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On The Application of Hollow Conductor as Electrical Earthing Electrode

Siow Chun Lim[1*], Tuan Haziq Arif Bin Tuan Mohamad[1] , Chandima Gomes[2], Wan Fatinhamamah Wan Ahmad[3]

[1]Centre for Electric Energy and Automation, Faculty of Engineering, Multimedia University, Cyberjaya, 63100, MALAYSIA

[2]School of Electrical & Information Engineering, University of Witwatersrand, Johannesburg, Wits 2050, SOUTH AFRICA

[3]Centre for Electromagnetic and Lightning Protection Research (CELP), Advanced Lightning, Power and Energy Research (ALPER), Faculty of Engineering, Universiti Putra Malaysia, Serdang, 43400, MALAYSIA

*Corresponding Author

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Abstract: Vertically driven solid copper electrode is a widely practiced earthing method due to its simplicity and cost effectiveness. With the rising price of copper, the need for cost optimization is imperative. In this project, hollow copper electrode is being experimented as an earthing electrode. Solid copper electrode is used as reference and vertically driven side by side with hollow copper electrode at two sites with uniform yet contrasting soil resistivity. Earth resistance of both setups was measured regularly using Fall of Potential method. It was found that the earth resistance of hollow copper electrode tends to be lower than solid copper electrode. The performance of hollow copper electrode is significantly better in site with high soil resistivity. This preliminary finding suggests that a more effective earthing system can be achieved with less material and further studies with prolonged period of measurement is required to ascertain the initial conclusion drawn and presented in this paper.

Keywords: Grounding, earth resistance, copper, earthing, hollow electrode

1. Introduction

Earthing system is designed to allow the neutralization of high magnitude fault current flow to earth thus providing an electrically safe environment for humans and equipment. Hence, an effective and efficient earthing systems is of utmost importance. An effective earthing system is usually characterized by a low earth resistance. The efficacy of electrical earthing systems to yield a satisfactorily low earth resistance largely depends on the soil resistivity and dimensioning of the earthing electrode [1].

There are several earthing methods which are advocated by widely referred international standards such as BS 7430 and IEEE 80 [2] [3]. Vertically driven earthing rod is one of the most popularly used methods due to its simplicity and ease of installation. In most if not all of its applications, solid rods are used. Interestingly, very few research has been done on the application of hollow rods instead. High frequency lightning current tends to flow along the surface of a conductor in accordance to the skin effect which potentially means that hollow rods should be just as effective as solid rods. In addition, hollow rods also require significantly less material as opposed to solid rods. It is therefore the objective of this paper to investigate the performance of hollow rods relative to solid rods.

*Corresponding author: clsiow@mmu.edu.my

2. Related Works

Various methods have been researched and deployed to achieve effective earthing [1] [4]. For sites with high soil resistivity, application of backfill material was proven to be viable [5]. Some of such backfill material were also tested at high voltage level to investigate on its behaviour under high frequency, high magnitude voltage condition [6].

Vertically driven copper electrode is one of the most extensively chosen method due to its simplicity and relatively low cost [7]. The electrical equivalent circuit of single vertical electrode was modelled in [8]. Recent efforts to develop a simplified evaluation tool of earth resistance was proposed to allow quick estimation of several methods including vertically driven earthing electrode [9]. A mobile application which can be used to quickly verify the design of an AC substation earthing system was proposed [10].

Field study of the aforementioned method at sites with varying environmental factor was also conducted [7] [11]. Comparative study on using copper and galvanised iron as earth electrode was performed and discussed in [12] [13]. Fall of Potential method is used to perform such measurements.

The usage of copper as a material for earthing rod have been a popular choice as their characteristic of having high conductivity and low permeability properties. These advantages make it easier for copper-based earthing rod to discharge fault current back to the earth in the event of fault conditions. Copper is chosen also due to their ability to resist corrosion thanks to its neutral characteristic compared with other metals and most of earthing system in Malaysia use copper as their material for earth rod [13].

Apart from earth resistance, soil resistivity is another element that needs to be taken into consideration when designing an earthing system as it dictates the flow of fault current path to the earth surface whenever there are fault occurs in the electrical power system. Thus a low soil resistivity is crucial for earthing system reliability. Several factors that can affect the value of soil resistivity are discussed in [14] [15] [16] [17] [18] [19].

