OPTIMISATION OF INSULATOR DESIGN FOR IMPROVED ELECTRIC FIELD PERFORMANCE

HAIRILASRI BIN AHMAD

A project report submitted in partial fulfillment of the requirement for the award of degree Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia

JUNE 2015
ABSTRACT

Insulators are the integral part of the power system. Among them polymeric insulators are essential for the better performance. Polymer insulators become popular due to various advantages offered such as light weight, ease of installation and lower cost. Despite numerous advantages offered, there are also some problems regarding the polymer insulators. One of the factors governing the electrical performance of polymeric insulator is characterized by its field distribution along their length. This thesis has been made to analyse insulator performance via their electric field distribution. By improving the electric field distribution, it will help in enhancing their long term performance of insulator. The COMSOL Multiphysics software has been employed to investigate the electric field stressss along the insulator’s surface. An 11kV of polymeric insulator in clean and dry condition is modelled for simulation. For electric field’s optimisation purpose, three different techniques are used to investigate its distribution along the insulator’s surface. The techniques employed are as follow: i) different configuration of metal end fittings design, ii) improve of insulator weather shed shape and iii) installation of corona ring at appropriate location. From the observation, all the techniques proposed have significant effect on electric field distributions. Simulation of insulator model has shown that the maximum value of electric field stress was found to be at the region of metal end fittings. After the application of all optimization techniques, the electric field stress performance of the proposed insulator is reduced by 83.97% to 9.643x10^4 V/m from 6.015x10^5 V/m at the beginning.
ABSTRAK

TABLE OF CONTENT

TITLE .................................................................................................................. I
DECLARATION ..................................................................................................II
DEDICATION ..................................................................................................... III
ACKNOWLEDGEMENT ..................................................................................IV
ABSTRACT ...................................................................................................... V
ABSTRAK ...................................................................................................... VI
LIST OF FIGURES ...........................................................................................X
LIST OF TABLES ............................................................................................. XII
LIST OF SYMBOLS AND ABBREVIATIONS ............................................. XIII

CHAPTER 1 INTRODUCTION ............................................................................ 1
  1.1 Background ............................................................................................. 1
  1.2 Problem Statement ................................................................................. 3
  1.3 Objectives .............................................................................................. 4
  1.4 Scope Of Project ..................................................................................... 5
  1.5 Thesis Outline ....................................................................................... 5

CHAPTER 2 A REVIEW ON POLYMERIC OUTDOOR INSULATOR .......... 7
  2.1 Introduction ............................................................................................ 7
  2.2 Polymeric Insulators ............................................................................. 8
  2.3 Electric Field .......................................................................................... 10
  2.4 Degradation of Polymeric Insulators .................................................. 13
    2.4.1 Electrical Stresses .......................................................................... 13
        2.4.1.1 Corona Discharges .............................................................. 14
        2.4.1.2 Formation of Dry Bands ..................................................... 15
        2.4.1.3 Wetting Discharges .......................................................... 16
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4.1.4</td>
<td>Insulator’s Flashover</td>
<td>16</td>
</tr>
<tr>
<td>2.4.2</td>
<td>Environmental Stress</td>
<td>17</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Mechanical Stress</td>
<td>18</td>
</tr>
<tr>
<td>2.5</td>
<td>Field Optimisation Techniques</td>
<td>18</td>
</tr>
<tr>
<td>2.5.1</td>
<td>End Fittings Design</td>
<td>19</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Weather Shed Insulation</td>
<td>20</td>
</tr>
<tr>
<td>2.5.3</td>
<td>Corona Ring</td>
<td>20</td>
</tr>
</tbody>
</table>

**CHAPTER 3 RESEARCH METHODOLOGY** ................................................. 21

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Introduction</td>
<td>21</td>
</tr>
<tr>
<td>3.2</td>
<td>Finite Element Method</td>
<td>22</td>
</tr>
<tr>
<td>3.3</td>
<td>COMSOL Multiphysics</td>
<td>22</td>
</tr>
<tr>
<td>3.4</td>
<td>Project Process Flow</td>
<td>23</td>
</tr>
<tr>
<td>3.5</td>
<td>Insulator Model</td>
<td>24</td>
</tr>
<tr>
<td>3.5.1</td>
<td>Modelling Simulation</td>
<td>24</td>
</tr>
<tr>
<td>3.5.2</td>
<td>Material Properties</td>
<td>25</td>
</tr>
<tr>
<td>3.5.3</td>
<td>Boundary Conditions</td>
<td>26</td>
</tr>
<tr>
<td>3.5.4</td>
<td>Meshing</td>
<td>26</td>
</tr>
<tr>
<td>3.5.5</td>
<td>Solver Study</td>
<td>26</td>
</tr>
</tbody>
</table>

