Modelling Grounding System Filled With Natural Enhancement Material Based On Electric Field And Electric Potential

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	3-Dimension
ATP	Alternative Transient Programmed
AC	Alternating Current
ANSYS	Analysis System
DC	Direct Current
EMTP	Electromagnetic Transient Program
FEM	Finite Element Method
GEM	Grounding Enhancement Material
kA	kilo Ampere
MATLAB	Matrix Laboratory
MV	Mega Volt

LIST OF SYMBOLS

α	Alpha
β	Beta
γ	Gamma
δ	Delta
η	Special corrector factor
ρ	Resistivity
V	Potential Difference
I	Current
R	Resistance
J	Current density
E	Electric Field

Sistem Pembumian Permodelan Diisi Dengan Bahan Peningkatan Semulajadi Berdasarkan Medan Elektrik Dan Potensi Elektrik

ABSTRAK

Sistem pembumian adalah penyambungan sambungan elektrik ke bumi dengan wayar atau konduktor lain. Tujuan utama sistem pembumian adalah untuk melindungi manusia, peralatan elektrik dan bangunan dari kejutan elektrik akibat kilat atau bentuk elektrik lain yang berbahaya. Oleh itu, untuk mencapai matlamat ini, bahagian asasnya mesti diambil kira. Secara ringkas, beberapa sistem pembumian dimodelkan, yangterdiri daripada konkrit penuh, konkrit tiga perempat, separuh konkrit dan konkrit seperempat dengan Bahan Peningkatan Pembumian (GEM) telah dirancang menggunakan perisian FEM. GEM yang digunakan adalah abu terbang arang batu dan bentonite. Terdapat dua jenis analisis yang dilakukan iaitu analisis medan elektrik dan analisis potensi elektrik. Pertama ialah analisis medan elektrik. Untuk bahagian analisis medan elektrik, nilai medan elektrik yang diperoleh dari semua sistem pembumian dimodelkan dengan kedua-dua GEM (fly ash dan bentonite) di posisi atas dan bahagian bawah kedudukan diukur dan dibandingkan dengan model sistem pembumian terbaik yang dinilai pada kedua-dua kedudukan. Ini kerana, medan elektrik yang lebih rendah dapat memberikan jalan impedans terendah ke tanah. Walau bagaimanapun, hasil yang diperoleh untuk model sistem pembumian dengan bentonite lebih baik daripada model sistem pembumian dengan abu terbang dari segi medan elektrik yang lebih rendah. Oleh itu, untuk medan elektrik yang diukur di kedudukan teratas, hasilnya jelas menunjukkan bahawa konkrit penuh dengan bentonite memperoleh nilai medan elektrik terendah. Sementara itu, untuk medan elektrik yang diukur di kedudukan bawah, konkrit seperempat dengan bentonite adalah model sistem pembumian yang paling sesuai berbanding model sistem pembumian yang lain. Kajian penyelidikan ini juga menganalisis prestasi potensi elektrik arus impuls yang disuntik menggunakan model Heidler pada kes berlainan model sistem pembumian. Untuk sistem pembumian dorongan yang disuntik dengan fly ash GEM dan bentonite, semua model konkrit menunjukkan bahawa konkrit penuh memperoleh potensi elektrik terendah diikuti oleh konkrit tiga perempat, setengah konkrit, konkrit seperempat dan potensi elektrik tertinggi adalah sistem pembumian rujukan. Namun, hasil yang diperoleh untuk model sistem pembumian dengan bentonite lebih baik daripada model sistem pembumian dengan abu terbang dari segi potensi elektrik yang lebih rendah. Hasil ini jelas menunjukkan bahawa konkrit penuh dengan bentonite adalah kes konkrit yang paling sesuai untuk menahan arus desakan kilat Heidler berbanding yang lain. Kesimpulannya,hasil keseluruhan yang diperoleh menunjukkan bahawa prestasi sistem pembumian dengan bentonite lebih baik daripada sistem grounding dengan abu terbang dari segi medan elektrik yang diturunkan dan nilai potensi elektrik. Oleh itu, dapat disimpulkan bahawa, konkrit penuh dengan bentonite adalah model sistem pembumian terbaik yang akan dipasang di tapak pembumian.

Modelling Grounding System Filled With Natural Enhancement Material Based on Electric Field And Electric Potential

ABSTRACT

Grounding system is the connection of electrical connection to the earth ground by a wire or other conductor. The main purpose of the grounding system is to protect humans, electrical appliances and buildings from electrical shock due to lightning or another form of electricity that hazardous. Therefore, to achieve this goal, the fundamental part must be taken into account. In brief, few grounding systems were modeled, which consist of full concrete, three-quarter concrete, half-concrete and a quarter concrete with Grounding Enhancement Material (GEM) has been designed using FEM software. The GEM used is coal fly ashes and bentonite. There are two types of analyses that were carried out which are electric field analysis and electric potential analysis. First is the electric field analysis. For the electric field analysis part, the electric field value obtained from all the grounding systems modeled with both GEM (fly ash and bentonite) at position top and position bottom was measured and compared to evaluate the best grounding system model at both positions. This is because, a lower electric field is able to provide the lowest impedance path to the ground. However, the result obtained for the grounding system model with bentonite is better than the grounding system model with fly ash in terms of lower electric field. Therefore, for the measured electric field at position top, the results clearly show that full concrete with bentonite obtained the lowest electric field value. Meanwhile, for the measured electric field at position bottom, a quarter concrete with bentonite is the most suitable grounding system model compared to the other grounding system model. This research study also analyzes the performance of the electric potential of the injected impulse current using the Heidler model on different cases of the grounding system model. For injected impulse on grounding system with both GEM fly ash and bentonite, all concrete model shows that full concrete obtained the lowest electric potential followed by three-quarter concrete, half concrete, a quarter concrete and the highest electric potential is reference grounding system. However, the result obtained for the grounding system model with bentonite is better than the grounding system model with fly ash in terms of lower electric potential. This result clearly shows that full concrete with bentonite is the most suitable concrete case to withstand the Heidler lightning impulse current compared to the others. In conclusion, the overall result obtained shows that the performance of the grounding system with bentonite is better than the groundings system with fly ash in terms of lowered electric field and electric potential value. Therefore, it can be concluded that full concrete with bentonite is the best grounding system model to be installed at the grounding site.

