OPTIMISATION OF ELECTRIC FIELD DISTRIBUTION AROUND POLYMERIC OUTDOOR INSULATOR

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ABSTRACT

Polymer insulators are widely used now a day in high voltage transmission lines to replace porcelain and toughened glass insulators due to their better service performance in polluted environment. Despite this advantage, the major cause of polymeric insulator failure is due to the polymer material aging and degradation which is caused by electrical stress on the high voltage terminal of the insulator. In this project, three techniques for optimising electric field on outdoor polymeric are simulated using COMSOL Multiphysics along the insulator profile. The techniques are by i) improve insulator weather shed shape, ii) corona ring installation optimisation location and iii) adding microvaristor compound as filler. An 11kV polymeric insulator model in clean and dry condition is used in the simulation and the results from the simulation shown all these three techniques can improve the electric field stress on the insulator. In the first technique, a parametric study is done by adjusting the weather shed shape to obtain the best result. From the study, it is shown the weather shed diameter can reduce 70% of the electric stress near the high voltage terminal of the insulator. As for corona ring optimisation installation, the corona ring and tube diameter, and distance from insulator is important in improving the electric field stress. By installing corona ring, the electric field has 37% improvement. In the third techniques, Zinc Oxide with cone shape is used as microvaristor compound filler in the insulator and the improvement is 38%.

ABSTRAK

Penebat polymer digunakan secara meluas pada dewasa ini untuk menggantikan penebat porselin dan kaca yang dikeraskan kerana ia mempunyai keupayaan yang lebih baik dalam persekitaran yang tercemar. Di sebalik kelebihan ini, penyebab utama kegagalan penebat polymer adalah penuaan dan degradasi bahan polymer tersebut yang disebabkan tekanan elektrik pada terminal voltan tinggi penebat. Dalam projek ini, tiga teknik untuk mengoptimumkan medan elektrik pada penebat polymer disimulasikan menggunakan COMSOL Multiphysics di sepanjang profil penebat tersebut. Teknik-teknik tersebut adalah dengan i) memperbaiki bentuk layang cuaca penebat, ii) memasang jejari corona pada lokasi yang optimum dan iii) menambah sebatian '*microvaristor*' sebagai isian penebat. Satu model penebat polymer 11kV dalam keadaan bersih dan kering digunakan di dalam simulasi dan keputusan daripada ketiga-tiga teknik ini menunjukkan bahawa ia boleh memperbaiki medan elektrik pada penebat tersebut. Dalam teknik pertama, kajian 'parametric' dilakukan dengan mengubah suai layang cuaca penebat untuk mendapatkan keputusan yang terbaik. Daripda kajian ini, diameter layang udara boleh menurunkan 70% medan elektrik berhampiran terminal voltan tinggi pada penebat. Manakala bagi pemasangan jejari corona, jejari dan tiub corona, dan jarak dari penebat adalah penting untuk memperbaiki tekanan medan elektrik. Dengan pemasang jejari corona, medan elektrik dibaiki 37%. Dalam teknik ketiga, Zinc Oxide dengan bentuk kon digunakan sebagai sebatian dan pembaikan adalah pada 38%.

CONTENTS

1.0 CHAPTER 1: INTRODUCTION

2.0 CHAPTER 2: A REVIEW ON POLYMERIC OUTDOOR INSULATOR

3.0 CHAPTER 3: METHODOLOGY

4.0 CHAPTER 4: SIMULATION RESULT, ANALYSIS AND DISCUSSION

5.0 CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATION

FEM	-	Finite Element Method
2D		2 Dimensional
EDPM		Ethylene Propylene Diene Monomer
EPS	-	Ethylene Propylene Silicon
FRP		Fiber Reinforced Rod
IEC	-	International Electrical Commission
TV		Television
ZnO	-	Zinc Oxide
UV		Ultra-violet
Si-O		Siloxane
kV	-	kilo Volt
rms		root mean square
cm		Centimeter
mm	-	Milimeter
m	-	Meter

E - Electric Field

F Force

Q Charge

εr - Relative Permittivity

σ - Conductivity

CHAPTER 1:

INTRODUCTION

1.1 Background

Insulators play important role in high voltage distribution system. In the early development, they are used in telegraph line as insulator with simple design. As electricity has become one of the most important necessities in human life, insulator has evolve and their durability in service is one of the most important factor before they are installed. Insulators are made from dielectric materials such as glass, ceramic and plastic(polymer). Beside providing electrical support by insulating between conductors and transmission tower or pole, and separating the conductors in the transmission line, they also provide mechanical support by supporting the load in the transmission line as shown in Figure 1.1. As such, there are many shapes and types of insulators used in power system transmission with different densities, tensile strengths and performing properties with the aim to withstand the worst conditions such as surge during lightning and switching operations which will voltage to spike.

Earlier insulators are made from high quality glazed porcelain and pre-stressed or toughened glass, or known as ceramic insulators. From research and service experience [1], they are reliable and cost effective for major outdoor insulations. Although porcelain and glass insulators have good performance over the years [2], their main disadvantages are due to their bulky size which make them difficult to install in remote area, vulnerable to vandalism and most importantly is their poor performance in polluted environment. This is due to ceramics' hydrophilic properties which enable water to easily form a continuous conductive film along the creepage path. This can lead to flashover and hence cause failure in the power transmission lines.

Figure 1.1 : Insulators in high voltage transmission line

Now a day, polymer insulators or known as non-ceramic insulators are widely used to replace porcelain and glass insulators in transmission lines. They were introduced in 1960's and start to be installed in United States in 1970's and since then, they become major option for utility companies around the world. They are easy to install due to it light weight and less prone to damage due to vandalism because of it elasticity surface [3]. The most important advantage of polymeric insulators is their better performance in polluted environment due to their good hydrophobic surface property (the ability of a surface to bead water) in the presence of wet conditions such as rain, fog and dew [4]. Due to their hydrophobic surface, leakage current is reduced since it prevents water to form solid conducting layer on it surface.