To ensure practicality and feasibility of a particular earthing method, the economic issue of escalation of material cost needs to be resolved. In line with such predicament, a novel earthing method of using hollow electrode is proposed in this paper. It is worth noting that no literature could be found on studying the efficacy of vertical hollow earthing electrode. BS 7430 groups both solid and hollow earthing electrode to be modelled by the same formula despite both having different geometry [2]. With this vacuum in knowledge gap in mind, this project is thus proposed to perform a comparative field study on both solid and hollow earthing electrodes.

3. Materials and Method

Before the study is being carried out, several factors were being considered to select a suitable site for the rod installation that includes [5]:

- Accessibility and safety.
- Area of free space presence at the site for rod installation purposes.
- Site soil resistivity value.

Referring to the foregoing points, two sites have been identified and selected for the experiment. These two sites are located within the vicinity of Multimedia University Cyberjaya campus (Site 1) and University Putra Malaysia (Site 2). The details about the sites are presented below:

- Site-1: Located at 2°55'42.7"N 101°38'19.8"E with rich vegetation and some large trees in its vicinity with a small slope that divides the site into lower level and upper level as shown in Fig. 1.
- Site-2: Located at 2°59'35.0"N 101°43'28.2"E with extremely dry and hard soil which has no vegetation in its vicinity as shown in Fig. 2.

Site 1 was chosen due to its relatively low soil resistivity value, typically lower than 100Ωm. Another factor was to observe the performance of hollow copper rod in soft and low resistivity soil and making comparison with solid copper rod performance. The rods installed in this site were labelled as Rod A1 - A5. Site 2 was chosen so as to make a comparison between the performance of hollow copper rod with solid copper rod at dry, rocky and hard soil condition which is indicative of high soil resistivity. The rods installed in this site were labelled as Rod B1 - B2. Note that a series of soil resistivity measurement was conducted prior to the identification of Site 1 as the site with low soil resistivity and Site 2 as the site with high soil resistivity. In fact, previous work has already indicated Site 2 is of high soil resistivity [5].

Fig. 1 - Satellite view of Site 1

Fig. 2 - Satellite view of Site 2

Solid copper-bonded rods having the length of 1.5 m and diameter of 15 mm were installed in the sites as shown in in Fig. 3 to Fig. 5. Hollow rods of similar length and total diameter were also installed as shown in Fig. 3 to Fig. 5. The hollow rods have internal and external diameter of hollow copper rod of 13 mm and 2 mm respectively. Internal diameter implies the diameter of the hollow cross section of the copper rod while the external diameter is the thickness of the hollow copper rod which is about 2 mm.

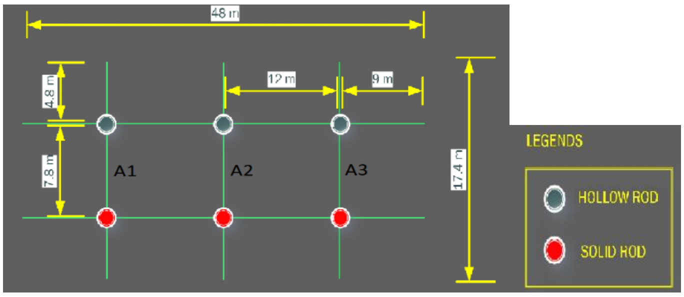

Fig. 3 - Rod configuration at lower level area of Site 1

Ten rods which consists of five solid and five hollow copper rods were installed in Site 1. Site 1 is divided into two zones. The first zone as shown in Fig. 3 is located at the bottom area of a mini slope (lower level area) while the second zone as shown in Fig. 4 is located at the upper area of the same mini slope. At the lower level area, three pairs of rods (A1, A2 and A3) were installed with each rod separated by 7.8 m while each pair of the rods were separated by 12 m as shown in Fig. 3. Rods in the upper level were separated by 8 m for both pairs of rods as shown in Fig. 4.

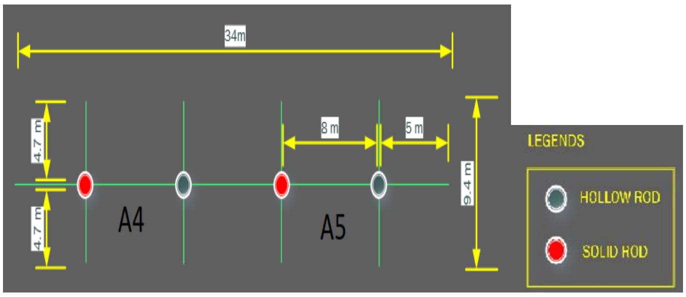

Fig. 4 - Rod configuration at upper level area of Site 1

In Site 2, four rods were installed that comprise of two pair of rods as shown in Fig. 5. The distance of each rods and the pair of rods were set to 4.5 m. The depth of the rods was also fixed at 0.9 m.

