Comparative field assessment of grounding enhancement material for electrical earthing system

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ABSTRACT

Grounding enhancement material (GEM) is used to lower the earthing resistance value of a given earthing system. In this paper, a commercially available GEM is experimented at the field alongside with Sodium Chloride, Copper II Sulphate and planting soil. The well established Wenner's 4 pole method and fall of potential method was employed to measure the soil resistivity and earthing resistance respectively. It was found that the salts i.e., Sodium Chloride and Copper II Sulphate are superior in reducing the earthing resistance as reduction of more than 85% were observed. However, the commercial GEM has exhibited the most stable earthing resistance value over a period of 101 days, exhibiting the lowest standard deviation. This seems to suggest that the commercial GEM has superior moisture retention capability. This study also proven that Sodium Chloride can be dissolved by heavy downpour and replenishing it periodically is needed in a tropical country like Malaysia with regular thunderstorms and heavy downpours.

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1. INTRODUCTION

Electrical earthing system is vital to ensure the safety of equipment and human. Ideally, the lower the earthing resistance is the better as it can then efficiently channel any fault current or excessive charge due to lightning strike to be neutralised by the surrounding soil i.e., the earth [1]. In certain countries, it is a regulatory requirement for the earthing system of an electrical installation to achieve a certain low-level earthing resistance [2]. For instance, the earthing resistance for domestic and commercial installations should not exceed 10 Ω in Malaysia [3], [4]. To accomplish the goal, one can either locate a site with low soil resistivity or maximise the dimension of the earthing electrodes. In the former alternative, most of the time the electrical engineer involved in the designing and installation of the earthing system would not have much control as the location of the building or facility is already decided by the developer or client. To further compound the matter, it was found that localized soil resistivity value differs significantly from the average soil resistivity value of a given plot of land [1]. In the case of the latter, space constraint could be an obstacle on top of rising copper price which has motivated a recent study on the application of hollow electrodes [5].

Fortunately, there is another approach that could assist to lower the earthing resistance without facing the limitation affecting the first two solutions which is by using grounding enhancement materials (GEM). The interests in using GEM in the design of grounding systems are due to challenges in the accessibility of the land, mainly due to limited available ground area which can be due to the costs, utilisation for underground cables and other services and greater development in housing/building developments, making it difficult to achieve a low earthing resistance value. With this limited ground space available, and other factors such as high soil resistivity and high fault currents, GEM can be a low cost and an effective solution to achieve a sufficiently low earthing resistance value [6].

Over the past decade, much research has been conducted to investigate the comparative performance of several types of GEM. Numerous studies on the use of of GEM to improve the surrounding soil, whether by field or laboratory measurements which include the studies of various types of GEM, corrosion study of the GEM, behaviour of GEM at high voltage, and optimisation of the use of the GEM in the design of grounding systems [7]–[13]. Bentonite-mixed concrete was extensively studied as GEM in [6]. Another study experimented with Bentonite-kenaf mixture as GEM [14].

In the industry, it is common practice to use salt as GEM especially by the electrical contractors. However, it is known that salt is only a short-term solution as it gets drained away fairly quickly although it could lower the earthing resistance within a short time [15]. In Malaysia, a commercially available GEM has gained market acceptance among the practicing engineers. Yet, there is no actual field study being conducted to investigate its effectiveness. Hence, this serves as the motivation of this paper which is to make available the pertinent information of the comparative performance of three types of GEM namely a commercially available GEM, Sodium Chloride, and Copper II Sulphate. Firstly, the procedures involved in setting up the experimental sites were explained. Then, the method used to measure the earthing resistance was debriefed. Finally, the measured results were analysed.

