ELECTRIC FIELD ANALYSIS OF WATER DROPLET DEFORMATION ON SOLID INSULATION SURFACE USING FINITE ELEMENT METHOD

NURINA BT ZULKIFLI

UNIVERSITI SAINS MALAYSIA

2017

ELECTRIC FIELD ANALYSIS OF WATER DROPLET DEFORMATION ON SOLID INSULATION SURFACE USING FINITE ELEMENT METHOD

by

NURINA BT ZULKIFLI

Thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Engineering (Electrical Engineering)

JUNE 2017

ACKNOWLEDGEMENT

My thesis will not complete if people around me do not help me in completing my final year project. Thus, first and foremost I am highly obliged to my supervisor Assc. Prof. Ir. Dr. Mohamad Kamarol Bin Mohd Jamil. He allowed me to spend his precious time from very beginnings of final year project till the completion. He also was not bored to repair my thesis a lot of time and gave advice to me for the best. His expert guidance, affectionate encouragement and critical suggestions provide me necessary insight into research problem and paved the way for the memorable and meaningful ending of my final year project in allocated time. I have no hesitation to say that without his constant supervision and valuable advice and suggestions from time to time, I could not complete the whole work in an efficient and proper manner. Beside that, I also express my heartfelt gratitude to my parents who always gave me full support and motivated me to finish my final year project successfully. I also would thank to all my friends who helped me a lot in finishing my final year project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SiR	Silicone Rubber
EPDM	Ethylene Propylene Diene Monomer
FEM	Finite Element Method
BEM	Boundary Element Method
CVP	Convergence Point
UV	Ultra Violet

LIST OF SYMBOLS

α : A Constant That Equal to 1 or 2 for Two or Three Dimensional Respectively.

ρs (r’) : Surface Charge Density at Position r’.

l : Boundary Between Different Regions.

r : Denotes a source point.

Φ *(r,r’): Fundamental Solution for Potential Problem.

ρ : Unknown Surface Charge Density Vector Matrix.

Φ : A Potential Vector Matrix.

$\hat{R}$: Unit vector pointing from *q* to *P*

R : Distance between charge and point *P*

ε : Electrical permittivity of the medium containing point *P*

q' : Test charge

E : Electric field

D : Electric flux density

ε_r : Relative permittivity / dielectric constant of the material

E : electric field

ε_0 : $8.85 \times 10^{-12} \approx (\frac{1}{36\pi}) \times 10^{-9}$

ANALISIS MEDAN ELEKTRIK TERHADAP UBAH BENTUK TITISAN AIR KE ATAS PERMUKAAN SOLID PENEBAT MENGGUNAKAN KAEDAH UNSUR TERHINGGA

ABSTRAK

Di dalam tesis ini, satu model dua-dimensi penebat komposit polimer dimodelkan untuk belajar pengagihan medan elektrik di atas permukaan penebat di bawah pengaruh titisan air yang berubah bentuk dengan sudut kenalan titisan air yang berbeza dan juga untuk menganalisis kesan penebat dengan keberadaan nano pengisi alumina dan ketidak beradaan nano pengisi alumina dengan pemuatan kepekatan yang berbeza. Ia disimulasikan menggunakan perisisan kaedah unsur terhingga (FEM) yang dinamakan Comsol Multiphysics versi 5.2a. Kaedah analisis ini mengikut standard pengesanan permukaan dan hakisan iaitu IEC 60587. Parameter yang digunakan di dalam simulasi ini ialah sudut kenalan titisan air, dan ketelusan relatif SiR/EPDM dengan kehadiran dan ketidakhadiran nano pengisi. Tahap pemuatan kepekatan nano pengisi yang digunakan ialah 1 Vol % dan 2 Vol % dan juga sudut kenalan titisan air di variasikan iaitu pada 30°,60°,90° dan 120°. Keputusan menunjukkan terdapat penumpuan medan elektrik di antara pertemuan permukaan titisan air,permukaan penebat dengan udara. Magnitud medan elektrik berubah daripada tinggi ke rendah dari keadaan hidrofilik kepada hidrofobik. Pertambahan nano pengisi mengurangkan magnitud medan elektrik. Hubungan antara pengedaran medan elektrik dan kesemua parameter dikenal pasti. Hubungan ini di pelajari dengan memplot graf pengedaran medan elektrik berlawanan dengan semua parameter yang digunakan.

ELECTRIC FIELD ANALYSIS OF WATER DROPLET DEFORMATION ON SOLID INSULATION SURFACE USING FINITE ELEMENT METHOD

ABSTRACT

In this paper, a two-dimensional composite polymer insulator was model to study the electric field distribution on the insulator surface in the influence of water droplet deformation with different contact angle and to analyze the effect of insulator material with and without alumina nanofiller with different loading concentration. It was simulated using the finite element software (FEM) named Comsol Multiphysics 5.a version. This method of analysis followed the standard of surface tracking and erosion which is IEC 60587. Parameters that were used in this simulation were the contact angle of the water droplet and the relative permittivity of the SiR/EPDM with and without nano-filler. The loading concentration of nanofiller used were 1 Vol % and 2 Vol % and the contact angle of water droplet were varies at 30°,60°,90° and 120°. The results showed that there were electric field intensification at the interface between the surface of water droplet, insulator surface and air. The electric field distribution changed from high to low in value from hydrophilic to hydrophobic state. The addition of nanofiller reduced the magnitude of the electric field. The relationship of the electrical field distribution and all of these parameters were figured out. These relationship were studied by plotting the graph of electrical field distribution versus all of these parameters used.

