OPTIMISATION OF INSULATOR DESIGN FOR IMPROVED ELECTRIC FIELD PERFORMANCE

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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

DEDICATION

To my family, parents and friends

for their endless love and support

ACKNOWLEDGEMENT

Alhamdulillah, my greatest thank to Allah, The God Almighty. Whose presence and blessings bring meaning, peace and hope to my life. Also with His permissions, I am able to finish my master project.

First and foremost, I wish to express my sincerest gratitude to my advisor, Dr Rahisham Bin Abd. Rahman who constantly guided, inspired and supported me throughout my studies. His invaluable guidance, insightful discussions and willingness to sacrifice his time has driven me to complete this final project. I would also like to thank the panels, Dr Muhammad Saufi Bin Kamarudin, Dr Erwan Bin Sulaiman and Dr Dur Muhammad Soomro for their kindness in participating and for all their constructive advice.

My deepest love and gratitude goes to my wife, Nuratul Farihah and my kid, El Fayyadh Anaqi who have shared the excitements and difficulties in my life with me. I am grateful for their understanding, invaluable support and encouragement throughout my period of studies. I would like to extend my warmest thanks to my parents, Mr Ahmad and Mrs Azizah for the education and love I received from them throughout my life. Their continuous inspiration and motivation has encouraged me to pursue my utmost goal. My thankful also goes to Mr Abd Thalib and Mrs Siti Halijah for their continuous support.

My appreciation goes to my fellow friends who have been together for the two and a half year in completing the course. Last but not least, thank you to everyone who has been involved directly or indirectly in the completion of this dissertation.

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 stresss 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 9.643×10^{4}V/m from 6.015×10^{5}V/m at the beginning.

ABSTRAK

Penebat adalah sebahagian daripada komponen yang penting dalam sistem kuasa. Penebat polimer dapat memberikan prestasi yang lebih baik. Populariti penebat polimer meningkat disebabkan berbagai-bagai kelebihan yang dimiliki oleh penebat polimer. Antara kelebihan yang dimiliki penabat polimer adalah lebih ringan, mudah untuk dipasang dan melibatkan kos yang lebih murah dan jimat. Disebalik berbagai kelebihan dimiliki, terdapat juga masalah berkenaan penebat polimer ini. Prestasi penebat polimer bergantung kepada pembahagian medan elektrik di sepanjangnya. Tesis ini dihasilkan untuk menganalisis prestasi penebat polimer melalui agihan medan elektriknya. Dengan meningkatkan prestasi agihan medan elektrik, prestasi jangka panjang penebat polimer dapat ditingkatkan lagi. Perisian COMSOL Multiphysics digunakan dalam mengkaji kekuatan medan elektrik di sepanjang penebat polimer. Model penebat polimer dengan voltan 11kV dibangunkan untuk disimulasi. Bagi tujuan mengoptimumkan medan elektrik, tiga kaedah yang berlainan telah digunakan untuk mengkaji agihan medan elektrik. Teknik-teknik tersebut adalah: i) konfigurasi berlainan pada rekaan pemasangan besi hujung, ii) penambahbaikan pada rekabentuk bahagian laying cuaca penebat dan iii) pemasangan jejari korona pada lokasi yang bersesuaian. Daripada penilaian yang dibuat, nilai setiap teknik yang dicadangkan mempunyai kesan terhadap agihan medan elektrik. Hasil daripada simulasi yang dibuat, nilai maksimum bagi tekanan medan elektrik didapati berada pada bahagian pemasangan besi hujung. Simulasi yang dibuat ke atas model penabat polimer menunjukkan nilai maksimum medan elektrik berada dalam kawasan berhampiran pemasangan besi hujung penebat. Selepas melaui beberapa teknik untuk mengoptimumkan prestasti medan elektrik penabat polimer, satu profil cadangan telah berjaya dihasilkan dengan prestasi medan elektrik berjaya dikurangkan sebanyak 83.97% kepada $9.643 x 10^5$V/m daripada $6.015 x 10^5$V/m pada peringkat permulaan.

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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	-	Milimetre
cm	-	Centimetre
m	-	Metre
E	-	Electric Field
F	-	Force
Q	-	Charge
ε_r	-	Realtive Permittivity
σ	-	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.

Figure 1.1 Polymeric outdoor insulators

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 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.