CHAPTER 1: INTRODUCTION

1.1 Research background

Preventing property damage from lightning strikes is one of a lightning protection system's most crucial task. Electrical energy diverted to the ground is rather than allowing to circulate throughout the building, the lightning protection system would be able to reduce the structural damage brought on by lightning. One of the methods for lightning protection system is grounding system. A grounding system connects electrical devices or cables to the earth's magnetic field using a wire or other conductor. The grounding system should always work properly in both typical and atypical circumstances. The two most frequent anomalous occurrences that can result in property damage, injury, even death due to ground faults and lightning strikes.

To guarantee that fault current or lightning hits divert primarily through the grounding electrode into the earth, the system for grounding should be able to design at low impedance route to the ground. Soil resistivity should also consider during constructing any grounding system to attain the low impedance path to the ground. This is due to grounding system is depending on texture of the soil and the soil resistivity value might vary. Finding a reliable model of soil resistivity is therefore essential for producing the desired outcome when constructing a grounding system.

The modification of soil properties with an enhancement filler material, soil characteristics will change when mixed with others material, is one of the options to

reduce soil resistivity. This is one of the methods that can be increase a ground system's effectiveness.

The enhancement material should have characteristics that able to improve the performance of the grounding system, such as able to protect the layer to prevent grounding electrode corrosion, able to change the soil parameter to be less resistive and able to maintain soil moisture. Therefore, it is important to choose suitable enhancement material by depending on the type and texture of the soil. This research aims to use coal fly ashes and bentonite as enhancement filler material to improves the grounding system.

By referring to IEE 142-2007, "the intentional connection of a phase or neutral conductor to earth to control the voltage to earth or ground within predictable limits. It also provides for the flow of current that will allow detection of an unwanted connection between system conductors and ground which may instigate the operation of automatic devices to remove the source of voltage. The control of voltage also allows reduction of shock hazard to the person who might encounter live conductor". From these, it mentioned that the grounding system is to control potential differences of neutral for system stability, also for personal safety and allow for operation of protection relays to the electrical system.

This is to ensure that human, electrical appliance, or facility asset have an excellence grounding protection system and not exposed to critical electrical shocks due to lightning or fault. Therefore, to achieve an effective grounding system, the fundamental part of the grounding system design must be considered before installing the grounding system practically. To achieve an excellent grounding system, the fundamental part in designing

the grounding system must be considered before installation the grounding system practically. This is critical since an improperly installed grounding system will cause more damage than not getting one at all (Pfeiffer, 2001).

In this research, a few analyses using the software were carried out to analyze and evaluate the distribution of electric field and the electric potential of the grounding system. According to (Pfeiffer, 2001) a grounding system with a lower electric field is capable of providing the lowest impedance path to the ground. Modelling of transient phenomena is also an essential part of lightning protection design and analysis. Therefore, this research also analyses the electric potential of the injected impulse using software to evaluate the performance of the grounding system modeled (Mešter, 2004). The results of the analysis on both distribution of electric field and electric potential are expected to assist in the preparation before the practical experiment is carried out.

1.2 Problem statement

The grounding system plays an important role in ensuring that human, electrical appliance or building in the vicinity of the grounding system area is not exposed to critical electrical shocks due to lightning or fault. Therefore, it is crucial to design the best grounding system model to improve the performance of the grounding system. The use of enhancement materials is one of the effective methods to improve the performance of the grounding system as it helps to reduce soil resistivity. Thus, providing the lowest impedance path to the ground to ensure fault current and lightning strikes to diverge mainly to the grounding electrode into the soil. Recent research shows that researchers tend to use enhancement material as a solution to the high resistivity of soil in the

grounding system. Therefore, in this study, coal fly ash and bentonite were used as grounding enhancement materials (GEM).

However, studies on the electrical field and electrical potential effect of the grounding system not clearly mentioned from previous researchers. This is because, the distribution of high electric field triggers damaging discharge activities to the grounding system (T.Imakoma Y.Suzuki 0. Fujii I.Nakajima, 1994). High electric fields also can accelerate premature aging of the grounding system which can cause flashover. Therefore, in this research, few grounding systems were modeled using software to recognize the best grounding system design that has the lowest electric field.

Moreover, the analysis of the electrical potential of the grounding system due to the lightning impulse current is also important (Stolzenburg & Marchall, 2009). Lightning is a natural phenomenon that has an incredible appearance and has always had a tremendous impact on humans and their communities due to its threats imposed on life and systems. With the growth of micro-electronics technology and the information industry, the loss caused by lightning increased every year (Stolzenburg & Marshall, 2009).

