STUDY ON NON-LINEAR GRADING MATERIAL AS STRESS CONTROL ON POLYMERIC OUTDOOR INSULATOR

NUR HANANI BINTI AHMAD SHUHAIMY

A project report submitted in partial fulfillment of the requirements for the award of the Degree of Master of Electrical Engineering

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

JANUARY 2014
ABSTRACT

Over the last few decades, polymeric insulators started to gain popularity amongst electric power utilities around the world. They are subject to mainly electrical stress more than mechanical or environmental stress. This paper investigates the potential use of non-linear grading material for optimising field distribution and the effectiveness in controlling the electric field stress on outdoor polymeric insulator. A two-dimensional (2D) asymmetrical modelling based on 11 kV polymeric insulator system voltage was modelled using a commercially available Finite Element Method (FEM) package. The electric field and potentials distributions along the leakage path on the surface of the insulator were computed using the FEM. Analysis of electric potential and field distributions on the insulator surface is under dry clean and contaminated surface conditions for non-graded polymeric insulator and microvaristor-graded polymeric insulator. Non-linear grading material was introduced at both insulator ends for controlling high field. The lightning impulse flashover test (1.2/50 µs), has been conducted for both graded and non-graded insulators to evaluate the effect of stress grading coating on the breakdown performance. The percentage of field reduction are almost 23% under dry-clean surface and 17% for wet-polluted surface at high voltage terminal. The approach of microvaristor grading material with an appropriate switching characteristic has improved electric field and heat distributions along the insulator profile.
ABSTRAK

## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>i</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF SYMBOL AND ABBREVIATIONS</td>
<td>xiii</td>
</tr>
</tbody>
</table>

### CHAPTER 1  INTRODUCTION

1.1 Background of Study                       | 2    |
1.2 Problem Statement                         | 3    |
1.3 Objectives                                | 4    |
1.4 Scope of Project                          | 4    |
1.5 Thesis Outline                            | 5    |

### CHAPTER 2  A REVIEW ON POLYMERIC OUTDOOR INSULATOR PHENOMENA

2.1 Introduction                              | 7    |
2.2 Polymeric Outdoor Insulator               | 8    |
2.2.1 Advantages and Disadvantages of Polymeric Outdoor Insulator | 9    |
2.2.2 Design and Structural Shape             | 10   |
2.3 Electrical Stress                          | 12   |
2.3.1 Corona                                  | 12   |
2.3.2 Water Droplet Discharge                 | 13   |
2.3.3 Insulator Flashover                     | 14   |
2.3.4 Dry Band Discharge                      | 15   |
CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion 54
5.2 Recommendations 55

REFERENCES 56
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1:</td>
<td>Material properties used for insulator modelling</td>
<td>30</td>
</tr>
<tr>
<td>Table 4.1:</td>
<td>Peak magnitude of tangential field on the dry-clean insulator</td>
<td>44</td>
</tr>
<tr>
<td>Table 4.2:</td>
<td>Peak magnitude of tangential field near end terminal for both conditions</td>
<td>47</td>
</tr>
<tr>
<td>Table 4.3:</td>
<td>Stress grading performance under impulse energisation at 50kV</td>
<td>50</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1.1: Outdoor insulator on overhead power line 2
Figure 2.1: Classification of insulator 7
Figure 2.2: (a) Polymeric Insulator; (b) Porcelain Insulator; (c) Glass Insulator 8
Figure 2.3: Polymeric insulator component 11
Figure 2.4: Corona on polymeric outdoor insulator 12
Figure 2.5: Electric field enhancement 14
Figure 2.6: Polymeric insulator damage 15
Figure 2.7: Pollution surface on polymeric outdoor insulator 16
Figure 2.8: Resistive of the grading compound 19
Figure 2.9: Effect of corona ring on live end electric field 21
Figure 2.10: Electric field magnitude distribution surrounding three different designs of end-fitting 22
Figure 3.1: Dimension of 11kV polymeric insulator under consideration 24
Figure 3.2: Block diagram of methodology 25
Figure 3.3: Process of insulator design 27
Figure 3.4: Insulator model without non-linear grading material 29
Figure 3.5: Material specification of dry clean surface 29
Figure 3.6: Material specification of wet polluted surface 30
Figure 3.7: Design process of ZnO Microvaristor in insulator 31
Figure 3.8: (a) Electric potential terminal, (b) Ground terminal 32
Figure 3.9: Normal meshing along the leakage path 33
Figure 3.10: Refinement meshing along the leakage path 33
Figure 4.1: Electric potential surface 35
Figure 4.2: Equipotential lines 35
Figure 4.3: Zoomed-in view of equipotential lines near high voltage terminal 36
Figure 4.4: Voltage profile along the insulator surface