CHAPTER 1

INTRODUCTION

1.1 Research Background

In electrical power system utilities, composite polymeric insulators is used in the worldwide replacing the old ceramic insulators. Mostly these insulators are used in the electrical transmission and distribution power system. These polymeric insulators served many benefits compared to old ceramic insulators such as light in weight, easy to handle, low in operation and maintenance costs, better mechanical strength and electrical performance during moderate to heavily polluted environment [1]. The example of polymeric insulator that is widely used is Silicone Rubber (SiR) with ethylene propylene diene monomer (EPDM). The EPDM is a type of elastomer that has strong mechanical strength and can withstand in the extreme environment such as heavily rained and polluted environment [2]. It also posses better dielectric properties at normal and even also at high temperature. SiR also posses excellent dielectric properties and has high stability in temperature. Combination of SiR/EPDM produced a new material with better in characteristics which has improved in aspect of dielectric properties, good in thermal stability and withstand a highly polluted environment.

SiR/EPDM is such an example for the composite polymeric insulator that shows strong hydrophobic property. The water from the raindrops, fog and dew tend to form discrete droplets on the insulator surface. These water droplets may come in various form of sizes and volume, thus these droplets are measured based on its contact angle between the surface of the insulator and surface of the water droplet. The contact angle can be categorized in two forms which are hydrophilic and hydrophobic. The water droplet that posses hydrophilic characteristic is the water droplet that has less than 90 degree contact angle while for hydrophobic is the water droplet that has more than 90 degree contact angle [3]. This property can help to reduce the leakage current and the possibility of dry band formation [6]. The research on the electrical insulation characteristics SiR blended with EPDM had been done before and shows a positive feedback [3]. This research is done to know the suitability of the SiR/EPDM to use as a polymeric housing material [3].

However, the problem rise when the hydrophobicity of the polymer insulators in service usually degraded due to environmental factor such as atmospheric pollution, ultraviolet radiation, acid rain and salt fog [4]. Water droplets on the surface of the insulator may cause the change of electric flux and also electric potential distribution [5]. When the electric field is applied, the water droplet that form on the insulator lead to electrical enhancement at the triple point. Triple point is the point of interface between three dielectric mediums which are the surface of the insulator, water droplet and the air of the surrounding [1]. The external partial discharge or flashover will occur due to the electric field enhancement at the triple point and resulting in temporary loss of hydrophobicity of polymeric insulator [1]. In the previous researched, the electric field vector at the junction of the triple point goes up to infinity and bring a difficulty to calculateaccurately on that triple point. Thus, calculating electric field exactly at the triple point seems impossible until now. Based on latest review, the investigation of the electric field in the presence of water droplets on polymeric insulating surface only test for plane-plane electrode [1]. The investigation on the electric field distribution of water droplet deformation on solid insulation surface using pin-plane electrode with different contact angle of water droplet with filled and unfilled nanofiller on insulator are still unknown.

Therefore, the investigation on the electric field analysis of water droplet deformation on solid insulation surface is carried out using pin-plane electrode with different contact angle of water droplet with filled and unfilled nanofiller on insulator. The water droplet deformation is analyzed starting from the hydrophobic to hydrophilic characteristic. The permitivity of the insulation material is changing due to nanofiller add on. The electric field distribution is analyzed in the absent and present of the nanofiller.

1.2 Problem Statement

The failure of the insulator to act as a shielding is due to the partial discharge or corona discharge that happen in a long time in a wet environment. The separated beads of water droplets will cause the distortion of the electric field and leads to partial discharge [7]. Long term of partial discharge will cause the insulator surface to become aging and corrodes because of the water that go inside the insulator and lead to rupture at the end [8]. Thus, it is important to know the electric field distribution on the insulator surface under influence of physical characteristic and properties of water droplet and the properties of the insulator itself. Thus, the purpose of this project is to enhance the result of the simulation on the previous research. The previous research faced some limitations in determining the better result of electric field distribution in influence of various parameter like contact angle of water droplet, volume, conductivity, shape of water droplet and multiple number of water droplet with the changing of the relative permittivity of the SiR/EPDM. Therefore, in this project, a insulator with the two electrodes, one sided for high voltage and another for ground was modelled. The purpose of this project is to simulate the electric field distribution on the insulator surface in the presence of water droplet with the influence of its parameters and also the influence of different concentration of nanofiller on the electric field distribution. Finite element method (FEM) is being used to performed the modelling which is the Comsol Multiphysics software .

1.3 Objective of Research

The aim of this project is to study the effect of water droplet deformation on the insulator surface with the electric field distribution. Thus, the objectives of this project are :

i. To simulate the electric field distribution of water droplet deformation on solid insulation surface using different contact angles.

ii. To analyze the effect of insulator material with and without nanofiller with different loading concentration on the electric field distribution.

1.4 Scope of Research

i. In this project, the electric field distribution of water droplet deformation on the solid insulation surface is analyzed using FEM. The solid insulator is modelled with two electrodes located on the insulator surface. One side of the electrode is assigned with the high voltage and the other side is grounded. Water droplet is modelled in between the electrodes on the insulator surface. The permitivity of the insulator is varied according to the simulated SiR/EPDM with and without nano-filler. The loading concentration of nano-fillers that are used in this simulation are 1 Vol % and 2 Vol % . The contact angles of the water droplet are varied from hydrophilic (angle less than 90 degree) to hydrophobic (angle more than 90 degree) which are 30°,60°,90° and 120°. The conductivity of the water droplet used are basic plain water which is 5.5e-6 S/m in value. The software use to determine the electric field distribution is the Comsol Multiphysics. The analysis is conducted to determine the pattern of the graph when there are different concentration of filler and without filler with different usage of contact angle waterr droplet.

1.5 Thesis Outline

This thesis contains five chapters in it. There are introduction, literature review, methodology, results and discussion and conclusion as the last chapter.

In chapter 2, the influence of water droplet deformation to electric field distribution is described in the literature review. The previous researched on the parameters of the water droplet that give influence to the electrical field distribution are described. Those parameters include the contact angle of water droplet, volume, shape, conductivity of the water droplet and also the effect of using the SiR/EPDM with and without nano-filler.

In chapter 3, methodology is discussed. This chapter include the flow chart that shows the flow of the project. The method to model the insulator is explained in modelling the two-dimensional polymeric insulator. The dimension of the model are included also. The parameter settings are described to give a clear information to the reader.

