BEHAVIOUR OF ELECTRICAL FIELD INTENSIFICATION DUE TO WATER DROPLET ON SOLID DIELECTRIC SURFACES.

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ABSTRACT

Outdoor polymeric insulators subjected to electric stress as well as to environmental condition such as rain, fog and dew. The presence of water droplets on the surface of polymer tends to deform the electric field distribution. The deformation is more due to increasing of the electric field strength. Due to this phenomenon, deterioration of the insulator surface may occur. The difference in relative permittivity, shape, conductivity and quantity of the droplets are among the factors that contribute such a behavior. Those factors were simulated to analyze the behavior intensification of electric field due to water droplet presence using COMSOL Multiphysics version 3.5a. The electric potential contour and tangential electric field on the dielectric surface simulated and analyses in the absence of water drop as a reference value. The results help to understand how the electric field distribution will be change in the presence of water droplet. The different parameter; shape, permittivity, conductivity and number of droplet has been considered and the tangential electric field has been analyzed and compared to dry dielectric surface. The identified four parameters were changed to see the difference. The results showed that the presence of water droplet on the dielectric surface material might intense the electric field about 3.36 times for flattened shape of water droplet and 1.56 times for semispherical water droplet which was verified with comparison on dry dielectric surface. The result also strongly shows that the increment of electric field is at the interface of the water droplet, air and the insulating material or triple point junction of water droplet. Furthermore, water droplet with contact angle less than 90^o will increases the tangential electric field almost twice. From this project, water droplet shows the significant in increment of electric field on outdoor polymeric insulator.

ABSTRAK

Ketengangan elektrik sangat berkaitrapat dengan penebat polimer terutama pada ketika cuaca hujan,berkabus dan embun. Titisan air yang berada di permukaan penebat polimer mampu mengubah struktur medan elektrik di persekitaran penebat. Perubahan struktur medan elektrik yang berlaku lebih kepada peningkatan nilai medan elektrik. Kesan kepada perkara ini adalah kerosakan kepada permukaan penebat.Antara faktor penyumbang adalah perubahan pada ketelusan bandingan, bentuk, keberaliran dan kuantiti titisan air yang terdapat di permukaanpenebat.Faktor-faktor ini disimulasi dan di analisismenggunakanperisian COMSOL Multiphysicsversi 3.5a.Sebagaipermulaan, kontur keupayaan dan medan elektrik tangen pada permukaan penebat disimulasi dan dianalisis tanpa kehadiran titisan air sebagai nilai rujukan. Hasil simulasi dan analisis membantu dalam membandingkan bagaimana perubahan pada medan elektrik berlaku pada ketika permukaan penebat terdapat titisan air. Simulasi seterusnya melibatkan perubahan pada nilai keempat-empat parameter dengan kehadiran titisan air pada permukaan penebat. Hasil simulasi menunjukkan kehadiran titisan air pada permukaan penebat meningkatkan medan elektrik sebanyak 1.56 kali bagi titisan berbentuk separuh sfera dan 3.36 kali lebih tinggi bagi titisan yang berbentuk rata jika dibandingkan dengan permukaan tanpa titisan air. Peningkatan medan elektrik berlaku pada titik pertembungan tiga bahan iaitu titisan air, udara dan material dielektrik. Tidak ketinggalan juga, titisan air yang mempunyai sudut lekitan kurang dari 90^{o} meningkatkan medan elektrik sebanyak hampir dua kali ganda. Dengan ini terbukti bahawa titisan air meningkatkan medan elektrik pada permukaan penebat polimer.

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LIST OF SYMBOLS AND ABBREVIATIONS

SiR	Silicon Rubber
EPR	Ethylene-propylene rubber
EF	Electric field
FEM	Finite element method
FRP	Fibre reinforced plastic
mm	millimeter
μS/cm	micro Siemen per centimeter
V/m	Volt per meter
m	meter

CHAPTER 1

INTRODUCTION

1.1 Introduction

Polymeric insulators are mainly used for outdoor applications as replacement of conventional glass and porcelain insulation system. They are started to gain popularity amongst electric power utilities due to their lightweight and outstanding electrical performance in moderate to heavily polluted environments [1]. Other significant advantages of polymeric insulators compared to porcelain and glass insulators are their higher mechanical strength, ease of transportation and installation, lower maintenance cost, hydrophobic properties, and comparable or better withstand voltage.

Figure 1.1: The polymeric outdoor insulator.

Outdoor insulator must be reliable under certain weather conditions such as fog, dew, rain and pollutants from the salty wind, ultraviolet radiation, chemical from industries and other contamination. Composite materials that used as insulator housing

have excellent hydrophobic surface property under wet conditions. Silicone rubber insulating materials are able to resist water filming and hence surface resistance for hydrophobicity. Water on the polymeric surface tends to form beads and remains as droplets.

Figure 1.2: Water droplets on the polymeric insulator surface

Hydrophobicity is the wetting property of rubber material because of which it resists formation of film of water by forming beads of water. Hydrophobicity status of polymeric insulators in service shows that a good direct proportionality exists between the hydrophobicity distribution and the electric field distribution. The more electric field will appear around the areas with more hydrophobicity degradation expected. This condition occurs due to the presence of low resistance path in hydrophobicity-degraded parts of an insulator.

