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Performance Comparison Grounding System Using Aluminium and Copper

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Abstract

This study presents a comparative analysis of aluminum and copper as grounding materials by evaluating their effectiveness through soil resistance measurements. Prototype grounding systems—including single rod, triple parallel rods, and grid configurations—were installed at a depth of 1.5 meters at an open field site at Universiti Tun Hussein Onn Malaysia (UTHM). Resistance values were recorded daily over 30 days using the Fall-of-Potential method. The results indicate that for the single rod configuration, copper exhibited a slightly lower average resistance (4.50 Ω) compared to aluminum (4.95 Ω). In the triple parallel rod setup, aluminum outperformed copper with an average resistance of 1.17 Ω versus 1.41 Ω. For the grid configuration, aluminum again demonstrated superior performance with an average resistance of 2.52 Ω, while copper recorded 3.51 Ω. These findings suggest that aluminum is a viable and often more effective alternative to copper in certain grounding system configurations, particularly in grid installations.

1. Introduction

The earthing system is a critical protective component in electrical installations that connects equipment to the ground, primarily to safeguard people and equipment from electrical hazards. It facilitates the safe discharge of leakage currents and electrical surges into the earth, helps maintain voltage stability, and reduces electromagnetic interference with connected devices. Effective earthing significantly minimizes the risk of electric shock, equipment damage, and operational disruptions.

Impedance is the most critical parameters of an earthing system. It is important to maintain a low earthing impedance over a long period of time [1], as high earthing resistance can result in flashover trips. The earthing system is often considered to be a zero-voltage reference point that is usually connected to the ground. It usually consists of a grid of horizontally mounted conductors, which are often reinforced with several vertical rods attached to the grid [2]. In some configurations, the rods are planted individually and progressively until the lowest possible resistance value is achieved [3].

The specific configuration of the grounding system and the surrounding environmental conditions play a significant role in determining its overall performance. In most electrical installations, soil is used as the grounding medium due to its relatively low electrical conductivity. Major research areas in grounding systems include the types of grounding configurations, the materials used, and the methods for measuring grounding resistance. Among these factors, soil resistivity is of great importance, as it affects the ability of the soil to conduct electrical current. Soil resistivity is influenced by several factors, including soil composition, moisture content, temperature, and mineral content [4].

As a critical parameter, soil resistivity directly affects the performance of substation grounding systems. It varies with depth and has a significant impact on important safety and operational parameters such as soil resistance, soil potential rise, and touch and step voltages. These parameters must be properly evaluated to ensure the effectiveness and overall safety of the grounding system. Therefore, this paper compares aluminum and copper to determine the more suitable material for grounding applications, incorporating soil analysis and theoretical calculations. The experimental setup was deployed in an open area at UTHM, where grounding rods and grids of both materials were installed for evaluation.

2. Methodology

Fig. 1 illustrates the flowchart for comparing copper and aluminum as grounding materials. The process begins with collecting comprehensive information about suitable materials for grounding systems. Once the necessary data is gathered, a prototype grounding system is designed and constructed using both copper and aluminum materials. Following prototype development, the next step involves data collection from both types of grounding systems. The collected data is monitored over a 30-day period to ensure sufficiency for meaningful analysis. If the data collected within this period is insufficient, the process loops back to continuing data collection. Once sufficient data is obtained, the results are analyzed, and conclusions are drawn regarding the performance of each material. The process concludes with the completion of the analysis.