Chapter 4 discusses about the simulation and result that obtained for the model with and without nanofiller at different contact angle of water droplet and different loading concentration of nanofiller.

Lastly, chapter 5 wraps up or concludes the discussion of the project and look towards the future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature review on behavior of water droplet deformation under the influence of applied voltage assigned is presented. The physical and properties of water droplet are also described referring to contact angle and conductivity of the water droplet. The effect of these parameter to the electric field distribution is described. The insulation characteristic of the polymeric insulator which is SiR/EPDM also included in this literature review. All of the mention above were referred to several papers of research. The electric field analysis used simulation based study in this project design.

2.2 Influence of water droplet deformation to electric field distribution

The existence of water droplet on high voltage insulator is common during the rainy day, or in a wet environment. This situation cannot be prevented as it always happen whenever it comes to that situation. Thus, a study on behavior of water droplet is important to know as it give some information on how it can influence the electric field distribution. The contact angle and the conductivity of the water droplet were considered in this investigation.

Based on the previous paper by Waluyo, et. Al [4] they investigated about the influences of water droplet size and contact angle on the electric field and potential distributions on an insulator surface. The author reported that the water droplet appeared on the insulator surface generate the electric field flux and electric field potential distribution [4]. Water drop on the insulator with high hydrophobicity surface tend to form bead-like droplet of different shape and sizes. Thus, formation of water droplet form is defined by the contact angle between the insulator surface and the water droplet surface. Radii of the water droplet play a role in determining the sizes of the water droplet itself. A two-dimensional insulator was presented in the simulation using the finite element method (FEM). This numerical analysis was presented to determine the electric field and potential distribution nearby the water droplets. One and two water droplets were considered in the simulation where the contact angle and radii were varied.The results of this research paper showed that the increase in water droplet radii give rise to the electric field around the water droplets especially nearby the high voltage region. When the radii increased, the volume also increased, therefore water droplet trapped more electric potential distribution. For the contact angle, the result showed that maximum electric field around the water droplet increased slightly when contact angle increased.

Another analysis method of electric field distribution apart from FEM is boundary element method (BEM). S.S. Dessouky and K.A. Helal used this method to determine the electric field distribution in their research paper [10]. The BEM focus on the charges distributed over boundaries where it approximate the real charge distribution on the surface. The equation of the electric potential due to surface charge density was given by equation (2.1). This equation represent the basic equation for BEM, where this system was needed to determine the unknown charge density. The equation (2.1) was simplified until get the new linear equation that satisfy the Dirichelt boundary conditions. This new equation is expressed by equation (2.2). The unknown value of charge density was obtained by solving the equations mentioned previously. Hence, from this charge distribution, values of potential and electric field distribution can be calculated. The author performed this analysis using two techniques in applying the electric field direction, one with tangential field direction to the sample and another one with normal field direction to the sample. Figures 2.1 and 2.2 show how these samples were modelled. There were two shape of water droplets been examined, which in sessile form and hemispherical form. The result showed that, the sessile form of water droplet under the tangential electric field direction had highest electrical field stress at the lower part of the sessile drop. Compared to sessile drop, hemispherical drop has much higher electrical field at the boundary. Therefore, water droplet with hemispherical shape has higher chances to cause the partial discharge due to electric field intensification. In normal field direction, the sessile drop deformed and elongated in the direction of electric field experienced. The highest electric field stressed was experienced at the top of the water droplet.

$$\Phi(r) = \left(\frac{1}{2\alpha\pi\varepsilon}\right)\int_{l}\rho_s(r')\Phi^*(r,r')dl(r') \qquad (2.1)$$

Where Φ (r) is the potential at location r

α : a constant that equal to 1 or 2 for two or three dimensional respectively.

ρs (r') : surface charge density at position r'.

l : boundary between different regions.

r : a field point while r' denotes a source point.

Φ *(r,r'): fundamental solution for potential problem.

$$[A].[\rho] = [\Phi] \qquad (2.2)$$

Where [A] : is a potential-coefficient vector matrix.

[ρ] : is a unknown surface charge density vector matrix.

[Φ] : is a potential vector matrix.

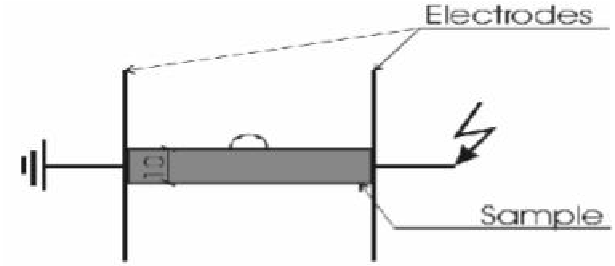


Figure 2.1 : Schematic diagram setup for tangential
field direction to sample. [10]

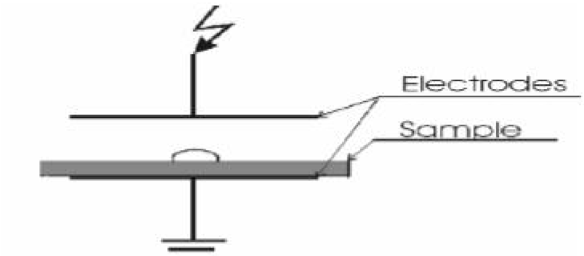


Figure 2.2 : Schematic diagram setup for normal
field direction to sample. [10]

S. Chatterjee, et. al were the researchers that investigate the electric field computation in presence of water droplets on polymeric insulating surface [1]. This paper focus the investigation on calculating the electric field enhancement factor for one and multiple drops of water droplets on a sheath model of insulator. This paper is limited on the work of trying to overcome the singularity effect of triple point. Triple point is the point where the surface of water, solid and liquid meet. The electric field vector rise up to infinity at this triple point, thus it become hard to calculate the electric field exactly at the triple point. The convergence point (C.V.P) is used as a location to determine the electric field where this point is the intersection point between the extremely fine and extra fine mesh size. Volume and contact angle of the water droplet were considered in this investigation, where electric field enhancement increased with the increased of the volume and decreased with the increased in contact angles. For the case of multiple water droplets, electric field enhancement showed a high value for three water droplets configuration compared to two water droplet configuration.

