice to enhance soil conductivity around grounding electrodes. Using graphite in grounding systems improves current transfer into the earth by increasing electrode-soil conductivity and minimizing resistance [11]. Graphite can enhance grounding system performance, its application might vary based on soil conditions, electrode materials, and specific site requirements.

2.4 New Soil Composition Development

In this project, there were two types of conductive compound that had been used to combine soil which is bentonite and graphite as shown in Fig. 2. The ratio of the mixture between the soil and the conductive compound is 1 feet depth of the holes equal to 50 g of conductive compound. Below are the lists of the samples that were conducted throughout this project:

i. Standard Copper
ii. Three branches copper
iii. Standard copper – Bentonite with local soil
iv. Three branches copper - Bentonite with local soil
v. Standard copper – Graphite with local soil
vi. Three branches copper - Graphite with local soil

(a) **(b)**

Fig. 2 *(a) Graphite, (b) Bentonite*

2.5 Driven Rod Method

In this project, the method for measuring ground resistance has been used is driven rod (three-point method) as shown in Fig. 3. The 3-point method, called the "fall of potential" method, comprises the ground electrode to be measured and two other electrically independent test electrodes, usually labelled P (Potential) and C (Current) as shown in Fig. 4. These test electrodes can be of lesser "quality" (higher ground resistance) but must be electrically independent of the electrode to be measured. An alternating current (I) is passed through the outer electrode C and the voltage is measured, by means of an inner electrode P, at some intermediary point between them [12].

Fig 3 *Taking measurement for the grounding resistance*

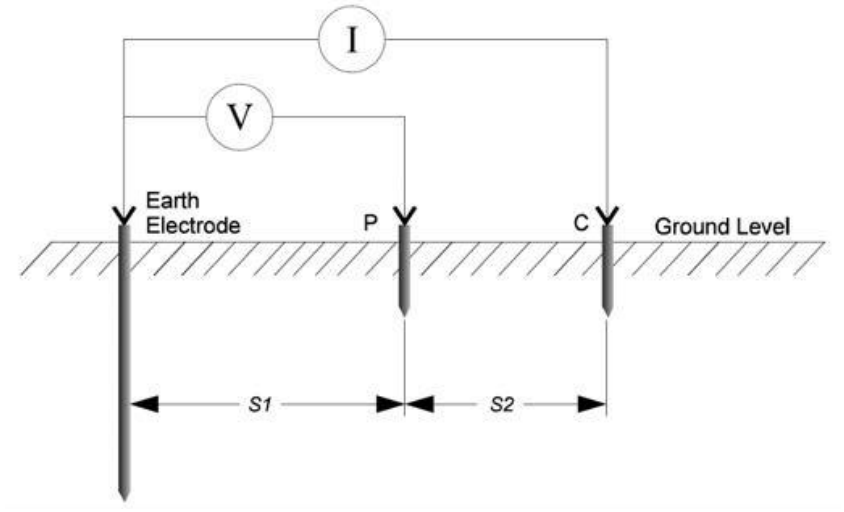

Fig. 4 *Driven rod method*

$$\rho_{ad} = \frac{2\pi l R}{\ln\left(\frac{8l}{d}\right)} \quad \text{Eq. 1}$$

where ρ_{ad} is apparent resistivity in ohm meter (Ωm), l is the length of the driven rod in contact with earth in meter (m), d is a driven rod diameter in meter (m) and R is the measured value of the resistance in ohm (Ω). Eq 1 had been used to calculate the grounding resistance, and the result is recorded in the table.

3. Results and Discussion

3.1 Design of Rods

Copper grounding rod was used in this work for the grounding rod construction because in conductor and low cost. According to research conducted by [13], copper is corrosion resistant underground; thus, copper will allow the flow of fault current smoothly to the earth when copper is buried underground. Other than that, type of electrode used in this project is roots electrode. Roots electrode used in this project because based on previous research, when there is more arms produce more leakage current that can go through the area [14], so the roots electrodes is suitable for this project where it has been provide high distribution of current density due to the numbers of arms on the electrodes. The prototypes of standard and three branches copper rod was developed by cutting and welding the combination of branches based on the size as shown in Table 2.