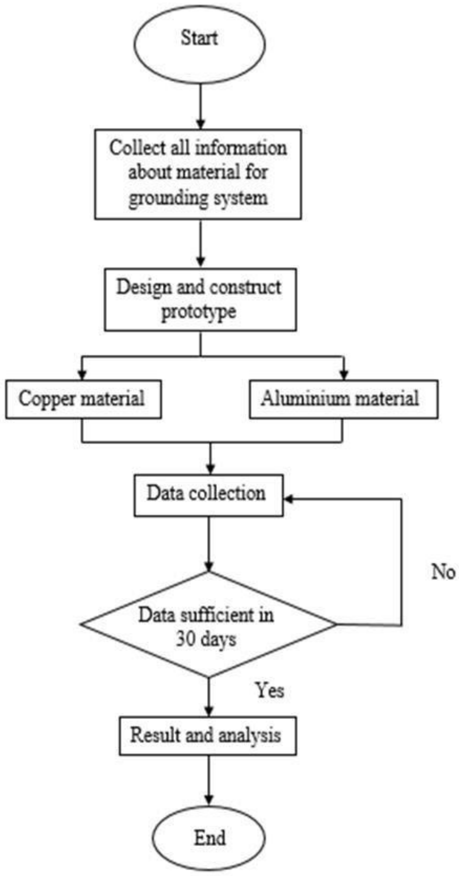


Fig. 1 *Flowchart of project*

2.1 Material and Tools

Table 1 shows the tools and materials used in the project, including copper and aluminum rods, conductive tape, PVC earth chambers, clamps and digital earth testers to construct and evaluate different earthing configurations. Supporting equipment such as additional electrodes, measuring cables, hammers and measuring tapes ensure accurate installation and resistance measurements. Each item contributes to an effective and reliable comparison between copper and aluminum as the base material.

Table 1 *Tools and Material*

Tool and Material	Specification	Quantity
Rod copper	1.5 meter with 12 mm diameter	4 nos
Rod aluminium	1.5 meter with 12 mm diameter	4 nos
Copper tape	0.9 x 0.6 meter	3 meter
Aluminium tape	0.9 x 0.6 meter	3 meter
PVC earth chamber	7 x 7 feet	10 nos
Clamp rod	25 mm	6 nos
Digital Earth tester	Kyoritsu model 4105A	1 nos
Auxiliary electrode	Iron metal	2 nos
Cable (red)	Current spike	15 meter
Cable (yellow)	Potential spike	10 meter
Cable (green)	Ground conductor	5 meter
Measuring tape	HTRO 5 meter	1 nos
Hummer	7 KG	1 nos

2.2 Grounding Installation

The grounding installation of both copper and aluminum rods is shown in Fig. 2 installation process of single grounding rods made of copper and aluminum. In this setup, each rod whether copper or aluminum was installed vertically into the ground to a depth of 1.5 meters. The process was carried out manually using a 7 kg hammer to ensure the rods penetrated the soil securely and remained stable for accurate resistance measurements.

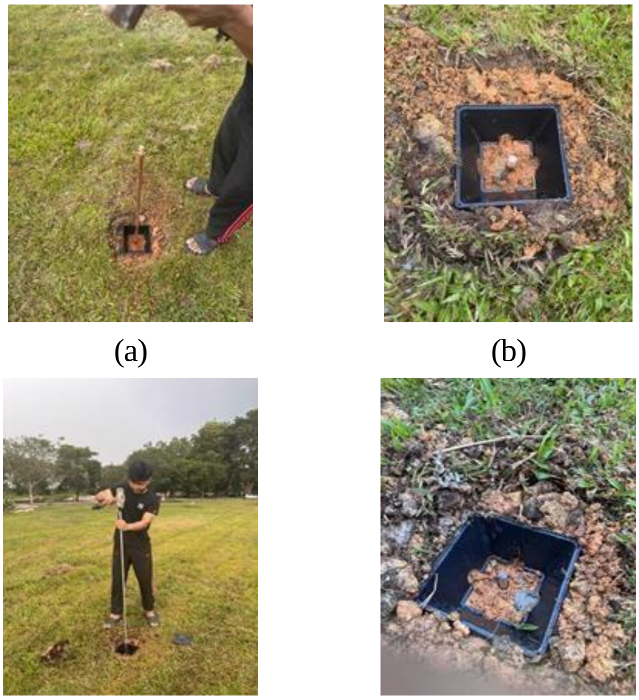
Subfigure (a) shows the initial stage of the installation, where the copper rod is being driven into the ground. Subfigure (b) presents the copper rod fully inserted in the soil, standing vertically as part of the single rod configuration. Similarly, subfigure (c) shows the aluminum rod being hammered into the ground, following the same method as used for copper. Lastly, subfigure (d) displays the fully installed aluminum rod.

