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Grounding Performance of Hydrogel, Silica Gel and Charcoal Ash as Additive Material in Grounding System

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ABSTRACT

Grounding enhancement materials (GEMs) are one of the additive materials which can change the grounding performance without lots of significant costs. The study aimed to assess the performance of laterite and peat soil, copper and galvanized conductors, and determine the effectiveness of additional materials in reducing grounding resistance. Altering soil characteristics can enhance the conductor's contact area, achieving lower grounding resistance without high costs. Hydrogel, silica gel, and charcoal ash were mixed with soil for testing. Grounding resistance values were measured and collected using the Fall-of-Potential Method using Kyoritsu Earth-Tester-Model-4102. The number of GEMs used were 300g and 600g. Hydrogel, silica gel, and charcoal ash added to soil reduced grounding resistance. Among the various Ground Enhancement Materials (GEMs) tested, hydrogel exhibited the most impressive performance, boasting the lowest grounding resistance at just 56% compared to the reference grounding system. Silica gel followed closely as the second-best performer, with an average grounding resistance of 77% relative to the reference system and lastly is charcoal ash with an average grounding resistance of 77% relative to the reference system. These GEMs significantly enhanced soil conductivity. Furthermore, when considering different soil types and conductor materials, it was observed that peat soil combined with galvanized conductors achieved notably lower grounding resistance in comparison to laterite soil and copper conductors, respectively.

Keywords: *Charcoal ash, Hydrogel, Silica gel, Grounding resistance performance*

1. INTRODUCTION

Grounding systems play a pivotal role in electrical installations across various domains, encompassing buildings, substations, power plants, and more. Their primary function is to ensure safety by diverting fault currents stemming from equipment failures, lightning strikes, or switching overvoltage safely into the ground. This protective measure safeguards both equipment and personnel. It's crucial to emphasize that consistent maintenance and strict adherence to established standards are fundamental for ensuring their efficacy [1].

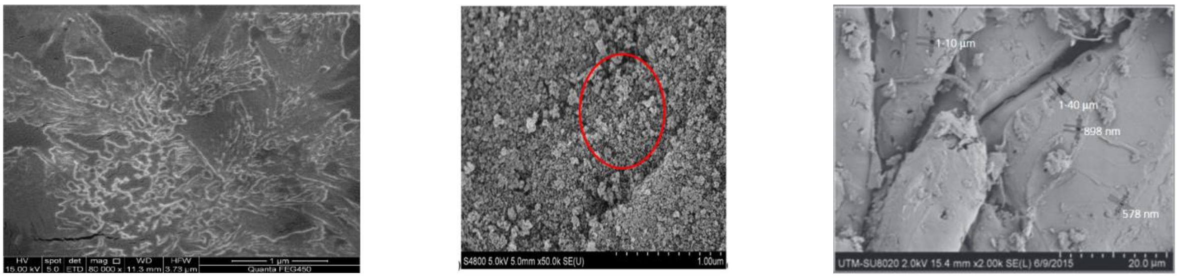
Two key characteristics define the efficacy of a grounding system: its ground resistance for low-frequency currents and its impulse impedance when subjected to high-impact circumstances. The key features of a successful grounding system are unquestionably low resistance and the capacity to quickly disperse fault currents into the earth. However, the ground resistance value depends on the conductor arrangement and soil resistivity, giving a significant degree of seasonality and weather variability.

To mitigate the challenges posed by high soil resistivity and elevated ground resistance values, engineers have explored a variety of solutions. These solutions often involve altering the form, size, or quantity of the grounding conductors employed [2]. The persistence of highgrounding resistance has, in fact, made the installation of grounding systems quite demanding. Consequently, there has been a growing trend in the engineering field towards the adoption of grounding enhancement materials (GEMs) to address this challenge [2].

A convenient and straightforward method to reduce resistance in grounding systems has emerged, involving the application of ground enhancing materials (GEMs) to the grounding conductors. Natural products like coconut coir peat, paddy dust, palm Kernel oil cake, bentonite etc and chemical products like concrete, synthetic resins, water-absorbent polymer, mixed inorganic salts, and others, have both been used extensively as GEMs throughout the world in recent decades, providing an appealing alternative to harsh, desert, and high resistivity terrains.