**CHAPTER 4 RESULT, ANALYSIS AND DISCUSSION** ................................. 27

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Introduction</td>
<td>27</td>
</tr>
<tr>
<td>4.2</td>
<td>Electric Field Analysis</td>
<td>27</td>
</tr>
<tr>
<td>4.3</td>
<td>Electric Field Optimization Techniques</td>
<td>29</td>
</tr>
<tr>
<td>4.3.1</td>
<td>End Fitting Design</td>
<td>29</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Insulator Weather Shed Profile</td>
<td>34</td>
</tr>
<tr>
<td>4.3.3</td>
<td>Corona Ring Installation</td>
<td>38</td>
</tr>
<tr>
<td>4.3.3.1</td>
<td>Horizontal Location of Corona Ring</td>
<td>40</td>
</tr>
<tr>
<td>4.3.3.2</td>
<td>Vertical Location of Corona Ring</td>
<td>41</td>
</tr>
<tr>
<td>4.3.3.3</td>
<td>Diameter of Corona Ring</td>
<td>42</td>
</tr>
<tr>
<td>4.4</td>
<td>Proposed Insulator Profile Design</td>
<td>43</td>
</tr>
</tbody>
</table>
CHAPTER 5 CONCLUSION ................................................................. 46

5.1 Conclusion ................................................................................. 46

5.2 Future Work Recommendation .................................................. 47

REFERENCES .................................................................................. 48
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>Polymeric outdoor insulators</td>
<td>2</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Classification of power line insulators</td>
<td>8</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Cross section of composite insulator</td>
<td>10</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Illustration of electric field</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Corona discharge effects in electrical transmission line</td>
<td>15</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Examples of the E-field distribution surrounding three different designs of composite insulator end fittings</td>
<td>19</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Flow chart of electric field optimisation for polymeric insulator</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Insulator model dimension</td>
<td>24</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>2D assymetric view of insulator model</td>
<td>25</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Electric field distributions along the 11 kV polymeric insulators</td>
<td>28</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Equipotential lines around polymeric insulators</td>
<td>29</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Three configuration of end fitting design for polymer insulator</td>
<td>30</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Equipotential plots at HV terminal for three configuration end fitting designs</td>
<td>30</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Tangential field distributions along the leakage path for three different configuration of end fittings</td>
<td>31</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>Optimisation of radius parameter for end fitting round edges</td>
<td>32</td>
</tr>
<tr>
<td>Figure 4.7</td>
<td>Electric field distribution closed to the HV terminal</td>
<td>33</td>
</tr>
<tr>
<td>Figure 4.8</td>
<td>Insulator profile with various distance between flanges to the shed: a) 7mm b) 24mm c) 35mm</td>
<td>34</td>
</tr>
<tr>
<td>Figure 4.9</td>
<td>Equipotential lines at HV terminal for different profiles</td>
<td>35</td>
</tr>
<tr>
<td>Figure 4.10</td>
<td>Tangential field distributions along the leakage path near end fitting</td>
<td>36</td>
</tr>
<tr>
<td>Figure 4.11</td>
<td>Shed designs with shed radius optimisation</td>
<td>37</td>
</tr>
<tr>
<td>Figure 4.12</td>
<td>Optimization parameters for corona ring study</td>
<td>38</td>
</tr>
<tr>
<td>Figure 4.13</td>
<td>Equipotential lines before and after installation of corona ring</td>
<td>39</td>
</tr>
</tbody>
</table>
Figure 4.14: Electric field distributions at leakage path 0.150m upwards.....................40
Figure 4.15: Design of proposed insulator.................................................................42
Figure 4.16: Equipotential lines for proposed insulator design .................................43
Figure 4.17: Electric field distributions closed to energized end fitting ......................44
Figure 4.18: Equipotential lines for proposed insulator design .................................45
Figure 4.19: Electric field distributions closed to energized end fitting ......................45
LIST OF TABLES

Table 3.1: Materials properties of insulator model ............................... 25
Table 4.1: Comparison of tangential electric field .................................. 32
Table 4.2: Reduction of electric field ...................................................... 34
Table 4.3: Comparison of tangential electric field .................................... 36
Table 4.4: Electric field performance of insulator with various radiiuses ........ 37
Table 4.5: Optimised values of parameter D1 ......................................... 41
Table 4.6: Optimised values of parameter D2 ......................................... 41
Table 4.7: Optimised values of parameter D3 ......................................... 42
LIST OF SYMBOLS AND ABBREVIATIONS