2. METHOD

The experimental site is located at a vacant plot of land in Multimedia University (GPS coordinates: 2.930643, 101.639971) with the configuration as shown in Figure 1. The field test area of the site is measured as 5390 m^2, (70 m × 77 m). Then the soil resistivity of the area is taken by using the Wenner method as described in IEEE 81-2012 along the traverses R1, R2, and R3 [16]. The measured soil resistivity values were then used to run simulation in CDEGS software to determine the characteristics i.e., the number of layers of soil of the site. The location of the grounding system each filled with different ground enhancement materials are on the traverses of R1 and R3, placed 30 m apart from each other. The reason for placing the grounding systems 30 m apart from each other is to provide adequate space to prevent cross-effect on the earthing resistance as recommended in [17].

Figure 1. Experimental site

A hole with the diameter of 7 cm is then augered 30 cm below ground level to a depth of 14 cm as shown in Figure 2(a). The installation plan in Figure 2(b) illustrates the side view of the grounding system installation. A 1.5 m copper rod was fixed in the centre of the auger hole and the surrounding of the copper rod was filled with GEM. 5 cm of the copper rod will be covered by the GEM in the 30 cm trench and 10 cm of the copper rod will be exposed from the GEM as shown in Figure 2(c). The earthing system is then covered to resemble an earth chamber as shown in Figure 2(d). Note that the installation methods are as per recommended by the manufacturer's datasheet.

The GEMs were then installed according to the site installation plan in Figure 1. System 1 is installed with a commercially available GEM in Malaysia (the brand or name of the manufacturing company is not provided to preserve neutrality), system 2 is installed with Copper II Sulphate salt, system 3 is installed with Sodium Chloride salt and system 4 is filled with planting soil. Note that the authors do not have access to the information of the exact composition of materials used to manufacture the commercial GEM. However, the manufacturer claims that the resistivity of the commercial GEM in powder form is less than 2 Ωcm. Finally, the earthing resistance of each setup is then measured using the fall-of-potential (FoP) as per [18] on a fortnightly basis.

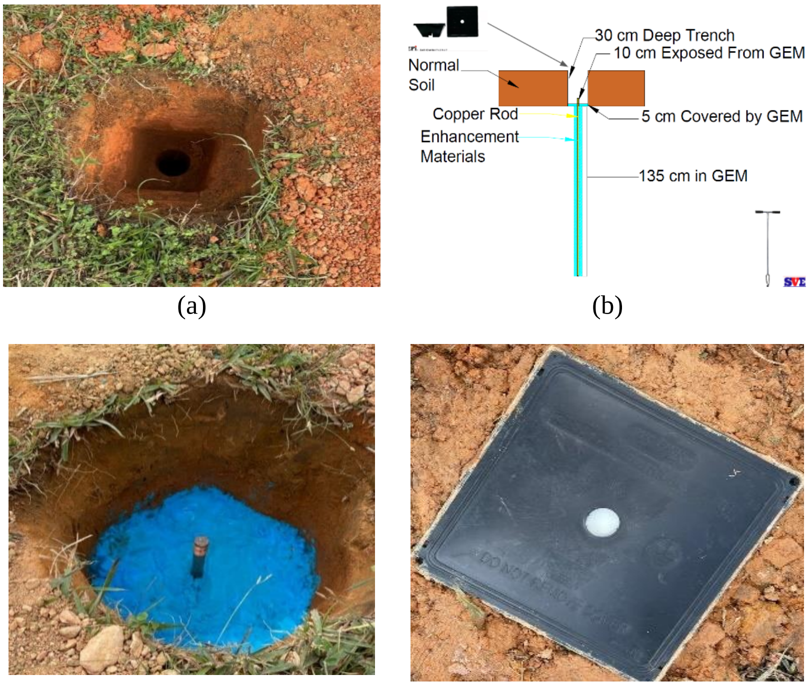

Figure 2. Design and installation of the experimental setup; (a) earthing pit for GEM, (b) side view of each pit, (c) the exposed rod above one of the earthing pits, and (d) earthing chamber

3. RESULTS AND DISCUSSION

Figure 3 shows the result of CDEGS simulation of the soil using the measured soil resistivity values. It can be clearly observed that the soil has 3 distinct layers excluding the air layer. The authors would like to advocate for the industry to study the characteristic of the soil by also determining the number of layers so that the earthing system can be designed in such a way where a significant portion of the electrodes are in contact with the soil layer of the least resistivity. Figures 4 to 7 illustrate the variation in earthing resistance against the probe distance before and 101 days after the installation of the respective earthing systems.