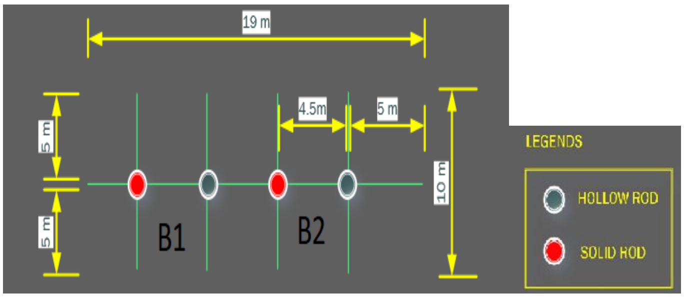

Fig. 5 - Rod configuration at Site 2

All of the aforementioned rods were buried up to a depth of 0.9 m.

Wenner 4-pole method was used to measure the soil resistivity profile for both sites [20]. Measurements were taken once to twice a week for a period of seven months and the average soil resistivity was 54 Ωm for Site 1 and 2000 Ωm for Site 2. Earth resistance measurements based on the Fall of Potential method were also taken once to twice a week over seven months. The distance from rod to the voltage probe was kept at 5m while the current probe was placed a further 5m away from the voltage probe in a straight line as described in [5].

4. Results and Discussions

Fig. 6 to Fig. 10 show the measured values of earth resistance for all rods (A1-A5) located at Site 1. The measurement period spans over seven months. In general, the earth resistance is lower during October-January compared to July-August period for both hollow and solid rods most probably due to the surrounding soil of the rods have compacted progressively as time advances and also the tendency to have higher amount of rainfall towards the last quarter of the year. It can be seen that hollow rods exhibited lower earth resistance compared to solid rods in three out of five scenarios namely A1, A3 and A5. This is interesting as it was initially hypothesized that the performance of both type of rods is expected to be similar.