2.3 Silicone Rubber

SiR become one of the most widely used insulating material now a days in outdoor high voltage system. This SiR is environmental friendly where it can decomposes under different environmental conditions [2]. It has many advantages such as good dielectric properties, excellent resistance to UV and posses better hydrophobicity [11]. On the other hand, it also posses some disadvantages such as poor mechanical strength, tracking resistance and costly. Therefore, in the advanced of technology now a days, silicone rubber and ethylene propylene diene monomer (EPDM) is blended to produce a material that posses various excellent characteristics. EPDM has excellent mechanical strength and tracking resistance and low in cost compared to silicone rubber. Therefore, the research paper by Vijayalekshmi.V described the development and characterization of SiR/EPDM nanocomposites for high voltage insulators [11]. The result of SiR and EPDM blending showed a positive improvement where this material had improve in mechanical strength, thermal and dielectric properties.

The investigation on the blending properties of SiR/EPDM also was conducted by R. Raja Prabu, S. Usa, K. Udayakumar, M. Abdullah Khan and S.S.M. Abdul Majeed. Their specific focus were on investigation about the electrical insulation characteristics of SiR and EPDM polymeric blends [3]. In conclusion from this paper, blending of SiR with EDPM can increase the mechanical strength without affect or reduced the electrical properties of the material itself. The weight percentage of SiR and EPDM is 50:50 where it showed a balanced mixed, therefore it posses a balanced electrical and mechanical properties. In addition,the result of the experiment also reported that higher content of EPDM blending in SiR posses better mechanical strength properties while lower content of EPDM in SiR posses better electrical properties and low the mechanical properties. They proposed to add some filler particles to acquire an excellent blend of SiR/EPDM.

2.4 Summary

Based on the literature review, it is understood that water droplet play an important role in generating the electric field and potential distribution on the insulator surface. The parameters like volume, contact angles, shape and number of the water droplet affect the uniformity distribution of the electric field and electric potential. For the SiR, it is important to study on the insulation behavior of this polymer. The behavior of polymer also influence the water droplet distribution on the surface. From the previous research in the literature review, it seems that mostly the investigation was focused on the experiment more rather that comparing the result of the simulation. Thus, in this project, it focused more on getting the best simulation result that bring the benefit to further investigation in future work to improve the quality of simulation.

CHAPTER 3
METHODOLOGY

3.1 Introduction

In this chapter, it explains the method to model a two-dimensional composite polymer insulator with water droplet on its surface in order to be able to analyze the electric field distribution along the surface of insulator by using FEM. The software namely Comsol Multiphysics have been used in analyzing electric field distribution on the insulator surface.

The modelling of a two-dimensional composite insulator with the electrodes arrangement dimension follow the IEC 60587 standard [9]. This standard is for electrical insulating materials used under severe ambient condition [9]. The parameter used to the model also is explained.

3.2 Process Flow of the Work

Figure 3.1 shows the flow chart for this project. The project was began with preliminaries study, where the research topics related to this title was studied to be as references. The information was collected from the sources of research and the method to model a two-dimensional polymeric insulator with water droplet was performed. This modelling is performed using Comsol Multiphysics software. The simulation was done for the insulator without and with alumina nanofiller for different concentration and also the contact angles of water droplet were varied. These contact angles are varied from hydrophilic (angle less than 90 degree) to hydrophobic (angle 90 degree and above). The data are collected and analyzed to see the electric field distribution on the insulator surface. Data are presented in graphical form to relate the electric field distribution with deformation of water droplet. Lastly, all results is presented in the final report.

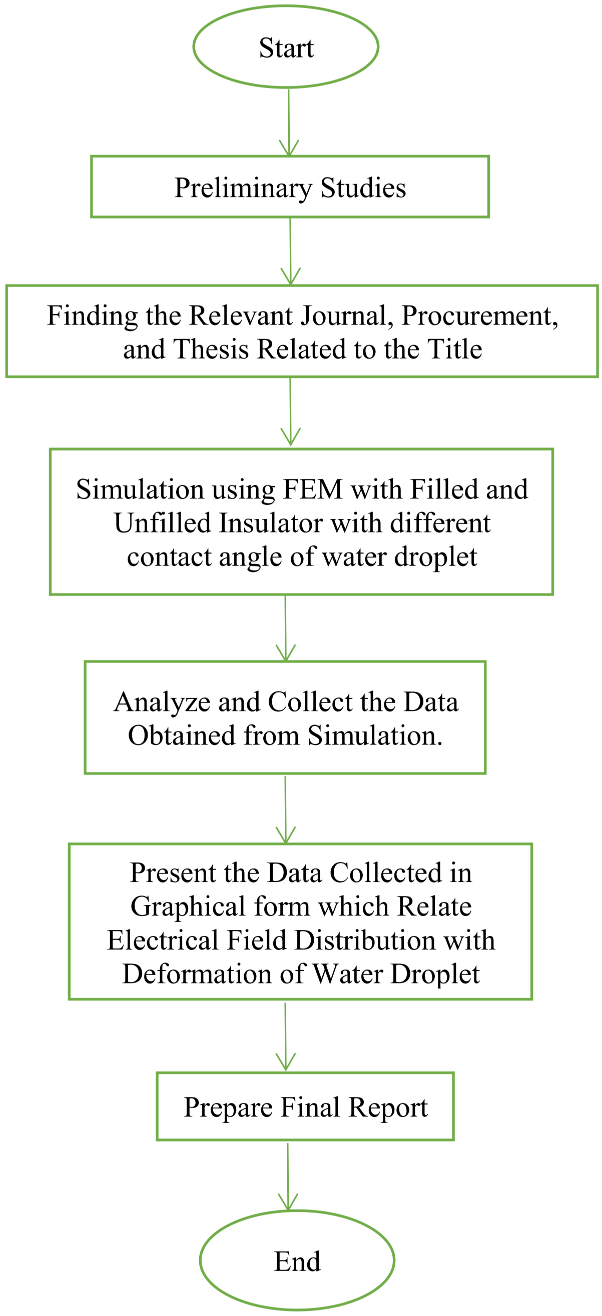


Figure 3.1 : Flowchart of the project.

