ELECTRIC FIELD ANALYSIS FOR POLYMER NANOCOMPOSITE UNDER DIFFERENT FILLER LOADING PARTICLES USING FEMM 4.2 SOFTWARE

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in partial fulfilment of the requirements for the degree of
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2024

DECLARATION

I declare that this thesis entitled "ELECTRIC FIELD ANALYSIS FOR POLYMER NANOCOMPOSITE UNDER DIFFERENT FILLER LOADING PARTICLES USING FEMM 4.2 SOFTWARE is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :

Name : FATIN DAMIEA BINTI NASRUDDIN

Date : 23 JUNE 2024

APPROVAL

I hereby declare that I have checked this report entitled "Electric Field Analysis for Polymer Nanocomposite under Different Filler Loading Particles using FEMM 4.2 Software", and in my opinion, this thesis fulfils the partial requirement to be awarded the degree of Bachelor of Electrical Engineering with Honours

Signature	:	....
Supervisor Name	:	TS. DR. NOR HIDAYAH BINTI RAHIM
Date	:	23 JUNE 2024

DEDICATIONS

Thank you to Allah SWT the most glorified and the most high for making this journey easier with His endless light and for giving me strength to complete this study. To my beloved mother and father who have been there since day one of my bachelor's degree, I would love to express my sincere gratitude for always believing in me and showering me with their endless support, love, and duas. Without both of you, I would be nobody in this world. I hope that achieving this will make you proud. Not to forget my siblings and best friend for always giving me moral support and not leaving my side to push me to be the best version of myself. Ultimately, thankfully to my supervisor Ts. Dr. Nor Hidayah binti Rahim for her guidance and patience throughout this journey.

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To my family, your prayers, love, and support are my pillars of strength, I would not be here if there were no support in terms of mental and also the money you have spent throughout these years.

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ABSTRACT

High-voltage insulators serve a crucial function in high-voltage electrical equipment. In order to have a good role as a dielectric for insulators, it needs to have good performance in electrical, mechanical, and thermal properties. Nanodielectrics have endless potential, making it crucial to conduct in-depth research on the interaction of electric field intensity with filler loading. By adding nano-filled elements, there is potential for improvement of dielectric characteristics in polymers. Using nanoscale filler in composite materials for nanodielectric frameworks, the addition of nanoparticles to the base polymer could influence the electrical properties of the materials. It shows that the tendency of materials to break down could be high due to a higher electric field. Therefore, the polymer nanocomposite upon different filler loading is modeled using Finite Element Method Magnetics (FEMM 4.2) software for this study. The effect of electric field distribution upon different filler loading particles was also determined. The electric field distribution of different filler-loading particles is investigated. This study uses four different filler loadings: 0.5 wt%, 1.5 wt%, 3.0 wt%, and 5.0 wt%. The polymers used were polyethylene (PE) and silicon dioxide (SiO_2) as fillers. The outcome of this project is that different filler loadings, it shows that it could affect the electric field. It is observed from the result that the higher the filler loading, the higher the electric field intensity will be.

ABSTRAK

Penebat voltan tinggi mempunyai fungsi penting dalam peralatan elektrik voltan tinggi. Untuk mempunyai peranan yang baik sebagai dielektrik untuk penebat, ia perlu mempunyai prestasi yang baik dalam sifat elektrik, mekanikal dan haba. Nanodielektrik mempunyai potensi yang tidak berkesudahan, menjadikannya penting untuk menjalankan penyelidikan mendalam tentang interaksi intensiti medan elektrik dengan pemuatan pengisi. Dengan menambah unsur-unsur yang diisi nano, terdapat potensi untuk penambahbaikan ciri-ciri dielektrik dalam polimer. Menggunakan pengisi skala nano dalam bahan komposit untuk rangka kerja nanodielektrik, penambahan zarah nano kepada polimer asas boleh mempengaruhi sifat elektrik bahan. Ia menunjukkan bahawa kecenderungan bahan untuk rosak mungkin tinggi disebabkan oleh medan elektrik yang lebih tinggi. Oleh itu, nanokomposit polimer pada pemuatan pengisi berbeza dimodelkan menggunakan perisian Magnetik Kaedah Elemen Terhingga (FEMM 4.2) untuk kajian ini. Kesan taburan medan elektrik ke atas zarah pemuatan pengisi yang berbeza juga ditentukan. Pengagihan medan elektrik bagi zarah pemuatan pengisi berbeza disiasat. Kajian ini menggunakan empat muatan pengisi yang berbeza: 0.5% berat, 1.5% berat, 3.0% berat, dan 5.0% berat. Polimer yang digunakan ialah polietilena (PE) dan silikon dioksida (SiO2) sebagai pengisi. Hasil daripada projek ini ialah beban pengisi yang berbeza, ia menunjukkan bahawa ia boleh menjejaskan medan elektrik. Ia diperhatikan daripada keputusan bahawa semakin tinggi beban pengisi, semakin tinggi keamatan medan elektrik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