The fundamental part of the appropriate grounding system modeled is necessary to assist in the planning before conducted physical studies. Therefore, this research is aimed to analyze the electric field and electric potential to recognize the best grounding system design to be installed at the grounding site.

1.3 Objective

This study embarks on the following objectives:

1) To model different 3-D cylindrical concrete cases of grounding system with GEM Fly Ash and Bentonite using FEM software.
2) To analyze the electric field of the grounding system with GEM of Fly Ash and Bentonite using FEM software.
3) To analyze the electric potential and impulse current of the system with GEM of Fly Ash and Bentonite using FEM software.

1.4 Research question

The research questions to this study as below listed:

1) What is the resistivity value of grounding system when adding with natural enhancement material of Fly Ash and Bentonite?
2) What is the effect of grounding system when analyze with electric field and electric potential?
3) What are the results will be obtained when performing different types of grounding with different model?

1.5 Research scope

The scopes of this study are:

1) Modelling different 3-D cylindrical concrete of grounding system with GEM Fly Ash and Bentonite using FEML software.
2) The volume and mixture of each concrete in the grounding system model are the same by 15404 x 10^{-6} meters^3.
3) Analyze electric field and the electric potential of the grounding system modeled using FEM software.
4) The usage of GEM Fly Ash and Bentonite are considered in the grounding system modeled as enhancement material with the vertical type of grounding rod.
5) The grounding system modeled used copper rod with a diameter of 0.014m and a length of 2m.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter covered literature review based on the previous studies for the grounding system. To ensure safety at the installed area, grounding systems are crucial for allowing fault current or lighting strikes through the soil. Therefore, a lot of researchers and engineers had involved in the research and installation of the grounding system. For this research, the tendency of choosing cylindrical shape grounding filter over rectangular shape grounding filler will be discussed. Then, the modifying soil characteristic's technique using Grounding Enhancement Material (GEM) also has been reviewed. Furthermore, the comprehensive selection of the copper grounding electrode is highlighted according to the previous research. Besides, the review of the previous study on the effect of the electric field is evaluated in this research to ensure the performance of the grounding system. Also, the different type of channel base lightning impulse current will be discussed in this chapter whereby the Heidler function is highlighted. All these subtopics would contribute to the improvement of the grounding system in this research.

2.2 Lightning Theory

For the last decade, one can clearly notice the enhancement of the effects of lightning related electrical environment on the industrial sector and civil life all over the world. Lightning also causes human casualties both directly and indirectly that lightning can ignite that may bring an entire building or a house down to ashes injuring the people

who are living sheltering within (R. L. Holler et al.,2010). Malaysia has recorded high number of lightning accidents which lead to death, injury, property damage and service disruption. Such ill-effect of lightning cause large scale financial losses to the country both directly and indirectly. It has been shown that lightning related damage and injuries are high in Malaysia both due to lack of awareness and misconceptions spread by vendors that sell unscientific system and techniques (C.Gomes and Z.kadir et al., 2011).

In most areas, rainstorms are the primary source of lightning. Storms produce intra-cloud, cloud-to-cloud, and cloud-to-ground lightning. Intra-cloud lightning is the most frequent, but cloud-to-ground lightning affects overhead distribution lines. The indication of lightning activity may be obtained from keraunic data (thunderstorm days per year). A world isokeraunic map as shown in Figure 2.1 whilst Figure 2.2 shows the average number of thunderstorm days (Meteorological Department of Malaysia).

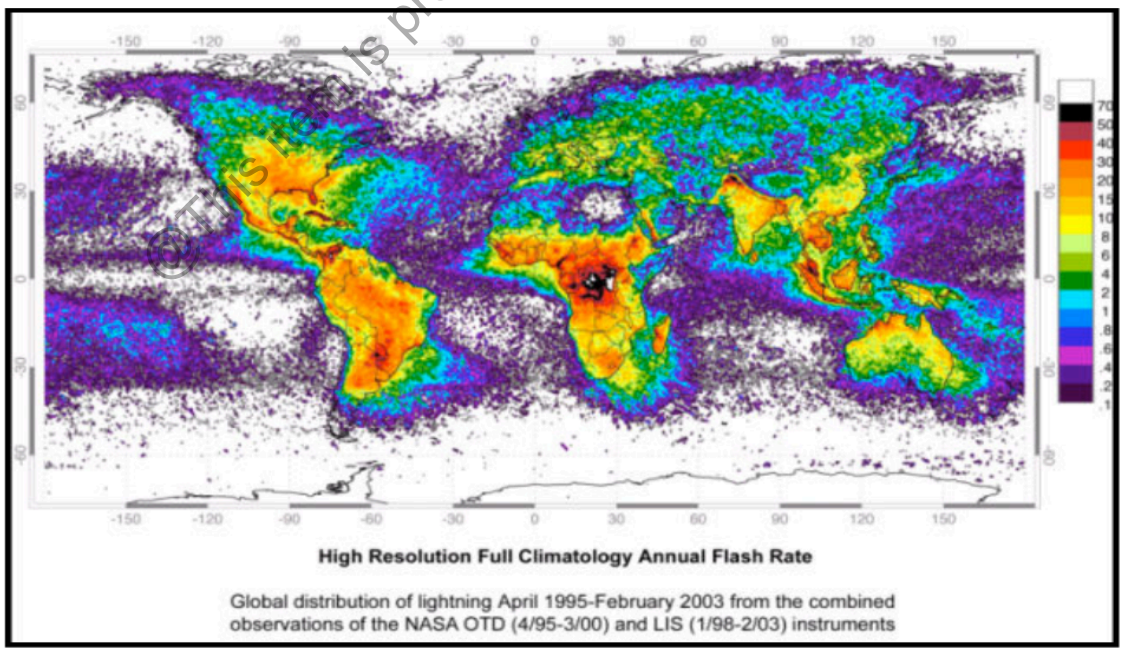


Figure 2.1 World isokeraunic map (http://thunder.nsstc.nasa.gov)