3.3 Modelling of Two-Dimensional Polymeric Insulator

A two-dimensional polymeric insulator was modelled according to the IEC 60587 standard. The arrangement of the electrodes follow the standard in aspect of size and dimension. The voltage and frequency assigned in the simulation was 4.5kV and 50Hz fixed throughout the simulation [9]. This voltage is fixed to act as a constant voltage throughout the simulation. Figure 3.2 shows a setup of modelling followed the IEC 60587 standard. There are two electrodes, top electrode and bottom electrode. Distance between both electrode starting from the end of tip is 50 mm [9]. Figure 3.2 shows that the test specimen (insulator) is mounted with the flat test surface at 45 degree angle underside [9]. Figure 3.3 shows the dimension of test specimen. In this project, the specimen is considered as the insulator which is SiR/EPDM. The dimension for this flat specimen is 50 mm X 120 mm with a thickness of 6 mm [9]. The dimension for top and bottom electrodes are shown in Figure 3.4 and Figure 3.5 where both have 0.5 mm of thickness [9].

In simulation, a model of two-dimensional insulator was drawn and arranged using finite element software (Comsol Multiphysics) as shown in Figure 3.6. There were three medium assigned in the drawing, which were solid (insulator), liquid (water droplet) and air. The distance between water droplet and electrode in right and left is same which is 25 mm in both sides. The contact angle of the water droplet are varied from hydrophilic to hydrophobic state. Figure 3.7 shows how contact angle is measured, where it is measured between insulator surface to the water droplet surface.

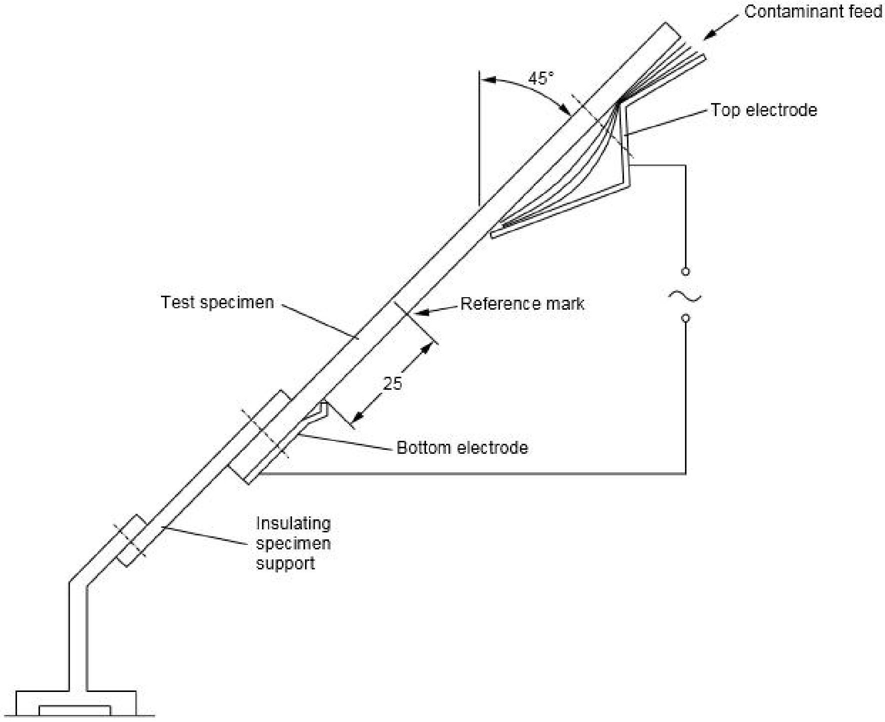


Figure 3.2 : Setup of the modelling according to IEC 60587 standard [9]

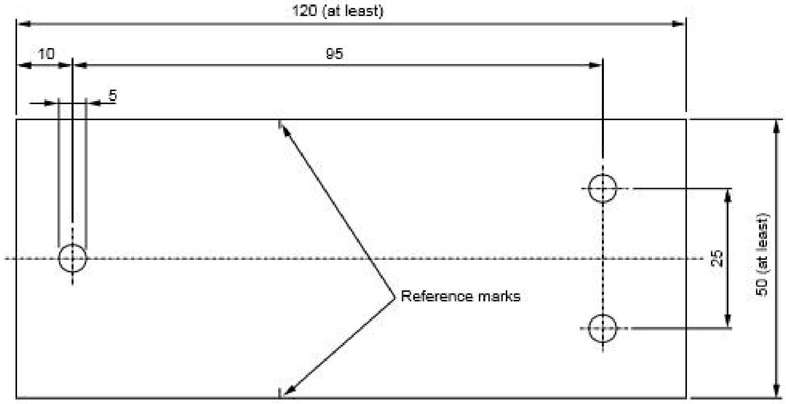


Figure 3.3 : Dimension of test specimen (insulator) [9]