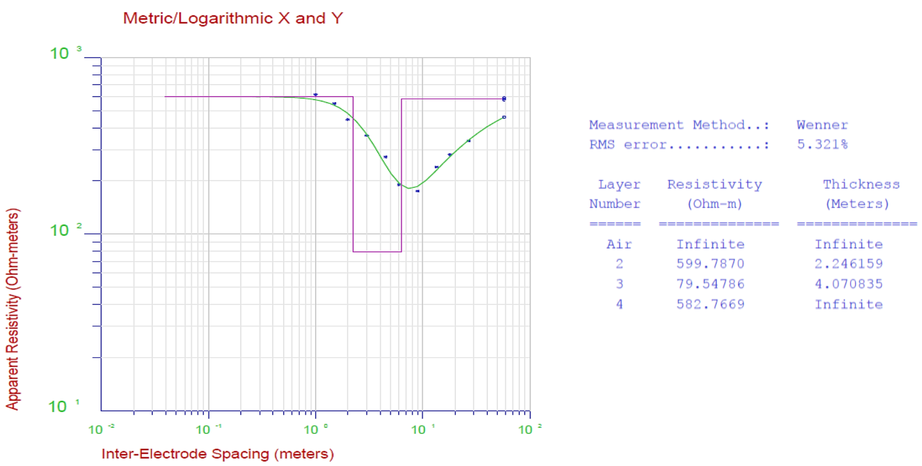

Figure 3. CDEGS simulation of the soil

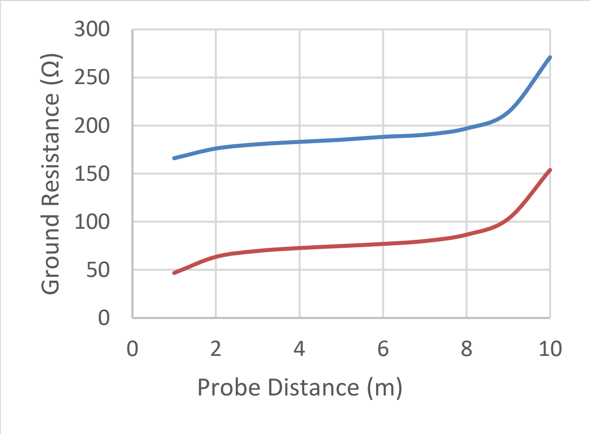

Figure 4. Earthing resistance before (blue line) and after the installation (red line)

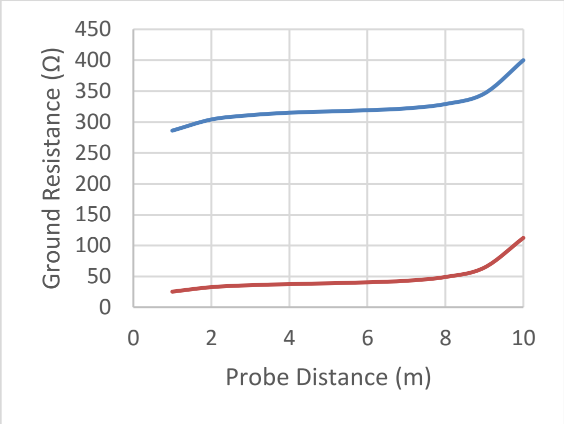

Figure 5. Earthing resistance before (blue line) and after the installation of Copper II Sulphate (red line)

