UNIVERSITI PUTRA MALAYSIA

COMPARATIVE STUDY ON THE PERFORMANCE OF BENTONITE, KENAF AND ZEOLITE TO REDUCE EARTH RESISTANCE OF GROUNDING SYSTEMS

LAI WAI LUEN

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By

LAI WAI LUEN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Chair : Wan Fatinhamamah Wan Ahmad, PhD
Faculty : Engineering

Grounding systems are designed to dissipate high magnitude fault current to earth and provide safety to persons working in or living near power system installations. It is also necessary that grounding systems are designed with low-magnitude earth impedance path so that the high magnitude and fast transient surges are dissipated to earth as fast as possible. Therefore, the performance of the grounding system must be in a top-notch condition as it governs the efficiency of the grounding system itself. Based on the local and international grounding standards, it recommended a minimum value of earth resistance need to be achieved for the grounding system to reach a top-notch condition. However, it is difficult to reach low earth resistance in ordinary soil condition as there are variation of soil resistivity from one place to another. Hence, the main objective of this study is to investigate the performance of natural enhancement materials in reducing the earth resistance of the installed grounding systems.

The experimental investigations on earth rod grounding system based on soil enhancement was carried out at the site located nearby School of Graduate Studies, UPM, Serdang, Selangor. This experiment was implemented by drilling thirteen cylindrical hollow hole with dimension of 0.13m diameter and 1.5m depth which were each of them filled with different ratio of natural enhancement materials, i.e. Bentonite, Kenaf and Zeolite. After that, thirteen of solid copper earth rod were driven into the centre of each cylindrical hollow hole to a depth of 1.4m. Also, there was another earth rod which was installed without any enhancement material around for comparison purposes. All the copper earth rods utilized were in the similar dimension of 0.013m diameter and 1.5m length. Note that, for all 14 grounding systems, the earth rod is only driven up to the depth of 1.4m with 0.1m allowance for earth resistance measurement purposes. At last, the concrete earth chambers were placed on all the installed grounding

systems. Earth resistance measurement was conducted using a 3 point fall of potential method on daily basis for a period of one year.

Over a year, the results of earth resistance measurements indicated that the best performed grounding system was Bentonite installation with highest reduction of earth resistance of 76% compared to the reference grounding system at day-0. While, for the worst performed grounding system, it was the mixture of Kenaf and Zeolite installation (with ratio of 30:70) with percentage of increment of earth resistance of 13% when compare with the reference grounding system at day-0. Furthermore, from the results, it is discovered that the increase of the amount of Kenaf or Zeolite used in the mixture of natural enhancement material for grounding system can leads to a reduction of earth resistance but much less effective compared to increase the amount of Bentonite used. The results also shows that Zeolite and Kenaf were not suitable to be used individually or mixed together as they present a poor performance. In conclusion, this study proves that Bentonite are still a better choice as an individual or mixed material for reduction of earth resistance compared to Kenaf and Zeolite.

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KAJIAN PERBANDINGAN TERHADAP PRESTASI BENTONIT, KENAF DAN ZEOLIT UNTUK MENGURANGKAN RINTANGAN SISTEM PEMBUMIAN

Oleh

LAI WAI LUEN

November 2018

Pengerusi : Wan Fatinhamamah Wan Ahmad, PhD
Fakulti : Kejuruteraan

Sistem pembumian direka untuk menghilangkan magnitud tinggi arus gagal ke bumi dan memberi keselamatan kepada orang yang bekerja di dalam atau yang tinggal berhampiran pemasangan sistem kuasa. Ia juga harus berada dalam magnitud galangan yang rendah supaya magnitud yang tinggi dan pusuan fana pantas dapat dilesapkan ke bumi secepat mungkin. Oleh itu, prestasi sistem pembumian mesti berada dalam keadaan terkemuka kerana ia mengawal kecekapan sistem pembumian itu. Berdasarkan piawaian asas tempatan dan antarabangsa, ia disyorkan nilai minimum rintangan bumi perlu dicapai untuk sistem pembumian mencapai keadaan yang terkemuka. Walau bagaimanapun, pencapaian rintangan bumi yang rendah dalam keadaan tanah biasa adalah sukar kerana perubahan rintangan tanah dari satu tempat ke tempat lain. Oleh itu, objektif utama kajian ini adalah untuk mengkaji prestasi bahan peningkatan semula jadi dalam mengurangkan rintangan sistem pembumian yang dipasang.