Table 2: *Rod specifications*

No	Design of rod	Prototype	Dimensions
1	Standard copper rod		Length: 76.2cm Diameter: 1.2cm

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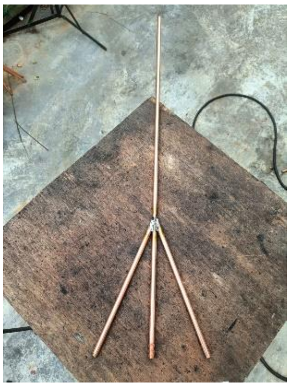
No	Design of rod	Prototype	Dimensions
2	Three branches copper rod		Length:76.2cm Branch length: 30.48cm Diameter: 1.2cm

3.2 Grounding Resistance for Standard Copper Rod

Fig. 5 illustrates the comparison graph of grounding resistance for standard copper rod between each conductive compound. It is observed from the graph that standard copper rod with graphite has lower grounding resistance value compared to others. Throughout the entire period, the resistance remains relatively stable, showing only fluctuation but maintaining overall consistency. In contrast, a more stable and consistent performance is demonstrated by bentonite with resistance value lower than standard copper rod without conductive compound. This is due to the various factor that can be affect the readings and one of the main factors is moisture contained [15]. The unpredictable weather in the first and third weeks causing the data obtained to be in the proper range. This is because the weather that week is cloudy and rainy, so the water contains in the soil more than the other weeks.

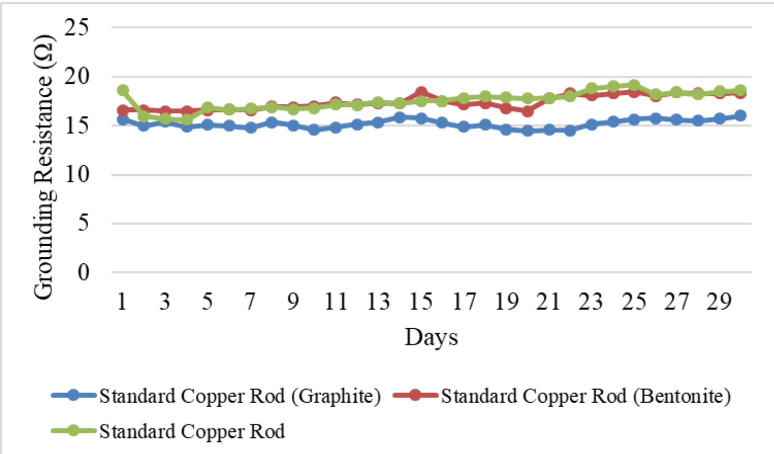


Fig. 5 *Grounding resistance graph for standard copper rod*

3.3 Grounding Resistance to Three Branches Copper Rod

Fig. 6 shows the comparison graph of grounding resistance for three branches copper rod between each conductive compound. It is noticed that the soil resistivity reading for three branches copper rod with graphite has blower grounding resistance value compared to others. However, three branches copper rod without conductive compound and three branches copper rod with bentonite start with a higher grounding resistance. Bentonite's conductivity is affected by temperature. In colder conditions, bentonite can have a higher initial resistance, as clay materials generally have less ion mobility in lower temperatures [16]. The fluctuations in weather particularly the presence of rain played a crucial role in altering the soil's conductivity, thereby affecting the consistency and accuracy of the grounding resistance measurements. This higher moisture level contributed to the readings falling within the proper range as moist soil generally has lower resistance. In contrast, during other weeks with drier conditions, the soil retained less moisture resulting in higher resistance readings. Drier soil conditions can significantly increase grounding resistance. When soil moisture decreases, the ions that conduct electricity become less mobile, reducing the soil's overall conductivity and increasing resistance.