This consistent installation method for both materials ensured fairness in comparison by eliminating any discrepancies that might arise from uneven installation techniques. By placing the rods to an identical depth and in the same soil conditions, the experiment ensured that the differences observed in resistance readings were due to the materials themselves rather than the installation process.

The installation process for the parallel rod configuration differs slightly from the single rod setup, as it involves the use of multiple rods and interconnecting tape. As shown in Fig. 3, this setup includes three rods driven into the ground in a linear arrangement. The rods are connected using copper or aluminum tape depending on the material used, forming an electrically continuous path to enhance current dissipation into the ground. Subfigure (a) shows the installation of parallel copper rods. Subfigure (b) illustrates the connection between the rods using conductive tape, ensuring good electrical continuity. Subfigure (c) presents the completed configuration of the three copper rods in parallel.

For the grounding grid installation, illustrated in Fig. 4, the method is more complex. The grid system consists of interconnected horizontal conductors forming a mesh, buried at a depth of 1 meter below the ground surface. The grid configuration used in this study measured 3 feet by 2 feet and was constructed using either copper or aluminum tape and rods. Subfigure (a) shows the completed copper grid system, while subfigure (b) displays the aluminum version. This configuration is commonly used in substations and industrial settings because it provides a low-resistance path to earth and enhances safety by minimizing step and touch voltages.

By using both parallel and grid configurations in addition to the single rod method, the project provides a comprehensive performance comparison of copper and aluminum across different grounding setups.



(a) (b)

(c) (d)

Fig. 2 *Single rod installation (a) Hit the copper rod, (b) Single rod copper, (c) Hit the aluminium rod and (d) Single rod aluminium*

(a) (b) (c)

Fig. 3 *Installation three parallel rod(a) Parallel rod copper, (b) Connecting rod and tape and (c) Parallel 3 rod copper*

(a) (b)

Fig. 4 *Grid installation (a) Copper grid grounding, (b) Aluminium grid grounding*

2.3 Calculation

The most used expression for calculating the resistance of a single rod in uniform soil can be found in classical electromagnetic theory [5]. This formula provides a basic and widely accepted theoretical estimate of the resistance of a vertical electrode embedded in the soil. Furthermore, this formula assumes that soil resistance is constant with depth. The equation is expressed as:

$$R = \frac{\rho}{2\pi\mathcal{L}}\left(in + \frac{4\mathcal{L}}{d}\right) \quad (1)$$

where R =Earthing resistance, ρ =Soil resistivity
$\mathcal{L}$ =Electrode length (meter), d =Diameter of electrode (meter)

For triple parallel rod grounding, the total resistance is reduced by combining the individual rod resistances, considering that the spacing between rods is approximately twice their length. The overall resistance of parallel rods can be estimated by dividing the resistance of a single rod by the number of rods (n), assuming adequate spacing to minimize mutual interference. Increasing the number of rods planted effectively lowers the grounding resistance, as the rods share the current flow and reduce the overall resistance to earth [2]. Proper spacing between rods is crucial to achieve this reduction, with typical recommendations suggesting spacing equal to or greater than the rod length to optimize performance. Therefore, the equation is as follows:

$$R = \frac{R1 + R2 + R3}{n} \quad (2)$$

where, R = Earthing resistance, R1 = Earrhing resistance first pin,
R2 = Earthing resistance second pin, R3 = Earthing resistance third pin