Polymer insulator has good characteristic when it is contaminate because of its high hydrophobicity. Electrical field strength needs to be control on the polymeric insulator to prevent significant discharge activity on the surface of polymeric insulator under both dry and wet conditions. This discharge activity may result in the degradation of pollution performance to the insulator.

Under rain and fog conditions, the presence of water droplets intensifies the electric field strength on the surface of a polymer insulator. It is due to high permittivity and conductivity of the water droplets. When water droplets exist under an electrical field environment, the electrical field force may change the contact states of the water

droplets. At the same time, the existing water droplets will also change the outer electrical field distribution. High electric field intensity and high voltage distribution believes might easily lead to corona surface discharge. As a result, the surface corona discharges from water droplets accelerate the ageing of the shed material of a polymer insulator. Consequently, polymer insulators tend to lose their hydrophobicity by weathering after some years of exposure. That might worsen the wet and contamination performance of polymeric insulators.

It is important to control the electric field distribution on the polymeric insulator since they have a synergetic effect on the insulator material ageing and on its overall performance. Aging leads to the gradual loss of electrical and mechanical strength of the insulator and to material deterioration.

1.2 Problem statement

Polymeric insulators are considering being a cylinder dielectric with potential difference will be set up between the terminals. The electric fields also will fill the space between the terminals. The electric field stress is governed by the distribution of capacitance along the insulator and their size. The field intensity falls away rapidly with increasing distance from the live terminal but it is impossible since the distance between the terminals is related to insulator creepage distance designed.

Polymeric material of the insulator acted as dielectric material in between the plates of a capacitor affects the value of the capacitances of the insulator. A dielectric is a material that easily polarized due to the influence of the charges on the plates. This means that the molecules that make up the dielectric will be able to align themselves with the charges on the plates. Inserting the dielectric, the molecules of the dielectric polarized, meaning that their ends have had a charge induced on them; the molecule has an induced electric field with the same magnitude, and opposite direction, that cancels the electric field due to the charges on the capacitor plates. However, the dielectric molecules do not occupy some places and here the electric field due to the charges on the plates is unchanged. By count, the number of field lines as a measure of the magnitude of the electric field when the dielectric inserted and called $E_{dielectric}$.

The electric potential or voltage acted as the altitude that called equipotential line. Equipotential are defined as the surfaces on which the potential takes a constant value; hence different equipotential never intersect. Equipotential lines are always perpendicular to the electric field. The electric field intensity, which can be calculate from the potential difference and distance between any two points, can vary or not be constant. When equipotential lines are closed to each other, the electric field is strong.

1.3 Aim and objectives

Recent research on polymeric insulator failure shows that the ageing and degrading of the insulator is caused by high electric field that distributed through the insulator. The main aim of this project is to evaluate the field intensification due to the present of water droplets on composite surface. The objectives include the following;

1. To analyze the electric field distribution in the vicinity of water droplet on the dielectric surface.
2. To evaluate the selected water droplet parameters towards electric field enhancement.
3. To model and simulate electric field performance around polymeric suspension outdoor insulator with the presence of water droplets.

1.4 Project scope

Focus of the project is on 66kV polymeric insulation of distribution power system. This project only involves with simulation study:-

1. To analyze electric field stress with the presence of water droplet on the polymeric insulator using Finite Element Methods (FEM) for electric field computation in axial symmetry (2D) design.
2. To simulate on 2 sheds structure near the conductor terminal, in ideal condition without nearby structure attached to the transmission line
3. To carry out study on 66kV polymeric outdoor insulator.

1.5 Project outline

This study is divided into five chapters. Chapter 1 constitutes the introduction and the information about polymeric outdoor insulators the purpose of study. Chapter 2 outlines review on polymeric outdoor insulator. Any characteristics that related to the study are briefly explained in this chapter. Chapter 3 is reviewing on the simulation procedure computer analysis the polymeric insulators modelling. Chapter 4 explains the results and evaluation of the simulation. Other than that, the effects of different electric field controlling methods are also discussed in this chapter. Chapter 5 concluded the study and covers the future work.

CHAPTER 2

REVIEW ON POLYMERIC OUTDOOR INSULATOR

2.1 Introduction

Insulators plays a vital role in the power system whereas they can be used in different shapes and various technical conditions based on the related application. Polymeric insulators are widely used because of the advantages of lighter weight, ease of handling, higher vandalism and the superior pollution flashover performance compared to ceramic insulators. This section is aimed at providing an insight into the available literature on the polymeric insulators. The first part of the chapter is dedicated to an overview of the electrical stress surrounding the polymeric insulator that caused the degrading of the insulator. Following this is a description of the influences of water droplet on the electrical stress surrounding the polymeric insulators.