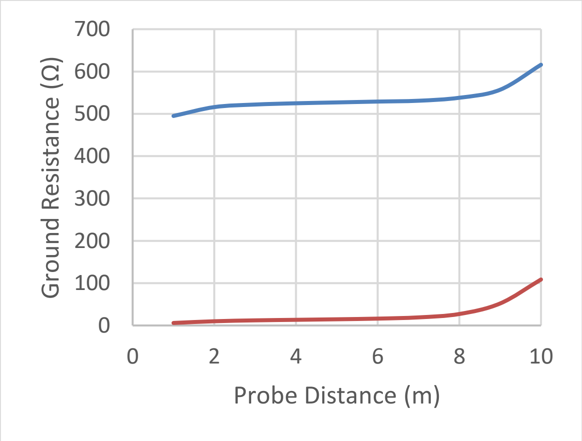

Figure 6. Comparison of the earthing resistance before (blue line) and after the installation of Sodium Chloride (red line)

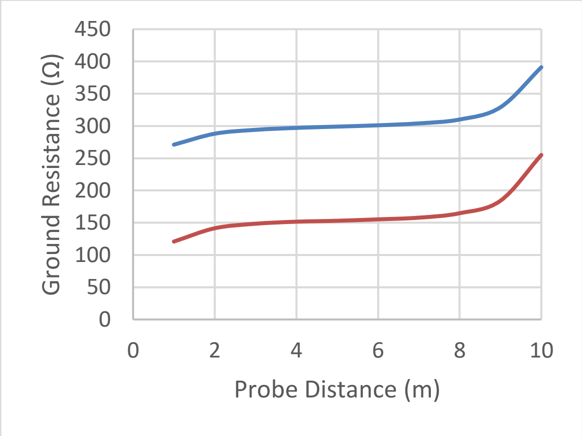

Figure 7. Comparison of the earthing resistance before (blue line) and after the installation of Planting Soil (red line)

Based on Figure 8, the graph displayed shows that the commercial GEM has the smoothest line which indicates that once the material installed has taken the time to set in, it is relatively stable and not highly affected by the weather. This point can be further supported by the fact that the commercial GEM only takes up to 9 days to set in completely, unlike the earthng system with Copper II Sulphate which stabilise around 31 days after installation. In terms of the ability to lower the earthing resistance, the earthing system with Sodium Chloride has the highest percentage reduction in value, i.e., -96.40%, at the end of the research as deducible from Figure 6. However, as shown in Figure 9, after a heavy rain before day 72, the Sodium Chloride installed earthing system seems to have been flooded with water which is safe to assume that part of the Sodium Chloride has been dissolved by the rain water. Hence, the great ability of the Sodium Chloride in reducing the earthing resistance of a grounding system shall be assessed with a longer timeline as replenishing of the material may be needed. Industrial practitioner should be mindful of the possibility of salts being dissolved by rainwater as this would mean that the effectiveness of this type of GEM will be significantly affected over time. In addition, it is also an established fact that salts such as Sodium Chloride are highly corrosive to the earthing electrodes [18].

The earthing system with Copper II Sulphate as GEM comes in second with -86.68% reduction at day 101. The earthing system with Copper II Sulphate has no visible physical changes compared to the Sodium Chloride installed system. As for the planting soil, it is the worst material of the foure in terms of its ability to reduce the earthing resistance. The earthing resistance of the system with planting soil is only reduced by 48% at the final day of measurement as compared to a 60% reduction by the commercial GEM. The ability to retain moisture is also not as good as the GEM installed grounding system. In a nutshell, while GEM did not exhibit the greatest ability in lowering the earthing resistance, it is superior at stabilizing the earthing resistace due to its moisture retention ability. Table 1 summarises the standard deviation of the variation of earthing resistance for the experimental setups. These findings further reinforced the observations made in [6].