Figure 2.2 Average number of thunderstorm days in Malaysia (Meteorological Department of Malaysia)

It very interesting to see that most of the areas closer to the Equator generally have more lightning flashes compared to the others. This is in part due to amount of sunshine received by those areas which produces cold fronts, sea and lake breezes and afternoon heating warm, moist air (E. Gourbiere et al.,1997)(R. J. Vavrek et al.,2018).

2.3 Shape in Grounding System

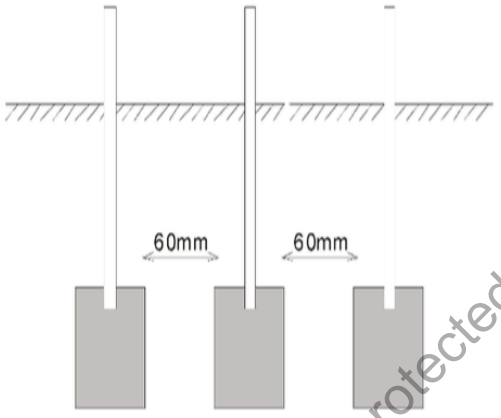
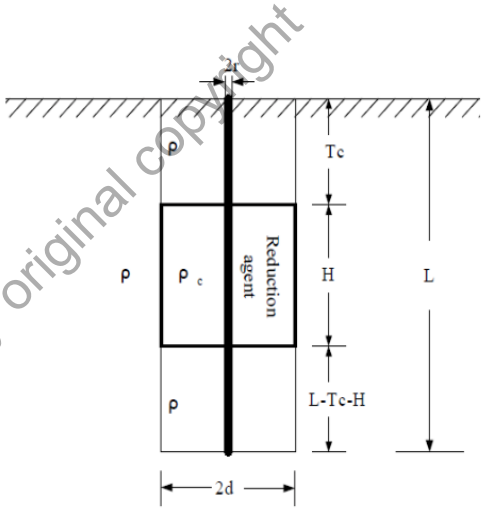
The grounding is a system that connect the air termination rod and down conductor to the ground. However, the grounding filler shape used by the researched in installing the grounding system does not seem to be consistent over the year as shown in the previous study. The rectangular shape and the cylindrical shape are the two different shapes of grounding system that have been practiced in the industry. In 2012, wood

ceramics with rectangular shape had applied for grounding system for investigation. H. Shimizu and N. Watanabe manufactured some ceramics wood plates with dimensions 78mm x 64mm x 7mm to act as an electrode. The rectangular wood ceramic is connected with a grounding wire and buried in 200mm depth with about 60mm separation between each electrode (Shimizu & Watanabe, 2012). Meanwhile, in 2013, Lim et al. proposed a rectangular shape of steel cages encased in concrete mixed with the various proportions of bentonite. In this study, the concrete mixed with various proportions of bentonite was applied in 8 pits aside. Based on these, there were no significant explanations or reasons on both rectangular shape wood ceramics and rectangular shape steel cages were chosen for their studies (Lim et al., 2013).

In 2016, Chen et al. used coal Fly Ash as a reducing agent to reduce the resistivity of soil at Kung Shan University of Technology. In this study, the authors buried five grounding bars in the ground at the Kung Shan University of Technology. The grounding bars were steel-core copper sticks of diameter 2.104cm and length 280cm. Out of five grounding bars, grounding bars No.1 to No.3 were only partially covered with a reduction agent in a cylindrical shape, and grounding bars No.4 and No.5 were not (Chen et al., 2006).

N.H. Halim proposed a cylindrical shape concrete which was filled with additive material to cover the electrodes in order to study research the performance of copper and galvanized steel electrodes using rice husk ashes in 2018(Halim et al.,2018). In the same year, bentonite and kenaf were studied as an enhancement material in the grounding system using a cylindrical grounding conductor constructed of copper that had a 1.5 m length and 0.013 m diameter (Wan Ahmad et al., 2018).

As can be seen in Figure 2.1, prior research from the years 2012 to 2013 tended to use a rectangular filler form for the purposes of the grounding system. However, the design of the grounding system filler has shifted to a cylindrical shape in recent years of study, from 2016 to 2018. As a result of the high resistance of soil in the grounding system, new study also reveals that researchers frequently utilize enhancement filler material.