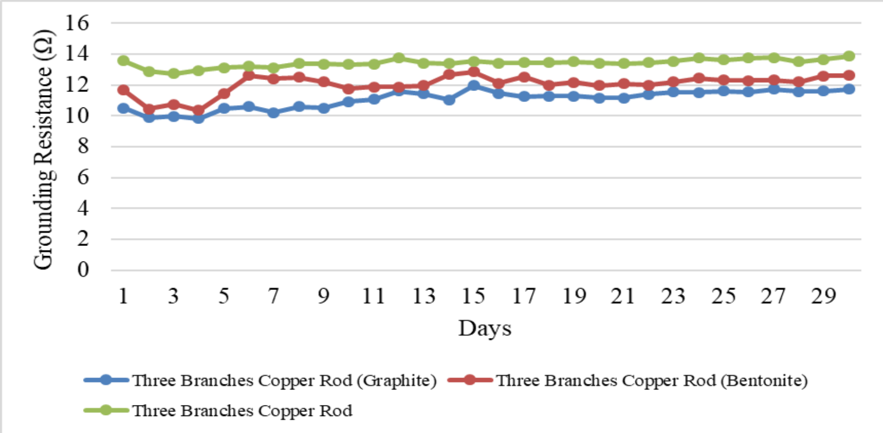


Fig. 6 *Grounding resistance graph for three branches copper rod*

3.4 Grounding Resistance For Standard Copper Rod And Three Branches Copper Rod

Fig. 7 illustrates the comparison graph of grounding resistance between standard copper rod and three branches copper rod. Overall, according to previous research done in January 2021 [17] incorporating graphite significantly improved the electrical resistivity behavior while maintaining acceptable mechanical properties crucial for electrical grounding purposes [18]. Initially, the standard copper rod with graphite and three branches copper rod with graphite exhibit the lowest grounding resistance in their category. In comparison, the three branches copper rod with bentonite also performs well, though not as effectively as the graphite. The resistance levels for this configuration are slightly higher but remain stable. On the other hand, the standard copper rod starts with the highest grounding resistance during the period. This configuration shows the least effectiveness compared to others.

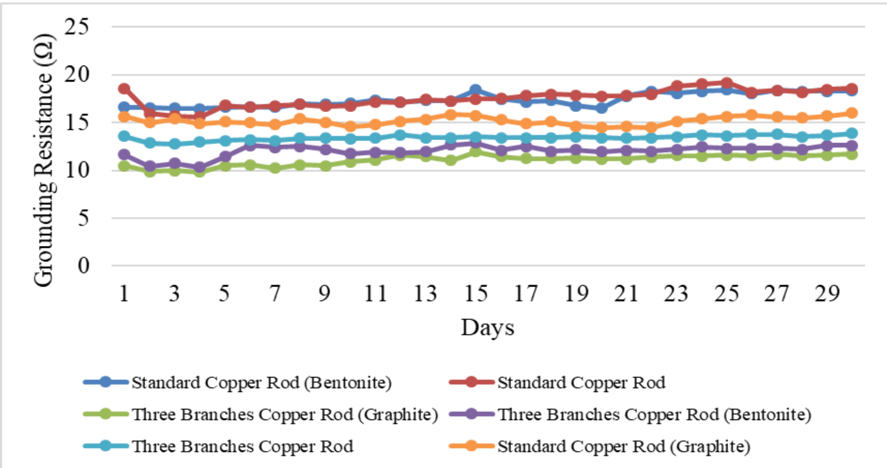


Fig. 7 *Grounding resistance graph for standard copper rod and three branches copper rod*

4. Conclusion

With the completion of these projects, the two types of conductive compound that have been used in this project, which are graphite and bentonite, proved that they could be used to improve the grounding resistance system by decreasing the values of grounding resistance. Other than that, this project present design and development of the ground rod to find the best performance for the grounding system. The design of those two ground rods which is standard copper rod and three branches copper rod aim to improve the dissipation of leakage current. Measurements were taken over 30 consecutive days, showing that grounding resistance can be improved by using conductive compounds with different designs of the copper rod.

Generally, the data clearly indicate that the three branches copper rod with graphite offers the most efficient grounding solution, achieving the lowest and most consistent resistance levels over time. Three branches copper rod with bentonite also provides an effective grounding solution, though with slightly higher resistance levels compared to three branches copper rod with graphite. These findings reinforce the significant advantages of using conductive compounds like Graphite and Bentonite in grounding systems, demonstrating their critical role in enhancing grounding efficiency and stability

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: study conception and design: Muhamad Faiz Hakimi Bin Ahmad, Nor Akmal Mohd Jamail, Qamarul Ezani Kamarudin; data collection: Muhamad Faiz Hakimi Bin Ahmad; analysis and interpretation of results: Muhamad Faiz Hakimi Bin Ahmad, Nor Akmal Mohd Jamail, Qamarul Ezani Kamarudin; draft manuscript preparation Muhamad Faiz Hakimi Bin Ahmad. All authors reviewed the results and approved the final version of the manuscript.

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