2.2 Polymeric insulator

Polymeric insulators comprise of three main parts i.e fiberglass core, end attachment hardware or end fittings and insulating housing with weather sheds. The core part provided the mechanical strength of insulator whereas it is usually fiberglass reinforced plastic (FRP) rod. The metal end fitting is directly connected to core part with appropriate isolation at connection part versus moisture whereas it is usually connected to core with the swaged or crimped fitting methods to increase reliability of insulator. The metal end fitting is usually made from forged, machined aluminum, malleable iron and forged steel based on the application. Weather sheds are set on the core part. The widely used weather sheds are classified into two main groups i.e. EPR and SiR. It should be mentioned that SiR group mostly is used compared to the other group due to its characteristic hydrophobicity and good performance in contaminated weather condition [12].

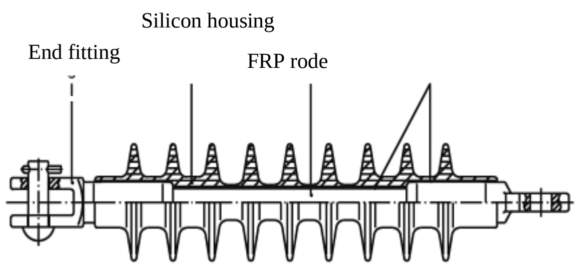


Figure 2.1: The structure of polymeric insulators.

2.3 Water droplet

Water drop on a suspension insulator has two kinds of location. One is pendant or sessile on the insulation shed and the other is clinging on the sheath of glass rod. These two kinds of location cause different relative positions between water drop and insulating materials in the electric field. The water droplets play several roles in the pollution flashover and aging of non-ceramic insulators [4]:

Water drop on a suspension insulator has two kinds of location. One is pendant or sessile on the insulation shed and the other is clinging on the sheath of glass rod. These two kinds of location cause different relative positions between water drop and insulating materials in the electric field. The water droplets play several roles in the pollution flashover and aging of non-ceramic insulators [4]:

- The water droplets increase the electric field strength at the insulator surface because of their high permittivity and conductivity.
- The surface corona discharges from water droplets age the weather shed material of the insulator.
- The corona discharge destroys the hydrophobicity locally causing the spread of water, and adjacent water droplets to coalesce.
- They will be deformed, always elongated along the direction of electric field, under applied voltage.

These distortions shorten the insulating distance, cause corona on the SiR surface, and finally bring about the surface discharge. The presence of water droplets layers intensifies the electric field strength on the surface of a polymeric insulator.

2.4 Electric field

An electric field is a region in space where one charge experiences a force from another charge. Electric potential is the amount of energy stored in an electric charge due to its position in an electric field. The strength of an electric field directly related to the magnitude of the electric charge producing the field. Equipotential lines are lines connecting points of the same electric potential. All electric field lines cross all equipotential lines perpendicularly. Closely spaced electric field lines indicate a strong electric field. The closer the lines, the stronger the electric field. Equally, spaced electric field lines indicate the electric field is uniform.

2.5 Parameter effecting E-field

There are a certain number of parameters influences the intensification of electric field surrounding polymeric insulator. The parameters influence the intensification of electric field by its nature factor.

2.5.1 Shape of water droplet

One of important parameters in the insulators is the hydrophobicity properties. Hydrophobicity is the wetting property of rubber material because of which it resists formation of film of water by forming beads of water [6]. A material is highly hydrophobic if the material surface resists flow of water dropped on it and is least hydrophobic if dropped water flows in form of track on its surface. The surface with hydrophobic property is water repellent, in contrast with a hydrophilic surface that is easily wetted. Hydrophobicity of a material can be described by a contact angle, Θ_c on the material surface that liquid drop makes when it comes into the contact with solid surface. This contact angle is a measure of the surface wettability.

The shape of the liquid droplet depends on the type of the solid material and physical and chemical state of its surface [13]. The smaller is the contact angle, more the surface is getting wetted and vice versa. The surface is assumed to be hydrophobic for contact angles greater than 90° and assumed to be hydrophilic when the contact angle is less than 35°, while the surfaces characterized by the contact angles from 35° to 90° are partially wettable. It was found that drops on highly hydrophobic surfaces were smaller and more circular than on less hydrophobic surfaces.

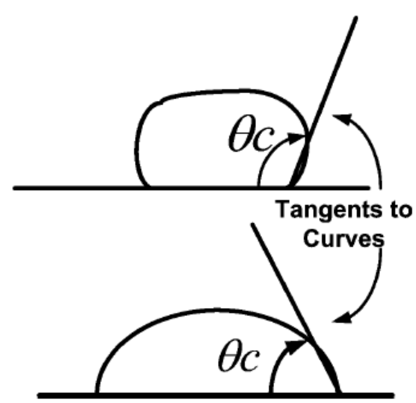


Figure 2.2: The angle of water droplet on (a) hydrophobicity surface and (b) less hydrophobic surface.

The hydrophobicity of weathered material, in example when polymeric material exposed to rain or moisture, produces a beads-like droplet [10]. When water droplets exist under an electrical field environment, the electrical field force may change the contact states of the water droplets. The existing water droplets will also change the outer electrical field distribution and may cause corona discharge on the surface of polymer insulating materials.

2.5.2 Conductivity, σ.

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water affected by the presence of inorganic dissolved solids. The addition of fresh water (rain) lowers conductivity because rainwater has low conductivity and the increase in water levels dilutes mineral concentrations. Conversely, during low flow conditions, the dissolved solids are more concentrated and therefore conductivity levels are higher. The conductivity of natural rainwater laid in the range 50 - 150μS/cm [21].