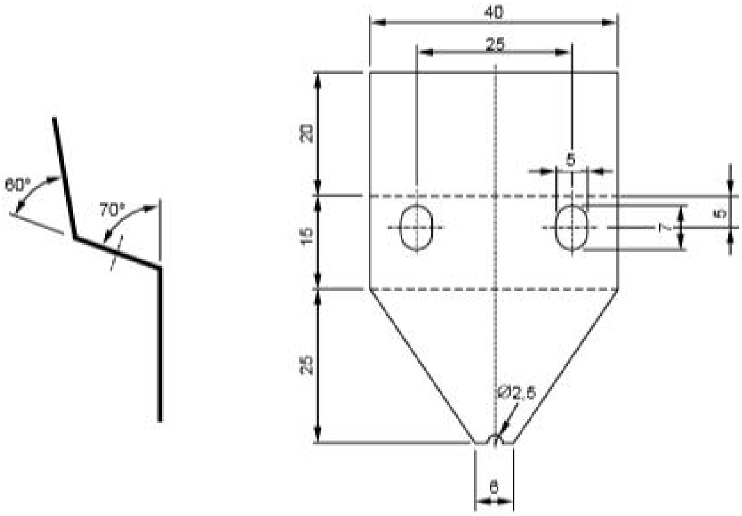


Figure 3.4 : Dimension of top electrode [9]

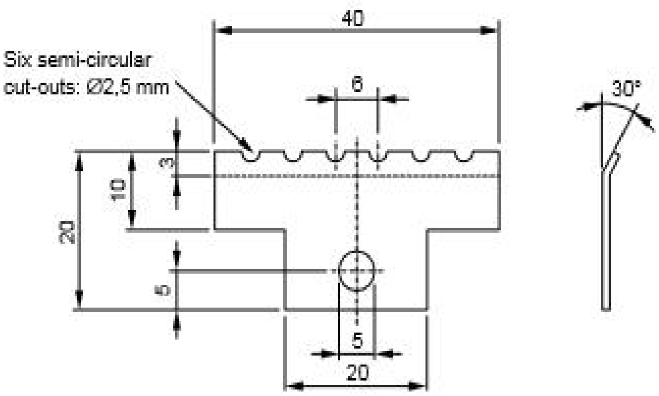


Figure 3.5 : Dimension of bottom electrode [9]

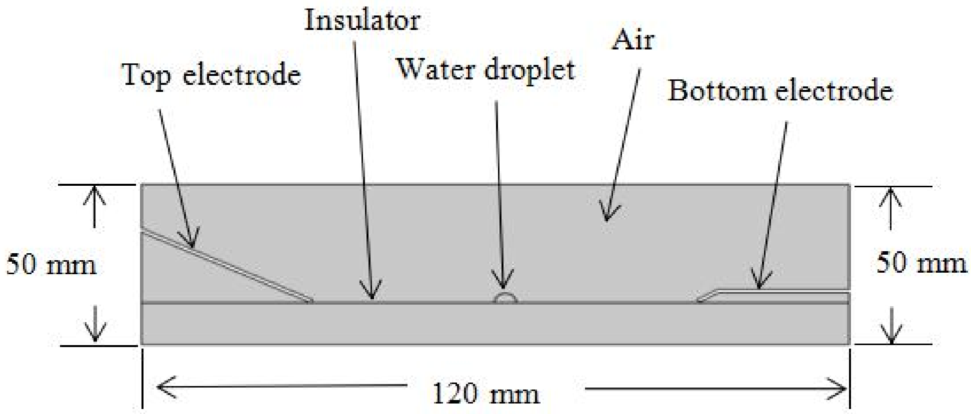


Figure 3.6 : Dimension of model in simulation

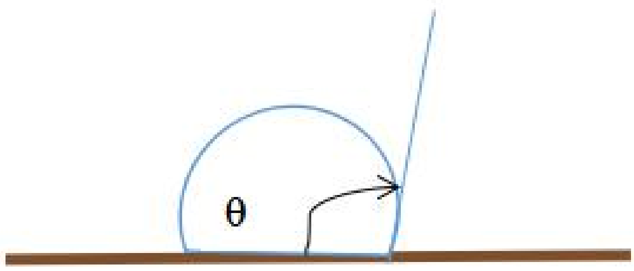


Figure 3.7 : Contact angle between surface of water droplet and insulator surface

3.4 Parameter settings

i. Table 3.1 shows the parameter settings to the model. In this setting, top electrode is set to high electric potential which is fixed to 4.5kV throughout this simulation. Bottom electrode is set to ground. In addition, the other parameter settings that are varied are contact angles of water droplet. The contact angles are varied from 30°,60°,90° and 120° from hydrophilic to hydrophobic state. The relative permittivity of SiR/EPDM with and without alumina nano-filler are tested. The value of relative permittivity without nano-filler is set to 3.3189 while for the rest of SiR/EPDM with 1 Vol% and 2 Vol % nanofiller are set to 3.3758 and 3.5452. The simulation of the electric field distribution are observed with the influence of these parameter settings.

Table 3.1: Parameter settings for simulation

Parameter	Value
Voltage (V)	4500
Ground (V)	0
Frequency (Hz)	50
Contact angles (°)	30°,60°,90°,120°
Conductivity (S/m) : Basic plain water	 5.5e-6
Relative permittivity : 1. SiR/EPDM (without filler) 2. SiR/EPDM (with filler 1Vol %) 3. SiR/EPDM (with filler 2Vol %)	 ii. 3.3189 iii. 3.3758 iv. 3.5452

CHAPTER 4

RESULTS AND DISCUSSION

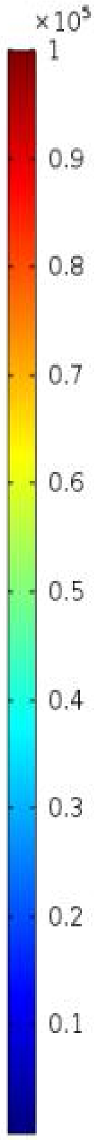
4.1 Introduction

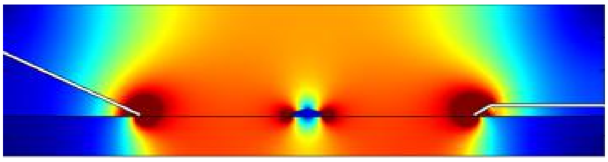
In this chapter, the results of simulation for electric field analysis of water droplet deformation on solid insulation surface were presented. This simulation was done to investigate the electric profile of the water droplet under the non-uniform electrical stress using the finite element method (FEM). The electric field distribution was investigated at the triple points of water droplet which was the interfacial point of three dielectric medium which were solid, liquid and air. This electric field distribution on solid insulation surface was important to know in able for the designer to design the outdoor high voltage insulation that can resist the high electric field stress under severe environment.