As a conclusion, all insulators must have high mechanical strength to carry conductors' tension and weight, and very high dielectric strength to withstand the voltage stresses in high voltage system.

1.2 Problem Statement

Although polymeric insulators perform well in polluted conditions, it will degrade because of it chemical changes on its surface. Continuous contamination due to environment and chemical exposure will cause the contaminants to accumulate on the insulator surface. Although it hydrophobicity ability will cleans it surface during rain and wind flow, the formation of contaminants on the surface may become conductive when expose to moisture due to fog and dew.

Hydrophobicity ability of polymeric insulator will reduce due to the formation of contaminants layer and this will leads to conductive film formation on its surface. The conductive film and resulting leakage current will cause dry band arcing. Dry bands arcing occur when the leakage current flowing on the insulator surface produces heat which causes the moisture conductive film to evaporate. Other than dry band, polymer insulator can degrade due to the uneven surface drying caused by non-uniform current density of the insulator shape that can lead to dry patches formation on the insulator surface.

Combination of potential gradients and high electric field will trigger electrical discharges on the surface. Under favorable condition, flashover may occur when the electrical discharge elongated over many dry bands on insulator.
One of the cause of electric discharge on the insulator surface is due to the electric field distribution on the insulator surface which controls the current density. The dry band location has the highest peak along the non-uniform electric field profile of the insulator.

Corona activity under dry or wetting condition in long term also can degrade the polymeric insulator. During wet condition, electric field around the insulator will be high due to discharge cause by high permittivity of the water contact with silicone. High electric field near the high voltage terminals will cause corona activity during dry condition.

1.3 Objectives

Recent research on the polymeric insulator failure shows insulator aging and degrading are caused by high electric field on the high voltage terminals. The main aim of this project is to optimize the electric fields around the polymeric insulator especially near the high voltage terminals area which include the following objectives :

1. Insulator wheather shed parametric study and simulation
2. To identify the best corona ring location installation to improve the electric field around the insulator below the corona threshold
3. To examine the effectiveness of non-linear grading material for electric field stress control around the polymeric insulator

1.4 Scope of Project

This project focus on 11kV insulation power distribution system and only involve simulation study for the three methods mentioned. The simulation is done by:

2 Using Finite Element Methods (FEM) for electric field computation
3 Simulation is in 2D asymmetry condition neglecting nearby structure
4 In clean environment without pollution elements

1.5 Project Outline

The report consists of five chapters. Chapter 1 is to introduce the background of the project, the problem that leads to this project, and summary of the project execution. Chapter 2 are studies on the polymeric insulators, factors that contribute to its aging degradation that leads to it failure and techniques to optimize the electric field on the high voltage terminals of the insulators. Chapter 3 describes the methodology been used in this project where how the simulation is done along 11kV polymeric insulator creepage profile. Chapter 4 is the simulation of the polymeric insulator with various parameters such as the weather shed intersection radius and distance, corona ring dimension and distance from insulators to obtain the optimise electric field, and weather shed profile shape that can improve the electric field distribution. From these simulations, analysis and discussion are made to show all these methods shows improvement of the electric field distribution on the insulator. Lastly, Chapter 5 discuss the conclusion from this project and future recommendation to improve the study of electric field on the polymeric insulator for more realistic applications.

CHAPTER 2

A REVIEW ON POLYMERIC OUTDOOR INSULATOR

2.1 Introduction

The main cause of insulators failure in high voltage distribution system is due to flashover between transmission line and the earthing under abnormal overvoltage in the system. Arcing will produce large enough heat which cause puncher in the insulator body during flashover. The materials used for electrical insulator has to possess specific electrical and mechanical properties to avoid this phenomenon. It mechanical strength must able to carry tension and weights of the conductors in transmission lines, the dielectric strength must be high to withstand the voltage stresses in high voltage system and high resistance to prevent leakage current to the earth. Besides the electrical and mechanical properties, the manufacturing process of insulators must be almost perfect to ensure the insulators are free from unwanted impurities. The structure should not porous to avoid any entrance of moisture or gasses.

In the 1970’s, polymeric insulators are introduced and widely used to replace porcelain and glass insulators due to their lightweight and better performance in polluted environment. Since then, extensive research has been done on polymeric insulator for better performance.

2.2 Electric Fields

Electric field is defined as the electric force per unit charge and it is a vector quantity since it depends on direction. The direction of the field is taken to be the direction of the force it would exert on a positive test charge. The electric field is radially outward from a positive charge and radially in toward a negative point charge.The equation for electric field strength is

$$\text{Electric Field Strength} = \frac{\text{Force}}{\text{Charge}}$$

In mathematical term :

$$\mathrm{E} = \frac{\mathrm{F}}{\mathrm{q}} \qquad \text{Equation (1)}$$

where the unit is Newton / Coulomb. Electric field strength is a quantitative expression of the intensity of an electric field at a particular location. The standard unit is volt per meter (v/m or $\text{v}\cdot\text{m}^{-1}$). A field strength of 1 v/m represents a potential difference of one volt between points separated by one meter.

Electric fields in high voltage cause polarization and electric losses in polymeric insulators [5]. Higher fields will induce additional mechanisms in the insulator such as cavity discharges and space charge accumulation during conduction and polarization. Polarization occurs when the electrons and polymer molecules tend to re-arrange under the effects of electric field. When the polymer reaches dielectric electrical breakdown, conduction will occur where the insulator become conductive. In long term, space charge accumulation can persist within the insulation and its surface and this can produce localised breakdown at the intense electric field regions which can lead to erosion on the insulator [6].

2.3 Polymer Outdoor Insulator

Polymeric insulators are also known as non-ceramic insulators or composite insulator. Two main materials have been used extensively as polymeric insulators are silicon rubber and Ethylene Propylene Diene Monomer (EPDM) [7]. Their Ethylene Propylene Silicon (EPS) combination is used to improve surface properties and material strength. Polymeric insulators has lighter weight since the insulator is made from fiber rod as the core and polymeric materials as the outer sheath. The most important properties of polymeric insulator are their hydrophobic surface which prevents the formation of continuous wet paths along its surface. With this advantage, they can perform better in polluted condition when other types of outdoor insulator suffer from dry-bands formation on the insulator surface and followed by localized discharges along the dry bands.