Figure 4.5: Tangential electric field distribution

Figure 4.6: Proposed microvaristor characteristics with different switching threshold at $E_0$ (1) 0.5 kV/cm, (2) 1.0 kV/cm and (3) 5.0 kV/cm.

Figure 4.7: Insulator Design 1

Figure 4.8: Tangential electric field profiles along the insulator surface for design 1 different microvaristor switching thresholds, $E_0$

Figure 4.9: Insulator Design 2

Figure 4.10: Tangential electric field along the insulator surface for design 2 at microvaristor switching thresholds 5kV/cm

Figure 4.11: Insulator Design 3

Figure 4.12: Tangential electric field profiles along the insulator surface with microvaristor switching thresholds at 5kV/cm

Figure 4.13: Equipotential line for new insulator design

Figure 4.14: Equipotential surface for design 3 at switching threshold 5kV/cm

Figure 4.15: Equipotential lines for thin grading layer

Figure 4.16: Comparison of tangential electric field

Figure 4.17: Comparison of tangential electric field under dry clean condition

Figure 4.18: Comparison of tangential electric field under wet polluted condition

Figure 4.19: Equipotential lines around polymeric insulator under (a) dry-clean, and (b) wet-polluted surface condition

Figure 4.20: Tangential field distribution along the leakage path at impulse instant of 1.2 μs with peak voltage 50 kV

Figure 4.21: Equipotentials line around the high voltage end at 1.2 μs with peak voltage of 50 kV

Figure 4.22: Tangential field distribution along insulator surface at different impulse instants (dry-clean insulator)

Figure 4.23: Power dissipation in the pollution layer near the insulator HV terminal
LIST OF SYMBOL AND ABBREVIATION

SiR — Silicone Rubber
GFR — Glass Fiber Reinforced
EPR — Ethylene Propylene Rubber
EPDM — Ethylene Propylene Diene Methylene
FEM — Finite Element Method
BEM — Boundary Element Method
2D — Two Dimension
3D — Three Dimension
RTV — Room Temperature Vulcanised
HTV — High Temperature Vulcanised
EPM — Ethylene Propylene Monomer
IEC — International Electrical Commission
kV — Kilo Volt
mm — Millimetre
cm — Centimetre
m — Metre
εr — Relative Permittivity
σ — Conductivity
°C — Celsius
ns — Nanosecond
μs — Microsecond
UV — Ultra Violet
E — Electric Field
N — Force
C — Charge
ZnO — Zinc Oxide
HV — High Voltage
CHAPTER 1

INTRODUCTION

1.1 Background of Study

High voltage insulators have developed rapidly since early this century, beginning with simple glass and porcelain insulators. These materials have outstanding insulating properties and weather resistance, but have the disadvantages of being heavy, easily fractured, and subject to degradation of their withstand voltage properties when polluted.

The development and use of polymeric insulators started during the 1960s. By the mid-1970s a number of new insulating materials had been developed, and the concept of a composite structure was advanced [1]. Since the 1980s, greater use has been made of Silicone Rubber (SiR) due to its weather resistance, which is virtually permanent, and its strong hydrophobic properties, where water on the polymeric surface tends to form discrete droplets. This property helps to minimise the leakage current, the probability of dry band formation and led to an explosive increase in the use of composite insulators [2].

An ideal design of outdoor insulator should increase the weather resistance of the material. It has to be able to reduce pollution accumulation and water condensation on the surface that could increase surface conductivity. An outdoor insulator should design to resist vandalism. In designing an outdoor insulator consideration should also be given to mechanical strength because an insulator also has role in construction support and load bearing in addition to the electrical
insulation role which require high electric strength. Moreover, resistance to weather and vandals depend on the mechanical and electrical properties of the material.

