ELECTRIC FIELD DISTRIBUTION IN NANOCOMPOSITES CONTAINING ONE-DIMENSIONAL NANOFILLER

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This project report is dedicated to,

my beloved wife, Dyg Norkhairunnisa binti Abg Zaidel ,

my beloved son, Muhammad Qaiser Harraz bin Mohd Ridhuan

my beloved parent, Mohd Sharip bin Abd Talib and Norma Ab Rahman

my beloved parent-in-law, Abg Zaidel bin Abg Pauzi and Siti Aishah Abdullah @Alice Bong Mun Jin,

and

all my siblings and in-laws

for their patience, love, cares, encouragements and endless full support over the entire period of my master study.

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ABSTRACT

The need of having novel insulation systems that are capable to operate in the long term is arising due to their promising features that can significantly improve the electrical, mechanical, thermal and chemical properties in high voltage equipment. In this, polymers show signs of improvement in dielectric properties with the addition of nano-filled materials. The unique dielectric properties of nanocomposites as insulators are closely related to the presence of the interphase, i.e., an interaction zone between the nanoparticle and the polymer matrix. In this study, one-dimensional (1D) nanofillers and their interphases were modeled and analyzed using the Finite Element Method Magnetics (FEMM) 4.2 software. Two possible models of the interphase structure surrounding a nanoparticle were analyzed, i.e., one with rectangular-shaped interphase and the other with circularly-shaped interphase. While the polymer and the nanoparticle were assumed to have fixed permittivity values, different values of the thickness and the permittivity of the nanofiller interphase were assigned to determine their effects on the electric field distribution within nanocomposites. The results showed that the presence of the interphase affected the electric field intensity of the nanocomposites. As adjacent nanoparticles displaced further away from each other, the electric field intensity between the nanoparticles reduced. An attempt was made to relate the presence of the interphase with the breakdown behavior of nanocomposites.

ABSTRAK

Keperluan untuk sistem penebatan baru yang mampu beroperasi dalam jangka masa yang panjang semakin meningkat disebabkan ciri-ciri mereka yang menjanjikan dalam aspek elektrikal, mekanikal, haba dan kimia untuk digunakan dalam peralatan voltan tinggi. Dalam hal ini, polimer menunjukkan tanda-tanda peningkatan dalam sifat penebatan elektrik dengan penambahan bahan nano. Sifat unik penebat elektrik komposit nano berkait rapat dengan kehadiran interfasa, iaitu lapisan interaksi antara partikel nano dan matriks polimer. Dalam kajian ini, partikel nano satu dimensi (1D) dan interfasanya telah dimodelkan dan dianalisa dengan menggunakan perisian Finite Element Method Magnetics (FEMM) 4.2. Dua model struktur interfasa sekitar partikel nano telah dianalisis, iaitu, yang pertama dengan interfasa berbentuk segi empat tepat dan yang kedua dengan interfasa berbentuk bulatan. Nilai-nilai permittiviti polimer dan partikel nano ditetapkan, manakala nilai-nilai ketebalan dan permittiviti interfasa partikel nano dipelbagaikan untuk menentukan kesannya terhadap pengagihan medan elektrik dalam komposit nano. Hasil kajian menunjukkan bahawa kehadiran interfasa menjejaskan keamatan medan elektrik komposit nano. Jika partikel nano bersebelahan berada lebih jauh antara satu sama lain, keamatan medan elektrik antara partikel nano berkurang. Percubaan telah dibuat untuk mengaitkan kehadiran interfasa dengan sifat kekuatan medan elektrik komposit nano.

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LIST OF ABBREVIATIONS

PD	-	Partial Discharge
DC	-	Direct Current
1-D	-	One-dimensional
2-D	-	Two-dimensional
FEMM 4.2	-	Finite Element Magnetics Method 4.2
MNT	-	Montrimontrille nanoclays
PE	-	Polyethylene
TiO_2	-	Titanium Dioxide
SiO_2	-	Silica Dioxide
PCNs	-	Polymer Nanoclay Nanocomposites
3-D	-	Three-dimensional
kHz	-	Kilohertz
mHz	-	Milihertz
Hz	-	Hertz
XLPE	-	Cross-linked Polyethylene
EVA	-	Ethylene-viny-acetate
nm	-	Mirometre
μm	-	Nanometre
QDC	-	Quasi Direct Current
Nano-Ag	-	Nano silver powder