FEMM	-	Finite Element Method Magnetics
PE	-	Polyethylene
wt%	-	weight percentage
dc	-	direct current
SiO_2	-	Silicon Dioxide/Silica
$\lvert E \rvert$	-	Electric Field Intensity
V	-	Voltage
kV	-	kilovolt
nm	-	nanometer

CHAPTER 1

INTRODUCTION

1.1 Background

Electric field analysis was performed using the electrostatics module in FEMM 4.2. Electrostatic analysis is commonly used to simulate electric field distributions in high voltage research, electromagnetics, materials science, experimental and particle physics, and medicine [1]. Polymer nanocomposites are polymers containing nanometer-sized fillers that are homogeneously spread at certain weight percentages (wt%). The terms "nanometric dielectrics", "nano dielectrics", or "dielectric polymer nanocomposites" have been used in the dielectrics field to refer to nano-composites of particular interest due to their dielectric properties. These materials, which are capable of improving the dielectric performance of traditional insulation systems, are envisioned as the potential of high-voltage insulation for electricity. This is due to the existence of a considerably smaller filler (nanometer-sized filler), which results in the presence of a large interphase with a reaction zone that links the nanofiller and the polymer [1].

Recent advancements in nanocomposite characterization and preparation techniques have played a key role in making nano-dielectrics more readily accessible, particularly in the field of electrical insulation. The creation of a nanometric-sized filler particle will culminate in a significant increase in the interface zone created by two dissimilar materials, nanoparticles and polymer matrix. Several investigations have shown that the existence of the interphase affects the macroscopic behavior of composites. Nanotechnology allows for the modification of composite dielectric characteristics by altering the microstructure and filler distribution in the polymer matrix. Nanodielectrics are considered to have a wide range of dielectric characteristics, involving partial discharge, space charge, high energy density storage, and high thermal conductivity [2].

Nanoscale materials are gaining popularity for their ability to change chemical and physical properties from macroscopic to molecular levels, making them suitable for various technological applications. Polymeric materials are being enhanced by building polymer nanocomposite systems for desired engineering applications because of their synergistic effects on the molecular nanoscale of both pure polymers and inorganic materials. Among the many possibilities for inorganics for nanocomposites, there has been special interest in polymer or clay nanocomposites consisting of a polymer and clay, in which the clay has been traditionally used as fillers in polymer compound research and practical applications [3].

1.2 Motivation

The rationale for doing an electric field study for polymer nanocomposites with variable filler loading particles using FEMM 4.2 software can be diverse and include numerous factors which are the understanding of material behavior as the first step in this endeavor. Polymer nanocomposites are materials having nanoscale fillers spread in a polymer matrix. The next step is to optimize filler loading, as differing filler loadings can have a substantial influence on the electrical characteristics of polymer nanocomposites.

The study seeks to discover the ideal loading for certain applications by analyzing the electric field under various filler loading circumstances. Furthermore, improving the dielectric qualities of the polymer nanocomposite dielectric is critical in electrical insulation applications. The electric field analysis aids in determining how filler loading impacts these parameters to improve dielectric strength and permittivity. Also, making a difference in nanocomposite research by giving insights into the electrical behavior of polymer nanocomposites, the work contributes to the larger area of nanocomposite research. This information may be useful to researchers working on comparable materials or investigating innovative uses in a variety of sectors. The application of FEMM 4.2 software for electric field analysis helps to advance computational simulation approaches. It enables a more complete and precise knowledge of the distribution of electric fields within complicated materials, which aids in the creation of realistic modeling approaches.

The lack of study about the simulation of Electric Field Analysis for polymer nanocomposite using FEMM 4.2 Software inspires the researcher to study more in this field. Therefore, it is motivated to investigate the effect of electric field distribution upon different filler loading particles for nanocomposite.