Siasatan eksperimen terhadap sistem rod pembumian berdasarkan peningkatan tanah telah dijalankan di tapak berdekatan Sekolah Pengajian Siswazah, UPM, Serdang, Selangor. Eksperimen ini telah dilaksanakan dengan penggerudian tiga belas lubang silinder yang berdimensi 0.13m diameter dan 1.5m kedalaman serta masing-masing dipenuhi dengan nisbah yang berbeza bahan peningkatan semula jadi, iaitu Bentonit, Kenaf dan Zeolit. Selepas itu, tiga belas rod tembaga bumi dipasang ke tengah setiap lubang silinder ke kedalaman 1.4m. Selain itu, terdapat satu lagi rod bumi yang dipasang tanpa apa-apa bahan peningkatan di sekitar kawasan rod bumi untuk tujuan perbandingan. Semua rod tembaga bumi digunakan adalah dalam dimensi yang sama iaitu diameter 0.013m dan panjang 1.5m. Ambil perhatian bahawa, untuk semua 14 sistem pembumian, rod bumi hanya dipasang sehingga kedalaman 1.4m dengan 0.1m peruntukan untuk tujuan pengukuran rintangan bumi. Akhirnya, ruang bumi konkrit telah diletakkan di atas semua sistem pembumian yang dipasang. Pengukuran rintangan bumi

dijalankan pada setiap hari selama tempoh satu tahun dengan menggunakan kaedah kejatuhan 3 titik berpotensi.

Selepas setahun, keputusan dari ukuran rintangan bumi menunjukkan bahawa sistem pembumian yang terbaik adalah pemasangan Bentonite dengan pengurangan tertinggi rintangan bumi sebanyak 76% berbanding dengan sistem pembumian rujukan pada hari-0. Manakala, untuk sistem pembumian yang paling teruk, ia adalah pemasangan campuran Kenaf dan Zeolit (dengan nisbah 30:70) dengan peratusan kenaikan rintangan bumi sebanyak 13% apabila dibandingkan dengan sistem pembumian rujukan pada hari-0. Tambahan pula, dari keputusan, ia didapati bahawa peningkatan jumlah Kenaf atau Zeolit digunakan dalam campuran bahan peningkatan semula jadi untuk sistem pembumian boleh membawa kepada pengurangan rintangan bumi tetapi kurang berkesan berbanding dengan meningkatkan jumlah Bentonite digunakan. Keputusan juga menunjukkan bahawa Zeolit dan Kenaf tidak sesuai untuk digunakan secara individu atau dicampur bersama-sama kerana mereka membentangkan prestasi yang miskin. Kesimpulannya, kajian ini membuktikan bahawa Bentonite masih pilihan yang lebih baik sebagai bahan individu atau bercampur bagi pengurangan rintangan bumi berbanding Kenaf dan Zeolit.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Wan Fatinhamamah Wan Ahmad, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Zainal Abidin Ab Kadir, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Jasronita Jasni, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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LIST OF ABBREVIATIONS

Al	Aluminium
B	Bentonite
BS	British Standard
C	Carbon
CB	Coke breeze
CEM	Chemical enhancement materials
CIP	Cast iron powder
EDX	Energy disperse X-ray spectroscopy
EUT	Electrode under test
FESEM	Field emissions scanning electron microscope
GEM	Ground enhancement material
GI	Galvanized iron
GP	Granite powder
H_2O_2	Hydrogen Peroxide
IEC	International Electrotechnical Commission
IEEE	Institution of Electrical and Electronic Engineers
K	Kenaf
LP	Limestone powder
MOP	Metal oxide powder
MS	Malaysia Standard
NaCl	Sodium Chloride
NEC	National Electric Code
NEM	Natural enhancement materials
O	Oxygen
pH	Hydrogen potential
PKOC	Palm kernel oil cake
Si	Silicon
UPM	Universiti Putra Malaysia
USDA	United States Department of Agriculture
Z	Zeolite

LIST OF SI UNITS

m	Metre
kg	Kilogram
Ω	Resistance
P	Resistivity
ºC	Celcius
Hz	Hertz
Pa	Pascal
ℓ	Litre

CHAPTER 1

INTRODUCTION

1.1 Background

In high voltage industries, high magnitude fault current has been a major concern as it can damaged any sort of equipment and even fatalities might occur. As a result, it can cause huge losses for any company and factory that possess high-end equipment when lightning occurs. Furthermore, Malaysia has been listed as one of the country with high lightning activity over a year [1]. Therefore, it is necessary to provide a safety protection for those high end equipment as well as to create a safe environment for all personnel working in the power system installations. In the 21st century, grounding can be considered as the most efficient solution for this sort of problems. Grounding systems are needed to be able to eliminate the high magnitude transient surges by transferring them to the earth along a low magnitude impedance path in the shortest time possible [3]. This will be effectively operated only when there is a low magnitude impedance path as the tendency of the fault current to be dissipated into the earth increases with the resistance of the surrounding soil and the installed grounding systems. For instance, the combination of buried earth grids, horizontal rods and vertical rods are implemented in the high voltage substation to provide a low impedance path to earth [4].