Next, the grid system calculation study for this system is mostly used in industries such as power plants and substations [6]. Through this grid system can also be studied theoretically with the formula that has been studied and issued by the IEEE standard for grounding safety with this formula used to find the calculation method for the grid system:

$$Rg = \frac{\rho}{4\mathcal{L}} \quad (3)$$

where, Rg = Earthing resistance grid,
ρ = Soil resistivity,
$\mathcal{L}$ = Electrode length (meter)

3. Result and Discussion

3.1 Result

Based on data collected over a 30-day period following two months of installing grounding rods and grids, a comparative analysis between copper and aluminum was conducted to identify which material exhibits lower resistivity. This comparison aims to determine the more effective grounding material, thereby ensuring improved system performance and enhanced stability of the grounding function. Table 2 shows the average results for measured resistivity grounding.

Table 2 *Average resistivity result*

Grounding material	Single Rod	Parallel 3 rod	Grid
Copper	4.50 Ω	1.41 Ω	3.15 Ω
Aluminium	4.95 Ω	1.71 Ω	2.52 Ω

Fig. 5 shows the results of different grounding configurations for copper material. It can be seen that the three parallel rod configuration gives the lowest value of resistivity. It is also observed that the resistivity value seems stable after 30 days of data collection. It is observed for single rod that the value is higher compared to the other two methods, namely three parallel rods and grid. This is because the longer or more cooper material in the soil, the lower the resistivity value that can be obtained. With this stable data, copper can be used in grounding systems with well-mixed and suitable soil conditions.

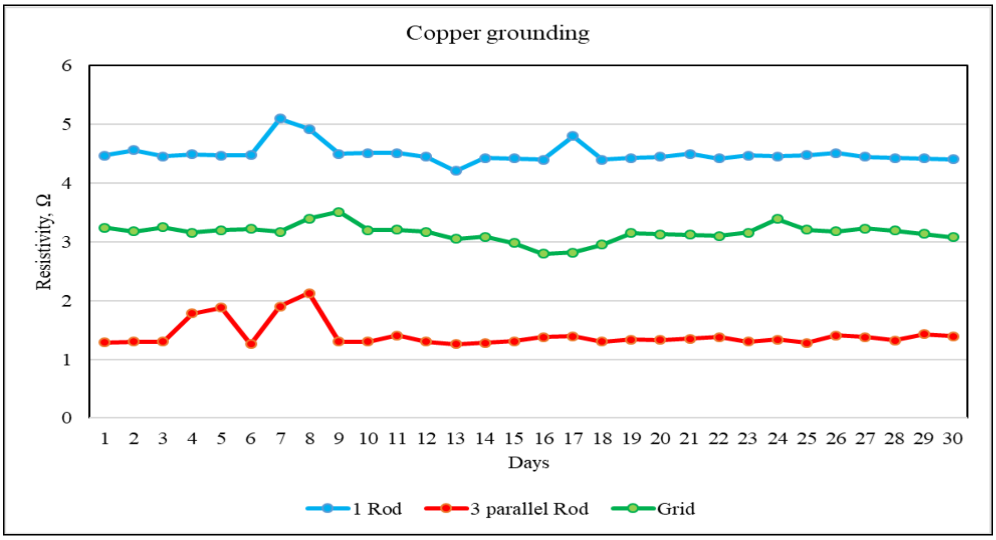


Fig. 5 *Graph for copper grounding*

For aluminum grounding rod cases, the measured value of grounding resistance is different from copper. It can be seen from Fig. 6 that the single rod is not stable compared to the other two methods, which show a decrease every day during the data collection process. The decrease in the grid method is probably due to the soil conditions that still need time to stabilize the reading. Meanwhile, for three rods in parallel, the data can be seen to be stable and suitable for use in the soil. Studies have shown that aluminum is a suitable material for grounding [7] however, a comprehensive evaluation of factors such as soil conditions and ventilation is necessary before selecting aluminum for this purpose.