Some researchers studied Field Scanning Electron Microscopy (FESEM) to understand the sample surface with higher resolutions and higher energy range. By comparing the morphology of each GEMs, it was found the shape of the GEMs were different from each other's and some of it have a lot of pores which may be able to hold and retain the moisture. This paper had collected some of the similar material from previous research as shown in Figure 1 for preliminary study.

Although GEMs have been utilized in grounding systems for many years, it was only in 2012 that international standardization addressed their usage. The IEC 62561-7 standard [3] was introduced to specify the requirements these commercial materials must meet and establish necessary tests. Due to the wide variety and numerous types of GEMs available, the primary objective of these tests outlined in the mentioned standards is to determine the effectiveness or ineffectiveness of different materials [4]. This paper aimed to assess the performance of peat and laterite soil, copper and galvanized conductors, and determine the effectiveness of GEMs in reducing grounding resistance.



(a) (b) (c)

Figure 1. (a) FESEM images of the hydrogel magnification factor of 80k adapted from [5] (b) FESEM images of the activated silica gel magnification factor of 50k adapted from [6] (c) charcoal FESEM images magnification factor of 2k adapted from [7].

2. EXPERIMENT SETUP

The experiment starts with planning, screening, modelling, choosing the best conditions and finally end with verification of the conditions. The design of experiments has been shown in Figure 2.

The fall-of-potential method, renowned for its practicality and reliability, was employed in this study to conduct a comprehensive grounding performance test. This method involves the measurement of the earth resistance surrounding a grounding conductor as shown in Figure 3. The experiment was conducted in two distinct locations in Kedah, characterized by peat soil and laterite soil, respectively.

Grounding resistances were measured for 7 weeks, weekly. The measuring period starts from October 2022 to November 2022 using fall-of-potential method. The Kyoritsu Earth Tester Model 4102A was used to measure the grounding resistance. The grounding conductor was linked to the resistivity measuring equipment with cables during the measurement as shown in Figure 4. Spike current (red) is planted at 8 meters while spike potential (yellow) is planted 61.8% of the spike current which is about 4.94 meters. The performance of each grounding system is visually depicted in Figure 3, while its weekly analysis can be conducted using equation (1). Here, 'n' represents the n-th week, enabling comparisons between each GEMs mixture grounding system and the Reference grounding system on week-n. The summarized results can be found in Table 2.

In this study, three types of grounding enhancement materials, namely hydrogel, silica gel, and charcoal ash, were employed in two different mixture ratios of 300g and 600g as an additive material in the grounding system. Additionally, a reference grounding system was examined in which the grounding conductor was installed without any grounding enhancement materials (GEMs) nearby, serving as a basis for comparison. This research was conducted based on improvements made in previous work [1, 8-11], considering different GEM materials and soil effects.