SiR - Silicone Rubber
EPDM - Ethylene Propylene Diene Methylene
EPR - Ethylene Propylene Rubber
FEM - Finite Element Method
BEM - Boundary Element Method
2D - Two Dimension
3D - Three Dimension
FRP - Fiber Reinforced Rod
IEC - International Electric Commission
ZnO - Zinc Oxide
UV - Ultra Violet
HV - High Voltage
kV - Kilo Volt
rms - root mean square
mm - Millimetre
cm - Centimetre
m - Metre
E - Electric Field
F - Force
Q - Charge
\( \varepsilon_r \) - Relative Permittivity
\( \sigma \) - Conductivity
CHAPTER 1

INTRODUCTION

1.1 Background

Outdoor insulators which are widely used in overhead transmission lines as suspension material have vital roles in power system distributions. Insulators are made from dielectric materials such as glass, ceramic and composite materials. An insulator ideally is a substance which does not allow electric charge to flow through it and has no effect to electric fields. Therefore, dielectric materials which have high electric resistance and dielectric constants are used as an insulator. Starting with simple glass and porcelain insulators, it has rapidly developed since early of the century. These types of insulators can be considered as classic insulators and may put into the same category called as ceramic insulators. From research and service experience [1], they are reliable and cost effective for major outdoor installations. 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.
Outdoor insulators are subjected to outdoor environmental stresses such as humidity, temperature and pollution. It has been used in electricity distribution systems to support, separate or contain conductors at high voltage. Therefore, it has dual functions as electrical equipment and also as mechanical equipment in the power system networks. As electrical equipment, it provides electrical support by insulating between conductors and transmission tower or pole and separating conductors in the transmission line. Insulators are used as mechanical equipment in providing mechanical support by supporting the load in the transmission line as shown in Figure 1.1 below.

The modern style of polymeric outdoor insulators was introduced to replace ceramic insulators. The reason of this replacement was not a failure of ceramic insulators but the benefits offered by polymeric insulators over ceramic ones. The early developments of modern polymeric insulators started in 1964 with prototypes for field installations started in 1967 [3]. A report in 1996 stated that insulators installed in 1969 were performing well [4]. There are different techniques in manufacturing composite insulators. One of the techniques is to first manufacture the sheds separately and push them onto the core which is abandoned because these insulators experienced a lot of problems. The weak spots were the interfaces between the sheds where moisture could penetrate into the insulator causing internal tracking. The other method of manufacturing
composite insulators is one shot moulding. This is the most commonly used technique today. By using this technique, the housing can be chemically bonded to the core. Therefore, the number of interfaces where moisture can penetrate is minimized.

Despite their lower weight, the easier handling, the reduced installation and maintenance cost and their better performance under high pollution conditions, composite insulators are more sensitive to the magnitude of electric field strength. High values of the electric field intensify the corona effect around conductors and causes general audio noise, radio noise, partial discharges and premature deterioration of the insulation quality [5, 6]. Moreover, environmental factors such as heat, ozone, UV radiation, salt and dust deposition, acid rain and wind are responsible for the gradual loss of the hydrophobicity of the polymer material [7].

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. Reliability of the insulator is the most important property that must take into consideration whether it is a polymeric (composite) insulator or ceramic insulator. The good insulator should offer optimum electrical and mechanical strengths.

1.2 Problem Statement

The performance of polymeric insulators is important for both dry and wet condition. The insulators are exposed to various environmental stresses, which include many forms of precipitation, UV radiation and pollution. Long term problems with polymeric insulators are related to the degradation of polymer materials used for the insulator, corona phenomena on the insulator’s surface and pollution flashover. When polymeric insulators are installed on power line, the presence of conductors, the hardware, the tower configuration and also the other two phases of three phase system may influence the electric field strength in the vicinity of polymeric insulators.
The presence of pollution layer on composite insulator is very frequent near industrial, agricultural and coastal areas. Existence of pollution layer and combination with moisture due to wet weather condition such as dew, fog or drizzle, becomes conductive and leakage current flows through it. Due to flow of leakage current, dry bands may form on the insulator surface and the distribution of electric field and potential to become distorted and flashover may occur.

The study of electric field on polymeric insulator when subject to high voltage provides an important insight to improve the performance of the insulator. The design of a post insulator plays an important role in the insulator’s performance. The insulator’s shed profile can affect the water collection on the insulator’s surface and may influence the electric field stress distribution along the insulator’s surface.

Therefore, for the electric field control purpose, it is important to study these effects from a practical standpoint. The design of end fitting shape of polymeric insulators need to carefully designed to ensure the occurrence of corona in the vicinity of end fitting on the insulator to be kept at minimum frequency as possible. The performance and reliability of insulators may improve with the continuous improvement in the design.