Today, modern polymeric insulators are used to replace glass and porcelain insulators and are extensively used in electric power systems such as sub-stations and distribution and transmission lines. Insulators have a major role to isolate the conductor from the support and also used as a support of the conductor itself. Polymeric insulators have many advantages over the ceramic and glass insulators such as good performance in contaminated environment, light weight, easy handling, maintenance free, and considerably low cost [3]. Because of these properties it is gaining popularity worldwide and replacing the conventional ceramic and glass insulators.

Figure 1.1: Outdoor insulator on overhead power line

There are three main types of insulator materials: ceramic, glass and polymer. Their use and designs are determined by their mechanical and electrical properties and the load or stress that they have to encounter in their application in addition to weather resistance and vandalism. Those materials act as the dielectric of the insulator, when it attaches to the terminal or end fitting.
A typical polymeric insulator consists of a Glass Fiber Reinforced (GFR), resin-bonded rod onto which metal end fittings are attached. To protect the core from environmental stresses, it is covered with housing materials which are Ethylene Propylene Rubber (EPR), Ethylene Propylene Diene Methylene (EPDM) or SiR [4].

The importance of polymeric insulators is the electrical stress, under both normal operating and transient overvoltage conditions. The high field regions especially near the high voltage conductor and the earth terminal, initiate corona and discharges on the surface that can lead to premature degradation and more seriously failure of the insulator. One of the main factors contributing to the development of discharges on insulator surfaces is the electric field distribution on the insulator surface, which in turn controls the current density. Considering these consequences, field control is greatly demanded to achieve stress relief on polymeric outdoor insulator.

1.2 Problem Statement

Due to their wide role in power transmission and distribution, insulators are subject to electrical, mechanical and environment stress. They are subject to mainly electrical stress more so than mechanical or environmental stress. Line insulators are mostly installed outdoors, and are subject to mechanical stress due to the conductor weight, sag, tension and wind. The unavoidable stress for the outdoor insulator is environment stress: a high temperature ambient and a wide range of surface pollution. The presence of pollutants covering the insulator surface could reduce the hydrophobicity of the polymeric material, thereby promoting the formation of a continuous conductive film. The resulting leakage current under system voltage generates resistive heating that evaporates water from the wet surfaces, risking the formation of dry bands.

There are different causes due to which failure of insulation in electrical power system may occur. The serious failure might occur such as partial damage, pin corrosion, external flashover, internal puncture, mechanical separation and aging [5]. Several grading techniques have been introduced to regulate the high field over the insulator surface. The grading ring is the most common device used for high-voltage
insulators to control excessive stress near the high-voltage and ground terminals [6]. Many researchers in recent years has shown that polymeric dielectrics are prone to degradation under stresses applied or induced in service which eventually leads to system failure. Due to these problems, it is more important to control the electric field and leakage current to avoid breakdown or flashover on polymeric outdoor insulator.

1.3 Objectives

Over the last few decades, polymeric insulators started to gain popularity amongst electric power utilities around the world. The main objective of this project is to contribute an alternative approach to the existing technique for optimising electrical field distribution on polymeric outdoor insulator. The specific objectives of this project are below:

i. To evaluate electric field distribution around polymeric outdoor insulators.
ii. To propose a techniques for controlling high electric field at insulator end fitting.
iii. To investigate the potential use of non-linear electrical properties for optimising field distribution on polymeric outdoor insulator.
iv. To examine the effectiveness of non-linear grading material in controlling the electric field stress on polymeric outdoor insulator.

1.4 Scope of Project

The Determination of electric field on the insulator surface is important to predict high stress region on the insulator. This project focuses on:

i. To analyse electrical field stress near the high voltage and ground terminal of polymeric outdoor insulator using Finite Element Method (FEM) package.
ii. The polymeric outdoor insulators in ideal condition without nearby structures attached to the transmission line.
iii. To reduce electrical field distribution on dry and wet condition at polymeric outdoor insulator end fittings.

iv. To carry out a model of 11kV polymeric outdoor insulators asymmetrical two-dimensional (2D) design.

1.5 Thesis Outline

This report is divided into five chapters:

CHAPTER 2 provides a literature review on polymeric outdoor insulator phenomena. General polymeric insulators are discusses including advantages, structural design, factors contributing to the ageing process are presented. The present techniques for controlling high electric field on insulator surfaces are reviewed, and the possibilities of different field grading material are considered.