Rectangular Shape	Cylindrical Shape
 A	 C

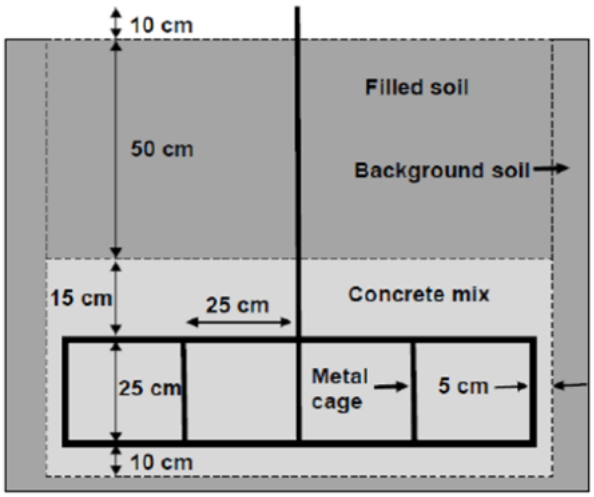
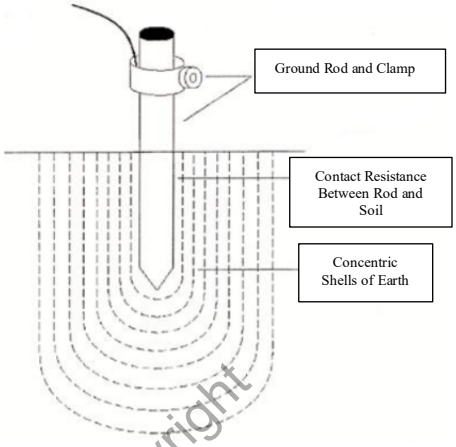
Rectangular Shape	Cylindrical Shape
 B	 D

Figure 2.3. a) Rectangular Shape 2012 (Shimizu & Watanable.,2012). b) Rectangular Shape 2013 (Lim et al.,2013). c) Cylindrical Shape 2016 (Chen et al.,2006). d) Cylindrical Shape 2018 (Halim et al.,2018)

2.4 Electrical Resistivity and Its Effect on Soil Parameter in Grounding System

It is well known that an earth electrode's resistance is tend influenced by the soil's resistivity under which it is driven. Measurements of soil resistivity are also crucial parameters when designing earthing installations. Moreover, a knowledge of the soil resistivity at the intended and their varies with parameters such as temperature, moisture content, and depth provides a valuable insight into the desired earth resistance value that can be obtained and preserved with the least cost over the life of the installation. Therefore, several factors, including soil resistivity, stratification, size and electrode utilized, type moisture and chemical content of the soil, and the depth which the electrode

is buried, must be taken into account to establish an excellent grounding system (Testing et al.,2020).

2.5 Electrical Resistivity in Grounding System

Low resistivity material will act as a good conductor and high resistivity material will act as a bad conductor. The commonly used symbol for resistivity as eq.(2.1)

$$R = \rho\, L/A \tag{2.1}$$

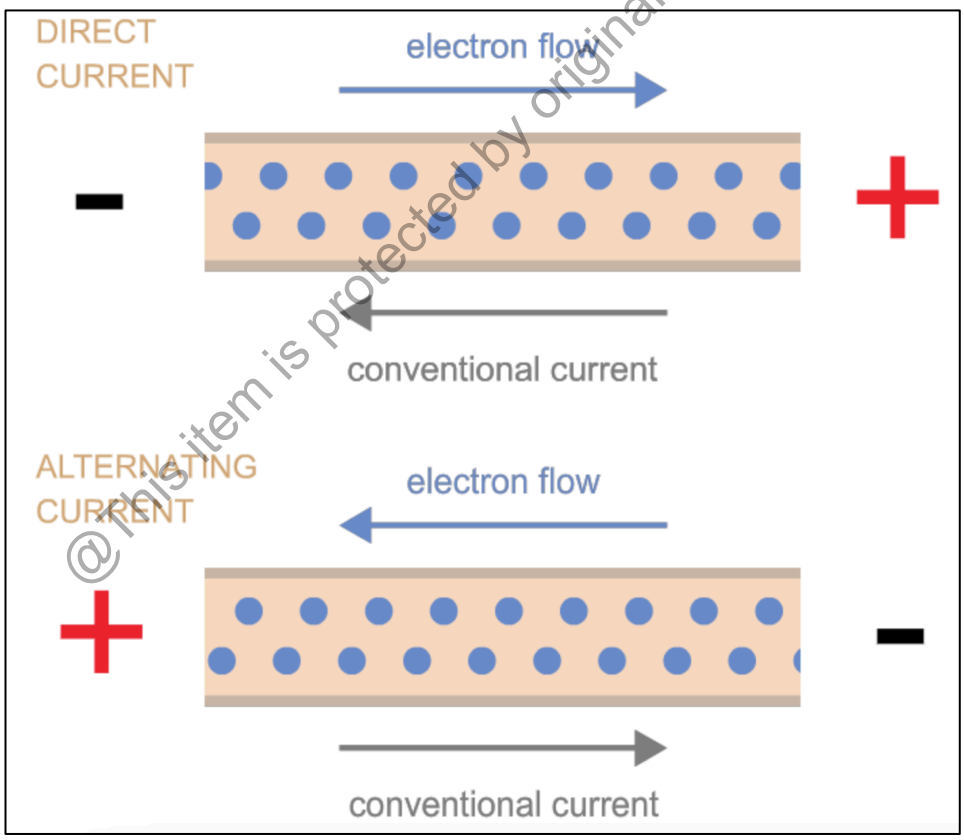


Figure 2.4 Basic Model of Electricity Flowing Through A Material When A Voltage is Applied

Theoretically, electricity is a movement of electrons through a material. Figure 2.2 shows a basic model of electricity flowing through a material when a voltage is applied. It is assumed that the material being measured is considered to homogeneous and isotropic.