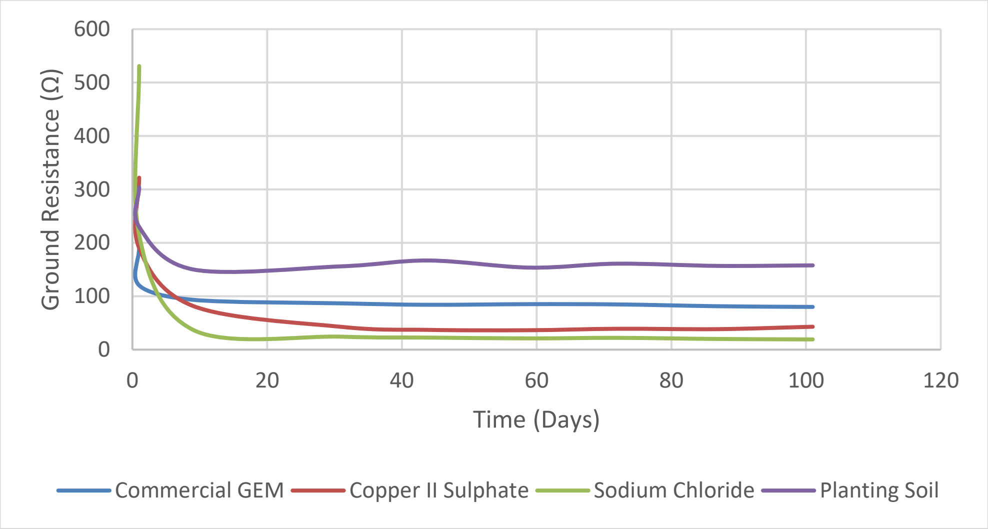

Figure 8. Earthing resistance of various GEM against time (days)

Figure 9. Earthing system with Sodium Chloride on day 72

Table 1. Fluctuation of earthing resistance

Type of GEM	Standard deviation (Ω)
Commercial GEM	36
Copper II Sulphate	100
Sodium Chloride	173
Planting soil	52

Moving forward, the effort to invent newer and better GEM should be continued. While there have been novel mixtures of Bentonite with other material which yield promising results at the laboratory, it has yet to be tested at the field [19], [20]. Field test is crucial to gain confidence of their actual performance once being deployed. Furthermore, the behavior of GEM under high current and transient events should be studied and assessed as these materials should also maintain its ability to reduce earthing impedance during lightning strike. The experimental setup in [11] can be replicated with high impulse current generator instead. This is because the efficacy of a lightning protection system also heavily relies upon the effectiveness of the earthing system [21]. Recent work in [22], [23] offered encouraging insights into the behavior of Bentonite and its various mixtures under high voltage AC and DC to be used as GEM for portable grounding applications. With more evidence in the literature supporting the effectiveness of GEM in improving electrical earthing system, it can be implied that application of GEM can contribute towards reduction of risk associated with the hazards and potential damage arising from lightning strike [24], [25].

4. CONCLUSION

To conclude, it was shown that the application of GEM does results in significant reduction of earthing resistance of a given earthing system. While the commercial GEM lacks in terms of absolute earthing resistance reduction ability compared to the salts i.e., Sodium Chloride (reduction of 96%) and Copper II Sulphate (reduction of 86%), it is superior in terms of minimizing the fluctuation in earthing resistance value over time as evidenced in its lowest standard deviation of its variation of earthing resistance. In addition, it was proven that Sodium Chloride is easily dissolved after heavy downpour which warrants immediate attention among practitioners such as electrical contractors who are strong advocates of the use of it to immediately reduce the earthing resistance to comply with regulatory requirement. Extra precaution has to be taken such as periodic replenishing of Sodium Chloride salt needs to be undertaken to ensure that its effectiveness as GEM is maintained. Otherwise, in terms of maintaining a stable earthing resistance, the commercial GEM seems to be a better alternative.

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REFERENCES

[1] S. C. Lim, C. Gomes, G. Nourirad, and M. Z. A. A. Kadir, “Significance of localized soil resistivity in designing a grounding system,” in *2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014)*, pp. 324–329, Mar. 2014, doi: 10.1109/PEOCO.2014.6814448.