LIST OF SYMBOLS

wt%	-	Weight percentage
V_b	-	Breakdown voltage
E_b	-	Breakdown strenght
ε_o	-	Permittivity of vacuum
ε_r	-	Dielectric constant
ε'	-	Real permittivity
ε''	-	Imaginary permittivity
°C	-	Degree Celsius
kV m^{-1}	-	Kilo Volts per metre
kV mm^{-1}	-	Kilo Volts per milimetre

CHAPTER 1

INTRODUCTION

1.1 Polymer Nanocomposites

Polymer nanocomposites are defined as a small amount of inorganic particles with the range of 1-100 hundred in nanometer size (nm), homogenously dispersed in a polymer matrix [1, 2]. The method to produce polymer nanocomposites plays an important role in the dispersion of the nanoparticles. There are four different methods in producing the polymer nanocomposites, which includes, in situ polymerization, melt blending, solvent method and sol-gel method [1, 3]. However, the most common methods used for manufacturing purposes are in situ polymerization and melt bending. The addition of only a few percentage of the nanoparticles in the polymer matrix system has given a very great impact to the polymer nanocomposites in terms of electrical, mechanical, physical and chemical properties [1, 4]. This phenomenon of nanotechnology has provided a path of improvement for electrical insulation systems.

1.1.1 One-dimensional (1D) Nanofiller

There are many types of nanofillers (or nanoparticles) available in the market that can be used to blend with polymer matrix to improve the materials properties. However, in order to produce the desirable nanocomposites, suitable nanofiller property and nanofiller concentration in the polymer matrix need to be chosen and it is depends on the perfect combination. In the nanofiller, dispersion of platelet (1-dimensional) nanofillers in the polymer matrix plays an important role on the materials properties as illustrated in Figure 1.1. These types of nanofillers are offering low-cost material and the gentlest nanofiller to disperse in the polymer matrix [5]. Therefore, it is suitable for large range applications such as in nanocomposites application.

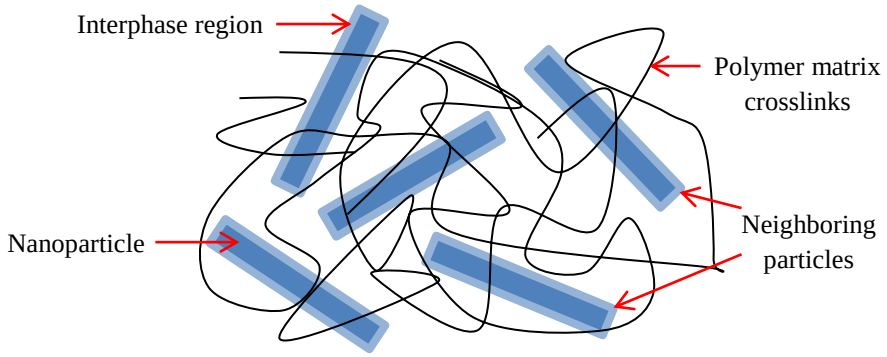

Figure 1.1 Platelets nanoparticle dispersion in the polymer matrix

1.2 Background of Study

The most important thing in the engineering field is the proper selection of materials to create products that can function optimally for long time service. The insulation system plays an important role in electrical engineering in providing a medium without allowing current through itself. Thus, in high voltage engineering, effective operation of high voltage equipment is mostly dependent on the correct

choice of electrical insulation for medium, high and extra high voltage level operation. However, most of the electrical insulators are made of glass, porcelain and ceramic. These types of insulators frequently failed to operate under large electrical fields due to electrical properties breakdown. Furthermore, the use of these types of insulators are no longer profitable as the glass, porcelain and ceramics density are too large, long, fragile and have high loss which will lead to higher cost of construction and maintenance for electric insulation application [6].

Therefore, many attempts have been done to explore other new alternatives as insulation materials in order to attain better insulation properties. Polymer materials exhibit good property as a new insulating material compared to the traditional insulators as aforementioned before. Polymers have several advantages such as lightweight, low cost, flexible and have good resistivity as electrical insulator. Since 1990s, the nanotechnology has provided many applications to produce new component as electrical insulator based on the polymer materials known as polymer nanocomposites [7].