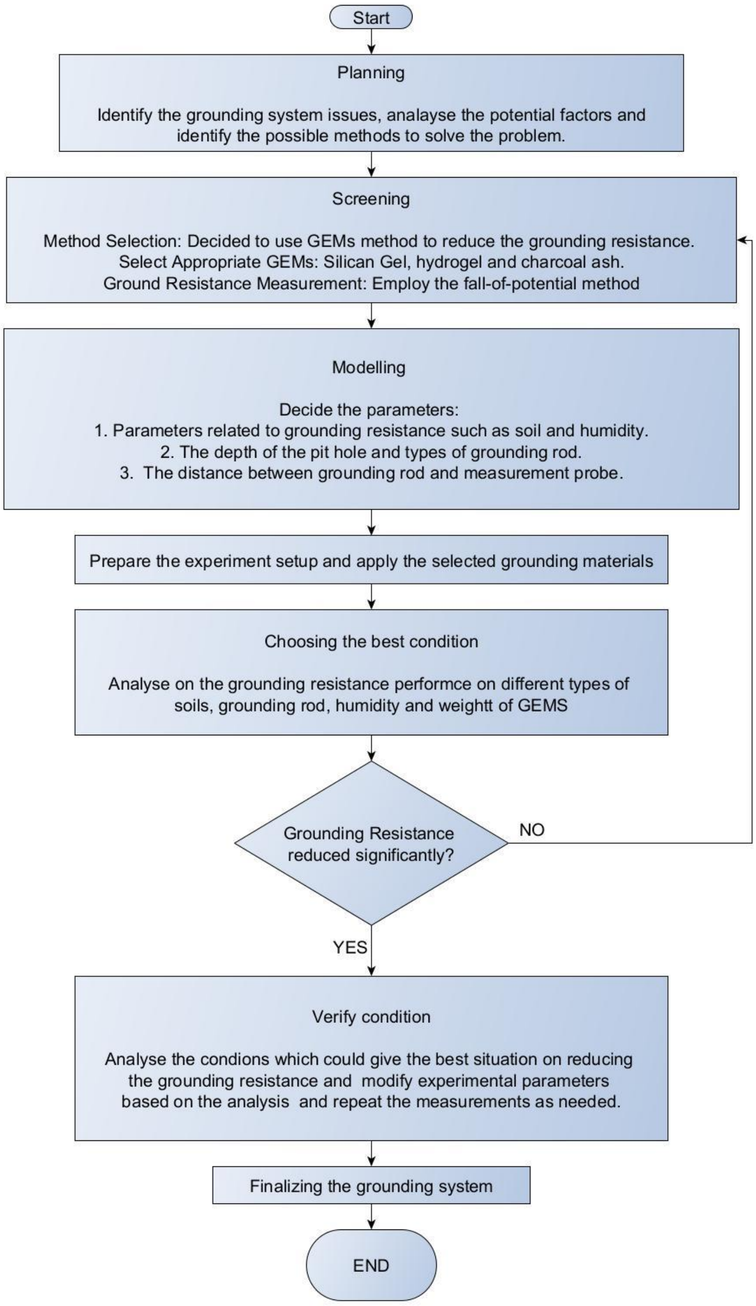


Figure 2. Flowchart for grounding resistance measurement with various GEMs.

$$\frac{R\_GEMs\_day\_n}{R\_Ref\_day\_n} \times 100\% \qquad (1)$$

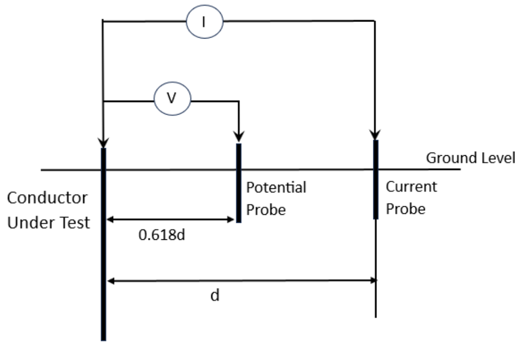
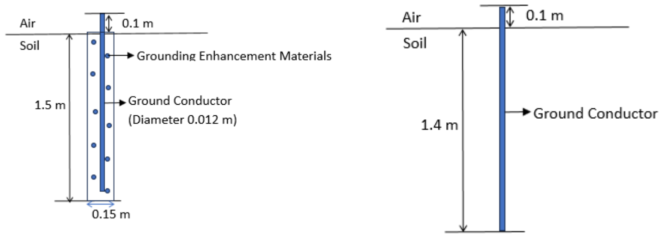


Figure 3. Fall-of-Potential method arrangement.

The experimental setup with installing two vertical grounding conductors namely copper grounding conductors and galvanized steel. Copper conductor has a length of 1.5 m and a diameter of 0.012 m was used. Galvanized steel installed are 0.0125m diameter and 1.5 m. The typical side view of the GEMs mixture and reference grounding system configurations were shown in Figure 4. Figure 4(a) shows the side view of GEMs mixture grounding system and Figure 4(b) shows the side view of reference grounding system consisting of soil only.