CHAPTER 3 presents the method for investigate the electric stress on polymeric insulators by using computer simulations. A commercial finite element package is employed for insulator modelling to determine electric potential and field distribution along the creepage path under dry-clean and wet-polluted surface conditions. A case study is carried out for a typical 11 kV polymeric insulator to examine the effectiveness of the non-linear grading material.

CHAPTER 4 presents the use of non-linear microvaristor coating is to relief stress in the high field region near terminals end. The use of a non-linear pollution model is to achieve a better and more realistic field simulation. The polymeric insulators model also tested under lightning impulse conditions. The simulation results are discussed in this chapter. Analysis of field distribution is under dry-clean and wet polluted conditions for both standard non-graded and microvaristor-
graded insulators. In addition, dissipated power is computed to examine surface heating and losses in the grading regions and for the complete insulator. The simulation results for both graded and non-graded insulators are compared and discussed in this chapter.

CHAPTER 5 presents general conclusions based on the findings in this study, and outlines some recommendations for future investigation.
CHAPTER 2

A REVIEW ON POLYMERIC OUTDOOR INSULATOR PHENOMENA

2.1 Introduction

Insulators are useful for separating electricity from objects and living things that it could damage. Power lines are separated from the metal tower by a stack of polymeric insulator. An insulator usually used non-metallic material that completely blocks the flow of electricity [7]. The determination of electric field needs to consider on various modelling criteria for computer simulation. In this chapter some reviews made on selected articles, journals and technical papers related to the concerning electric stress control on polymeric outdoor insulators. High voltage insulators have developed rapidly since early this century, beginning with simple porcelain insulators. A classification of the main types of insulators [8] is shown in Figure 2.1 and Figure 2.2.

![Figure 2.1: Classification of insulator](image_url)
2.2 Polymeric Outdoor Insulator

The history of polymeric insulators began in the 1940s when organic insulating materials were used to manufacture high voltage indoor electrical insulators from epoxy resins [9]. These materials were light weight, impact resistant, and could be used to form large complex parts. Polymeric insulators for outdoor application on transmission lines were not developed until the late 1960s and 1970s. Polymeric insulators finally came into general use on transmission lines in the 1980s.

This type of insulator is called composite because it consists of three parts:

i) A core made of glass fibre,
ii) External weathersheds made of polymer, and
iii) Metal fittings for attachment.

The idea of using fibreglass as a core is to improve the load bearing ability and also to act as an insulating part. Today, vinyl ester resin has also been introduced as a core. The weathersheds are made from various polymer materials and designs in many different shapes to provide maximum insulation. Various types of polymer shed material have been utilised including Teflon, Epoxy Resin, Room Temperature Vulcanised (RTV) Silicone Rubber, High Temperature Vulcanised (HTV) Silicone Rubber, Ethylene Propylene Monomer (EPM), Ethylene Propylene Diene Monomer (EPDM) [3].
In recent years, polymeric insulating materials with excellent weather resistance and mechanical performance have been developed. Polymer insulator comprises a core material, end fitting, and a rubber insulating housing. To protect the core from environmental stresses, it is covered with polymer weather shed. Inorganic fillers were introduced in some polymers in order to improve their performance, particularly strength and surface discharge resistance. Basic polymer shed materials used are SiR, EPM, and EPDM [3].

2.2.1 Advantages and Disadvantages of Polymeric Outdoor Insulator

Polymeric transmission line insulators offer significant advantages over porcelain and glass insulators, especially for high voltage transmission lines. Although polymeric materials are much more sensitive to aging than conventional porcelain and glass materials, polymeric materials are applied to insulator surfaces, because of several advantages in the field of outdoor high voltage insulation.

One major advantage offered by polymeric materials is to impart a hydrophobicity to insulator surfaces. The hydrophobicity can prevent contaminated water films from forming on the insulator surface even in wet conditions, which contributes to a suppression of leakage current [4].