1.3 Problem Statement

The performance of materials in terms of mechanical and electrical properties can be affected by the addition of nanoparticle filler to the polymer matrix. However, the tendency of polymer nanocomposites to break down is much higher after being filled with nano-particles. Therefore, it is important to investigate the electric field intensity distribution of the polymer nanocomposite's performance before it can be used as an alternative insulation in the future [4]. Insulation breakdown is known to be closely related to the electric field produced across the insulator. Partial discharge will take place across a dielectric's impurities when the electric field is sufficiently generated. The dielectric will age and finally break down as a result of repeated partial discharges [5]. One of the factors that affect the electric field distribution in nanocomposites is the different loading of nanofiller particles. By introducing an interphase region between it, the material properties will be varied, thus affecting the electric field distribution. However, there are lack of studies on the relationship between electric field distribution with filler-loading particles using software analysis. Therefore, it is proposed to investigate the effect of electric field analysis for polymer nanocomposites under different filler loading using FEMM 4.2 software.

1.4 Objective

The objectives of this study are:

(a) To model the polymer nanocomposites upon different filler loading using Finite Elements Method Magnetics (FEMM) 4.2 Software.

(b) To determine the effect of electric field distribution upon different filler loading particles using Finite Elements Method Magnetics (FEMM) 4.2 software.

1.5 Scope of Work

The scope of work of this study are:

- A Polyethylene (PE) as a host matrix was used in this study.
- A nanofiller used was Silicon Dioxide (SiO_2) and the amounts of the nanofillers were interpret as 0.5wt%, 1.5 wt%, 3.0 wt% and 5.0 wt% with a 10nm sized nanomaterial.
- Finite Element Method Magnetics (FEMM) 4.2 software were used to run the simulation.
- The type of distribution conducted was a homogeneous type.

1.6 Thesis Outline

This work arrangement is as follows where there are five portions to this work. The first chapter presents an overview of the study. The problem statement, the objectives of the study, the scope of work, and the thesis outline were all covered in this chapter.

Following that, Chapter 2 presents the backdrop of the electric field analysis polymer nanocomposite literature review. This section discusses filler types, interphase, and material permittivity.

This research study technique will be explained in Chapter 3. This section will begin with the chapter's introduction, followed by a study of design and technique, as well as a Gantt Chart and the FEMM 4.2 Software.

Chapter 4 contains the result and analysis, as well as all of the discussion from Chapter 3. Furthermore, this chapter summarizes the findings of an electric field investigation performed on chosen materials with varying filler loading. The results and theory are then used to make comparisons.

Chapter 5 discusses the project's conclusion, including ongoing discussion and future work on the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed the Literature Review of the project. Nanocomposite materials are gaining popularity for their unique properties and potential uses in several fields. Nanocomposites qualities are governed by the matrix properties, morphology, and interfacial features. Hence, the study of Electric Field Analysis for Polymer Nanocomposites Under Different Filler Loading Using FEMM 4.2 Software. Polymer nanocomposites are a type of innovative material that combines polymers and nanoscale fillers to greatly improve mechanical, thermal, and electrical properties. These composites take advantage of the distinct features of nanofillers such as carbon nanotubes, graphene, and metallic nanoparticles to enhance the overall performance of the basic polymer matrix.

One of the most important characteristics of these materials is the electrical behavior, which is heavily impacted by the kind, size, and concentration of nanofillers. The investigation of electric fields within polymer nanocomposites is critical for understanding and optimizing the electrical properties for a variety of applications, such as sensors, actuators, and electronics [6]. The distribution and intensity of the electric field can influence the dielectric characteristics, conductivity, and overall performance of the nanocomposite. As a result, precisely modelling and analyzing the electric field behavior in these materials is critical.

The current study employs FEMM 4.2 software to analyze electric fields in polymer nanocomposites with various filler loadings. This study seeks to give a comprehensive understanding of the interaction between filler properties and electrical behavior by exploring how different concentrations and types of nanofillers influence the electric field distribution.

This understanding will aid in the design of polymer nanocomposites with tailored properties for specific applications, paving the path for the creation of new materials with higher performance.

2.2 Polymer Nanocomposites

Polymers are a popular material class because of their flexibility, and they may be found in a wide range of commercial applications. Polymer performance may be improved further by adding nano-sized additives, and their characteristics can be tuned to meet the unique needs of high-demanding applications [7]. It has long been known that adding micrometer-sized particles to polymers can increase their stiffness. Nano additives, with one dimension < 100nm, require mechanical reinforcement based on filler size, unlike ordinary micro composites. This side effect is a significant property of polymer nanocomposites, as established in several experiments. Nanocomposites outperform traditional micro composites because the size effect leads to larger reinforcement ratios [7].