(a) (b)

Figure 4. (a) Side view of GEMs mixture grounding system (b) Side view of reference grounding system consisting of soil only.

Grounding system installation starts with making marks on the selected grounding system as shown in Figure 5. Figure 5 illustrates the configuration of grounding conductor placements. The spacing between each grounding conductor measures 2 meters, while each pit has a diameter of 6 inches. The grounding conductors without any additives are positioned in the front row, specifically samples 7 and 14. Following this, in the first row, we have 2 samples with hydrogel (samples 1 and 4), in the second row, 2 samples with charcoal ash (samples 2 and 5), and in the third row, 2 samples with silica gel (samples 3 and 6). The same arrangement was replicated for galvanized steel conductors in samples 8-14.

Figure 5. Configuration of 14 samples consisting of 12 Pits and 2 reference grounding system.

Table 1 Materials and Grounding Conductors involved in all the 14 samples

Copper Grounding Conductor		Galvanized Grounding Conductor	
Samples	**Materials Involved**	**Samples**	**Materials Involved**
1	Soil mixed with hydrogel 300g	8	Soil mixed with hydrogel 300g
2	Soil mixed with hydrogel 600g	9	Soil mixed with hydrogel 600g
3	Soil mixed with charcoal ash 300g	10	Soil mixed with charcoal ash 300g
4	Soil mixed with charcoal ash 600g	11	Soil mixed with charcoal ash 600g
5	Soil mixed with silica gel 300g	12	Soil mixed with silica gel 300g
6	Soil mixed with silica gel 600g	13	Soil mixed with silica gel 600g
7	Reference system with soil only	14	Reference system with soil only

Then, for each grounding system involving GEMs, a cylindrical pit was dug using crane auger as shown in Figure 6(c). The GEMs were mixed with soil and compressed to each pit using PVC pipe with a diameter of 6 inches in order to minimize the space and air between the GEMs as shown in Figure 6(a) and 6(b). The purpose of compression is to maximize the grounding system GEMs packing density [4].

(a) (b)

(c)

(d)

Figure 6. (a) Copper conductor Installation work (b) Galvanized conductor planting work (c) Crane auger machine digging the pit (d) Measurement humidity of the soil

3. RESULTS AND DISCUSSION

This study involved several manipulated variables that underwent changes during the data collection process. Firstly, the choice of materials for conductors was variable, encompassing both copper and galvanized steel conductors. Secondly, the investigation included three types of GEMs mixed with the soil: hydrogel, silica gel, and charcoal ash. Two quantities, 300g and 600g, were utilized for each GEMs, mixed with the existing soil to fill a single pit. Furthermore, we monitored certain variables, including soil moisture, which naturally fluctuated in response to weather and environmental conditions. Once the experimental setup was established, data collection commenced immediately. Table 1 presents the results of grounding resistance tests conducted on both laterite and peat soils. To provide a reference point for comparison, grounding resistance values for soil without additive materials were also recorded. This comprehensive experiment spanned a duration of 7 weeks.

Analysis of the data in Table 2 reveals that the reference grounding system, consisting solely of pure soil, exhibits the highest grounding resistance compared to the systems incorporating Grounding Enhancement Materials (GEMs). Table 2 illustrates the consistent collection of over 80 data samples on a weekly basis, employing various types of grounding conductors and GEMs within a specific soil type. Data collection has been consistently conducted on a weekly basis for a consecutive duration of 7 weeks with the total data collected of 196 measurements. Notably, in the first week, the 600g hydrogel configuration demonstrates the lowest earth resistance value and performs exceptionally well. This suggests that hydrogel and silica gel, with their low ground resistivity values, could be promising additions to grounding systems in the initial week.

Upon closer examination of Table 2, which assesses the impact of the three additive materials on reducing grounding resistance, it becomes evident that hydrogel consistently delivers the lowest grounding resistance. By the fifth week, both 300g and 600g hydrogel configurations exhibit the lowest grounding resistance values, measuring 7 and 4 Ω, respectively. Silica gel follows closely as the second-lowest, with grounding resistance values of 9 and 7 Ω. In contrast, charcoal ash consistently yields the highest grounding resistance among these three GEMs, regardless of whether it is placed in laterite or peat soil. To assess the long-term performance of these GEMs in reducing grounding resistance, average values were calculated over the 7 weeks.