The specific advantages, compared with ceramic insulators are:

1. Light weight: Suitable for lower construction and transportation costs.
2. Vandalism resistance: Less gunshot damage.
3. High strength to weight ratio: It will give longer spans or new tower.
5. Improved transmission line aesthetics.
The main disadvantages of composite polymeric insulators are:

1. They are subjected to chemical changes on the surface due to weathering and from dry band arcing.
2. Suffer from erosion and tracking which may lead ultimately to failure of the insulator.
3. Life expectancy is difficult to evaluate.
4. Long reliability is unknown.
5. Faulty insulators are difficult to detect.

2.2.2 Design and Structural Shape

The general structure design of polymeric insulators comprises three components. The central fiber glass rod attached to two end fitting provides the mechanical strength to the insulator. The polymer weather shed consisting of the sheath provides the electrical strength under all condition. Many groups of polymers have been tried but only silicone rubber and ethylene propylene rubbers were found to perform satisfactorily. The rubber housing provides electrical insulation and protects the FRP from the elements. The rod is attached to the aluminium or malleable iron end fitting by means of a crimp, wedge or glue [10].

The selection of outdoor insulators is essentially governed by the minimum specific creepage distance, taking into account two important aspects as recommended in IEC 60815 Standard [11]:

i) System requirements, and
ii) Environmental conditions

Since polymeric insulators have excellent resistance to pollution and mechanical impact, these features can be used to reduce the size of transmission lines. Figure 2.3 shows the assembly component of the typical polymeric insulator.
1. **Core Rod**: The core is the internal insulating part of a composite insulator. It is intended to carry the mechanical load. It consists mainly of glass fibers positioned in a resin matrix so as to achieve maximum tensile strength.

2. **Housing/sheath**: The housing is external to the core and protects it from the weather. It may be equipped with weather sheds. Some designs of composite insulators employ a sheath made of insulating material between the weathersheds and the core. This sheath is part of the housing.

3. **Weathersheds**: Weathersheds are insulating parts, projecting from the housing or sheath, intended to increase the leakage distance and to provide an interrupted path for water drainage.

4. **End Fitting**: End fitting transmit the mechanical load to the core. They are usually made out of metal. The most widely use is compression of the metal end fitting onto the rod.

**Figure 2.3: Polymeric insulator component [10]**
2.3 Electrical Stress

The electrical stress withstand of insulators depends upon the dielectric material properties. They have high electric strength to minimise the materials used to reduce cost for the higher voltages. Insulators also have to be able withstand heat due to high temperature without losing their dielectric strength, so they have to have low dielectric loss. Moreover, they also have to have appropriate material properties to prevent electrical tracking and erosion during service. Electrical performance of high voltage insulators is governed by the distribution of electric fields around the insulator profile. Non-uniform and high fields could lead to electric discharges in the form of corona, dry band arcing and flashover.

2.3.1 Corona

The assembly and physical structure of polymeric insulators with low permittivity materials causes large potential gradients to occur at the high voltage and ground terminals. The potential distribution depends on the insulator length and the voltage stress at the terminal is proportional to the line voltage and then fall rapidly with the increasing distance from terminal [12]. Corona as a result of the high voltage stress occurs easily on the composite insulator. Corona is an electrical discharge occurring in a high electric field, general in the vicinity of conducting surfaces, but also near insulating surfaces, due to the ionization of air. Corona produces acids that get into the core through voids on the shed. Figure 2.4 shows the corona occur near polymeric insulator end fittings.

![Figure 2.4: Corona on polymeric outdoor insulator](image-url)
Two common by-products from corona activities are ozone and nitrogen oxide, which are converted into nitrous and nitric acid in the presence of moisture [13]. The acid attacks the insulation surface by destroying crosslinks in the polymeric compound, and the combined effect of chemical and thermal stress consequently results in the degradation of the insulation material and is believed to causes mechanical failure on the entire insulator. However, through the experimental investigations [14], have rejected the possibility of thermal heating that leads to material degradation. The highest surface temperature recorded during the corona test was far less than the threshold level of 200-300°C required to initiate degradation.

### 2.3.2 Water Droplet Discharge

Under wetting conditions on outdoor insulation the high relative permittivity of water droplet gives rise to localized distortions in the electric field above the corona onset level. The electric field enhancement factor varies with the size and number of droplets but for single droplets the threshold field for corona is between 3 and 3.5 kV/cm. The corona discharge phenomena from water droplets have been investigated in recent publications [15]. They studied the corona onset level and found that the typical electric field strength threshold value for the onset of water droplet corona lies between 5 to 7 kV/cm.