2.5.3 Relative permittivity, ε_r.

The permittivity of a substance is a characteristic that describes how it affects any electric field set up in it. A high permittivity tends to reduce any electric field present. Air or vacuum has minimum value of permittivity. The absolute (or actual) permittivity of air or vacuum is $8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.The absolute permittivity ε of all other insulating materials is greater than ε_0. The ratio $\varepsilon / \varepsilon_0$ called relative permittivity of the material. Relative permittivity indicates how easily materials being polarized by imposition of an electric field on an insulator.

2.6 Corona discharge

Corona discharge occurs on the surface of the insulator when electric field intensity exceeds the breakdown strength on the air. The corona generation is effected by the atmospheric condition; air density and humidity. The geometry of the insulator itself has a role in the ignition of corona activity. Corona can occur within voids in insulators as well as at the conductor or insulator interface. When corona generation occurs on wet surface, it results in 'wetting corona activity'; a non-uniform wetting causing high electric field. Corona is a phenomenon that has the capability for degrading insulators and causing systems to fail.

2.7 Ageing process of the insulator.

Ageing is defined as slow and irreversible alteration of a material's chemical or physical structure. This alteration has normally a detrimental effect on the material properties. It leads to gradual loss of the design function and ultimate failure or unacceptable loss of efficiency. Ageing can be categorized into two types. The early ageing is the ageing process starts with the ignition of the partial discharge. In this phase the ageing process will affect the loss of material due to erosion on the surface which results in an increase of surface roughness and loss of hydrophobicity. Late ageing processes on the polymeric surface will start as soon as thermal effects of the leakage current appear. The partial activity is intensified and the leakage current value is higher in this phase caused deep erosion lines and tracking on the surface. Tracking paths are electrically conductive and may lead to flashover.

2.8 Insulator flashover.

The flashover of non-ceramic insulators during rainy conditions shows that a discharge bridges the weather sheds and the leakage distance along the surface of the insulators is not used efficiently [5]. The arc produced by the flash over is usually away from the surface of the dielectric.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This project investigates and evaluates the polymeric insulator models by the finite element analysis computer program, COMSOL Multiphysics® version 3.5a. The basic steps in simulation procedure steps are explained in this chapter.

3.2 Finite element method

Finite element method is a convenient technique for the computer solution of complex problems in different fields of engineering such as civil engineering, mechanical engineering, nuclear engineering, biomedical engineering, hydrodynamics, heat conduction, geo-mechanics and many others. It is a tool for the approximate solution of differential equations describing different physical processes. The success of FEM is based on the basic finite element procedures used including the formulation of the problem in variation form, the finite element discretization of this formulation and the effective solution of the resulting finite element equations. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution [22]. It is well suited to problems with complicated geometry since it is a flexible method. The

FEM leads to comparatively simpler techniques for estimating fields at highly curved and thin electrode surfaces with different dielectric materials.

3.3 Comsol Multiphysics

Computer simulation has become an essential part since digital analysis of components, in particular, is important when developing new products or optimizing designs. The simulations with COMSOL Multiphysics® version 3.5a software are demonstrated in three basic steps. The steps are pre-processing, solution procedure and post processing. The pre-processing step involves the model properties. The model properties are included geometrical, input and meshing. Proceed to the solution procedure, the boundary conditions are applied and the program solves. The contour plots are obtained as the output graphics of this project. In the post-processing step, the graphical plotting and reading of the output is done to evaluate the results.

3.3.1 The Pre-processing

The pre-processing step created the finite element model of the geometry. The electric potential is typically calculated using the in-plane electric current approximation. Dielectric geometry with related part material, conductivity and permittivity is defined. The material use is silicon rubber with a relative permittivity of 4.3 and the relative permittivity of the water is 80 [12].

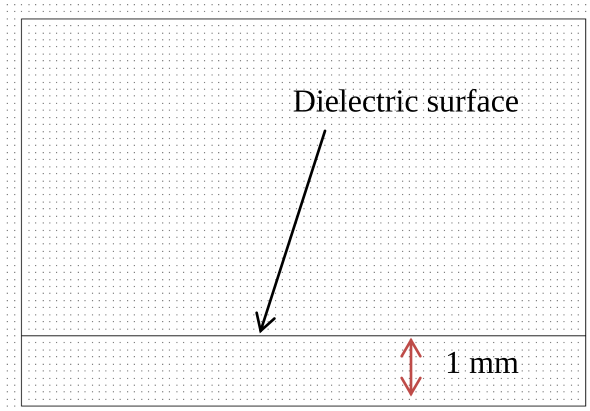


Figure 3.1: The solid dielectric material

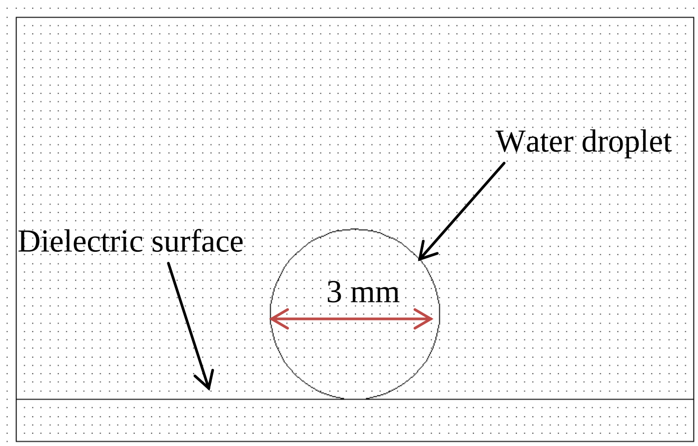


Figure 3.2: The dielectric surface with water droplet on surface.