Polymeric insulators consists of three parts : i) steel/aluminium end fitting terminals to support mechanical loads on conductors, ii) fiber reinforced rod (FRP) core to carry mechanical load and insulation between two terminals, and iii) polymeric weather shed housing to protect the FRP rod against environmental influences, external pollution and humidity. Figure 2.1 shows the structure of polymeric insulators with all three components flanges are crimped to a fibre reinforce rod (FRP) encapsulated within weather shed polymeric housing.

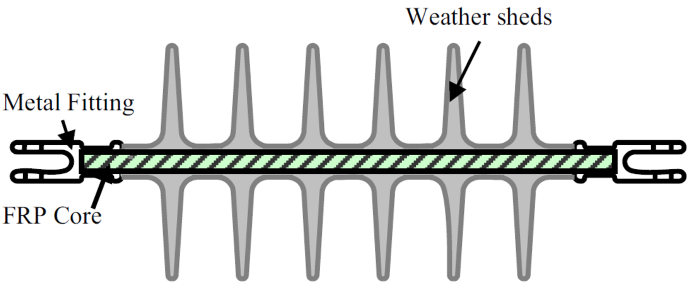

Figure 2.1: Polymeric insulator structure [8]

The insulators selection for different voltage rating is depends on the minimum specific creepage distance and IEC 60815 standard requirements [9].

2.4 Degradation of Polymeric Iinsulators Surfaces

Polymeric insulators can degrade faster compared to other insulators due to it compound chemical bond is subjected to chemical reaction. Beside insulator material and design, other factors that contribute to it degradation and ageing is electrical, mechanical and environmental stress [10-11].

2.4.1 Electrical Stress

The electric field distribution is not uniform along high voltage insulator where the highest field regions are at the high voltage end terminals and core areas. Electric discharges in the form of corona, dry band arcing and flashover will occur due non-uniform and high fields on the insulator [12].

2.4.1.1 Corona Discharge

Corona discharges occur at the insulator surface when the electric field gradients on the surface exceed the air breakdown strength. Corona formation is dependent upon atmospheric conditions such as air breakdown, humidity and insulator geometry. Corona cause radio and TV interference, noise, ozone, and energy loss. Corona accelerates the polymer aging by producing ozone and ultra-violet light [13-14]. Figure 2.2 shows corona discharge activity for 500 kV transmission in dry condtion

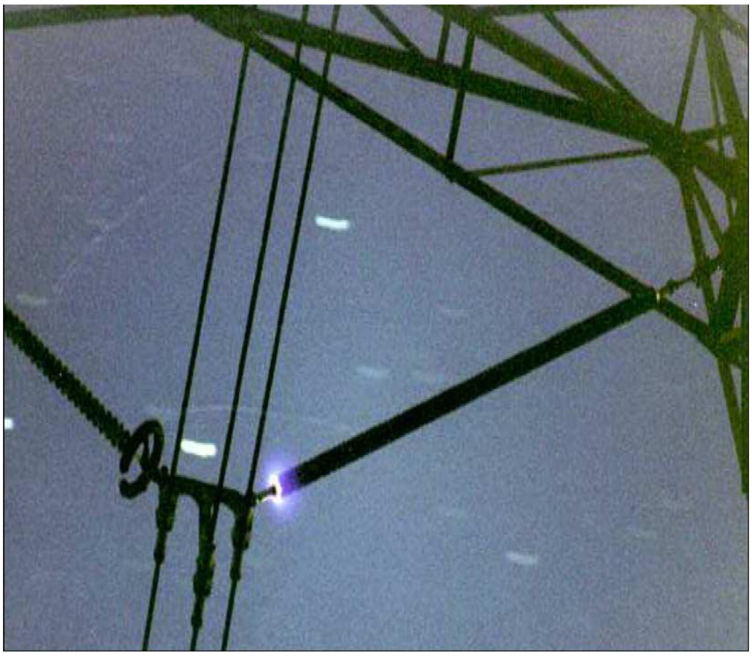

Figure 2.2 : Dry corona activity from the metallic end fitting in 500 kV transmission line [14]

2.4.1.2 Wetting Discharge

The presence of water droplets during rain, fog and dew condition increase the electric field around the insulator [14]. If the magnitude of the surface electric field strength exceeds a threshold value of 0.5-0.7 kVrms/mm, water droplet corona discharges may occur [15]. These discharges usually occure between water droplets and degrade the polymer hydrophobicity material surface. The high temperature of this discharge also thermally degrades the insulator surface. As such, the surface corona discharges due to water droplets will accelerate the aging of the polymer material. This will cause the surface damage due to tracking and erosion and increase the possibility of flashover of the polymeric insulator.

2.4.1.3 Dryband Discharge

Dry bands discharge occur when the leakage current flowing on the insulator surface produces heat which causes the moisture conductive film to evaporate[14]. During drying process, the leakage current flows from conductive bands over the dry bands. The leakage current will continue to flow until the dry band resistance become very large to interrupt the current flow. If the current continuously flow on the same dry band surface for a long time, it will cause premature aging of the elastomeric material which leads to tracking and erosion.

2.4.1.4 Insulator Flashover

Continuous corona, wetting and dry band discharge lead to thermal heating and cause further drying on the insulator surface. The dryband distance elongates as the dry band regions widen. Under favorable condition, flashover may occur when the electrical discharge elongated over many dry bands on insulator. Figure 2.3 shows the flashover development under continuous wet and dry band discharge.