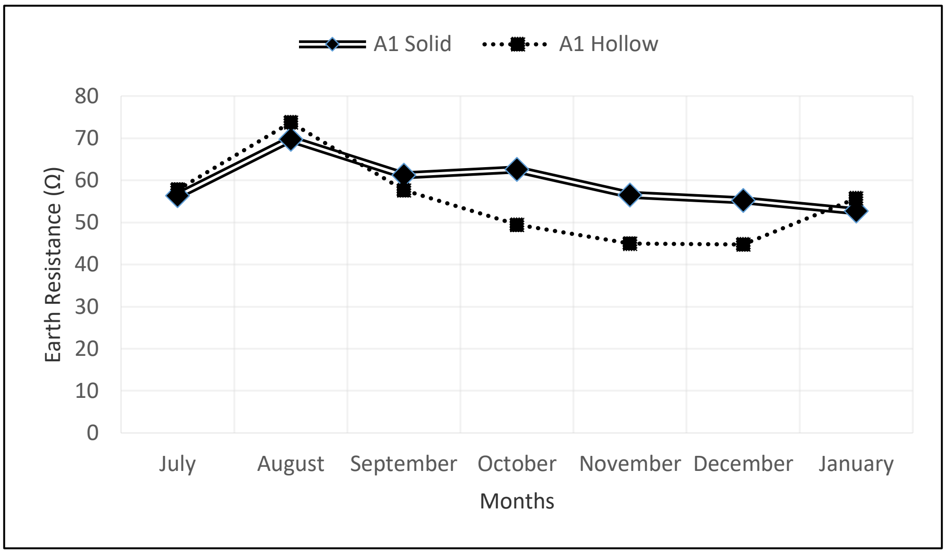

Fig. 6 - Earth resistance of rods A1

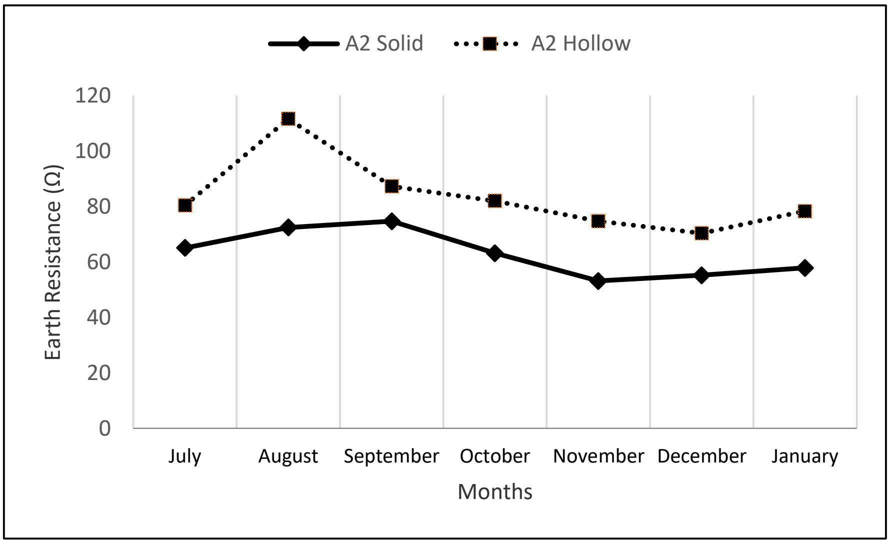

Fig. 7 - Earth resistance of rods A2

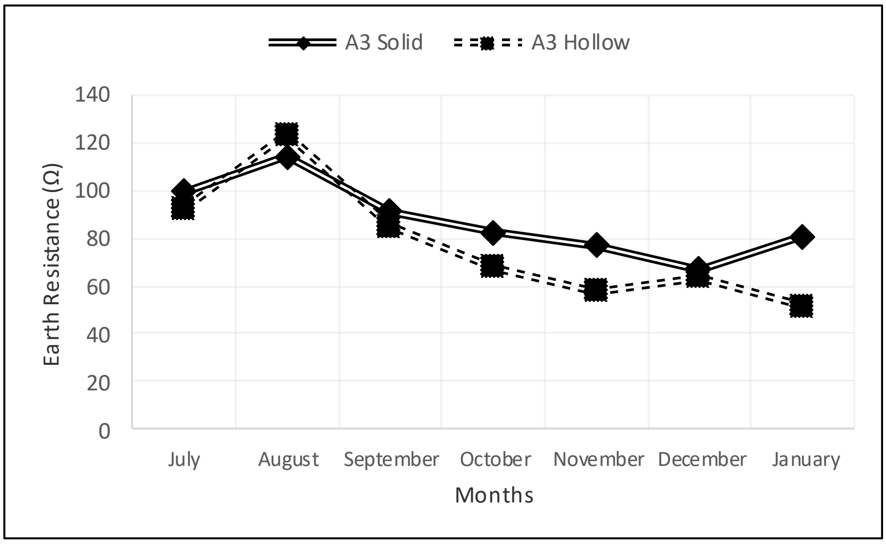

Fig. 8 - Earth resistance of rods A3

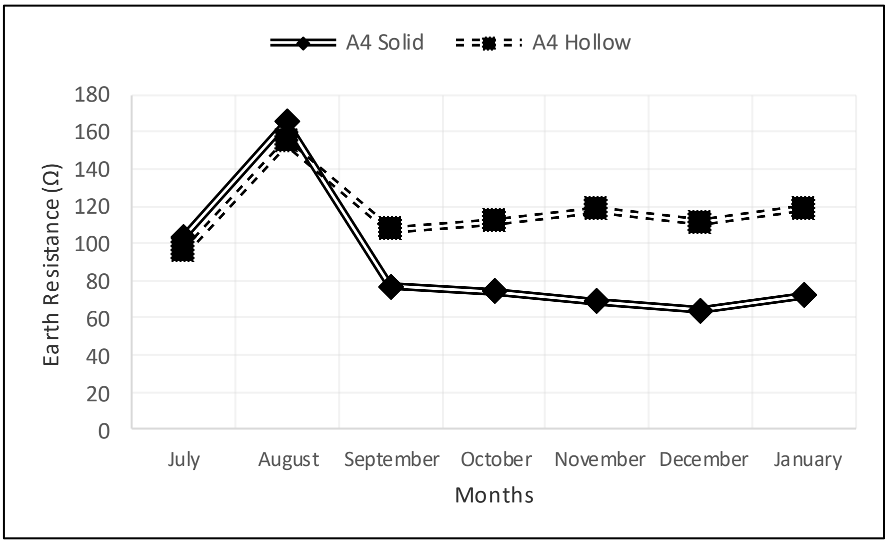

Fig. 9 - Earth resistance of rods A4

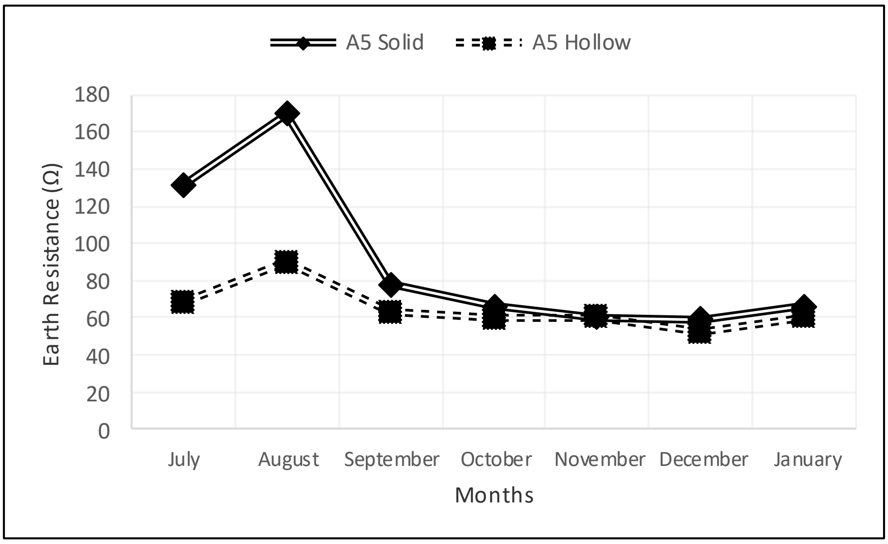

Fig. 10 - Earth resistance of rods A5

Fig. 11 and Fig. 12 shows the earth resistance of all copper rods in Site 2. Unlike Site 1, Site 2 has significantly higher soil resistivity resulting in much higher earth resistance value. The soil texture in Site 2 was significantly drier and harder. Instead of directly hammering the rods into the soil as per the practice in Site 1, the soil in Site 2 had to be drilled first before rod installation can be conducted. Fragments of rock were drilled through throughout the installation process. Once again, the hollow copper rods consistently demonstrated lower earth resistance value than solid copper rods. Table 1 summarised the average earth resistance of each rod over the stipulated measurement period.