Adding nanoparticles to polymers can significantly increase their dielectric characteristics. Recent research has shown that the introduction of nanoparticles in polymeric insulating materials can improve dielectric characteristics when compared to micro-filled and unfilled materials. Nanoparticles added to polymers have been shown to reduce space charge buildup, enhance resistance to surface discharges and treeing, improve thermal conductivity and durability, and increase electrical breakdown strength. Significantly, these advantages have been linked to the existence of a large volume proportion of the interphase between the nanoparticles and the polymers, which has distinct structures and characteristics from the nanoparticles and polymers. Researchers are increasingly interested in simulating nano dielectrics to gain a better understanding of their processes. Lau et al. [8] previously used Finite Element Method Magnetics (FEMM) 4.2 software to model Figure 2.1 where nano dielectrics are made of polyethylene and nano-silica particles [9]. Therefore, this study aims analyze the electric field intensity towards different filler loading.

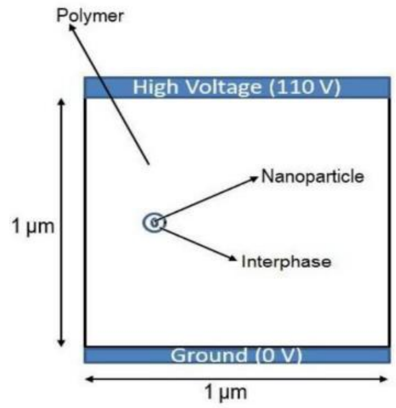

Figure 2.1 Two-Dimensional Nanocomposite Slab

with 1µm x 1µm dimensions [9]

2.3 Interphase

In the early 2000s, Lewis and Tanaka et al. devised two models to predict the occurrence of interphase in nanodielectrics [1]. According to Lewis' diffuse electrical double layer model, a Stern layer and a Gouy-Chapman diffuse double layer are considered to exist at the filler-polymer interface. The creation of these layers was assumed to alter the internal charge activity and subsequent electrical potential distribution at the interphase, influencing the dielectric characteristics of the ensuing nano dielectrics. Tanaka et al. suggested a multi-core model, which assumed the presence of four layers inside the interphase: the bonded layer, the bound layer, the loose layer, and the Gouy-Chapman diffuse layer [10]. The multi-core concept allows a nanoparticle's interphase to overlap with that of its neighboring nanoparticle, resulting in a far-field effect and a cooperative effect between the nanoparticles [1]. Shortly before the publication of Lewis' Nanometric Dielectric, the interphase layer was considered insignificant at the microscale filler level. At the nanoscale, polymer nanocomposites rely heavily on interphase layers. Many academics have expressed interest in further investigating the interphase layer. Several studies have presented distinct interphase models, while others focus on how the interphase region affects the electrical properties of nanocomposites. Moreover, research suggests that the interphase area of nanocomposites can have a direct impact on their overall properties, including optical, electrical, and mechanical [11]. Thus, the research must be continued to study more on Electric Field Analysis.

2.3.1 Interphase Models

This seemingly commonplace scenario alters dramatically when thickness contacts between particles and polymer matrix Figure 2.2 are considered. The interaction of filler particles and polymer matrix with differing structures creates a transition or interaction zone within which the characteristics shift from filler particle to bulk polymer matrix [12].

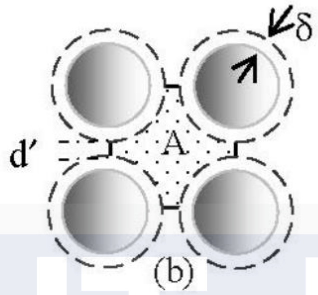

Figure 2.2 Array with Interface Thickness [12]

Another element that can give the interface supremacy is the presence of an electrical double layer that overlies at least a portion of the interface and is mutually interacting [12]. Figure 2.3 illustrates the Gouy-Chapman diffuse layer. This model includes an interface AB (charge distribution) between filler particle A and polymer matrix B. The particle A gets charged, presumably due to the equalisation of Fermi levels or chemical potential, resulting in real processes such as surface group ionisation and ion adsorption from polymer B. The polymer replies by creating an extra counter charge environment that screens the charge on A [13].