Homogeneous means the material properties area the same properties in all directions. A more exact definition of resistivity (ρ) relating a local applied electric field to the resultant current density in eq.(2.2), where (E) is the electric field (V/m), (J) is the current density (Am^{-2}) and (ρ) is resistivity (Ω m). Equation 2.2 is one form of Ohm's law. Therefore, the validity of Ohm's Law depends on the fulfillment of the relationship eq. (2.2).

$$E = \rho J \tag{2.2}$$

2.6 Finite Element Method (FEM)

The Finite Element Method (FEM) is a numerical method commonly used by researchers and engineers to perform difficult or impossible-to-perform research that is high-risk and requires costly laboratories equipment.

There are two methods of numerical analysis. The analysis is done by the equation analysis and the second is the representation. However, the approach based on both methods is highly scalable and not applicable to many practical problems. As a result, researchers and engineers prefer to conduct numerical analysis techniques using computers for modelling and simulation because it offers more effective and faster analysis.

FEM uses a process by which a domain is divided into smaller parts where the smaller section for a 3D object triangular. Figure 2.3 shows a 3D structure is broken down into triangles in FEM software for analysis purposes. The fractions of the triangle shape can be seen to differ very much based on the researcher need, this relies on the researchers need due to the analytical accuracy depends on the size of the formed triangles. The smaller the element, the precise the intensity of the field strength.

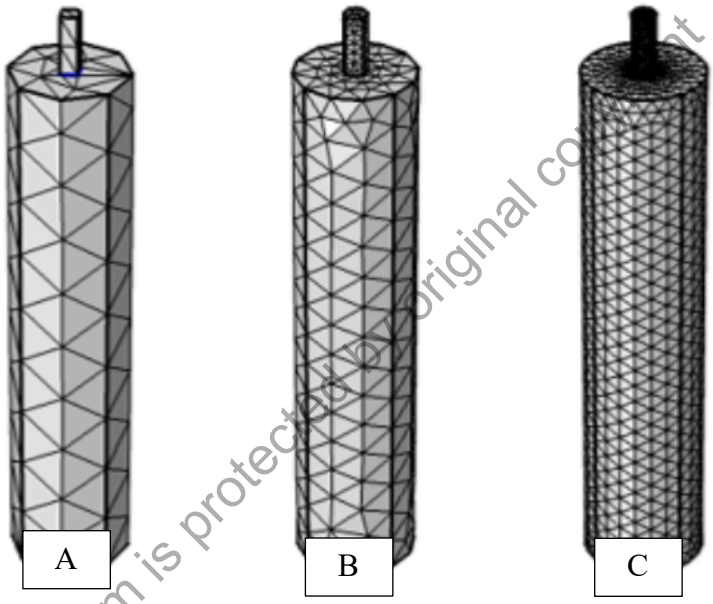


Figure 2.5 Example triangular element size for studies in FEM software. A) Coarse, B) Fine, C) Extra Fine.

A simplified approximation of the mathematics will be assigned to every element formed. Then the analysis will be carried out to achieve the physical system global solution. The FEM approach is very effective in the analysis of closed boundaries. If the analysis is carried out on an open boundary, it becomes less effective because the time for the analysis also depends on the geometrical size and may cause error. Furthermore, the FEM approach allows the evaluation of electric field stresses and potential difference in the location that is not possible to evaluate and measure experimentally.

2.7 Grounding Enhancement Material (GEM) in Grounding System

Soil treatment using Grounding Enhancement Material (GEM) is a good way to improve the resistance of the grounding electrodes, especially in rocky soil, where the grounding electrode cannot be driven deeper into the ground due to the rocky soil. Since extending an existing grounding system by installing additional electrodes is either costly or impossible on certain cases, a common alternative method to modifying the soil characteristic by installing GEM around the grounding electrodes is used (Androvitsaneas et al.,2012). The use of grounding enhancement material in grounding systems could reduce grounding resistance significantly (Azmi et al.,2019).

In the last decades, numerous studies have been performed on grounding enhancing materials. Firstly, an experiment was conducted by (Yong C. W. et al., 2016) using palm oil ashes as a grounding enhancement material. According to the findings, the ground resistivity value without the additive material is 17.3Ω. The result show improvement of 9-12%. According to this experiment, the resistivity of soil was improved after palm oil ashes were applied as backfill materials.

In 2016, (Shuhada et al.,2016) has used bentonite as grounding enhancement. From the result, the usage of bentonite as grounding enhancement materials can be reduce the grounding resistance. However, the humidity of the soil, moisture, surrounding temperature and the amount of rainfall can influence the performance of bentonite (Shuhada et al.,2016).

According to (Kusim et al.,2013), soil resistivity can be improved by adding salts to the soil. It is proven by the result of the research study. When there is no salt added to the sandy loam soil, the soil resistivity is 10,700 ohm-cm. The soil resistivity decreased to 460 ohm-cm when 1% salt was added. The salts were added more until 20% and the result shows the soil resistivity further reduced to 100 ohm-cm (Kusim et al.,2013).

2.7.1 Coal Fly Ash

In this research, coal Fly Ash was proposed as grounding enhancement material (GEM). Power plants that use coal in the operation generate millions of tons of Fly Ash per year. These by-products are often disposed of by dumping them on (Rossow,2013). The Fly Ash material is hazardous to both human and environmental health. The mismanagement and inadequate control of this Fly Ash substance can lead to an increase in tits hazardous nature and environments (Karantonis, 2012).