In this study, two different soil types, namely laterite and peat soils, were involved across two distinct locations. Upon examination of the average results in Table 2, it can be concluded that peat soil exhibits slightly lower grounding resistance values when compared to laterite soil. When considering the range of grounding resistance values, it is observed that for laterite soil, this range is encompassed between 6 and 27 ohms, while for peat soil, it falls within the range of 4 to 24 ohms, indicating a notably similar range between the two soil types.

Table 2 Grounding Resistance measured in laterite and peat soil using galvanized steel and copper conductors with three types of GEMs

Weeks	Temp (°C)	Humidity	Conductor Materials	Laterite Soil (Ω)							Peat Soil (Ω)						
				Soil	Hydrogel		Silica Gel		Charcoal Ash		Soil	Hydrogel		Silica Gel		Charcoal Ash	
				-	300 g	600 g	300 g	600 g	300 g	600 g	-	300 g	600 g	300 g	600 g	300 g	600 g
1	28	Wet	Galvanized	16	11	8	13	11	14	13	14	9	6	11	8	12	10
			Copper	21	16	14	18	16	19	17	19	14	11	16	12	17	15
2	33	Dry	Galvanized	20	16	14	18	16	19	18	17	12	10	13	10	14	12
			Copper	24	20	18	22	20	23	22	23	18	16	19	16	20	18
3	34	Dry	Galvanized	22	18	17	19	17	21	20	20	16	14	18	16	19	18
			Copper	27	23	22	24	22	24	23	24	20	17	11	18	22	21
4	30	Wet	Galvanized	19	15	13	16	14	18	17	17	13	10	13	11	13	12
			Copper	24	20	18	22	19	21	20	20	16	12	7	13	16	14
5	27	Wet	Galvanized	15	9	6	11	8	12	10	13	7	4	9	7	10	8
			Copper	19	13	10	16	13	17	15	16	10	8	9	9	13	11
6	29	Wet	Galvanized	18	14	11	15	13	16	14	15	10	9	13	9	13	12
			Copper	23	20	17	21	18	21	20	20	17	12	18	13	18	17
7	28	Wet	Galvanized	17	12	9	14	12	15	13	14	9	6	12	9	13	11
			Copper	22	18	16	19	17	20	18	20	15	11	17	14	19	17
Average Value				20.5	16.1	13.79	17.71	15.43	18.57	17.14	18	13.29	10.4	13.29	11.8	15.64	14
Minimum Value				15	9	6	11	8	12	10	13	7	4	7	7	10	8
Maximum Value				27	23	22	24	22	24	23	24	20	17	19	18	22	21

The analysis of the data presented in Table 3 reveals significant insights into the impact of GEMs grounding systems compared to the reference grounding system during week-N. It is evident from the table that the percentage difference in grounding resistance highlights the effectiveness of GEMs in reducing grounding resistance values. Table 3 further supports this conclusion, showcasing the variations in average grounding resistance percentages for different materials. Among these materials, 600 grams of hydrogel placed in peat soil stands out as the most effective, with the lowest average grounding resistance percentage recorded at 56%. Silica gel follows closely with a 64% reduction in average grounding resistance, and charcoal ash demonstrates a respectable 77% reduction. In summary, these findings underscore the significant potential of GEMs, with hydrogel in peat soil leading the way as the most efficient solution for reducing grounding resistance.

