ELECTRIC FIELD STUDY OF SILICON RUBBER INSULATOR USING FINITE ELEMENT METHOD (SLIM)

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ABSTRACT

Silicone rubber provides an alternative to porcelain and glass regarding to high voltage (HV) insulators and it has been widely used by power utilities since 1980's owing to their superior contaminant performances. Failure of outdoor high voltage (HV) insulator often involves the solid air interface insulation. As result, knowledge of the field distribution around high voltage (HV) insulators is very important to determine the electric field stress occurring on the insulator surface, particularly on the air side of the interface. Thus, concerning to this matter, this project would analyze the electric field distribution of energized silicone rubber high voltage (HV) insulator. For comparative purposes, the analysis is based on two conditions, which are silicon rubber insulators with clean surfaces and silicon rubber insulators with contamination layer taking place over its surfaces. In addition, the effect of water droplets on the insulator surface is also included. The electric field distribution computation is accomplished using SLIM software that performs two dimensions finite element method. The finding from this project shows that pollution layer distort the voltage distribution along the insulator surface while different pollution layer material and variation in zone of incidence would contribute different profile of electric field. Existence of water droplets would create field enhancement at the interface of the water droplet, air and silicon rubber material. Also, the intensification field created by water droplet is depending on the droplets size, number of droplets and the proximity of water droplets to each other.

ABSTRAK

Getah silikon memberikan alternatif kepada porselin serta kaca yang digunakan sebagai penebat voltan tinggi dan ia telah digunakan secara meluas oleh pembekal kuasa semenjak 1980-an memandangkan prestasinya yang baik semasa kehadiran bahan pencemar. Kegagalan penebat voltan tingi di kawasan terbuka pada kebiasaannya melibatkan bahagian di sempadan penebatan antara udara dan bahan penebat. Sehubungan dengan itu, informasi mengenai penyebaran medan disekitar penebat voltan tinggi adalah amat penting bagi menentukan tekanan medan elektrik yang terbentuk di atas permukaan penebat, terutamanya di bahagian udara pada sempadan antara penebat dan udara. Oleh yang demikian, merujuk kepada perkara tersebut, projek ini akan menganalisa penyebaran medan elektrik bagi penebat getah silikon voltan tinggi. Bagi tujuan perbandingan, analisa yang dilakukan adalah berdasarkan kepad dua situasi, getah silikon yang mempunyai permukaan yang bersih dan getah silikon yang mempunyai lapisan bahan pencemar di sepanjang bahagian permukaannya. Selain daripada itu, kesan titisan air yang terdapat di atas permukaan penebat juga dirangkumkan. Pengiraan bagi sebaran medan elektrik pada permukaan penebat disempurnakan menggunakan perisian SLIM yang melaksanakan kaedah elemen tak terhinnga dua dimensi. Hasil daripada projek ini menunjukkan bahawa kehadiran lapisan pencemar memesongkan pengagihan voltan di sepanjang permukaan penebat sementara bahan pencemat yang berbeza serta variasi kepad zon yang terlibat akan menyumbang kepada profil medan elektrik yang berbeza. Kehadiran titisan air akan menghasilkan pertambahan medan di sempadan antara air, udara dan bahan getah silikon. Disamping itu, pertambahan tekanan medan yang dibentuk oleh titisan air adalah bergantung kepada saiz titisan, bilangan titisan dan jarak di antara satu titisan dengan titisan yang lain.

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LIST OF SYMBOLS / ABBREVIATIONS

D	-Distortion factor.
H	-Size of the element.
R	-Diameter of the largest circle in the element.
V	-Volt
m	-Meter
h_i	-Axial height
r_e	-Electrode radius
r_{ec}	-Electrode corner radius
r_i	-Core radius
r_{ic}	-Inner corner radius (the radius of curve fitting between shed and sheath)
r_o	-Shed radius
r_{oc}	-Outer corner radius (the radius of curve fitting between the upper and bottom shed)
E_{max}	-Maximum field at the surface
θ	-Shed slope angle (the slope angle of the upper shed)
ε	-Permittivity
^{o}	-Degree

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CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter would describe the overall overview of the project which includes the project objective, scope, project schedule and the outline of the thesis.

1.1 The Objective of the Project

The main objective of this project is to carry out a study on the electric field distribution of energized silicon rubber insulator under clean and contaminated condition using finite element method which is simulated by SLIM software.

1.2 The Scope of the Project

In order to limit this project under certain degree, the objectives of this project are assisted by certain scopes. Those scopes are as listed below:

a) To appreciate the application of two dimensional linear finite element numerical method in electric field calculation.

b) To observe and investigate the properties of silicon rubber.

c) To implement the finite element method technique using SLIM.

d) To model the contamination layer on the surface of silicon rubber insulator.

e) To study the electric field pattern of silicon rubber insulator under clean and contaminated condition of energized silicon rubber insulator.