A mass of international and national standards have been created for grounding design purposes. They provide a guideline in designing the grounding system under transient conditions. However, there is a common suggestion from all the standards that the connection between installed earth rod grounding system and substation equipment involved should be at low resistance and reactance [4]. In order to obtain such result, the connection between them should be as short and as straight as possible. Moreover, there are several methods provided by the standards to improve the performance of the earth rod under transient conditions. For example, the vertical rods should be implemented at the perimeter of the grid in order to dissipate the fault current into the earth. Whereas, the horizontal rods should be used as an enhancement system for the installed grounding systems located in areas with high magnitude of soil resistivity in order to reduce the overall earth resistance. In accordance to the standard IEEE Std. 80-2000 [6], an investigation on soil resistivity is needed to understand its effect towards the performance of the installed grounding systems.

Soil resistivity is considered as the main factor in designing a grounding system as it governs the performance of the grounding systems [13]. As a result, researchers have developed various techniques in lowering the earth resistance and those techniques have been classified into earth rod enhancement and soil enhancement methods. In the application of earth rod enhancement method, it involves of increasing the length of the rod itself or adding more rods to reduce the resistivity of soil. While, the soil enhancement method involves of utilization of natural or chemical enhancement materials to treat the soil around an earth rod in order to lower its resistance value. Both of this techniques have their own advantages and disadvantages when applying in the grounding system itself. However, this thesis aims only to study on the soil enhancement method. In detail, it is the method of reducing earth resistance by using natural enhancement materials (NEMs) which are further discussed in **Chapter 3**.

1.2 Problem Statement

Understanding soil resistivity and how it changes with depth in the soil is very important for designing the grounding system of an electrical power substation, or for specifying lightning conductors. The assessment of soil resistivity must be carried out before any installations takes place as this parameter can cause the grounding system may not reach its expected earth resistance value due to the complexity of the soil structure. In order to achieve a low earth resistance in a site which contain varies of soil resistivity from one place to another, there are two types of method can be implemented which are earth rod enhancement and soil enhancement method. However, in this study, only soil enhancement method is taken into consideration. This method involves of the utilization of enhancement material to treat the surrounding soil of an earth rod in order to lower the earth resistance value.

In the current market, the enhancement material were classified into two categories, i.e. chemical and natural based. However, there is a disadvantages of using CEM as its effect is not permanent as it would gradually being carried away and dissipated by natural drainage in the soil [18, 61]. Therefore, CEM need to be replenished to ensure the performance of the grounding system is at its best. Furthermore, in accordance to the IEEE Std. [3], a justification was compiled that the utilization of chemical based material will increase the conductivity of the surrounding soil, but will also cause possible pollution to the surrounding soil and corrosion to the earth rod as well. Also, this method might not be recognized by government legislation as it could detriment the surrounding environment. Therefore, in this study, only natural based materials were used in order to reduce the soil resistivity of the surrounding soil to maintain a low earth resistance even in high soil resistivity and dry soil conditions.

NEM are usually known as agricultural waste products. These materials are considered quite popular in the study relates to ground enhancement material

for grounding system purposes. In accordance to the research done by Okyere et al. [26], it justified that the NEM are suitable to be used for grounding system as they are claimed to be environmental friendly, low in cost production and may resulted optimum earth resistance for installed grounding systems. However, there is a drawbacks in utilization of NEMs for soil treatment whereby it tends to biodegrade within 3-4 months and create a void in the vicinity of the earth rod can leads to the increase of the resistance of the grounding system. As a result, it is advisable to replenish the NEM when there is a constant increment in the resistance of the grounding system from the daily measurement. Note that this issue has been taken care of in this study and further discussed in **Chapter 4**.

There are many types of NEMs have been applied in the field of grounding system. However, as in this study, the NEMs utilized for grounding system are Bentonite, Kenaf and Zeolite. In the case of Bentonite, many researchers recommended the use of Bentonite when it comes for the reduction of earth resistance for grounding system as it provides an optimum value of earth resistance for the installed grounding system. However, when comes to Kenaf, it was exactly opposite to Bentonite as it gives a poor performance when it utilized as an enhancement material. However, Kenaf can be easily obtained in Malaysia and low in cost compared to Bentonite. While, for Zeolite, it can considered as one of the purpose of carried out this study. In detail, Zeolite has not been used in the grounding system as an enhancement material. Therefore, with this study, Zeolite can be a good candidate to challenge Bentonite as it has a similar characteristics with Bentonite. For instance, both of these materials have a capability of absorb and store water moisture in the soil which are greatly helpful increasing effectiveness of the grounding system. Moreover, there might be a possibilities that when Zeolite mixed with Bentonite or Kenaf or both of them, the performance of the mixture is better than the performance of the material by itself. Note that various ratio of NEM mixtures, i.e. Bentonite, Kenaf and Zeolite used for grounding systems in this study. Also, note that the review of Bentonite, Kenaf and Zeolite as an enhancement material were detailed on **Chapter 2**.