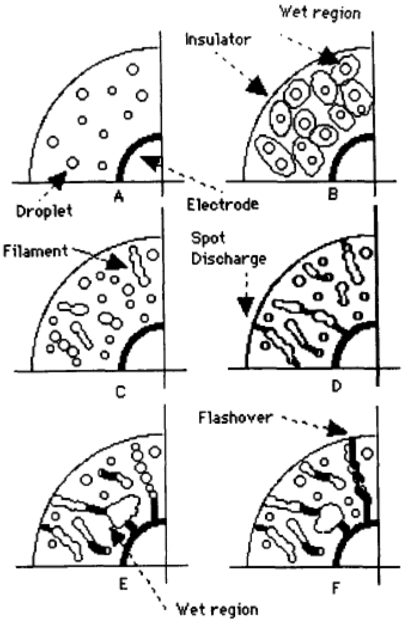

Figure 2.3 : Flashover development [16]

2.4.2 Environmental Stress

2.4.2.1 Ultra-violate Radiation

Outdoor insulator are exposed to sunlight under ultraviolet (UV) radiation. UV radiation will cause scission of molecular bonds in polymeric materials due to photo-oxidation[7]. Photo-oxidation occurs during ionization of the surface molecules and attraction of the oxygen when there is sufficient photon energy. Scission occurs when if the energy of the photon is higher than the bonds between the molecules or the polymer in the backbone of a single polymer. Silicone rubber has high energy of siloxane (Si-O) bonds which cause it to has high damage resistant by the UV radiation. However, the hydrocarbon groups in the polymer can be damaged. UV resistance is usually increased by the use of carbon-based fillers which have the disadvantage of affecting the insulating properties of the material. Intense UV exposure can lead to reduction of the silicone polymer on the surface of the material and this will increase the filler. It is known as depolymerisation and it will accelerate the loss of hidrophobicity and increase surface leakage current.

2.4.2.2 Chemical Process

Chemical process attack occurs due to pollution products and following discharge activity on the insulator surface [7]. It will formed uniform thin pollution layers on the surface. Sea or coastal pollution contains salts, while inland pollution comprises dust, industrial particles and agriculture fertilizers. When wetted, the polymer will react with the pollution products under the action of the applied field. In tropical climates, micro-organism was found on the insulator surfaces. It can enhance the surface leakage current and warms the insulator surfaces, which will encourages the growth of bacteria. Partial arcs destroy the organism but it leaves biological residue in the form of slimy surface. Water ingress in polymeric insulators in 3 ways: i) Through pool seal at the end fittings, ii) Through surface damages/defects, and iii) Absorption of water into the polymeric material itself

Corrosive chemicals and/or ionisable contaminants carried by the water affect the mechanical strength of the FRP rod and cause brittle fracture. Water absorption causes depolymerisation and polarization of the interface between the polymer and the filler. It increase the permittivity and loss tangent and decrease the dielectric strength. It the most important factor that cause heavy erosion and shed puncture due to moisture ingress.

2.5 Field Optimisation Techniques

Electric field distributions in polymeric insulators are usually highest at high voltage terminal ends. Continuous corona and surface discharge process on the insulator contribute to premature degradation. As such, various techniques can be used to minimise the degradation factor.

2.5.1 Weather Shed Insulation Profile

The electric field on polymeric insulator is non linear since it depends on the insulator geometry which result in different capacitance for different shape. The electric field along the insulation housing length is larger at the intersecting point between the sheath with sharp edges curvature. Since the electric field at the region near energize end is the highest, it is important to control the electric field at this region. Polymeric housing with large arc radius can reduce the electric field by redistribute equipotential lines over a wider surface area. If the radius is sufficiently large, the arcs between two sheds will merge to form a rounded surface on the shank regions. Chakravoti et al. [17] have done parametric studies to investigate the effect of insulator design parameters such as shed slope angel and diameter, core radius, axial length and arc radius. From the result, it is showed stress is reduce when increasing the insulator axial length, shed and arc radius. However, the increase core radius causes slight improvement on the insulator surface.

2.5.2 Corona Rings Dimension and Position

Corona rings are made from round edges conductive and usually installed near the energize end of the insulator [18]. Corona ring location and dimension must be properly installed and chosen since it will mitigate the electric field near the energize end at the most high electric stress region. Improper installation and choice of corona rings will cause higher electric stress on the insulator since the electric field is not redistribute properly. Figure 2.4 shows the location of corona ring along the insulator.

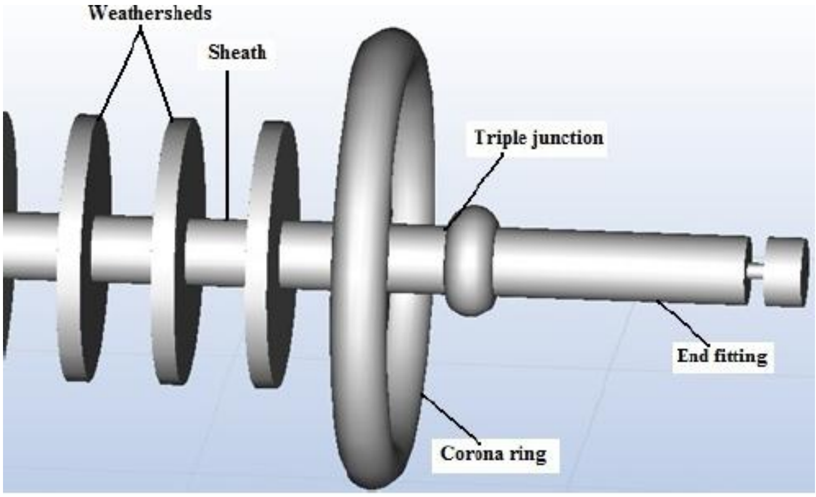

Figure 2.4 : Corona ring installation and position [19]

2.5.3 Field Grading material

Field grading material has been used to control electric stress on high voltage application such as cable termination and machine windings. There are grouped into two categories ; capacitve and resistive grading, which are classified based on the nature of current displacement within the material. Field grading action occurs within the materials, which results in redistribution of equipotential on the surrounding region such as on the insulation surfaces. Zinc oxide microvaristor is one of the material that shows these properties. It has high non-linear voltage-current characteristics and their energy absorption capability [20].