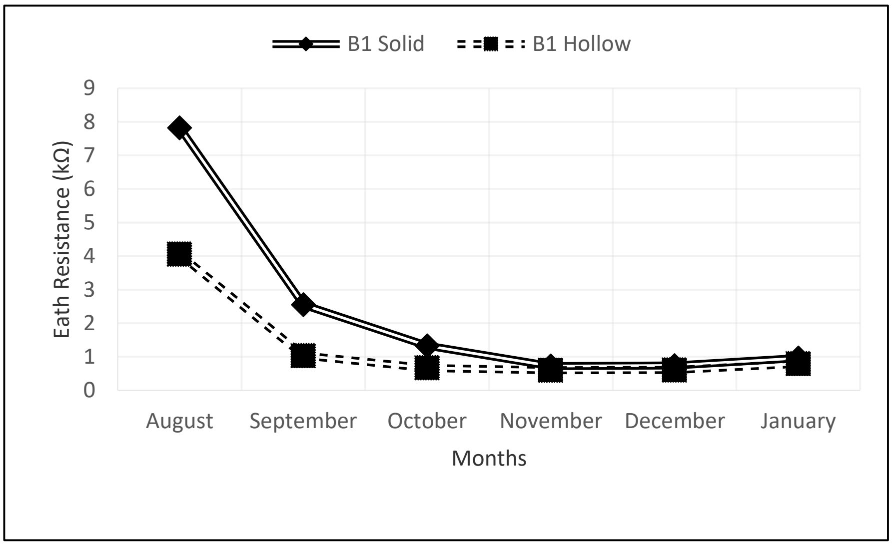

Fig. 11 - Earth resistance of rods B1

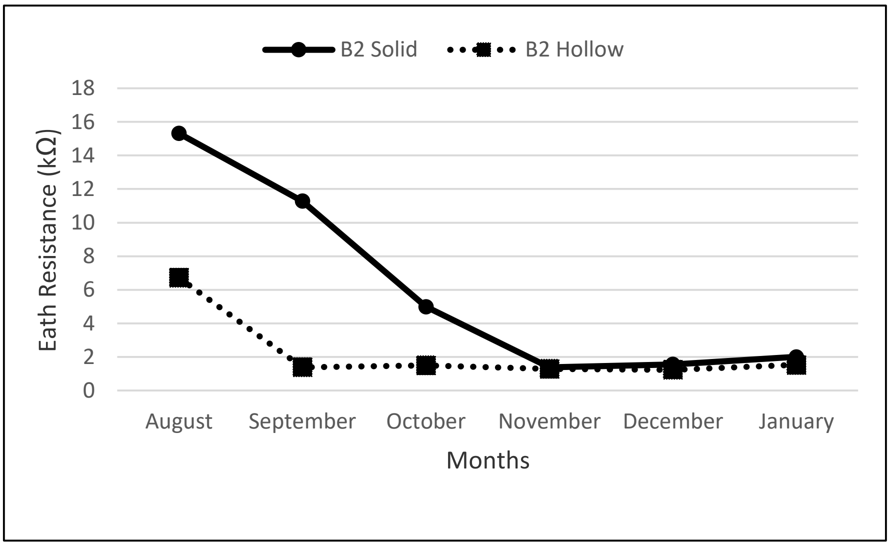

Fig. 12 - Earth resistance of rods B2

Table 1 - Average earth resistance of all rods

Rod	Solid (Ω)	Hollow (Ω)
A1	58.5	53.5
A2	63.1	83.5
A3	87.4	77.3
A4	89.3	116.8
A5	91.6	66.2
B1	2351.8	1287.1
B2	6085.1	2274.5

Independent t-test was then performed to determine whether there is any statistically significant difference in the earth resistance of solid and hollow copper rod for all pairs. Levene's test for equality of variances was used in independent t-test to determine the significant differences between those two rods. If the value of sig. (2-tail) is lower than 0.05, the null hypothesis can be rejected and this indicates that there is a statistically significant difference between the earth resistance of solid and hollow copper rods.

All of the rods in Site 1 were significantly different with each other by having their sig. (2-tail) values less than 0.05 as shown in Table 2. Thus, it showed that three out five rods that were having lower earth resistance value for hollow copper rod were significantly different with the solid copper rod. In Site 2, only rods B2 demonstrated that there is statistically significant difference between the earth resistance of solid and hollow rods as shown in Table 3.

Table 2 - Independent t-test on the earth resistance of rods at Site 1

Rod	Equal Variance Assumption	Sig.	t	df	Sig. (2-tail)
A1	Yes	0.119	2.023	68	0.047
	No		2.023	58.462	0.048
A2	Yes	0.048	-5.498	68	0.000
	No		-5.498	50.812	0.000
A3	Yes	0.035	2.139	68	0.036
	No		2.139	55.828	0.037
A4	Yes	0.003	-3.362	68	0.001
	No		-3.362	54.914	0.001
A5	Yes	0.000	2.989	68	0.004
	No			43.354	0.005

Table 3 - Independent t-test on the earth resistance of rods at Site 2

Rod	Equal Variance Assumption	Sig.	t	df	Sig. (2-tail)
B1	Yes	0.123	1.389	36	0.173
	No		1.389	24.281	0.173
B2	Yes	0.000	2.746	36	0.009
	No		2.746	24.280	0.011

Based on Table I, five out of seven pair of hollow rods actually have lower earth resistance than solid rods. Possible explanation is due to the hollow rods having larger effective contact surface area with the surrounding soil than solid rods. However, this trend can only be ascertained with an extended measurement period.

5. Conclusions and Further Research

In this project, it was found that the performance of both solid copper rod and the hollow copper rod is indeed statistically and significantly different. Hollow copper rod actually demonstrates lower earth resistance than solid copper rod in most of the cases. It is possible that the effective contact surface area between the hollow electrode and the surrounding soil is larger than solid electrode resulting in a lower earth resistance as seen in five of the seven pairs of rods. This warrants further investigation at prolonged measurement period. It would also be interesting to investigate the behaviour of hollow rods when subjected to high current and high voltage impulse to attempt to understand its response to lightning strike.

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