This study suggests using Fly Ash as a lowering agent for grounding resistance to preserve this natural resource. Experimental results by (Chen et al.,2006) confirm that the reduction agent using Fly Ash can effectively reduce the grounding resistance. Experimental results by (Chen et al.,2006) confirm that the reduction agent using Fly Ash can effectively reduce the grounding resistance. Therefore, in this study, Fly Ash has been as a grounding enhancement material (GEM)

2.7.2 Bentonite

As a grounding enhancement material (GEM), bentonite is also used in this study and the value of resistivity has significantly increased as a result of using bentonite as a grounding material, claim Mohd Tadza et al. (2019). Developed from volcanic formation, bentonite is a fine-grained, highly flexible clay. As a grounding material or as a sand substitute in concrete, bentonite is utilised in aggregate forms as a backfill material.

Bentonite were examined as backfill materials for grounding purposes in (Mohd Tadza et al., 2019). Bentonite is used in research (Mohd Tadza et al., 2019) as a substitute grounding ingredient in a cement mix to create conductive aggregate. Bentonite's lowest resistivity measurement, 2.4 m, was made in a moist environment. Water content controls how bentonite behaves in terms of resistivity. The bentonite's pores contain water that serves as particle bridging for electrical currents.

2.8 Grounding Electrode in Grounding System

Ideally, the grounding electrode must penetrate into the moisture below ground level. It also must consist of a metal or the combination of metals that do not corrode excessively over the expected period of operating time (Testing el al.,2020). A grounding system’s electrodes must be conductive and corrosion-resistant for a minimum of 15 years after installation (Guerrero et al.,2016). Copper is the most widely used for grounding electrodes, due to its high conductivity and corrosion resistance. Copper has a better corrosion resistance that other types of conductors due to its natural characteristics.

Additionally, its capability for current to flow and discharge to the earth due to higher conductivity level (Ahmad et al.,2014).

(Halim et al.,2018) found that in terms of lifetime or service life, the copper electrode outperforms the galvanized steel electrode. According to the finding, in terms of the long-life materials, the copper electrode was the best option on this project's grounding system material. Therefore, copper rod proposed as grounding electrode in this research.

2.9 Electric Field in Grounding System

Numerous studies have demonstrated that a reduced electrical field or electrical stress influences the provision of the ground's lowest impedance value. A grounding system with the lowest electric field would reduce the grounding system's resistance value. As the resistance reduce, the transient voltage also decreases and is easily grounded during lightning flows. The grounding system is used to prevent possible hazardous voltages between the metal structure and the ground in case of a system fault or lighting surge (Manikandan et al.,2011). Besides, the distribution of high and low electric fields in combination with other stresses triggers damaging discharge activities to the grounding system (T.Imakima et al.,1994). Therefore, a grounding system understanding is a must to prevent any unwanted incident.

The electrical field distribution in the grounding system can be measured using two methods which are experimental measurement and numerical computation. However, numerical analysis using FEM tools is very popular method among researchers. This

method is preferred since experimental laboratory studies are difficult or impossible to perform (Kurdi et al.,2012).

The analysis of the traditional system of grounding and the proposed system of grounding system was done by (Manikandan et al.,2011) This study proposes different designs for wind turbine grounding systems. Maximum electric field distribution is obtained for each grounding system. Thus, this research introduces a new grounding system that reduces the distribution of electric fields in the grounding foundation used for wind turbines during lightning strikes. The proposed approach shows that the electric field can be reduced by increasing the base area of the foundation. Both the analysis which is made in MATLAB and ANSYS uses the finite element method for the electric field analysis. The proposed approach reduces the electrical field in MATLAB by 30% and ANSYS by 1,568%, which us an estimated result in real-time (Manikandan et al.,2011).

FEM software can also be used for complex analysis. Electric field distribution and voltage investigations in the 1000kV substation ceramic insulator string were carried out in (Li et al., 2012). FEM software was used to simulate and analyze a 1000kV substation in three dimensions. This study is to determine of electric field distribution and electrical potential for the insulator by using 3D FEM numerical simulation. The examination of the electrical field and voltage distribution may help with preparation before the real experiment is conducted, even if this research does not use a grounding system.

In the research (Muhamedin et al.,2016), has used FEM-based software known as QuickField^{TM} Professional to simulate a single unit of suspension insulator. This simulation aims to study the effect of pollution on the distribution of electric field and

the voltage around it. A thin film that acts as pollution is modeled on the surface of the suspension insulator to carry out the analysis. As a result, changes in the distribution of voltage and electric fields can accelerate premature aging which can possibly cause flashover.

As shown in Table 2.1, is the summarize of electric field testing that has been conducted by using FEM software.

Table 2.1 Summarize of Electric Field studies by using FEM Software

No	Research Description	Researcher
1	Introduce a new grounding system that reduces the distribution of electric fields in the grounding foundation used for wind turbines during lightning strike. The analysis conducted by using MATLAB and ANSYS software.	Manikandan et al.,2011
2	To determining of electric field distribution and electrical potential the for insulator. Research conducted to investigate 1000kv substation ceramic insulator string by using FEM software	Li et al.,2012
3	To simulate a single unit of suspension insulator. This simulation aims to study the effect of pollution on the distribution of electric field and the voltage around it by using FEM Software	Muhamedin et al.,2016

2.10 Channel base current function

Diverse functions area considered based on measured values in the simulation of the channel base current. The commonly used base current channel functions is Heidler function.