2.5.3.1 Capacitive Grading

In capacitive grading, the electric field is controlled by a material that has a high dielectric constant and the current is predominantly capacitive. Equipotentials are redistributed when passing through different dielectric materials with different permittivity values. The lines become farther apart and field distribution is reshaped along the insulation surface. High permittivity materials result in lower surface impedance, which could reduce the field stress [21]. Capacitive grading can be used with proper geometrical shapes of conducting or high permittivity material to redistribute field stress. Most of the electric field control method such as corona rings structure made on conductive material helps to grade the equipotentials at the energize end.

2.5.3.2 Resistive Grading

Resistive grading material controls field distribution by means of the bulk conductivity of the material, and the current is predominantly resistive. The selection of resistive coating with appropriate amount of conductive fillers is important to obtain a compound with desired electrical properties for specific applications. Zinc Oxide microvaristor [22] and Silica Carbide [23] can be used as functional fillers in polymeric compounds to exhibit non-linear current-voltage dependency to the grading compound. Figure 2.5 shows examples of electrical characteristics of ZnO microvaristor with different field switching threshold, Eth at approximately 200 V/m and 700 V/m. In the linear region where the current density is low, the grading material operates as an insulator. An increase in the electric field causes minimal change in current density. As soon as the electric field exceeds the threshold levels, the material enters a high conduction region. These properties can be used as excellent field grading material.

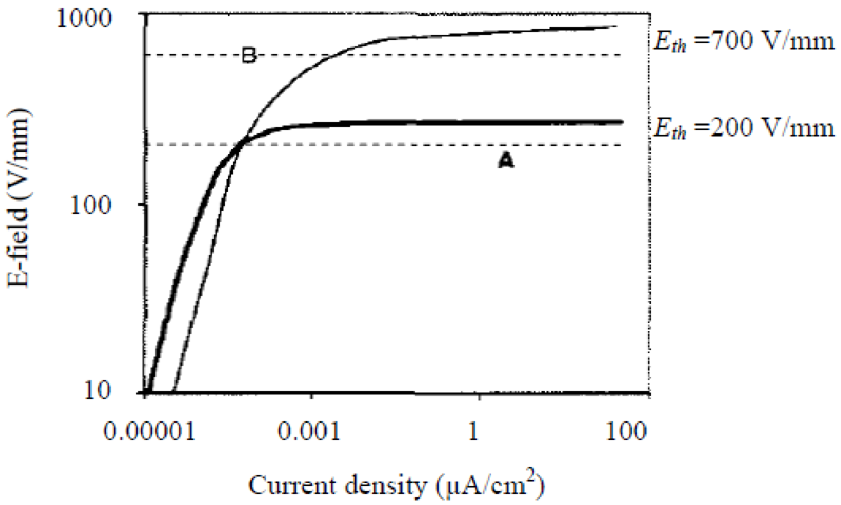

Figure 2.5 : Electrical characteristic of microvaristor with different switching filled composite as a function of electric field [24]

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, methods to investigate electric field along the creepage path along the polymeric is shown. The purpose is to locate the highest field region and from the result, electric field optimisation techiques is applied to minimise the electric field, and hence, improve the polymeric insulator reliability. There are two methods can be used to determine the electric field distribution, i) experimental measurements and ii) numerical computations. For this project, numerical computation using Finite Elements Method is used to investigate the electric field distribution. Advance in computing technology has enabled various numerical computational simulation to solve various engineering problems. Finite Elements Method offers accurate computation results and hence, minimise error.

3.2 Finite Element Method

Finite element method (FEM) is a numerical method to solve various partial differential equation (PDE) that represents a physical system. It discretize the entire domain problem to a number of smaller non-overlapping subdivisions called domain. FEM is suitable for small domain problems with limited and closed boundary conditions and less effective for solving large problem with open boundary condition. In this project, COMSOL Multiphysics is used to simulate the finite elements for the insulator. The simulation is performed in three consecutive stages namely pre-processing, solving, and post processing stages. Geometrical, material and boundary properties, and meshing criteria of the elements are the inputs in the pre-processing stage. The mathematical model express as differential equations that describe the physical problem is executed in solving stage. Finally, plot processing stage is when the plot generated by simulation in terms of variables or parameters.

3.3 Simulation Process Flow

For any problem investigation, it is important to identify the process that involved to obtain desired result. Figure 3.1 shows simulation process during the electric field study.

3.4 Insulator Model

In this project, a standard 11 kV polymeric outdoor insulator as shown in Figure 3.2 is used as model for electric field investigation. The insulator is simulate under dry-clean and uniform wet-polluted conditions for electric field investigation without considering other attachment such as tower, conductors and other hardware peripherals. The standard 11kV polymeric insulator is modified with three techniques to obtain the best optimisation techniques. The techniques are i) modify the polymeric shape, ii) installation of corona rings at proper location and suitable ring size, and iii) adding non-linear material as insulator filler.