The next step is meshing. The finite element model is divided into nodes and small areas called elements. The meshing process is automatically generated after specifying the element size and attributes. The better meshing could be obtained by option of mesh modifying. In order to get accurate results from the analysis, the critical areas are re-meshed by using the mesh modify tool. Therefore, mesh density is increased without increasing the complexity of the whole model.

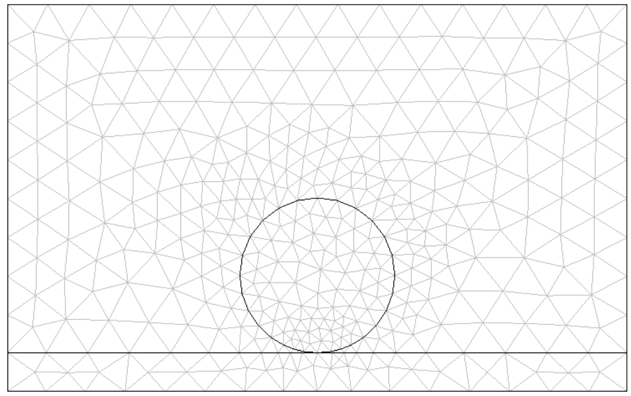


Figure 3.3: Meshed model of dielectric material

3.3.2 The Solution Process

In the solution process, boundary conditions are applied on the model in order to obtain the nodal solution. In this study, the results are the set of equations that defines the electric potential at nodes of each element. Then, the electric field distribution is obtained over the model. This analysis boundary is selected with an outer air region going to infinity to simulate real time application as shown in Figure 3.5. The voltage at the one end of dielectric materialis set at the operation of 66 kV and the other terminal of dielectricis set as ground for all simulations.

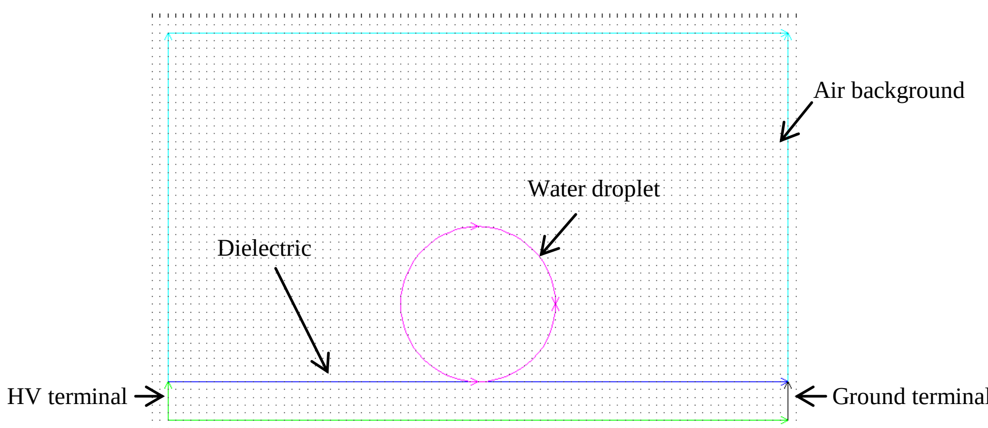


Figure 3.4: The analysis boundary of dielectric material.

3.3.3 The Post-processing

The postprocessor step is to see the graphical display of the analysis results on a plot and read the files of the result data. The graphic capabilities are important for the analysis of desired design construction. The simulations include result of contours plots and streamline plots which are used for the output plots throughout this work.

3.4 Simulation procedure

The simulation procedure aims to compute the electrical field distribution over the dry dielectric surface and with the existence of water droplet. The results then being analysed and the same method is used on the insulator modelled. The analysis on the insulator model is used to see the influence of water droplet to the electric field surrounding the polymeric insulator. The flow chart shows the process involved starting from the initial stage until the objective achieved.