1.3 Objectives

The main aim of this project is to optimize the electric field distribution around the insulator and furthermore to improve electric field performance. The objectives to be achieved are:

a. To simulate and analyse electric field distribution around polymeric insulators.
b. To evaluate the effect of insulator shape and attachment structure towards electric field performance under various weather conditions.
c. To propose and optimised insulator profile for best electric field distribution and performance.
1.4 Scope of Project

For this project, polymeric insulator model chosen to develop is used for 11 kV. The focuses on this project are as follow:

i. The modelling and simulation work is accomplished using Finite Element Methods (FEM).

ii. 2D modelling and simulations for more realistic and accurate electric field computations.

iii. Insulator developed is ideal without considering any attached or nearby structure.

1.5 Thesis Outline

The thesis can be divided in five main chapters. Chapter 1 mainly focuses on the background of the project which is the problems faced by polymer insulators and the objectives that driven this project. The limitation of the project has been discussed in scope of project section.

Chapter 2 briefly discusses on polymeric insulators and factors that affecting insulators degradation. The influence of electric field on insulator performance and the techniques to optimize the electric field are reviewed.

In chapter 3, the method to investigate electric field distribution on insulator via computer software simulations is discussed. Finite element method is employed for insulator modelling to determine electric potential and field distribution along the leakage path under dry clean conditions. A model of 11 kV polymer insulators is used to identify the effectiveness of optimization techniques employed.

Results of the project and analysis are discussed in chapter 4. The results from various simulation of the insulator model with different parameters such as end fittings design, configuration of weather sheds shape and installation of corona ring at appropriate
location are obtained. All the simulation results, discussion and analysis are made to study the influence of proposed methods on electric field distribution on the insulator.

Finally, chapter 5 presents the conclusions based on the findings from this study. By referring to the findings, some recommendations for future investigation are outlined.
CHAPTER 2

A REVIEW ON POLYMERIC OUTDOOR INSULATOR

2.1 Introduction

Insulators are widely used in electrical power systems to provide electrical insulation property and mechanical support for overhead transmission lines. There are three main types of insulator materials that usually used in power system distribution networks which are ceramic, glass and polymer. Figure 2.1 below shows the classification of the main types of insulators. It also has many shapes of insulators used in power system transmission with different densities, tensile strengths and performing properties. The intentions of high voltage insulators are to withstand any kind of worst conditions such as lightning and switching operations which may cause voltage to spike.
Porcelain insulators have a long journey of history. Initially, it has been used in the telegraph line at the beginning of the fourth decade of 19th century before the expansion of the usage for power lines area. In the 1960’s an insulator having porcelain sheds supported by an epoxy resin fiberglass rod was developed [40]. However, the usage was not wide because of further developments in lighter weight polymeric insulating materials has taken place. Both porcelain and glass have outstanding insulating properties and weather resistance. However, they are lack in terms of their bulky size which becomes more difficult to install in remote area, vulnerable to vandalism and also the performance in polluted area are poor. This is due to its hydrophilic properties which enable water to easily form a continuous conductive film along the creepage path. This formation has encouraged the flashover and could cause the failure in power transmission lines.

2.2 Polymeric Insulators

Polymeric insulators are increasingly being used in both the distribution and transmission voltage ranges and are steadily capturing a wider share of the market [8]. Before the introduction of polymeric, porcelain and glass have been traditionally used widely as insulating materials for high voltage power transmission line applications. They were introduced in 1960’s and started to be installed in United States in 1970’s and
since then, they became major option for utility companies around the world. After the introduction of polymeric insulators, the privilege to use it as a replacement for glass and ceramic has tremendously increase globally since the wide range of attractive advantages offered. They are easy to install due to their light weight and less prone to damage due to vandalism because of their elasticity surface. One of their major advantages is their low surface energy [9, 10] and thereby able to maintain a good hydrophobic surface property in presence of wet conditions such as fog, dew and rain [11]. Due to their hydrophobic surface, leakage current is reduced since it prevents water to form solid conducting layer on its surface.