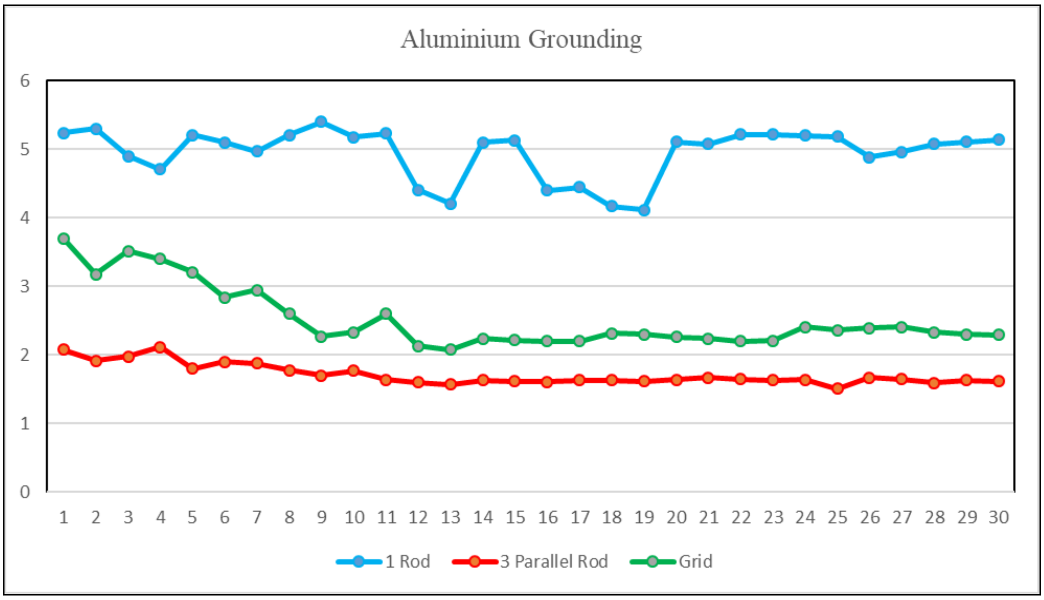


Fig. 6 *Graph for aluminium grounding*

For data analysis, measurements were complemented by calculations using the relevant formulas for each grounding installation method. Fig. 7 presents a comparative graph of the three methods alongside their theoretical calculations. In the single rod configuration, aluminum exhibited resistance values higher than the theoretical prediction, while copper showed lower values. For the triple parallel rod setup, both materials displayed similar trends, with aluminum slightly exceeding the calculated values and copper remaining below the expected resistivity. In the grid system, both aluminum and copper demonstrated low resistance readings, closely aligning with theoretical calculations, indicating effective grounding performance. Among the three methods, the grid configuration yielded the lowest resistance for aluminum, significantly outperforming the other planting methods; however, it requires considerably more labor and preparation prior to installation.