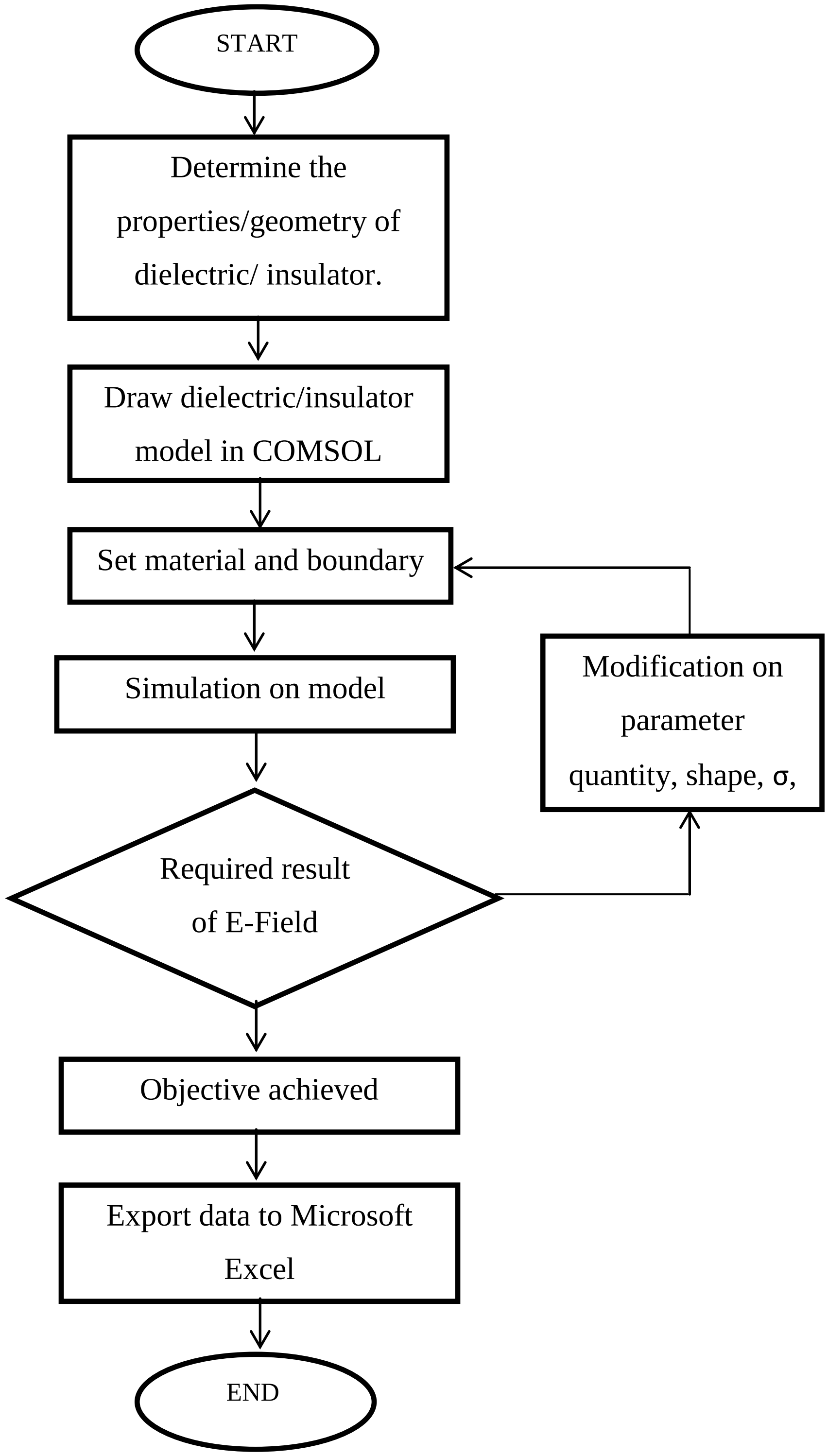


Figure 3.5: The flow chart of the simulation procedure.

3.5 Application on polymeric insulator modelled.

During the pre-processing, solution and post-processing steps, the parameters are chosen for analysis as described in this chapter. As the results on surface dielectric is obtained, the same method used on the polymeric insulator modelled.

The insulator that is considered in this analysis is a standard 66 kV polymeric outdoor insulator. The polymeric insulators model consist of three main components comprises metal end fitting made of forged steel. Both the end fittings are crimped to a fibre reinforced plastic (FRP) rod function as a core that placed in the middle axis to provide essential mechanical strength and support to the overhead line conductor.

The geometrical model of the analysis is the clean and dry polymeric insulator and also considered in ideal condition without considering any attached or nearby structure and other hardware peripherals.