With the improvements in design and manufacturing, it becomes more attractive to the utility companies around the world to utilize it. The developments of new materials continue to grow with a number of new insulating materials that have been developed and the concept of a composite structure which is advanced. Polymeric insulators consist of a fiberglass core rode covered by weathersheds of skirts of polymer such as silicone rubber, polytetrafluoroethylene, ethylene propylene diene monomer (EPDM) and equipped with metal and fittings. Materials such as Ethylene Propylene Rubber (EPR), Ethylene Propylene Diene Methylene (EPDM) or SiR are used to protect the core from environmental stresses. Silicone rubber is mainly used for polymer insulators or composite insulators as housing materials [12]. A housing material should have the ability to protect the load bearing core and provide sufficient pollution withstand. Rubbers have been chosen instead of ordinary plastic because of the ability of the rubber to be flexible enough to follow the changes in dimension caused by temperature or mechanical load. It is called composite insulators since it has been made with at least two insulating parts which are a core and housing equipped with end fittings. Figure 2.2 below shows the cross section for polymeric insulator component.
Figure 2.2 Cross section of composite insulator

The insulators selection for different voltage rating is depending on minimum specific creepage distance and IEC60815 standard requirements [41]. Regarding to the electrical and mechanical characteristics, the insulators are designed to satisfy the requirements set forth in IEC61109. During designing a perfect insulator, internal and external discharge activities are consider under normal condition [13].

Despite the numerous advantages offered by polymeric insulators, there are also some disadvantages of these insulators. The main disadvantages of composite polymeric insulator are that they are subjected to chemical changes on the surface due to weathering and from dry band arcing [19], suffered from erosion and tracking which may lead ultimately to failure of the insulator [20], the difficulty to evaluate life expectancy, long reliability is unknown and faulty insulators are difficult to detect.

2.3 Electric Field

Electric field influences the performance and the life of insulators. In the design process, the behaviour of electric field should be given the main consideration to ensure it will give the satisfaction in term of performance. The intensity of electric field which is produced due to the potential of dielectric may result in electric stresses upon the dielectric. The distribution of electric field for polymeric insulators is different
compared to porcelain insulators. Electric field distribution of a composite insulator generally is more nonlinear than that of porcelain insulators.

The electric field intensity or known as the electric field strength is defined as the electrostatic force, \( F \) per unit positive test charge, \( q \) placed at a particular point, \( p \) in a dielectric [14]. It is denoted by \( E \) with the SI unit is Newton per Coulumb which is equivalent to volt per meter. Since force is a vector, then the electric field is classified as vector quantity which the direction of the field is taken to be the direction of the force it would exert on positive test charge. Field strength of 1 v/m represents a potential difference of one volt between points separated by one meter. The electric field is radially outward from a positive charge and radially inward toward a negative point charge. The relationship between electric field and force is given in equation below:

\[
E = \frac{F}{q}
\]

Equation 1

Referring to the Equation (1), the magnitude of the force is equal to \( qE \) and the direction of the force on a positively charged particle. The force on a negative particle is opposite to the field direction.

Electric field strength is a quantitative expression of the intensity of an electric field at a particular location. The electric field strength is often called as the electric field stress experienced by a dielectric. Field strength of 1 Vm\(^{-1}\) represents a potential difference of one volt between points separated by one meter. Any electrically charged object produces an electric field. This field has an effect on other charged objects in the vicinity. The field strength at a particular distance from an object is directly proportional to the electric charge in Coulomb on that object. The field strength is inversely proportional to the distance from a charged object.
Figure 2.3 Illustration of electric field

Figure 2.3 shows the potential difference $U_{ab}$ between point $a$ and point $b$ having scalar potential $\phi_a$ and $\phi_b$ in an electric field, $\vec{E}$, which is defined as the work done by an external source in moving a unit positive charge from $b$ to $a$.

$$U_{ab} = -\int_b^a \vec{E} \cdot dx = (\phi_a - \phi_b)$$

Equation 2

The rate of change between potential with distance will give the magnitude of electric field intensity. When the direction of $\vec{E}$ is opposite to the direction in which the potential is increasing most rapidly, the magnitude of the field intensity is at maximum.

$$\left| \frac{dU_{ab}}{dx} \right|_{\text{max}} = |\vec{E}|_{\text{max}}$$

Equation 3

A physical interpretation of the electric field intensity finding process from the scalar potential, $\phi$ is given by Equation (3). The electric field intensity can be obtained from the potential gradient operation on the potential as shown in equation below:

$$\vec{E} = -\nabla \phi$$

Equation 4
Electric fields in high voltage cause polarization and electric losses in polymeric insulators [15]. High values of the electric field intensify the corona effect around conductors and cause in general audio noise, radio noise, partial discharges and premature deterioration of the insulation quality [16, 17]. When the insulator is exposed to the higher electric field, it will suffer from the phenomenon of electrical breakdown. Insulators become conductive when they reach at the breakdown level. 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 [18].