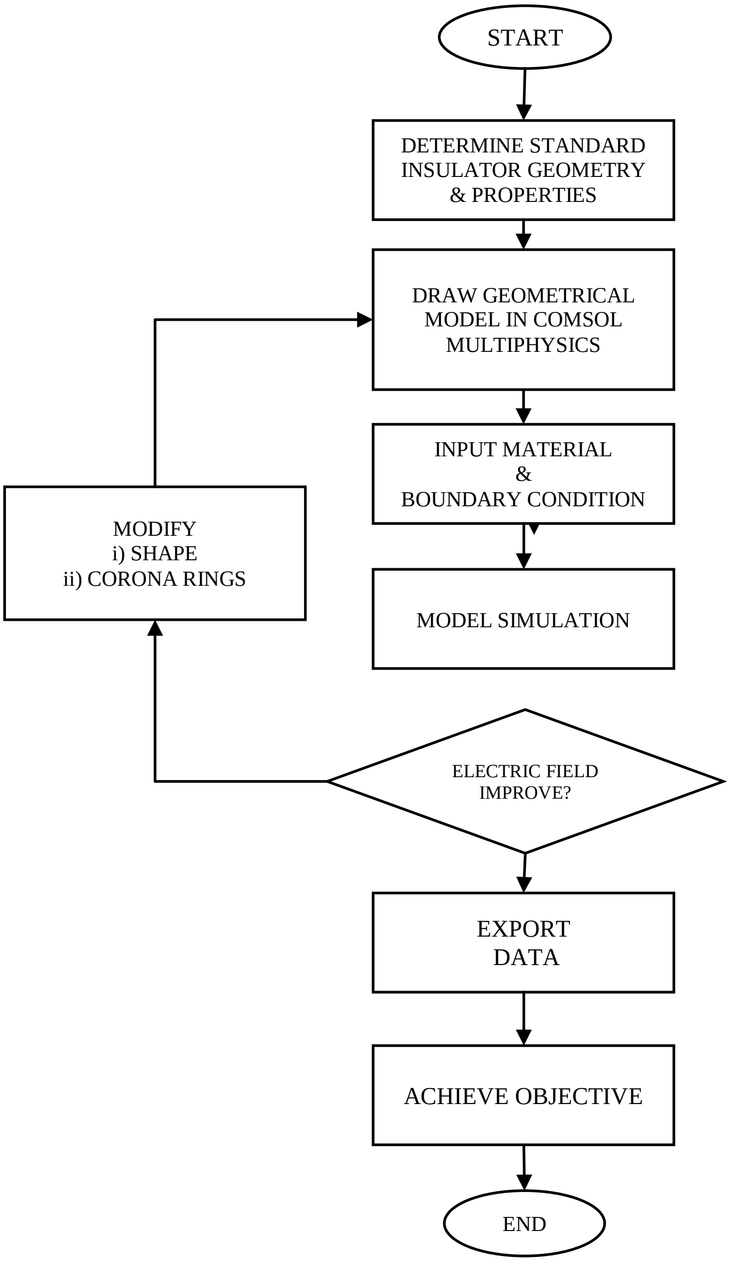

Figure 3.1 : Process flow for electric field optimisation

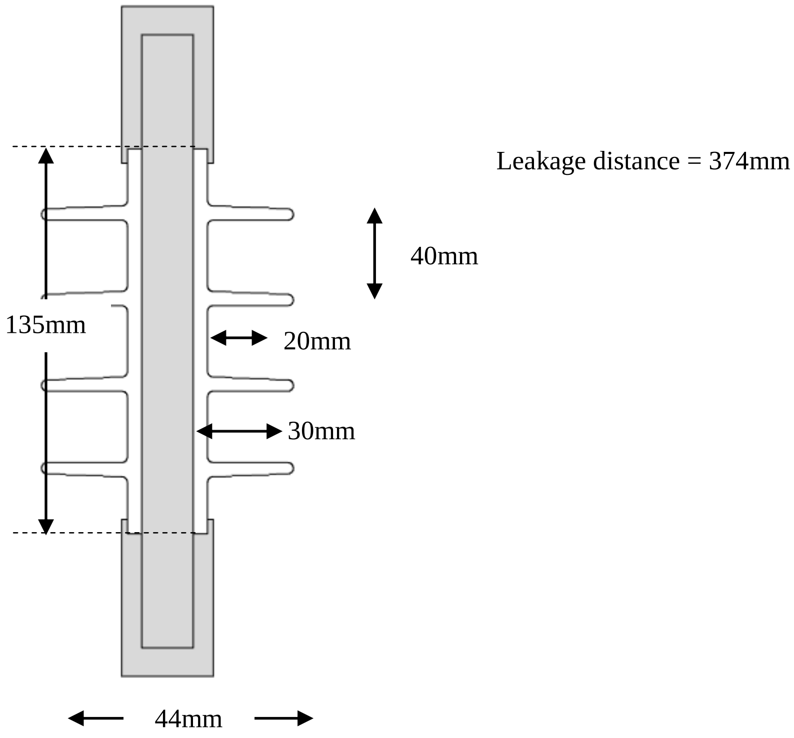

Figure 3.2 : Insulator model dimension

3.4.1 Modelling Simulation

The polymeric insulator model as shown in Figure 3.2 was created by using CAD drawing tools available in the COMSOL Multiphysics. Since the insulator geometry is cylindrical shape, the modelling is simplified into a two-dimensional (2D) problem. The simplication made the simulation faster without affecting the simulation result accuracy. The 2D assymmetric geometry is shown in Figure 3.3.