2.10.1 Heidler function

Equations (2.3) and (2.4), in which i_0 is the channel base current amplitude, τ_1 is the front time constant, τ_2 is the decay time constant, and n is an exponent (2~10), Figure 2.4 shows a description of a simulated channel base current based on Heidler function in which the current parameter is obtained from Table 2.2 (Terespolsky, 2015).

$$i(0,t) = \frac{i_0}{\eta} \frac{\left(\frac{t}{\tau_1}\right)^n}{1+\left(\frac{t}{\tau_1}\right)^n} \exp\left(\frac{-t}{\tau_2}\right) \tag{2.3}$$

$$\eta = \exp[-(\tau_1/\tau_2)\left(n\frac{\tau_2}{\tau_1}\right)^{\frac{1}{n}}] \tag{2.4}$$

Table 2.2 Typical initial parameters for Hedler function (Rachidi et al.,2001)

(Terespolsky 2015)

I_0 (kA)	τ_1 (μs)	τ_2 (μs)	n
28	1.8	95	2

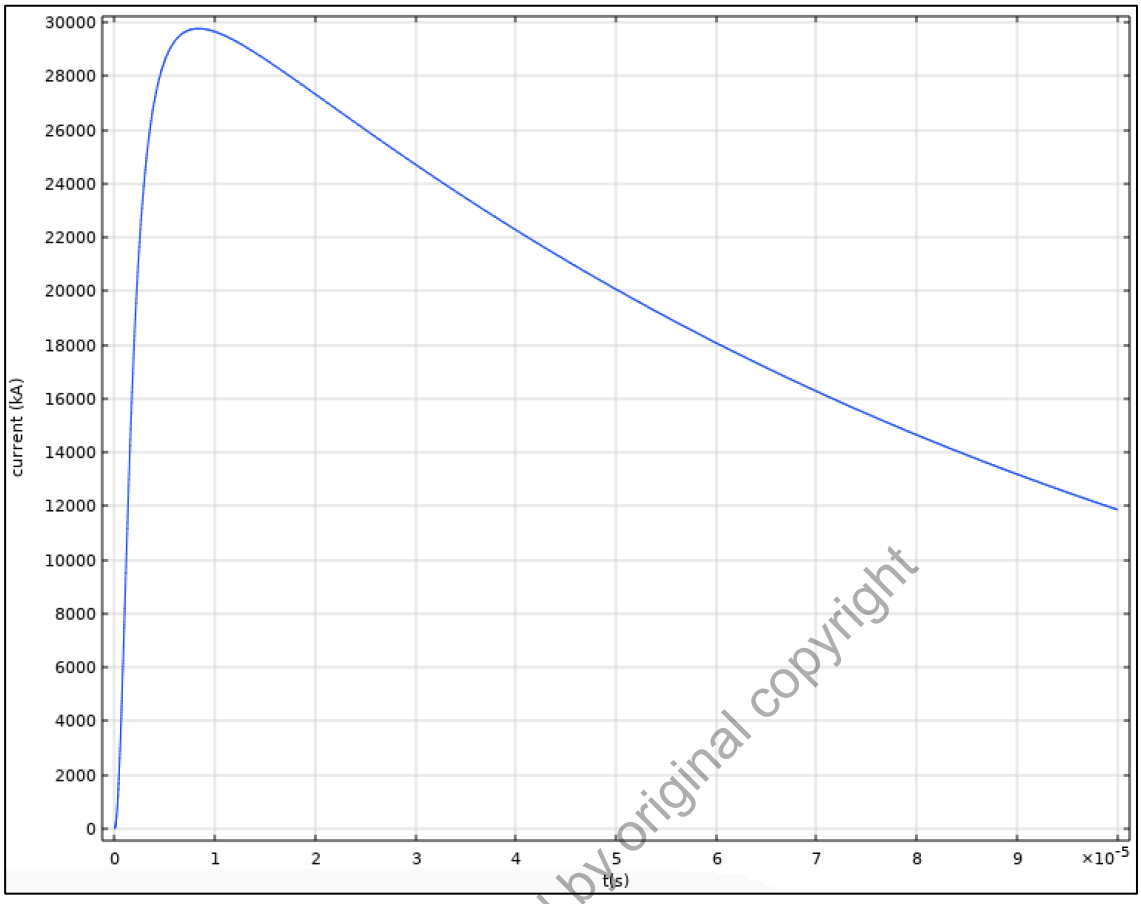


Figure 2.6 The channel base current based on Heidler function and initial parameters form Table 2.2 (Rachidi et al., 2001)

Heidler model of lightning current from research by (Furgal, 2020) was utilized in Electromagnetic Transients Programmed and Alternative Transient Programmed (EMTP and ATP). The study of the simulation data showed that the maximum and course values of the simulated overvoltage were both impacted by the lightning current model that was utilized in the simulations.

The EMTP and ATP often used in overvoltage simulations in electrical system networks. The Heidler model is one of the selecting models of the lightning current base which can be used in simulations.

2.20 Summary

According to the previous study, the use of enhancement material is an efficient way to increase the grounding system's performance since it lowers soil resistivity. To ensure that lightning strikes mostly divert towards the grounding electrode in the earth, the lowest impedance possible must be provided to the ground. Therefore, in research Fly Ash and Bentonite will use as enhancement materials (GEM) for the grounding. The performance of the GEM will be obtained through simulation process by using FEM software. Furthermore, this study also decides to analyze the electric field because the lower the electric field providing low impedance path to the ground (Manikandan et al., 2011). The distribution of high electric field triggers damaging discharge activities to the grounding system (T. Imakoma et al.,1994). The Heidler model of lightning base current is chosen to be injected at the grounding system modeled as the equation is simple and the Heidler model is widely used in EMTP/ATP computer programs (Furgal,2020).