2.4 Degradation of Polymeric Insulators

The performance of polymeric insulators may be affected and weakened by multiple stresses encountered in service. Reservations have been voiced in the past regarding the use of polymeric insulators, given their organic nature. Continuous service stress can lead to deterioration of the surface of the properties such as loss of hydrophobicity, discoloration, chalking and cracking. When the environmental stresses overwhelm or the severe contamination dominate, the material starts degrading [21]. Polymeric has weaker ionic bonds in contrast to covalent bonds in ceramic because of its compound chemical bond is subjected to chemical reaction. Beside material and design of the insulator, other factors that contribute to its degradation and ageing are electrical, mechanical and environmental stress [22, 23]. Polymers unlike ceramic and glass are organic materials that can degrade or age under these stresses.

2.4.1 Electrical Stresses

Electrical stresses in polymeric insulators include corona discharges, formation of dry bands, wetting discharges and insulator flashover. The strength of insulators in withstanding the electrical stresses is depending on its properties of dielectric materials. Insulators should have low dielectric losses to be able to deal with the high temperature and maintain their dielectric strength. The appropriate material properties can help the insulators to avoid electrical tracking and erosion during service.
2.4.1.1 Corona Discharges

Corona is phenomenon that has the capability for degrading insulators, and can cause systems to fail. It is also known as partial discharge where type of localized emission resulting from transient gaseous ionization in an insulation system when the voltage stresses or voltage gradient exceeds its critical value. There are three types of corona which are plume, brush and glow. Plume is the most spectacular corona and it is called as so because of its general resemblance to a plume. It also has audible manifestations which are rather intense snapping and hissing sound. Brush corona is a streamer projecting radially from the conductor. The audible manifestation that is associated with brush corona is generally a continuous background type of hissing or frying sound. The glow corona is a very faint, weak light which appears to hug the conductor’s surface and there is generally no sound that is associated with it.

Corona can occur within voids in insulators as well as at the conductor’s or insulator’s surface. The formation of corona is dependent upon atmospheric conditions such as air breakdown humidity and insulator’s geometry. High potential area for the formation of corona discharge is at highly curved regions on electrodes, such as sharp corners, projecting points, edges of metal surfaces or small diameter wires. The high curvature causes a high potential gradient at these locations. Therefore, to suppress corona formation, terminals on high voltage equipment are frequently designed with smooth large diameter with rounded shape and corona rings are often added to insulators of high voltage transmission lines. The potential distribution depends on the insulator’s length and the voltage stress at the terminal that is proportional to the line voltage and then fall rapidly with the increasing distance from terminal [24].

Corona phenomenon in electric power transmission line is shown in Figure 2.3. Corona accelerates the aging of polymer by producing ozone and nitrogen oxide which are converted into nitrous and nitric acid in the presence of moisture [25]. It produces acids that get into the core through voids on the shed. These acids attack the insulation surface by destroying crosslinks in the polymeric compound and the combined effects of
chemical and thermal stresses consequently results in the degradation of the insulation material and is believed to causes mechanical failure on the entire insulator.

Figure 2.4 Corona discharge effects in electrical transmission lines

Audible and radio frequency noises that are generated from corona discharge may affect the area particularly near to electric power transmission lines. Corona discharge is undesirable in power transmission since it will cause the loss of power. Furthermore, ozone and nitrogen oxide that are produced can also be harmful to human’s health where power lines run through settlements area.

2.4.1.2 Formation of Dry Bands

Dry band arcing is known as electrical flash that occurs between wet and dry spots over the contaminated surface of an insulator. During clean and dry condition, there is no significant effect by the induced voltage. When water has the opportunity to wet the insulator, a thin film of water will form on its surface. It will allow the flow of leakage current along the conductive path and cause a surface current to arise which is causing heat. The current density increases and tends to cause the greatest heat close to the fittings. Due to this condition, dry bands can develop when the supply of rainwater diminishes. The formed dry bands interrupt the conductive surface and it may cause arcing and can lead to flash over. If the current flow is allowed to continue for an extended time across at the same dry band surface on a polymer insulator, it could prematurely age the elastomeric material leading to tracking and failure [26].
2.4.1.3 Wetting Discharges

The water droplets play several roles in the pollution flashover and aging of composite insulators, because of high permittivity and conductivity of water droplets, electric field intensity increases at the insulator surface [27]. It may lead to the breakdown of the insulator even though without the presence of actual contaminants. The surface corona discharges from water droplets age the weather shed material of the insulator. This phenomenon has led to the demolishing hydrophobicity and causing the dispersed of water and adjacent water droplets to coalesce. One of the aging mechanisms responsible for the failure of the insulators is discharges on the surface of polymeric insulators. The discharges usually occur between water droplets on the insulator’s surface. This will create several radicals and ionized species that may chemically react with the insulator’s surface. Therefore, the original properties of dielectric materials may change. Water droplets will intensify the electric field strength on the insulator’s surface under rainy and foggy conditions.