1.3 The Project Schedule

This project was accomplished in two consecutive phases which are Project I and Project II where Project II is the continuation from Project I. The theoretical part is being covered mostly within the Project I timeframe while Project II depict the simulation analysis of the project. Those project schedules are given separately by Appendix A.

1.4 Thesis Outline

This thesis is being divided into six consecutive chapters where each chapter review different issues regarding to the project objectives. Chapter 1 covers the introductory section of the project while Chapter 2 and Chapter 3 described the literature review and theoretical background that related to finite element method and silicon rubber respectively. The following chapter is Chapter 4 where this chapter provides the explanation on project methodology used throughout the operation of the project. Simulation results and analysis is explained individually in Chapter 5 and the last chapter, which is Chapter 6, considers the future recommendations in extending the project into a better prospect.

CHAPTER 2

FINITE ELEMENT METHOD

2.0 Introduction

There are several methods for solving partial differential equation such as Laplaces and Poisson equation. The most widely used methods are Finite Difference Method (FDM), Finite Element Method (FEM), Boundary Element Method (BEM) and Charge Simulation Method (CSM). In contrast to other methods, the Finite Element Method (FEM) takes into accounts for the nonhomogeneity of the solution region. Also, the systematic generality of the methods makes it a versatile tool for a wide range of problems. The following topics in this chapter would describe briefly on the concept of Finite Element Method (FEM).

2.1 Historical Background of Finite Element Method

The ideas that gave birth to the Finite Element Method (FEM) evolved gradually from the independent contributions of many people in the fields of engineering, applied mathematics, and physics. Finite Element Analysis (FEA) was first termed by R.W. Clough in a paper published in 1960, but the roots of the theory relates back to the Ritz method of numerical analysis, first introduced in 1909.

The origins of the finite element method can be traced to two sources. A mathematician call Courant proposed the theoretical basis of the Finite Element Method (FEM), in the 1940s but his work was not followed up at that time. Later, practical Finite Element Analysis (FEA) was developed independently in the 1950s by Boeing engineers investigating structural dynamics problems in delta wing aircraft.

Hrenikoff (1941) found out that the elastic behavior of a physically continuous plate would be similar, under certain loading conditions, to a framework of physically separate one-dimensional rods and beams, connected together as discrete points. The problem then handled for trusses and frameworks with similar computational methods.

Courant`s (1943) paper is a classic for finite element methods. To solve the torsion problem in elasticity, he defined piecewise linear polynomials over a triangularized region. Schoenberg's (1946) paper gave birth to the theory of splines, recommending the use of piecewise polynomials for approximation and interpolation. Synge (1957) used piecewise linear functions defined over triangularized region with a Reitz variational procedure.

With the introduction of high-speed digital computers, Langefors (1952) and Argyris (1954) took the framework analysis procedures and reformulated them into a matrix format suited for efficient automatic computation. McMahon (1953) solved a three-dimensional electrostatic problem using tetrahedral elements and linear trial functions. Polya (1954), Hersh (1955), and Weinberger (1956) used ideas similar to Courant's to estimate bounds for eigenvalues.

Turner *et al.* (1956) modeled the odd-shaped wing panels of high-speed aircraft as an assemblage of smaller panels of simple triangular shape. This was a breakthrough as it made it possible to model two- or three-dimensional structures as assemblages of similar two- or three-dimensional pieces rather than of one-dimensional bars. Greenstadt (1959) divided a domain into cells, assigned a different function to each cell, and applied a variational principle. White (1962) and Friedrichs (1962) used triangular elements to develop difference equations from variational principles. The name of the method, "*finite elements*", first appeared in Clough's (1960) paper. Melosh (1963), Besseling (1963), Jones(1964), and Fraeijs de Veubeke (1964) showed that the FEM could be identified as a form of the Ritz variational method using piecewise-defined trial functions. Zienkiewicz & Cheung (1965) showed that FEM is applicable to all field problems that could be placed in variational form.

By the early 70's, Finite Element Analysis (FEA) was limited to expensive mainframe computers generally owned by the aeronautics, automotive, defense, and nuclear industries. Since the rapid decline in the cost of computers and the phenomenal increase in computing power, Finite Element Analysis (FEA) has been developed to an incredible precision. Present day supercomputers are now able to produce accurate results for all kinds of parameters.

With the advent of micro-computers (personal computer and workstations) in the 1980's, however, the methods have become more widely used. During that time, a number of general purposes software packages have been developed. It is now possible for engineers in virtually every industry to take advantage of this powerful tool.