Water droplet corona has been shown to age polymeric insulation and the reduction of the surface electric field in the design of outdoor insulation is imperative for long life [16]. **Figure 2.5** provides examples of equipotential and field distribution profile indicating the high field region. The water droplets play several roles in the pollution flashover and aging of polymeric insulators:

i) The water droplets increase the electric field strength at the insulator surface because of their high permittivity and conductivity.
ii) The surface corona discharges from water droplets age the weather shed material of the insulator.
iii) The corona discharge destroys the hydrophobicity locally causing the spread of water, and adjacent water droplets to coalesce.
Insulator Flashover

The deposition of pollution on the insulator surface produces an electrolytic layer when it is wet by dew, rain or fog. It then allows leakage current to flow on the surface, which causes dry bands in the high current density region. The voltage across the insulator is then applied across the dry bands causing high electric stress which is sufficient to ionise the air and a discharge in the gas is then established. It is mostly self-limiting, but if surface resistance is sufficiently low, discharges will be
self-sustaining and overtime can propagate, and bridge terminals thus causing flashover. This is a slow process [17].

A sudden flashover event is caused by a switching surge or lightning surge and contamination and can result in insulator failure. Contamination increases surface conductivity which causes flashover to persist after the arc has been initially cleared, allowing subsequent flashover to occur on reclosure. It is believed that failure due to such flashover is very much dependent on the duration of the fault current [18]. Figure 2.6 shows the effect of flashover along the polymeric insulator.

![Figure 2.6: Polymeric insulator damage](image)

### 2.3.4 Dry Band Discharge

One of the critical environmental challenges for the optimum performance and life of a composite insulator is when contamination deposits, in the presence of moisture, settle on the surface of the insulator. Dry band discharges normally occur when water has the opportunity to wet the polymeric surface, thus allowing the flow of leakage current along the conductive path. The resulting resistive heating leads to surface water evaporation and drying of the wet insulator surface. Dry bands are likely to appear on the smallest circumferential region where the current density and dissipated power are greatest [19]. Large potential difference sustained between the electrode-like filaments combined with the highly non-uniform electric field can result in intense electric discharges to bridge the dry region.
Dry band arcing is a phenomenon that occurs when the leakage current flowing on the surface of an insulator produces heat which causes the moist conductive film to evaporate. As the film dries, the leakage current then flows between the moist ‘conductive bands’ over the ‘dry bands’. The current continues to flow until the resistance of the dry band gets large enough to interrupt the current flow. If the current flow is allowed to continue for an extended time across this same dry band surface on a polymer insulator, it could prematurely age the elastomeric material leading to tracking and failure [20]. Figure 2.7 show a dry band is formed at the surface of the polymeric insulator.

![Figure 2.7: Pollution surface on polymeric outdoor insulator](image)

### 2.4 Environmental Stress

Most environmental stress is cause by weather and by the surrounding environment, such as industry, sea or dust in rural area. The environmental stresses affect both mechanical and electrical performance. Environment effects can reduce insulation properties of insulators, in particular the polymeric insulator. High temperatures increase the electrical conductivity, and UV sunlight causes a certain change in chemical bonds of the polymer because of crosslinking reaction [20]. Moisture will obviously decrease the surface insulation resistance. This condition is exacerbated by the presence of surface contamination due to pollution.
The continuous depositing of the particle increases the thickness of deposits. However, the natural cleaning effect of wind, which blows loose particles away and limits the growth of deposits. Occasionally, rain washes are one part of the pollution away. By the cleaning effects of rain, deposits are lighter on the top of the insulator and heavier on the bottom. The development of a continuous pollution layer is compounded by chemical changes.

Environmental effects on the polymer insulator provide a substantial area for researchers to investigate [21]. The rate at which new polymer materials have been used has outstripped the work being done on ageing rates of such materials. In coastal environments and in tropical environments, salt is the most common contaminant. Salt will act as an electrolyte under humid conditions. Electrical conduction on the surface layer can cause discharges to occur on the surface and cause surface degradation. This condition weakens the surface insulation significantly and may lead to breakdown/failure.