2.4.1.4 Insulator’s Flashover

Operation of composite insulators is also exposed to the flashover phenomenon that is caused by switching surge or lightning surge and contamination. It can result in insulator’s failure. Contamination increases surface conductivity which causes flashover to persist after the arc has been initially cleared, allowing subsequent flashover to occur on reclosed. It is believed that failure due to such flashover is very much dependent on the duration of the faulty current [35].

When insulators are installed near industrial, agricultural or coastal areas, air bone particles are deposited on the insulators and the pollution builds up gradually. It will result in the flow of leakage current during wet weather conditions such as dew, fog or drizzle. The leakage current density is non-uniformed over the insulator or surface and in some areas when sufficient heat is developed, it will lead to the formation dry bands [36]. High electric field intensity across dry bands is caused by voltage redistribution along the insulator is resulted in the formation of partial arcs. For the
polymeric insulators, the creation of partial arcs will lead to erosion and chemical
degradation on the insulating material. These partial arcs’ discharges will elongate along
the insulator’s profile due to the surface resistance which is sufficiently low and may
eventually cause the insulator’s flashover.

2.4.2 Environmental Stress

Polymeric insulators perform satisfactorily at the beginning of their service but
will deteriorate due to continuous exposure to the stresses including environmental
stress. Both mechanical and electrical performance of the insulators can affect by the
environmental stresses. The environmental effects include ultraviolet (UV), moisture,
heat, light, atmospheric pressure and biological degradation which are caused by
microorganism in air [28]. Depending on the application and location of the installed
insulator installed, one or more factors can act together to cause aging.

One of the major factors responsible for degradation of polymeric insulator is
ultraviolet light. Insulators are exposed to sunlight under ultraviolet radiation. The main
sources of ultraviolet light are sun, corona formation and dry band arcing activities on
insulator’s surface. The ability to resist degradation resulting from ultraviolet exposure
is an important factor in determining the service life of insulators. The energy from
sunlight that is destructive to polymers is between 320 nanometers and 270 nanometers
[29]. The absorption of this UV radiation is the result of mechanical and chemical
degradation of the polymer structure which can affect the dielectric and weathering
properties of that polymer. The rate at which the degradation occurs is dependent upon
the intensity and wavelength of the radiation.

The presence of moisture obviously will accelerate the effects on the insulator’s
surface. This condition is becoming even worse by the presence of surface
contamination due to pollution. Ultraviolet radiation on polymer will result in negative
effects as include:

i. Crazing, checking or cracking of the surface

ii. Loss of hydrophobicity

iii. Discoloration.
Pollution is one of the main causes of flashover in the insulators. When the pollutants exist in the air settle on the insulator’s surface and combine with the humidity of the fog, rain or dew, it will drive the insulator to fail. Chemical attack occurs due to pollution of the products and following of discharge activity on the insulator’s surface. The mixture of pollutants, plus the humidity forming a layer that can become conductor and allowing passing currents will facilitate the conditions of short circuit. This is due to a decrease of the resistance of the insulator surface and could cause the tracking and erosion surface materials of polymeric insulators.

Water ingress in polymeric insulator occurs in three ways: i) through poor seals at end fittings, ii) through surface defect or damages, iii) through absorption of water into the polymeric material itself [30]. Corrosive chemicals and/or ionisable contaminants that are carried by the water affect the mechanical strength of the FRP rod and this is known to cause brittle fracture. Water absorption causes depolymerisation as well as polarisation of the interfaces between the polymer and the fillers. The permittivity and loss tangent will increase while the dielectric strength will decrease.

2.4.3 Mechanical Stress

Direct mechanical stress on insulators can be tensile, compressive or cantilever loading [30]. These stresses can cause the failure by damaging the fibre reinforced plastic (FRP) core. Mechanical stresses usually affect the insulator in combination with other stresses. Indirect mechanical stresses trap during the manufacturing process. This will provide arcing regions which would cause tracking and erosion.

2.5 Field Optimisation Techniques

Electric field (E-field) plays a major role in the aging processes of insulators mainly because it is the factor that triggers partial discharges. The long term and short term performances of insulators are directly affected by electric field due to corona and arcing. In order to extend its life span, E-field distribution along insulators must be controlled and kept below the threshold value. Furthermore, the maintenance cost of the
insulator can also be reduced. Hence, various techniques can be considered in controlling E-field distribution along insulators.

### 2.5.1 End Fittings Design

The design of the end fitting has an influence on the E-field distribution within the composite insulator on the surface of weather shed material and on the surface of the metallic end fittings. The large end fittings design with rounded edges tends to reduce the peak magnitude of the E-field values in close proximity of the end fittings [31]. Figure 2.4 below shows the distribution of E-field for three different end fittings designs.