4.2 Electric field distribution on SiR/EPDM insulation surface under the influence of water droplet with different contact angle.

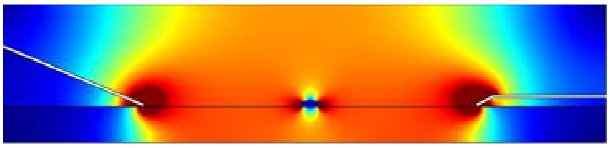
4.2.1 SiR/EPDM without nanofiller

Figure 4.1 shows the surface plot of the electric field distribution on the solid insulation surface for difference contact angle of water droplet which were 30°,60°,90° and 120°. The colour range indicate the magnitude of the electric field distribution, where the blue colour indicate the lowest in magnitude of the electric field and the red colour indicate the highest magnitude of electric field distribution. The presence of water droplet under the non-uniform electric field give rise in the enhancement of electric field at the triple point. This lead to the external partial discharge or even flashover. The red colour on the water droplet region shown that the electric field stress is high at that point. Based from the hydrophilic to hydrophobic criteria, the electric field intensity at the triple point near the water droplet was decreasing from high field intensity to low field intensity follow up from less contact angle to high contact angle.

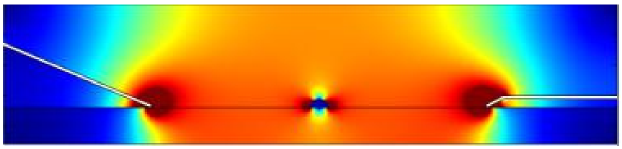




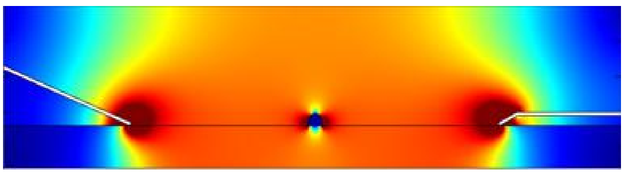
(a) Surface plot for 30° contact angle



(b) Surface plot for 60° contact angle



(c) Surface plot for 90° contact angle



(d) Surface plot for 120° contact angle

Figure 4.1 : Surface plot of electric field distribution for difference contact angle of water droplet simulated by comsol multiphysics software

Figure 4.2 shows the graph of electric field distribution along the insulation surface starting from the high voltage part of the electrode until the grounding. The electric field distribution was analysed at the triple point of water droplet, where the interface point among insulator, water droplet and air media. Referred the Figure 4.2, the water droplet with 30° contact angle had same electric field for both high voltage and ground part. The magnitude of the electric field for both high voltage and ground part show dominant or highest in value compared to all the contact angles of the water droplet. The least value in magnitude of electric field was for the contact angle of 120 degree near the high voltage part whereas near the ground side was slightly higher than the high voltage side.

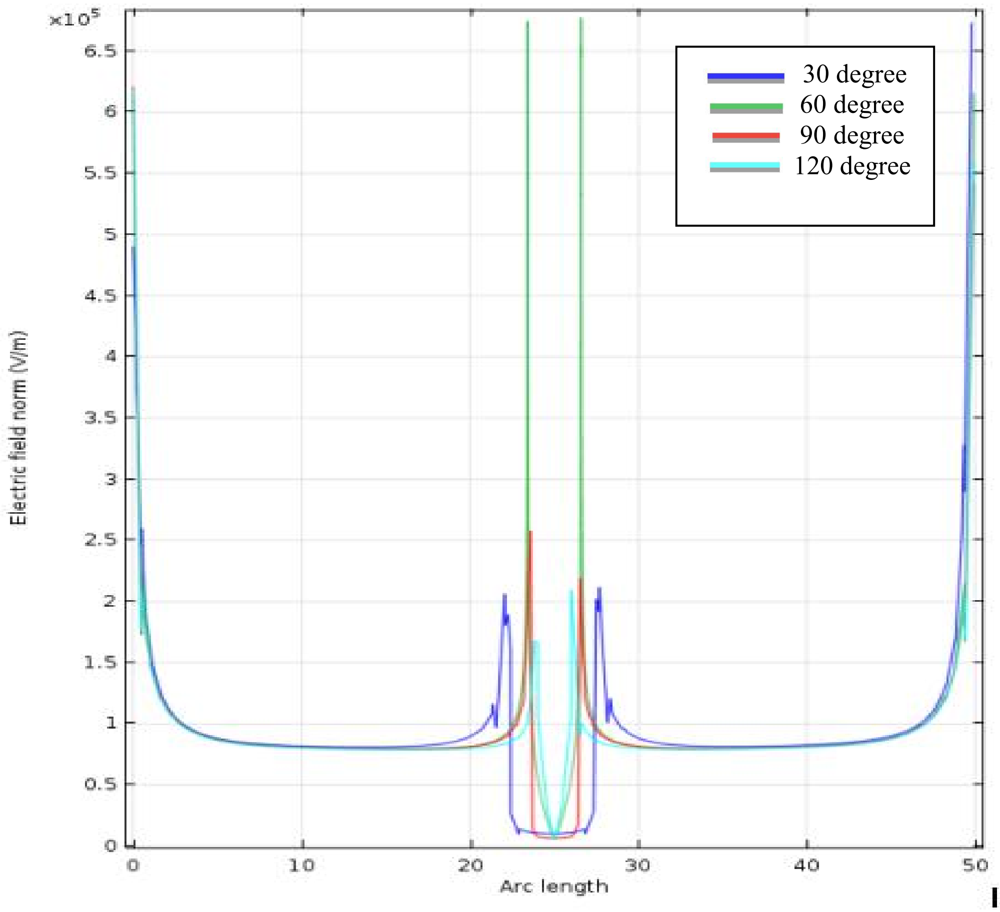


Figure 4.2 : Combination graph plot of electric field normal versus the arc length for all contact angles of water droplet