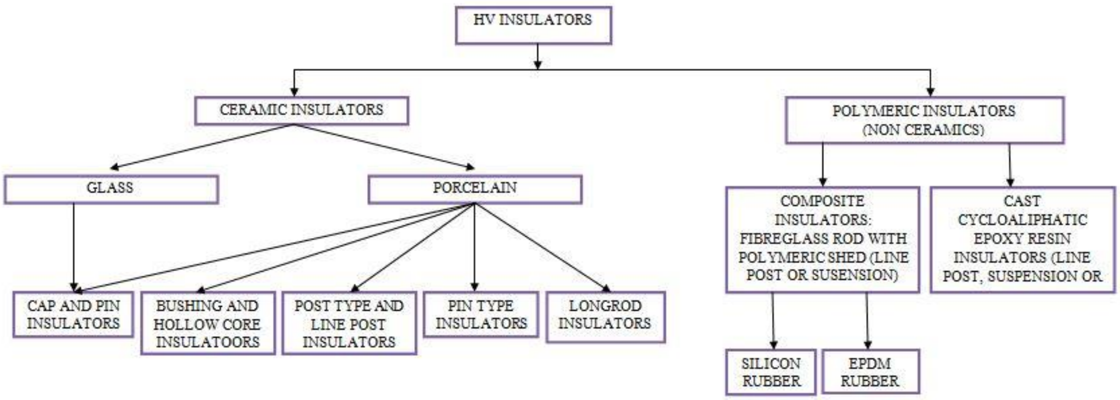

Figure 2.1 Classification of power line insulators

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.

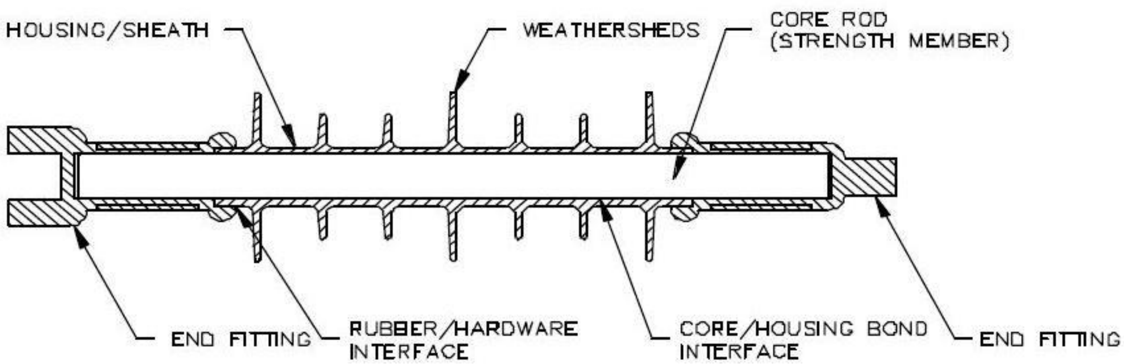

Figure 2.2 Cross section of composite insulator

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 Coulomb 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:

$$E = \frac{F}{q} \qquad \text{Equation} \quad 1$$

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.

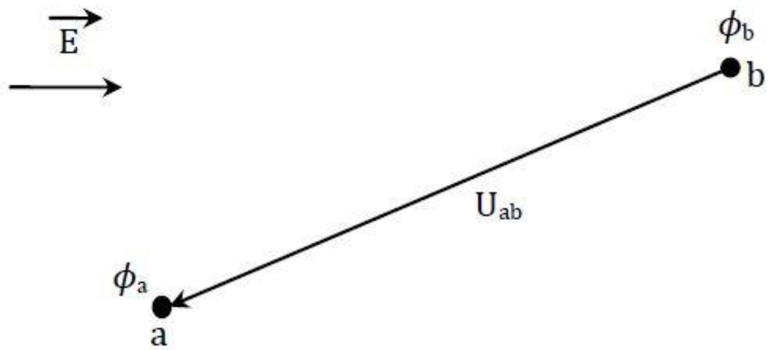

Figure 2.3 Illustration of electric field

Figure 2.3 shows the potential difference U_{ab} between point *a* and point *b* having scalar potential ϕ_a and ϕ_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.**

$$U_{ab} = -\int_b^a \left|\vec{E}\right| dx = \left(\phi_a - \phi_b\right) \qquad \text{Equation 2}$$

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.

$$\left.\frac{dU_{ab}}{dx}\right|_{\max} = -\left|\vec{E}\right|_{\max} \qquad \text{Equation 3}$$

A physical interpretation of the electric field intensity finding process from the scalar potential, ϕ 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:

$$\vec{E} = -\nabla \phi \qquad \text{Equation 4}$$

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