[2] L. S. Toh and K. W. Leong, “Foundation Earthing System – Its Application and Electrical Safety Considerations,” *The Journal of The Institution of Engineers, Malaysia*, vol. 83, no. 1, Jul. 2023, doi: 10.54552/v83i1.172.

[3] S. Malaysia, “MS 1936 2016 Electrical installations of building-Guide to MS IEC 60364 (First revision),” *Department of Standards Malaysia*, pp. 49–50, 2016. [Online]. Available: http://www.doc88.com/p-2146485246914.html.

[4] M. Standard, “MS 1979: 2015 Electrical Installations of Buildings – Code of Practice,” *Department of Standards Malaysia*, pp. 5–21, 2015, Accessed 25 July 2023.

[5] S. C. Lim, T. H. A. B. T. Mohamad, C. Gomes, and W. F. W. Ahmad, “On the application of hollow conductor as electrical earthing electrode,” *International Journal of Integrated Engineering*, vol. 14, no. 6, pp. 184–193, Nov. 2022, doi: 10.30880/ijie.2022.14.06.016.

[6] S. C. Lim, M. Z. A. Ab Kadir, C. Gomes, and N. Azis, “Steady state performance of improvised ufer grounding practice,” in *2014 International Conference on Lightning Protection, ICLP 2014*, pp. 572–580, Oct. 2014, doi: 10.1109/ICLP.2014.6973190.

[7] F. M. S. Sinchi, F. A. P. Quizhpi, H. P. C. Guillen, and S. N. N. Quinde, “Soil treatment to reduce grounding resistance by applying low-resistivity material (LRM) and chemical ground electrode in different grounding systems configurations,” in *2018 IEEE International Autumn Meeting on Power, Electronics and Computing, ROPEC 2018*, Nov. 2018, pp. 1–6, doi: 10.1109/ROPEC.2018.8661403.

[8] I. G. N. S. Hernanda, A. B. Ksatria, I. M. Y. Negara, I. P. C. Suardana, D. A. Asfani, and P. J. Mirnafandi, “Effect of Grounding Rods Position and Fly Ash Material on Grounding Resistance in Limestone Soil,” in *2022 International Seminar on Intelligent Technology and Its Applications: Advanced Innovations of Electrical Systems for Humanity, ISITIA 2022 - Proceeding*, Jul. 2022, pp. 371–376, doi: 10.1109/ISITIA56226.2022.9855301.

[9] Z. Zhang, P. Gao, J. Zou, G. Liu, Y. Dan, and D. Mei, “Study on alternating current corrosion of carbon steel grounding electrode,” in *Proceedings of 4th IEEE International Conference on Applied System Innovation 2018, ICASI 2018*, pp. 385–388, Apr. 2018, doi: 10.1109/ICASI.2018.8394263.

[10] O. Kherif, S. Robson, A. Haddad, and D. Thorpe, “On the optimization of Grounding Design of Rods Covered by Low Resistivity Materials,” in *2022 57th International Universities Power Engineering Conference: Big Data and Smart Grids, UPEC 2022 - Proceedings*, pp. 1–6, Aug. 2022, doi: 10.1109/UPEC55022.2022.9917937.

[11] S. C. Lim, C. Gomes, M. Z. A. A. Kadir, G. Nourirad, and Z. A. Malek, “Behaviour of backfill materials for electrical grounding systems under high voltage conditions,” *Journal of Engineering Science and Technology*, vol. 10, no. 6, pp. 811–826, 2015.

[12] R. Wang, C. Chen, J. Li, and Y. Song, “The effect of salinity on the resistivity of frozen soil,” *ECITech 2022 - 2022 International Conference on Electrical, Control and Information Technology*, pp. 750–753, 2022.