Recently, the research on the polymer nanocomposites using the nanometric sizes of filler materials (nanoparticle) blended with the polymer materials have led to the initiative to develop novel insulation properties [8]. On the other hand, the combination of the polymer materials and the nanoparticles (nano-composite) provides advantages such as improved resistance to degradation, thermal, electrical and mechanical properties compared to micro-composite [9, 10]. The addition of nanoparticles in polymer matrix systems has been recognized to change in particular characteristics in terms of non-electrical and electrical properties. A range of investigations clarifies in improving the dielectric properties such as improving resistive due to partial discharge (PD), DC breakdown strength, high voltage arcing, water treeing and electric insulation properties [1, 8, 11, 12]. Appreciation of nanocomposites with high and good quality is a part of insulation field configuration.

A polymer nanocomposite also exhibits breakdown mechanism, which is the similar mechanism that leads to failure in the pure polymer. As a consequence, similar research claimed that interphases region-a layer between the polymers matrix and the nanofiller are able to increase and improve the material properties. This will

not only contribute to the electrical properties such as increasing the value of the breakdown strength, but may also lead to positive electric field stresses.

In order to clearly understand the role of the interphase in the nanocomposites, it is important to study the influence of the interphase behavior in the nanocomposite materials. In this research the analysis of the effect of interphase on the electric field distribution on electric performance by modeling one-dimensional (1D) nanofiller as nanoparticle filler in polymer matrix is presented.

1.3 Problem Statement

As mentioned earlier in the introduction part, the addition of nanoparticle filler into polymer matrix can contribute to materials properties in term of mechanical and electrical performance. However, most of the work focused on only on polymer matrix and nanoparticle, with the interphase region ignored. The electric field distribution in nanocomposites is depending on the type of nanofillers particle. By introducing interphase region between it, the material properties will be varied, thus affecting the electric field distribution. Consequently, the modeling of polymer containing one-dimensional (1D) nanofillers is challenging as the influence of interphase may alter the electric field distribution.

This study focused on a polymer nanocomposite containing one-dimensional (1D) nanofillers. As the influence of their interphase with finite thickness may alter various properties already figure out in nanocomposite as dielectric focus the electric field distribution. On the other hand, the permittivity effect of the nanofillers interphase can vary the electric field distribution in the nanocomposites. It is believed that the electric field distribution will vary as well as the influence interphase due to the content of its permittivity.

1.4 Objective of the Research

The objectives for this research are:

i. To model nanocomposite systems containing one-dimensional (1D) nanofillers.
ii. To analyze the effect of one-dimensional (1D) nanofillers and their interphases on the electric field distribution of the resulting nanocomposites.

1.5 Scope of the Research

This project focuses on the effect of one-dimensional (1D) nanofillers (e.g. clay) and their interphases on the electric field distribution of the resulting nanocomposites. The modeling of the 1D nanofillers and their interphases will be performed using the Finite Element Method Magnetics (FEMM) 4.2 software. Two different structures of the nanofillers will be introduced in this project; with and without interphases. Then, the permittivity of the nanofiller interphase will be varied in order to examine its effect on the electric field distribution in the resulting nanocomposites.

1.6 Thesis Outline

This thesis is organized into five chapters. In Chapter 1, an overview of the project is given. This includes the project background, problem statement, research objectives, explanation on the research scope and thesis organization.

Chapter 2 focuses on the literature reviews. An introduction and basic concepts of nanocomposites, nanofiller, nanoclays (MNT), breakdown strength, interphase and permittivity are further discussed in this chapter. The theory of the interphase model is introduced. Available models of the interphase region are described in this chapter.

Chapter 3 discusses the methodology of this research project. The research workflows of the whole research are presented in this chapter. The simulation software, Finite Element Magnetics Method (FEMM) 4.2 is utilized to get a clear visualization of overall design. In addition, the analyzed process including the step of modeling using Finite Element Magnetics Method (FEMM) 4.2 is explained.

In Chapter 4, the design and modeling the one-dimensional (1D) nanofillers and their interphases for this research are presented. The design parameters and specifications are also introduced in this chapter. The results of the two possible models of the interphase structure surrounding a nanoparticle were analyzed; one with rectangular-shaped interphase and the other with circularly-shaped interphase are explained in this chapter. The simulation and measurement results for all designed nanocomposites are discussed and analyzed on the parametric study of the interphase including the shape of interphase analysis and thickness of interphase analysis are explained. Elaboration on the effect of neighboring particles results are also discussed in this chapter.

In the last chapter, i.e., Chapter 5, this research work is concluded. In addition, the finding of the project and recommendations for future work are proposed and described in this chapter.

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