Table 3 The percentage difference of grounding resistance of GEMs grounding system on week-N compared to the grounding resistance of the reference grounding system on week-N

Weeks	Temp (C)	Humidity	Conductor Materials	Laterite Soil (%)							Peat Soil (%)					
				Soil	Hydrogel		Silica Gel		Charcoal Ash		Hydrogel		Silica Gel		Charcoal Ash	
				Soil	300 g	600 g	300 g	600 g	300 g	600 g	300 g	600 g	300 g	600 g	300 g	600 g
1	28	Wet	Galvanized	100	69	50	81	69	88	81	64	43	79	57	86	71
			Copper	100	76	67	86	76	90	81	74	58	84	63	89	79
2	33	Dry	Galvanized	100	80	70	90	80	95	90	71	59	76	59	82	71
			Copper	100	83	75	92	83	96	92	78	70	83	70	87	78
3	34	Dry	Galvanized	100	82	77	86	77	95	91	80	70	90	80	95	90
			Copper	100	85	81	89	81	89	85	83	71	46	75	92	88
4	30	Wet	Galvanized	100	79	68	84	74	95	89	76	59	76	65	76	71
			Copper	100	83	75	92	79	88	83	80	60	35	65	80	70
5	27	Wet	Galvanized	100	60	40	73	53	80	67	54	31	69	54	77	62
			Copper	100	68	53	84	68	89	79	63	50	56	56	81	69
6	29	Wet	Galvanized	100	78	61	83	72	89	78	67	60	87	60	87	80
			Copper	100	87	74	91	78	91	87	85	60	90	65	90	85
7	28	Wet	Galvanized	100	71	53	82	71	88	76	64	43	86	64	93	79
			Copper	100	82	73	86	77	91	82	75	55	85	70	95	85
Average				100	77	66	86	74	90	83	72	56	74	64	86	77
Minimum				100	60	40	73	53	80	67	54	31	35	54	76	62
Maximum				100	87	81	92	83	96	92	85	71	90	80	95	90

Table 4 displays a comparison of grounding resistance reduction achieved by galvanized steel and copper conductors for each sample, measured in terms of percentage difference. When considering the two types of grounding conductors, it is observed that galvanized steel conductors are found to be more effective than copper conductors in terms of reducing grounding resistance. The grounding resistance difference between galvanized steel and copper conductors can range from 11% to 50%, as demonstrated in Table 2. It is noteworthy that a reduction in grounding resistance ranging from 11% to 50% is consistently observed in galvanized steel conductors when compared to copper grounding conductors. The more noticeable reduction effects are observed in weeks 5 to 8 when soil conditions are wetter. However, it should be emphasized that a strong explanation for this phenomenon has not been concluded in this study. It is anticipated that further research and investigation will be required in the future to dig deeper into this matter.

Table 4 Summary percentage differences of grounding resistance of galvanized steel conductor on week-N compared to the grounding resistance of copper conductor the system on week-N

	Laterite Soil (%)							Peat Soil (%)						
	Soil	Hydrogel		Silica Gel		Charcoal Ash		Soil	Hydrogel		Silica Gel		Charcoal Ash	
	-	300 g	600 g	300 g	600 g	300 g	600 g	-	300 g	600 g	300 g	600 g	300 g	600 g
Average Value	21	27	34	26	28	21	23	23	31	34	25	27	25	27
Minimum Value	17	20	22	18	20	13	13	15	19	17	14	11	14	14
Maximum Value	24	33	44	31	38	29	33	30	41	50	35	38	32	35

Considering the data presented in Table 4, it becomes evident that 600 grams of GEMs yield a lower grounding resistance when compared to 300 grams. Hence, it can be deduced that a greater quantity of GEMs leads to a more effective reduction in grounding resistance. Notably, in this study, peat soil was identified as having the lowest grounding resistance, and galvanized steel emerged as the most effective grounding conductor. Figure 7, therefore, primarily focuses on comparing the grounding resistance of a GEMs system utilizing 600 grams of GEMs in peat soil with a galvanized grounding conductor. The observations revealed that the grounding resistance values of the GEMs system exhibited fluctuations during the initial 1-3 weeks after GEMs were introduced. This fluctuation can be attributed to two potential factors: first, instability in the materials used, and second, variations in weather conditions. This trend aligns with findings from a previous study [4], which also noted that GEMs exhibited initial fluctuations and unreliability during the first 2 weeks of installation, subsequently stabilizing after week 3. It is possible that the GEMs started holding onto moisture from the soil, especially when it rained. This could have caused the grounding resistance to decrease because the soil had more moisture. Moreover, it's worth highlighting that, during this period, the measured grounding resistances of the GEMs grounding systems were consistently more reliable and significantly lower than those of the reference grounding system.