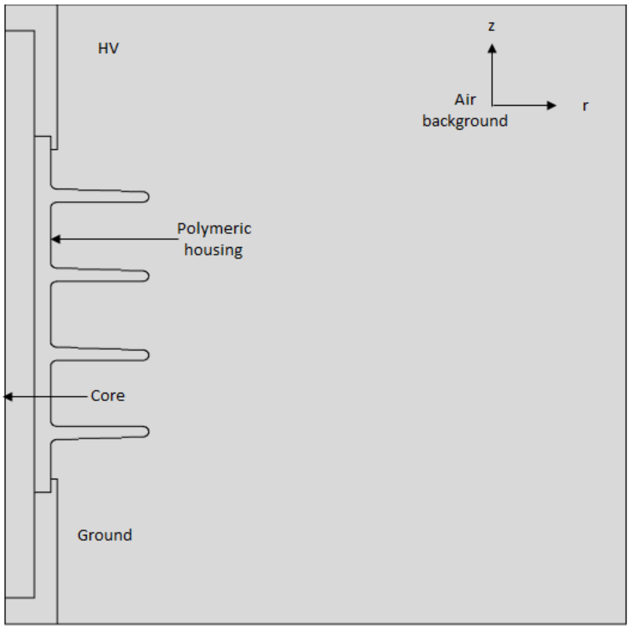

Figure 3.3: Insulator model in 2D asymmetric

3.4.2 Material Properties

In finite elements methods, each component material properties and boundary need to be assigned for mathematical calculation. The components material are available in standard material library where each material properties can be changed according to required specification. The HV and ground terminal are from forged steel with conductivity, $\sigma = 5.99\text{x}10^{7}$ S/m. The FRP core and silicon rubber housing has low conductivity, $\sigma = 1.0\text{x}10^{-13}$ S/m. The pollution layer relative permittivity is assume 80, considering water as the dominant substance when the pollution layer is completely wet and saturated with moisture. The conductivity of the pollution is set to 0.6 µS/m, obtain from laboratory measurement report [25]. Pollution layer was assume homogenous and uniformly distributed along the creepage path at 0.5mm thickness. The air surrounding insulator was specified with a very low conductivity, $\sigma = 1.0\text{x}10^{-14}$ S/m. Since ZnO microvaristor is a non-linear material, it's conductivity is depends on it's characteristic function given by equation [3.1].

$$\sigma (E) = \sigma 0 \exp |E| \qquad (3.1)$$

The material properties in this simulation are summarise in Table 3.1.

Table 3.1: Insulator dimension and material properties

Material	Relative Permittivity, ε_r	Conductivity, σ (S/m)
Forged steel	1.0	5.9×10^{-7}
FRP core	7.1	1.0×10^{-13}
Silicone Rubber	4.3	1.0×10^{-13}
Pollution layer	80	6.0×10^{-7}
Air background	1.0	1.0×10^{-14}
ZnO microvarister	12	$f(E)$

3.4.3 Boundary Conditions

In this project simulation, the HV terminal is set at 11 kV, while the ground terminal is 0 V. The air is made large enough to minimise it effect on electric field distribution along the insulator and both terminals. The outer edges of the air background region are assume zero external current.

3.4.4 Meshing

After completing all the material properties and boundary conditions, the entire domain problem was discretized into non-overlapping triangle elements during meshing process as shown in Figure 3.4. For better accuracy on the interest region, the meshing refinement can be done by selecting proper meshing size. The smaller the meshing size, the accuracy become higher and increase the processing time.

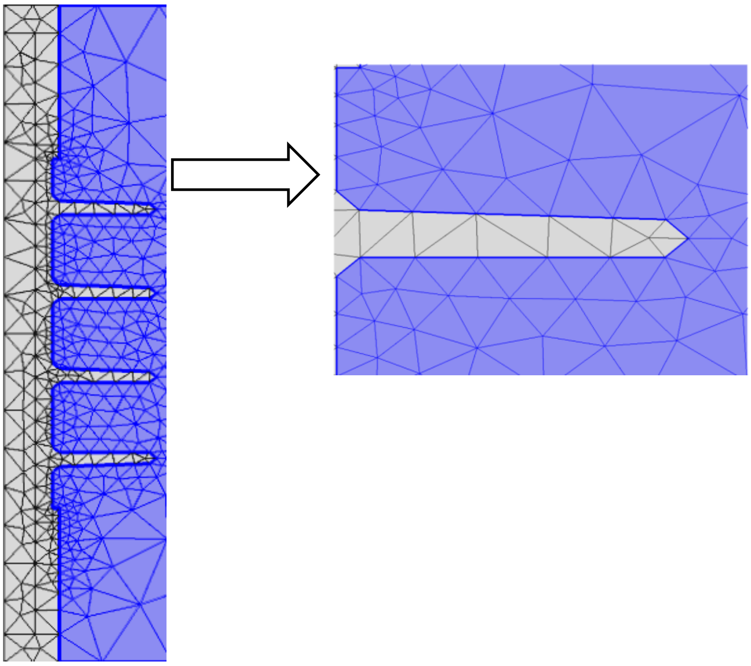

Figure 3.4: Domain discretization with mesh refinement

3.4.5 Solver Study

The study used in this insulator model was simulated by using AC/DC quasi-static electric current solver, where the material conductivity and permittivity can be specify by user. Quasi-static method current and electromagnetic fields vary slowly which is useful for this project simulation.

CHAPTER 4

SIMULATION RESULT, ANALYSIS AND DISCUSSION

4.1 Introduction

In this chapter, three methods of optimizing electric field distribution on polymeric insulator are discussed. The first method is by modifying insulator weather sheds profile, second method is by installing corona rings at appropriate location near the insulator and the last method is by applying non-linear field grading material as insulator fillet.

4.2 Equipotential Distribution

Equipotential lines is a quantitative way of viewing electric field potential in two dimensions. The contour distance between the equipotential lines represent the electric potential distribution. Figure 4.1 shows the equipotential distribution of the insulator in normal condition where the insulator is in dry-clean environment without contaminant element. There are 20 equipotential lines along the insulator, where each interval represent 5% from the total equipotential. From the figure, it shows that contour lines distance are narrower around the high voltage terminals where around 35% of the electric field potential are concentrated at both energize ends. To analyse the voltage potentials along the leakage path, the leakage distances are measured along the polymeric insulator, starting from the ground terminal and moving up to the high voltage terminal. From Figure 4.2, it is shown that the voltage increase along the leakage path as the leakage path near the energize ends.

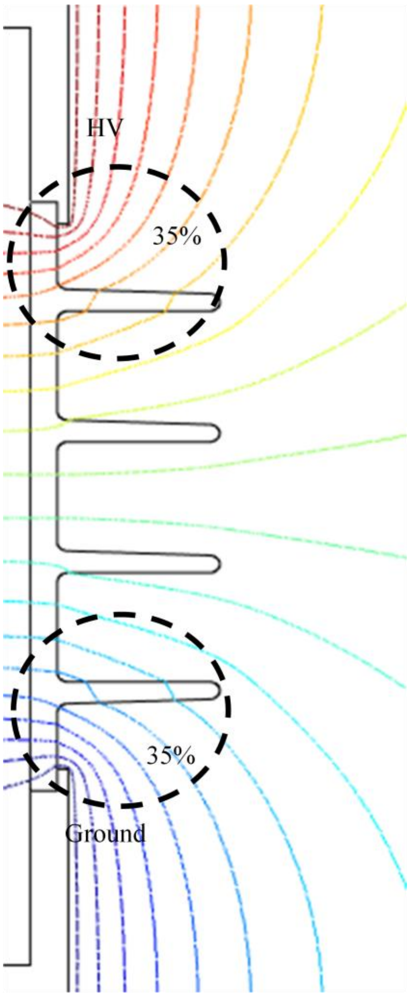

Figure 4.1 : Equipotential lines around polymeric insulator

REFERENCES

[1] Hackam, R., "*Outdoor high voltage polymeric insulators*", Proceedings of 1998 Interntational Symposium on ISEIM, pp. 1-16, 1998.