Figure 2.4 shows the distribution of E-field for three different end fittings designs:

- **End fitting closed to the last shed**
- **End fitting at a short distance from the last shed**
- **End fitting partly covered by silicone rubber**

Figure 2.5 Examples of the E-field distribution surrounding three different designs of composite insulator end fittings
2.5.2 Weather Shed Insulation

In controlling the E-field magnitude, the geometrical shape of polymeric insulators should be taken into consideration. The weather sheds provide the required leakage distance and currently are supplied with different materials, shapes, diameters, thickness and spacing. In the compounding of the weather sheds, fillers are added to enhance the resistance to tracking and erosion as well as to provide improved mechanical performance in tensile strength, abrasion resistance, tear strength, modulus and to reduce flammability.

Gorur et al. [31] has conducted a study on the effect of polymer insulator profile on the erosion and tracking performance in salt fog. From the study, it was found that insulators with protected profiles maintained their initial surface hydrophobicity for a much longer time with low levels of leakage currents than other designs. The self-cleaning aspect of insulators is important for polymeric insulators with large shed spacing and insulators with alternating diameter sheds have shown better performance under both desert and coastal conditions that insulator with straight sheds, which also allows for reduced shed spacing designs [32]. As such, from the previous studies, it has shown that the shed profile influences the performance of insulators, particularly under contaminated conditions.

2.5.3 Corona Ring

A corona ring which is also called an anti-corona ring is a toroid of conductive material usually metal which is attached to a terminal of high voltage equipment. Corona ring is used to eliminate or reduce ionisation of the air with associated corona discharge. The performance and life span of insulator may be affected with corona discharge and can cause catastrophic insulation failure. 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. Corona rings also improve the voltage distribution along the insulator string by reducing the percentage of the voltage on the unit nearest to the power transmission line. Moreover, they also alleviate corona degradation of non-ceramic materials [33, 34].
CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter is discussing how the work is carried out in order to obtain the aims of this project. The purpose of this project is to identify the highest electric field region along the polymeric insulator. After the determination of the highest region, optimisation technique is used to control and reduce the electric field. The reduced intensify of electric field can help the insulator to improve its performance and furthermore will improve its reliability. Several methods have been developed for the computation of electric fields and potentials along an insulator string.

For this project development, numerical computational technique has been applied. The potentials and electric fields distribution along developed polymeric insulator has been evaluated by using Finite Element Method (FEM) computational simulation.
3.2 Finite Element Method

Finite element method (FEM) is a numerical analysis technique which is used to obtain solutions to the differential equations. It has been applied widely in a variety of physical and also non-physical problems. These problems include diversity from solid, fluid and soil mechanics to electromagnetism or dynamic. 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 [39].

The FEM is most convenient for a field with many dielectrics, heterogeneous and non-linear materials, complex fields and a field containing distributed space charges and singular point. It is one of the most successful numerical methods for solving electrostatic field problems because it involves discretization of the domain according to the anticipated value of field distributions [38]. It is also a flexible method that is well suited to problems with complicated geometry. 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

Finite elements simulation for the developed insulator is carried out using COMSOL Multiphysics software. It is the software that is used as a finite element analysis, solver and simulation software for various physics and engineering applications especially coupled phenomena or multiphysics.

There are basically three stages involved which are pre-processing, solving and post processing. The properties of geometrical and electrical, materials, boundaries and meshing criteria are the input that involve in the pre-processing stage. In the solving stage, the boundaries of each geometric condition are applied and the mathematical model express as differential equations that describe the physical problem is executed.
For the evaluation of the results, the plot is generated by simulation in terms of variables or parameters.

### 3.4 Project Process Flow

In obtaining and analysing electric fields distribution, the process flow of the project can be simplified in Figure 3.1. The flow chart shows all of the processes involved starting from the initial stage until the desired results is obtained.

![Figure 3.1 Flow chart of electric field optimisation for polymeric insulator](image-url)
3.5 Insulator Model

For the project purpose, the model of insulator with rated voltage of 11 kV was developed. The model of insulator is shown in Figure 3.2 below. Simulation of the insulator is being considered to be under dry clean condition and uniform wet pollution. Insulator model is also considered in ideal condition without considering any attached or nearby structure and other hardware peripherals.

![Insulator model dimension](image)

Figure 3.2 Insulator model dimension

3.5.1 Modelling Simulation

Insulator model developed for this project simulation was created by using CAD drawing tools available in the COMSOL Multiphysics software. Only half of insulator model was developed since its geometry shape is cylindrical. The model of two-dimensional (2D) assymetric insulator geometry is shown in Figure 3.3 below.
REFERENCES