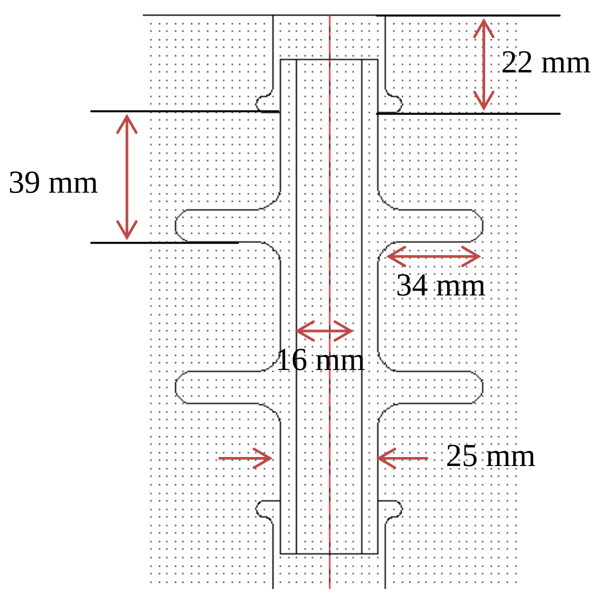


Figure 3.6: The polymeric insulator model geometry

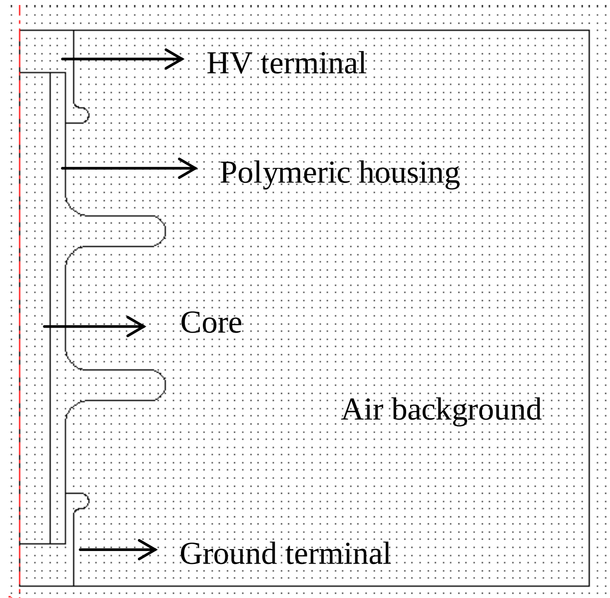


Figure 3.7: 2D axial-symmetric view of insulator model

The electric potential is typically calculated using the quasi-static approximation. Model geometry with related part material, conductivity and permittivity is defined as shows in Table 1.

Material	**Relative Permittivity, ε_r**	**Conductivity, σ (S/m)**
Forged steel	1.0	5.9×10^{-7}
FRP core	7.2	1.0×10^{-13}
Silicone rubber	4.3	1.0×10^{-13}
Air background	1.0	1.0×10^{-14}

Table 1: Materials properties of the insulator model

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

Analysis of electric field is investigated in this chapter. The simulation results demonstrated the intensification of electric field. The results are graphically plotted in order to visualize and understand the problem.

First simulation based on basis analysis of dielectric without and with water droplet to compare the result and to proof the intensification of electric field with the existences of water droplet on the dielectric surface. The simulation then continued with the analysis on polymeric outdoor insulators. The tangential electric field distribution is observed.

4.2 Electrical field distribution on the plane polymeric surface.

For parallel electrode terminal of high voltage and ground, the equipotential lines are parallel to the both terminals and the electric field is perpendicular to the electrodes. As to prove that water droplet caused the electric field intensification, analysis has been done to a model of surface dielectric by simulation and investigation the interaction between electric field and a water droplet. Figure below shows the electric potential contour on the dry surface of dielectric.

A model of sample polymeric surface is connected to high voltage supply at one end and ground terminal the other end. A voltage of 66 kV is supply to analyze the equipotential lines distribute between both HV electrode terminal and ground terminal.

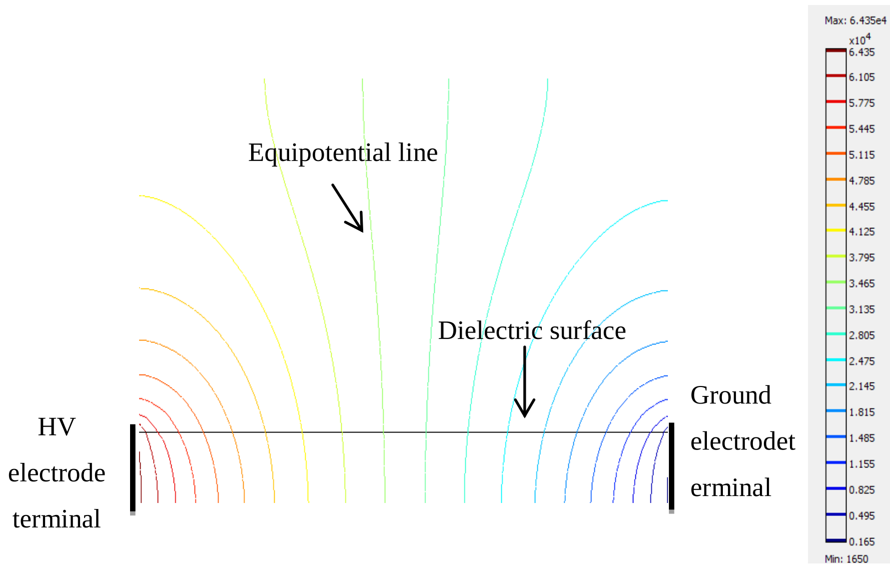


Figure 4.1: The electric potential contour and tangential electric field on the dry dielectric surface.

The electric potential contour uniformly distributed on the dry dielectric surface as show in Figure 4.1. As can be seen, the lines form curves shows the concentration toward the electrode terminals indicate the electric potential is high about 1.71x106 V/m due to the accumulation of charges at the electrodes. The Figure 4.2 shows that the high of electric potential indicates high electric field distribution at both terminals affected by the accumulation of equipotential lines near the electrodes. The electric field distribution gives the non-linear shape for tangential electric field graph due to a non-uniform potential distribution between the electrodes.