[2] R. S. Gorur, D. Shaffner, W. Clark, R. Vinson, D. Ruff, "*Utilities Share Their Insulator Field Experience*", Transmission & Distribution World, pp. 17-27, 2005.

[3] Kikuchi T., Nishimura S., Nagao M., Izumi K., Kubota Y., and Sakata M., "*Survey on the use of non-ceramic composite insulators*," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 6, pp. 548-556, 1999.

[4] Abd-Rahman., Haddad, A., Harid, N., Griffith, H., "*Stress control on polymeric outdoor insulator using Zinc oxide microvaristor composites*", IEEE trans on DEI, Vol. 19, pp. 700-713 , 2012

[5] Celine A. Mahieux, *Environmental Degradation in Industrial Composites*. [online] Elsevier, 2005.

[6] Varlow B.R., Robertson J. and Donnelly K.P, "*Nonlinear fillers in electrical insulating materials*, " IET Sci. Meas. Technol., vol 1 (2), pp. 96-102,2007.

[7] Laughton, M.A., Warne, D.F., *Electrical Engineer's Reference Book*. [online] Oxford, Newnes., 2002.

[8] Marungsri B., Onchantuek W., Oonsivilai A and Kulworawanichpong T.,"*Analysis of electric field and potential distributions along surface of silicone rubber insulators under various contamination conditions using finite element method*", International Journal of Electrical and Computer Engineering, 2010

[9] DD IEC/TS 60815 – 3: 2008 – *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions* - Part 3: Polymer insulators for a.c systems : British Standard Institution Std., 2008

[10] Spellman C. A., Young H. M., Haddad A., Rowlands A. R., and Waters R. T., "*Survey of polymeric insulator ageing factors*," in Proceedings of the Eleventh International Symposium on High Voltage Engineering, Conf. Publ. No. 467, 1999, pp. 160-163 vol. 164.

[11] Souza, A.L., Lopes, I.J.S., "*Electrical field distribution along the surface of high voltage polymer insulators and its changes under service conditions*", IEEE International Symposium on ELINSL, pp. 56-59. 2006

[12] Mackevich J. and Shah M., "*Polymer outdoor insulating materials. Part I: Comparison of porcelain and polymer electrical insulation*," IEEE Magazine on Electrical Insulation, vol. 13, pp. 5-12, 1997.

[13] Venkatesulu B. and Thomas M. J., "*Corona agind studies on silicone rubber nanocomposites*," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 17, pp. 625-634, 2010.

[14] A.J. Phillips, et al., *"Electric Fields on AC CompositeTransmission Line Insulators*", IEEE Trans.on Power Delivery, vol. 23, pp. 823-830, 2008.

[15] A.J. Phillips, et al., "Water drop corona effects on full-scale 500 kV non-ceramic insulators", IEEE Trans.on Power Delivery, vol. 14, pp. 258-265, 1999.

[16] Karady G. G., Shah M., and Brown R. L., "*Flashover mechanism of silicone rubber insulators used for outdoor insulation-I*," IEEE Transactions on Power Delivery, vol. 10, pp. 1965-1971, 1995.

[17] Chakravorti S. and Steinbigler H., "*Boundary element studies on insulator shape and electric field aroun HV insulators with or without pollution*," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 7, pp. 169-176, 2000.

[18] Cruz Domínguez D., Espino-Cortés F. P., and Gómez , P., "*Optimized design of electric field grading systems in 115 kV non-ceramic insulators*," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 20, pp. 63-70, 2013.

[19]Doshi T., Gorur R.S, Hunt J., "*Electric Field Computation of Composite Line Insulators up to 1200 kV AC*," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 18, pp. 861-867, 2011

[20] Haddad A., "*Chapter 5: ZnO surge arresters*," in Advance in High Voltage Engineering. vol. 40, Haddad A. and Warne D. F., Eds., ed London: The Institutional of Electrical Engineers, 2004.

[21] Roberts A., "*Stress grading for high voltage and generator coils*," IEEE Magazine on Electrical Insulation, vol. 11, pp. 26-31, 1995.

[22] Greuter F., Siegrist M., Kluge-Weiss P., Kessler R., Donzel L., Loitzl R., and Gramespacher H. J., "*Microvaristor: Functional fillers for novel electroceramic composites*," Journal of Electroceramics, vol. 13, pp. 739-744, 2004.

[23] Donzel L., Martensson E., Gafvert U., Gustafsson A., and Palmqvist L., "*Electrical properties of field grading materials influenced by the silicon carbide*

grain size," in Proceedings of IEEE International Conference on Conduction and Breakdown in Solid Dielectrics, " Eindhoven, Netherlands, 2001, pp. 43-45.

[24] Donzel L., Christen T., Kessler R., Greutur F., and Gramespacher H., "*Silicone composites for HV application based on microvaristors,*" in Solid Dielectrics, 2004. ICSD 2004. Proceedings of the 2004 IEEE Intenational Conference on, 2004, pp. 403-406 Vol.401.

[25] Williams D. L., Haddad A., Rowlands A. R., Young H. M., and Waters R. T., "*Formation and characterization of dry bands in clean fog on polluted insulators*," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 6, pp. 724-731, 1999.