2.5 Mechanical Stress

An important function of the line insulator is to transfer mechanical support from the transmission tower to hold the heavy overhead conductor well in the air. Mechanical stress include tension loads (suspension and tension strings), Compressive loads (braced post insulators) and cantilever loads (post insulators) [22]. For example, when suspension insulators installed on transmission towers, the constant axial stress by the loading of bundle cables in which the weight could reach up to several tonnes. Over the time, continuous strain could weaken the joint between the core and the terminal, which will eventually result in the mechanical failure of the polymeric insulators.

Extra mechanical stress may develop when strong winds move the line, causing vibration. The consequent vibrations can cause the formation at the joint interface between the core and the metal flanges. In some cold countries, ice accretion on weather sheds housing could generate additional loading stress on the polymeric insulator. In hot desert regions, the average temperature can easily reach 40˚C during the day, and drop below 10˚C at night. This considerable change in
ambient temperature results in thermal expansion and shrinkage that can loosen the connection at the end fitting, affecting the mechanical strength of the insulators.

2.6 Electric Field Distribution

The electric field distribution within and around high voltage insulators is a very important aspect of the design of the insulators. An electric field surrounds electrically charged particles and time-varying magnetic fields. The electric field depicts the surrounding force of an electrically charged particle exerted on other electrically charged objects [23]. Determination of field strength and its distribution on insulator surface is important to study electrical discharge activities. Leakage current along the wet pollution film is largely driven by the tangential electric field. The flow of current causes surface heating, leading to the formation of dry bands [24]. The electric field (V/m) at a point is defined as the force (N) per unit charge (C) on a charge at that point [25]:

\[ E = \frac{F}{q} \quad (2.1) \]

From this definition and Coulomb's law, it follows that the magnitude of the electric field \( E \) created by a test charge \( Q \) [25]:

\[ E(r) = \frac{Q}{4\pi r^2 \varepsilon_0} \quad (2.2) \]

An electric field is created in an insulating medium if an electric voltage is applied across it. The electrode configuration determines whether the field will be uniform or not. A parallel plate electrode system and a sphere electrode system ensure a uniform electric field. In a uniform field the electric field stress \( E \) is related to the voltage, \( V \) by \( E=V/d \), \( d \) being the electrode separation [26]. Non-uniform and high electric field, combined with other stresses, triggers damaging discharge activities on the insulator surface. Determination of the electric field provides a better understanding of the phenomena associated with surface discharges to avoid such undesirable consequences.
2.7 Non-linear Field Grading Material

The purpose of a non-linear grading material is to reduce the local surface stress, so it does not exceed the breakdown strength in any location. Grading is determined by the relative values of the resistive and capacitive current densities to control electrical stress on many high voltage applications.

2.7.1 Resistive Grading

Resistive grading material controls field distribution by means of the bulk conductivity of the material, and the current is predominantly resistive. Sufficient amounts of conductive elements such as carbon black filler are added into the polymer matrix to establish a path for current conduction within the material. Electroceramics particles such as ZnO microvaristor and Silica Carbide can be used as functional filler in polymeric compound as a non-linear grading compound [27,28]. Figure 2.8 shows example of resistivity of the grading compound used for this study. In the linear region in which the resistivity is high, the material operates as an insulator. When the field reaches the threshold level of about 1.0kV/cm, it starts to conduct.

Figure 2.8: Resistive of the grading compound
2.7.2 Capacitive Grading

In capacitive grading, the electric field is regulated by a material that has a high dielectric constant and, hence, the displacement current is predominantly capacitive. Equipotential are redistributed when passing through different dielectric materials having different permittivity values. The lines become farther apart and this reshapes field distributions along the insulation surface. In addition, high permittivity materials result in lower surface impedance, which could further reduce field stress [29]. Capacitive grading techniques can also be realised by using appropriate geometrical shapes of conducting or high permittivity material to alleviate field stress. For example, the use of rounded edges for end fitting design improves field distribution on the polymeric surface. The integration of the corona ring structure made of conductive material helps to grade concentrated equipotential at the high voltage and ground terminals.