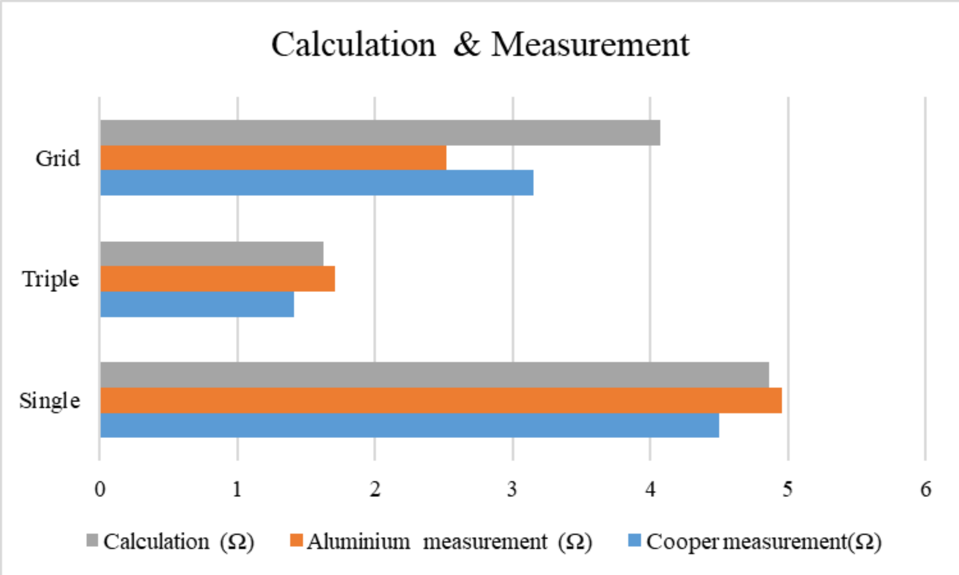


Fig. 7 *Graph for calculation and measurement for material grounding*

3.2 Discussion

Based on the results and analyses of the performance of copper and aluminum grounding systems using three configurations single rod, triple parallel rod, and grid all tested in peat soil, which is known for its high electrical resistivity [8], the findings revealed that copper consistently outperformed aluminum in most aspects.

In addition to the measured resistivity values, the comparison between calculated and experimental data further supports this conclusion. Copper's results are closely aligned with theoretical predictions, particularly in the single rod and triple parallel rod configurations. This indicates reliable and consistent performance under various conditions and reinforces its suitability for sensitive and critical grounding applications.

In both the single rod and triple parallel configurations, copper demonstrated lower and more stable resistance values compared to aluminum [9]. This superior performance is due to copper's higher electrical conductivity and lower reactivity with environmental factors, making it more dependable in soils with varying moisture levels. In contrast, aluminum exhibited greater fluctuations in resistance values, suggesting that it may not provide long-term stability or durability in grounding systems.

While aluminum occasionally outperformed copper in terms of average resistance, especially in the grid configuration it also showed greater measurement variance. This variability is likely due to aluminum's susceptibility to corrosion and chemical reaction in moist or acidic soils, such as peats. The observed discrepancies between calculated and measured values indicate that aluminum's grounding performance may degrade more quickly over time, potentially due to oxidation and soil interactions.

Although aluminum recorded a slightly lower average resistance than copper in the grid configuration, the higher variation in measurements implies inconsistent performance over time [10]. This inconsistency is likely a result of aluminum's higher tendency to corrode or react with the soil. Therefore, despite its initially promising resistance values, aluminum is not considered a reliable material for long-term grounding solutions, particularly in corrosive environments.

Furthermore, the installation of a grounding grid using aluminum requires considerable labor and preparation. Given the potential for long-term performance degradation, such efforts may not be justified. When selecting materials for permanent infrastructure, factors such as maintenance requirements, environmental conditions, and long-term material stability must be carefully considered. Overall, copper proved to be the more reliable and durable material for long-term grounding applications, especially in challenging soil conditions.

4. Conclusion

Based on the comparative analysis of copper and aluminum grounding systems using single rod, triple parallel rod, and grid configurations in high-resistivity peat soil, the results clearly indicate that copper is the superior material for grounding applications in such environments. Copper exhibited lower and more stable resistance values, closely aligning with theoretical predictions, particularly in the single rod and triple parallel rod configurations. This highlights copper's superior electrical conductivity and durability, making it highly suitable for sensitive and critical grounding applications. In contrast, aluminum showed greater fluctuations in resistance and measurement variability, especially in corrosive and moist peat soils. Although aluminum occasionally recorded slightly lower average resistance in the grid configuration, its performance was less reliable due to its susceptibility to corrosion and chemical reactions with the soil. These factors contribute to performance degradation over time, raising concerns about aluminum's long-term effectiveness and stability in grounding systems.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception, design, data analysis and manuscript preparation****: Nik Hamizan Hakim Nik Hassan;* ***manuscript verification****: Nordiana Azlin Othman. All authors reviewed the results and approved the final version of the manuscript*

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