Figure 4.3 shows analysis of electric field versus the contact angle of the water droplet for both near high voltage and ground part. A graph of electric field versus the contact angle of water droplet was plotted based from the simulation graph shown in Figure 4.2. The changed of contact angle of the water droplet gave an effect to the electric field distribution on the insulation surface. These contact angle were varied at 30°,60°,90° and 120° which were from hydrophilic to hydrophobic characteristics. Starting from 120° contact angle it exhibit hydrophobic characteristic, where the surface of the water droplet tend to form the angle of 120° with the insulation surface. The higher the contact angle, the less the diameter of the water droplet contacted with the insulation surface. Thus, the magnitude of electric field distribution for the contact angle at the triple point was the least compared to all the contact angles shown. In an electrostatic simulation, at direct voltage applied from the electrode, the long time exposure of water droplet to the high voltage of the electrode cause the water droplet tends to slowly elongated towards the electrode and deformed at a certain time. This process can happened after a while again. The elongation of the water droplet was due to the charges that exhibit in the water droplet that attracted to the different polarity of charges of electrode. This cause the contact angle of water droplet became lesser and water droplet deformed on the insulation surface. The deformation of water droplet increases the magnitude of the electric field distribution because of the unstable distribution of the charges in the water droplet cause the electric field sometimes to become high at certain point resulted from the repellancy of the same charges. This was shown in the graph of simulation in Figure 4.2 where the magnitude of the electric field at 60 degree contact angle become higher or sparks high compared to the other contact angles. All the magnitudes of the electric field used to plot the graph in Figure 4.3 were taken at the triple point of the water droplet. The sets of value for magnitude of electric field with different contact angle was shown in Table 4.1. In this table, the changes value of the electric field can be seen from high to low in magnitude.

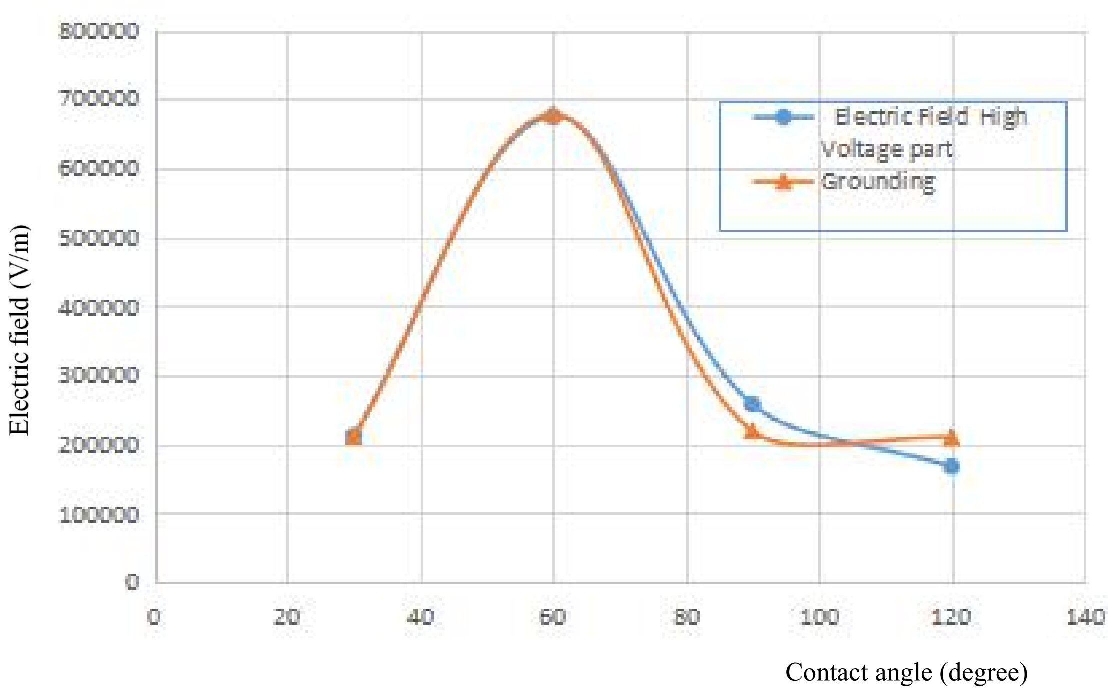


Figure 4.3 : Graph of electric field versus contact angle of water droplet for both near the high voltage and ground part.

Table 4.1 : Value of electric field with different contact angle of water droplet for unfilled insulator

Contact angle (degree)	Electric Field (x10^5 V/m)	
	High Voltage part	Grounding
30	2.12	2.12
60	6.74	6.77
90	2.58	2.19
120	1.68	2.10

4.2.2 SiR/EPDM with nanofiller

Adding nanofiller to the SiR/EPDM blends could improve the electrical properties of the insulation. Based from the basic formula of Coulomb's law, an isolated charge *q* induced an electric field *E* at every point in space, and at the specific point *P*, *E* was shown as below;

$$E = \hat{R}\frac{q}{4\pi\varepsilon R^2} \qquad \text{(V/m)} \qquad (4.1) \qquad [12]$$

Where $\hat{R}$: unit vector pointing from *q* to *P*

R : distance between charge and point *P*

ε : electrical permittivity of the medium containing point *P*

In the presence of electric field *E* at a given point in space which was due to a single charge or distribution of charges, there was a forced acting on a test charge *q* when placed at *P* which shown below ;

$$F = q'E \qquad \text{(N)} \qquad (4.2) \quad [12]$$

Where F : force acting on test charge q'

q' : test charge

E : electric field

For a material with electrical permittivity ε , the electric field quantities *D* and *E* were related by ;

$$D = \varepsilon\text{E} \qquad (4.3) \qquad [12]$$

with $\varepsilon = \varepsilon_r\varepsilon_0$ (4.4) [12]