2.8 Zinc Oxide Microvaristor

Zinc Oxide are widely used as surge arresters and device protectors because of their nonlinear properties. Zinc Oxide Varistor are ceramic semiconductor devices with highly non-linear current-voltage characteristics and with an extremely good energy capability. Zinc Oxide Varistors consist mainly of zinc oxide (about 90% by weight) and small amount of other metal oxides such as bismuth, cobalt, antimony and manganese-oxide [30]. By doping with other elements to replace either the zinc or the oxygen, the conductivity can be varied over a very wide range.

According [31], composite insulator having a core fully coated with thin microvaristor layer was modelled, and the result of electric field distribution along the insulator surface was improved. Microvaristor filled polymers show non-linear current voltage characteristics and can be used for over-voltage protection purposes, for example to protect sensitive electronics from electrostatic discharges. Non-linear materials composed of a polymer matrix filled with conductive and/or semi-conductive and/or insulating particles are known and used for over-stress protection of electronic chips.
2.9 Field Optimisation Techniques

These days, electric power equipment tends to be compact and be operated under higher voltage. In the equipment, the solid insulators play the most critical role for electrical insulation. It is important to control the electric field distribution around the insulators to improve the insulation performance of the insulators,

2.9.1 Corona Ring

Generally, the corona ring is level with the first or second shed. There is no fixed standard to specify the size of the grading ring required for a particular voltage level. The positioning of the corona ring along the length of the insulator will influence the degree to which the electric field value will be reduced at the insulator surface. The trends indicate in [32], the field for the insulator used decreases in some parts and increases in other parts of the insulation distance as the ring position is increased further above its normal position. The key is to find the ring height which minimizes the maximum field. For the insulator used, the optimum height was 40 mm above the normal position. It has been suggested in [33] that one corona ring on the high voltage end is sufficient for a power system at 220 kV. However, additional rings at both insulator ends are required for systems that operate at 400 kV or higher [34]. Figure 2.9 shows the impact the ring has in reducing the electric field at the live end. It can be seen that the field can be significantly reduced close to the fitting when a ring is used.

Figure 2.9: Effect of corona ring on live end electric field [33]
2.9.2 End Fittings Design

The design of polymer insulators must be sufficiently large to avoid corona discharges, otherwise a shielding or corona ring (grading ring) needs to be installed on the insulator. To assess the need for a secondary corona ring, many researchers have investigated end-fittings of polymer insulators by voltage distribution simulations and electrical tests. End fitting design changes the magnitude of the electric field on the surface of insulators. Large end fittings with rounded edges tend to reduce the peak magnitude of the E-field values closer to the end fittings [35]. Examples of electric field distributions for different end fitting designs are shown in Figure 2.10.

Design (a): End fitting close to the last shed
Design (b): End fitting at a short distance from the last shed
Design (c): End fitting partly covered by silicone rubber

Figure 2.10: Electric field magnitude distribution surrounding three different designs of end-fitting
2.9.2 Weather Shed Insulation

Other than the corona ring and fitting design, the geometrical shape of polymeric weather shed housing is equally important in controlling field distribution on the insulation surface. The weathersheds provide the required leakage distance and currently are supplied with different materials, shapes, diameters, thicknesses and spacing. In the compounding of the weathersheds, 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. Result from study by [36] have reported a significant field reduction, from 1260 V/mm down to 390 V/mm when increasing the distance of the first shed from the electrodes from 10 mm to 35 mm. This optimised distance will, however, vary depending on the insulator profile and configuration in practice.
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains in detail the materials, procedures and data gathering methods that involve in this project. Many researchers have employed numerical simulation techniques using commercially available electromagnetic software which appears to be more practical and cost-effective, avoiding expensive and complex laboratory experiments that are often difficult to carry out.

In this chapter, computer simulation based on the Finite Element Method is used to compute potential and electric field distributions along the creepage path of weather sheds housing. The insulator model is developed and simulated under dry-clean and wet-polluted surface conditions. The insulator that was considered in this investigation, and for the entire research programme, is a standard 11 kV polymeric outdoor insulator, shown in Figure 3.1.

![Figure 3.1: Dimension of 11kV polymeric insulator under consideration](image-url)
REFERENCES


[7]. ‘Conductor and Insulators, Chapter 4’,


[16]. ‘Electric Field Computation’,
http://www.power.uwaterloo.ca/HVEL/Research_Electricfield.htm


Retrieved on 1 December 2013.