1.3 Objectives

This study was conducted with an aim to tackle the area with high soil resistivity by the utilization of the NEMs in the vicinity of earth rod. Through this utilization, it can be helpful in obtaining a low earth resistance. Also, the main interest presented by this research is to determine the effectiveness of the NEM mixtures in reducing the soil resistivity. A research regarding this matter was carried out at the spacious site which located nearby to School of Graduate Studies, UPM. The objectives were;

1) To perform a soil resistivity evaluations in order to find the most suitable site for grounding system installations. Note that the site which possess high resistivity is chosen in order to observe a significant reduction of earth resistance when NEM mixtures were added into the grounding systems,

2) To investigate the best ratio of the amount of Bentonite, Kenaf and Zeolite in attaining the lowest earth resistance.

1.4 Structure of Thesis

This thesis is divided into five chapters. Start from **Chapter 2**, the details on the grounding systems, the influence of soil resistivity on the grounding system, and the configurations of the grounding systems were discussed. Also, an extensive review of published studies on the utilization of natural and chemical enhancement materials in the grounding system was included. **Chapter 3** described the procedures for site selection which involves of collection of soil samples, experimental test for soil analysis and soil resistivity measurements. In addition, in the aspect of grounding system itself, this chapter also detailed on the installation of grounding system and the method of earth resistance measurement which were carried out in this study. Note that only the methodology of the soil resistivity assessment, soil analysis, installation of grounding systems and earth resistance measurement were discussed in this chapter. In the **Chapter 4**, it focused on the results for soil resistivity assessment, soil characterization and earth resistance measurement which were carried out in this study. In detail, all of the results are presented, analysed and discussed. Finally, **Chapter 5** concludes this study as well as provide recommendations for further studies.

1.5 Contributions

The study conducted have led to the following contributions;

1) An extensive critical review of grounding systems performance under the effect of NEMs was carried out.
2) An improved understanding on the soil resistivity measurement and soil characterization for site selection purposes.
3) The behaviour of earth rod grounding systems under the effect of NEMs, i.e. Bentonite, Kenaf and Zeolite was investigated experimentally. The experimental results are shown for individual material and the mixture of material in various ratio. Moreover, the properties of the material itself was used to analysis the behaviour of earth rod grounding system as well.

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BIODATA OF STUDENT

Lai Wai Luen was born in Kuala Lumpur, Malaysia on 14th September 1991. He went to Methodist Boys School and graduated with Malaysian Higher School Certificate (STPM) in year 2011. He then received the B.Eng. Degree in Electrical and Electronic Engineering from the Universiti Putra Malaysia, Malaysia in 2015, with a FYP thesis focused on the study of Sulphate Chemical Earth Rod grounding systems. Later on, he also further his Master of Science studies at Universiti Putra Malaysia focusing on grounding technology, lightning protection and high voltage and insulation technology.

LIST OF PUBLICATIONS

W. L., Lai, W. F. H., Wan Ahmad, J., Jasni, and M. Z. A., Ab Kadir**,** *A Review on the Usage of Zeolite, Perlite and Vermiculite as Natural Enhancement Materials for Grounding System Installations*, Proceedings of the 2017 IEEE Student Conference on Research and Development (SCOReD 2017), Putrajaya, MALAYSIA, 13-14 Dec 2017.

W. L., Lai, W. F. H., Wan Ahmad, J., Jasni, and M. Z. A., Ab Kadir**,** *Variations of Soil Resistivity Values due to Grounding System Installations with Natural Enhancement Material Mixtures*, 34th International Conference on Lightning Protection, Rzeszow, POLAND, 2-7 Sept 2018.

W. L., Lai, W. F. H., Wan Ahmad, J., Jasni, and M. Z. A., Ab Kadir, *A Study on Comparing the Performance of Bentonite, Kenaf and Zeolite to Reduce Earth Resistance*, 2016 MyHVnet Colloqium, UTM, JB, MALAYSIA, 25 Jan 2016.

W. L., Lai, W. F. H., Wan Ahmad, J., Jasni, and M. Z. A., Ab Kadir, *A Review on Application of Natural Enhancement Material on Installed Electrode Grounding Systems*, (Submitted to Journal of Electric Power Systems Research)

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