[13] N. A. F. M. Nasir *et al.*, “Effect of earthing enhancing compound (EEC) on improving tower footing resistance of a 500 kV tower in a rocky area,” *Applied Sciences (Switzerland)*, vol. 11, no. 12, p. 5623, Jun. 2021, doi: 10.3390/app11125623.

[14] W. F. H. W. Ahmad, M. H. M. Roslan, J. Jasni, and M. Z. A. Ab-Kadir, "Performance of Bentonite and Kenaf Mixtures as Grounding Enhancement Materials," in *APL 2023 - 12th Asia-Pacific International Conference on Lightning*, pp. 1–5, Jun. 2023, doi: 10.1109/APL57308.2023.10181500.
[15] W. W. Ahmad, K. H. Tan, M. Z. A. A. Kadir, and J. Jasni, "Performance of Sodium Chloride, Bentonite and Conductive Cement as Grounding Enhancement Materials," *2015 Asia-Pacific International Conference on Lightning*, pp. 23–27, 2015.
[16] IEEE 81, "IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System," *IEEE Std 81-2012 (Revision of IEEE Std 81-1983) - Redline*, vol. 2012, no. December, pp. 1–192, 2012, doi: 10.1109/IEEESTD.2012.6392181.
[17] IEEE, "IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems," *IEEE Std 142-2007 (Revision of IEEE Std 142-1991*, pp. 1–225, 2007, doi: 10.1109/IEEESTD.2007.4396963.
[18] V. P. Androvitsaneas, I. F. Gonos, and I. A. Stathopulos, "Research and applications of ground enhancing compounds in grounding systems," *IET Generation, Transmission and Distribution*, vol. 11, no. 13, pp. 3195–3201, Sep. 2017, doi: 10.1049/iet-gtd.2017.0233.
[19] E. Al-Ammar, Y. Khan, N. Malik, and N. Wani, "Development of low resistivity material for grounding resistance reduction," in *2010 IEEE International Energy Conference and Exhibition, EnergyCon 2010*, pp. 700–703, Dec. 2010, doi: 10.1109/ENERGYCON.2010.5771771.
[20] R. Ahmad *et al.*, "Simulation and breakdown characteristics of china clay and silica sand for improved grounding system," in *2nd International Conference on Electrical, Communication and Computer Engineering, ICECCE 2020*, pp. 1–6, Jun. 2020, doi: 10.1109/ICECCE49384.2020.9179377.
[21] S. C. Lim, M. Z. Ab Kadir, C. Gomes, and J. Jasni, "Ambiguity of grounding specifications: IEC 62305 revisited," in *2012 31st International Conference on Lightning Protection, ICLP 2012*, pp. 1–6, Sep. 2012, doi: 10.1109/ICLP.2012.6344293.
[22] R. Ahmad *et al.*, "Application of mineral compounds for a high-voltage portable grounding system: An experimental study," *Electronics (Switzerland)*, vol. 10, no. 16, p. 2043, Aug. 2021, doi: 10.3390/electronics10162043.
[23] R. Ahmad, F. Khan, I. Ullah, N. Ahmad, S. Khan, and B. Khan, "Portable Grounding System using Backfill Materials," in *4th International Conference on Power Generation Systems and Renewable Energy Technologies, PGSRET 2018*, pp. 1–5, Sep. 2019, doi: 10.1109/PGSRET.2018.8686033.
[24] A. Aizat, N.A. Ahmad, L. K. Yiew, and Z. Abdul-Malek, "The Use of Enhancement Material in Grounding System: A Review," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 13, no. 2, p. 453–460, Feb. 2019, doi: 10.11591/ijeecs.v13.i2.pp453-460.
[25] M.A. Malelak and R. Zoro, "Lightning Protection System for High Voltage Transmission Line in Area with High Grounding Resistance," in *International Conference on High Voltage Engineering and Power Systems, ICHVEPS 2017*, pp. 350-355, Oct. 2017, doi: 10.1109/ICHVEPS.2017.8225869.

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