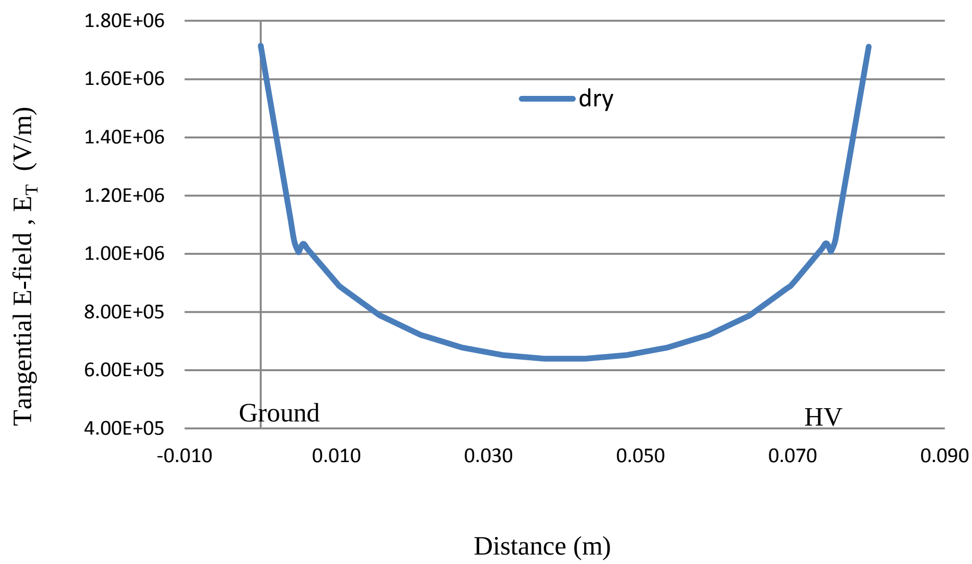
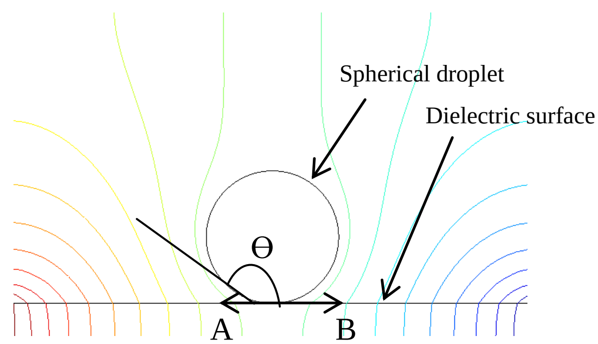
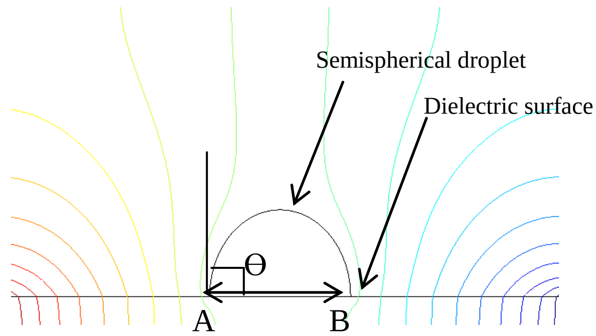


Figure 4.2: Tangential electric field on the dry dielectric surface.

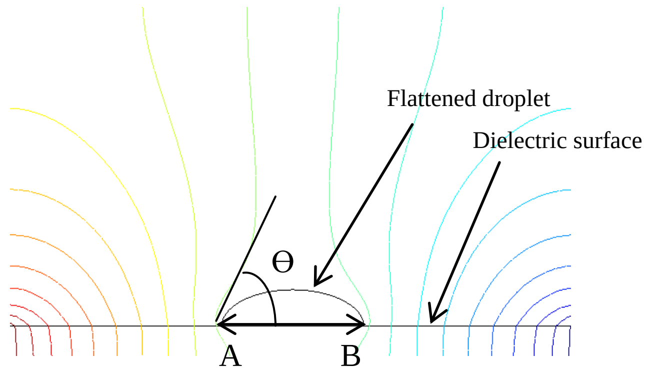
4.2.1 Effect of water droplet contact angle.



a



b



c

Figure 4.3: The electric potential contour on the surface dielectric with the existences of various shape water droplet.

Figure 4.3 shows the view of the equipotential contours around the various shape of water droplet positioned on the dielectric surface. The angle, Θ indicates contact angle between water droplet and dielectric surface. Contact angle is an important factor to describe the hydrophobic ability of the insulator. Figure 4.3 (a) and Figure 4.3 (b) shows the spherical droplet that gives the contact angle of 90^0 and above. It is indicates that the surface is hydrophobic, and has a low surface energy. Figure 4.3 (c) shows a small contact angle of below than 90^o between surface of dielectric and droplet such flattened droplet. It means that the surface is hydrophilic and has a high surface energy. The surface hydrophobicity of insulators prevents water droplets to join and form a wet and highly conductive path. The above figure shows clearly that the equipotential lines distorted at the vicinity of water droplet. The distortion of lines affected the pattern of

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