An increase in grounding resistance was observed when the soil had lower moisture content due to its dry condition. For instance, during weeks 2 and 3, higher grounding resistance was noted, primarily attributed to hot and dry weather conditions. The performance ranking of the three GEMs was as follows: 600 grams of hydrogel, 600 grams of silica gel, 600 grams of charcoal ash, and the reference system. In the comparison of grounding resistance percentages between the hydrogel, silica gel, and charcoal ash systems and the reference system in week 2, percentage differences of 70%, 80%, and 90% were respectively observed. Similarly, in week 3, percentages of 77%, 77%, and 90.91% were respectively noted. These results could be noticed in table 2. Based on the study conducted, the optimum conditions was achieved when 600 grams of hydrogel was employed, and galvanized steel was utilized as the grounding conductor where lowest grounding resistance of 4 ohms was displayed in Figure 7.

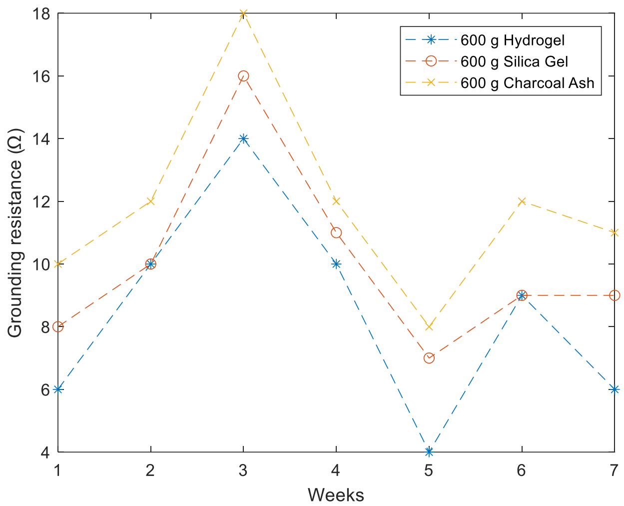


Figure 7. Comparison of 600 g GEMs in peat soil with galvanized steel grounding conductor.

4. CONCLUSION

In conclusion, the assessment of the performance of peat and laterite soils, copper and galvanized conductors, and determine the effectiveness of GEMs in reducing grounding resistance has been carried out. It was found that the addition of hydrogel, silica gel, and charcoal ash as supplementary materials to the soil has proven effective in reducing grounding resistance. The percentage difference in grounding resistance between the GEMs grounding system and the reference grounding system in week-N ranges from 30% to 87% for hydrogel, 53% to 91% for silica gel, and 61% to 95% for charcoal ash. This range encompasses variations in both grounding conductor and soil type. Notably, among the three GEMs, hydrogel emerges as the most effective.

Moving on to the use of grounding conductors, galvanized steel conductors have demonstrated superior performance compared to copper conductors in reducing grounding resistance, particularly in laterite and peat soils. The galvanized steel conductor consistently exhibits a grounding resistance reduction ranging from 11% to 50% compared to copper grounding conductors. This underscores the effectiveness of galvanized steel as a grounding conductor, offering a low-impedance pathway for current discharge.

Furthermore, this experiment aimed to determine the optimal soil type for reducing soil resistance, considering laterite and peat soils. The results unequivocally indicate that peat soil is superior in reducing grounding resistance. Specifically, the lowest average grounding resistance percentage (56%) was achieved with 600 grams of hydrogel in peat soil compared to the reference grounding system in week-N. Silica gel followed with an average grounding resistance percentage of 64%, and charcoal ash with 77%. Looking ahead, future work should encompass investigations into the durability of GEMs over longer experimental periods and a more detailed examination of the morphology and energy dispersive spectrometry of these GEMs.

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