In order to better conform to curve boundaries, curved finite elements have been widely used in recent years (Ertürk, 1995). Such elements are called the isoparametric elements (Zienkiewicz, 1971). Irregular computational grids have become increasingly popular for a wide variety of numerical modeling applications as they allow points to be situated on curved boundaries of irregularly shaped domains.

2.2 Finite Element Method (FEM) Application in Electrical Engineering

Numerical techniques have long been recognized as practical and accurate methods of field computation to aid in electrical design. Precursors to the Finite Element Method (FEM) are Finite Differences and Integral Equation techniques. Although all these methods have been used and continue to be used either directly or in combination with others for design, Finite Element Method (FEM) has emerged as appropriate techniques for low frequency applications. Recent literature also shows several applications in radio frequency (RF) scattering and propagation.

Since the late 1960`s, when first applications of the so called "triangular finite differences" were made by A. Winslow to accelerator magnets, and the first real finite element solution of the scalar Helmholz equation was presented by P. Silvester at the Alta Frequenza Conference, Finite Element Method (FEM) have advanced a great deal. Two-dimensional nonlinear magnetostatic techniques for electrical machines were first presented in the early seventies [1, 2, 3, 4].

These were followed by linear eddy current methods for telluric and magneto telluric geophysical prospecting and for evaluating eddy current losses in metallic slabs [5]. Various other applications of the steady state and transient eddy current methods soon followed [6], which included rotating machinery and power conditioners. Further applications included electronically commutated motors, electric furnaces and power lines. Coupled eddy current problems were modeled by finite elements [7]. Several papers have appeared on finite element modeling of solid state devices as shown in references. Applications in the high frequency area for radio frequency (RF) scattering and propagation problems have also been documented in the literature [8].

Alongside the above developments for practical engineering applications, techniques development had also taken place. To name a few: vector and scalar potential modeling, reduced scalar potential modeling with sources in the entire volume or only in permeable media, surface formulation for reduced scalar potentials; open boundary problems [9], 3D vector and scalar techniques for magneto static problem and 3D eddy current solutions [10]. With the increase in size of the geometry and its detailed modeling, the number of unknowns resulting from Finite Element modeling also increased by orders of magnitude. These have necessitated developments in equation solvers such as direct and iterative solvers, accelerated convergence methods, absorbing boundary conditions for RF problems to reduce problem size and others. Advances in computer aided engineering methods (CAE) include grid generation techniques, post processing methods and displays, and user interfaces for facilitating data input and file, transfers. Another important development has been in the use of numerical integration methods for matrix assembly, and the use of isoparametric and sub parametric elements.

2.3 Definition of Finite Element Methods (FEM)

The Finite Element Method (FEM) is a numerical analysis technique used by engineers, scientists, and mathematicians to obtain solutions to the differential equations that describe, or approximately describe a wide variety of physical and non-physical problems. Physical problems range in diversity from solid, fluid and soil mechanics, to electromagnetism or dynamics.

The underlying premise of the method states that a complicated domain can be sub-divided into series of smaller regions in which the differential equations are approximately solved. By assembling the set of equations for each region, the behavior over the entire problem domain determined.

In other words, using the Finite Element Method (FEM), the solution domain is discretized into smaller regions called elements, and the solution is determined in terms of discrete values of some primary field variables φ (e.g. displacements in x, y z directions) at the nodes. The number of unknown primary field variables at a node is the degree of freedom at that node. For example, the discretized domain comprised of triangular shaped elements is shown below in Figure 2.1. In this example each node has one degree of freedom.

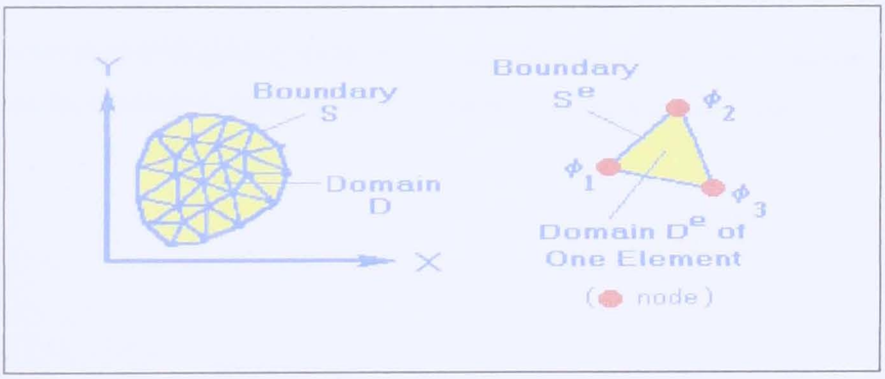

Figure 2.1 Typical finite element subdivisions of an irregular domain and typical triangular element

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