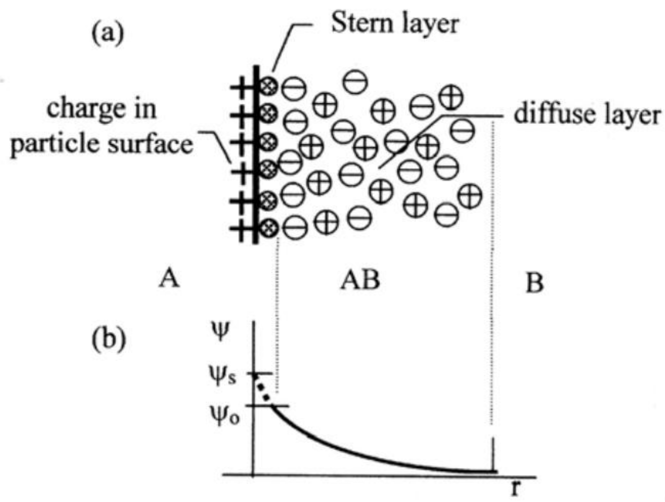

Figure 2.3 Charge Distribution in a Polymer-Inorganic Interphase in Case of an Inorganic Positively Charged [13]

2.4 Filler Loading

The use of micrometric filler particles in medium voltage insulation has a long history. The reduction of particle size by three orders of magnitude to nanometric dimensions provides two important physical characteristics. To begin, for a given weight of filler particles, the inter-particle spacing for nanometric particles can be comparable to polymer-particle interface dimensions and polymer segment length, making it a dominant aspect of the composite. Oxides, a type of semi-insulator, exhibit electrical features like wider band gap, discretized energy states, and coulombic blockade, which are commonly connected with quantum dots and electronic devices [12]. The recent discovery of nanoscale fillers, such as carbon nanotubes, graphene, and nanocellulose, enables polymer nanocomposites to be regulated and improved. However, standard polymer nanocomposite synthesis techniques are incapable of maximizing the reinforcing of these nanofillers at high filler concentrations. To enable future applications, methods for synthesizing high-content filler polymer nanocomposites are recommended [4]. Based on previous research, mechanical mixing was used to create the nanocomposite samples. A laboratory two-roll mill was used to mix the necessary amount of nano-silica (1 wt%, 3 wt%, and 5 wt%) with polyethylene (LDPE or HDPE) [1].

Compared to this study that uses lower sizes of nanoparticles where as the number of nanoparticles was equated to 0.5 wt%, 1.5 wt%, 3 wt% and 5 wt%. Therefore, it can be concluded that from previous studies showing that at a higher filler load, the tendency of a material to break is higher.

2.5 Electric Field Analysis

For each dielectric material, it is feasible to define a threshold electric field that causes irreversible changes in the medium and the commencement of an intensive and disruptive flow of charges. The abrupt loss of insulation caused by an extremely strong electric field is known as dielectric breakdown of the material. The minimal field that causes such an effect is known as the breakdown field or breakdown strength (Ebreak) [2]. The electric field was found to be uniformly distributed in the unfilled polymer. The electric field intensity of the unfilled polymer was found to be constant. Adding a nanoparticle with higher permittivity than the polymer resulted in reduced electric field intensity within the nanoparticles. The electric field strength, however, is immediately near to the nanoparticle's surface [1]. Finite element simulations offer a statistical analysis of the local electric field distribution in nanocomposites. When high dielectric constant fillers are utilized, the polymer matrix can withstand the majority of the electrical stress, and the locally enhanced field can be related to the electrical breakdown strength for a short-term breakdown process. Significantly, the overall permittivity of a composite material is frequently related to the compatibility of its constituents, therefore the electrical performance of the composite [1].

Thus, this study aims to investigate the electric field intensity behavior for case where the polymer is unfilled, polymer added nanoparticles and also at different filler loading particles.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discussed the project's methodology which covers the research design and procedure of the project. The research design refers to the overall structure and plan of a research study as shown in Figure 3.1, Table 3.1, and Figure 3.2. The procedure of the project is more to know what are the required steps for conducting the research study of Electric Field Analysis for Polymer Nanocomposite under Different Filler Loading Particles using FEMM 4.2 Software.

3.2 Research Design

The research design was conducted by sketching the flow of the project by using a flowchart diagram to know the project flows. Based on Figure 3.1 this paper was then tabulated on a Gantt Chart table as in Table 3.1 to estimate the time taken to finish the research.

3.2.1 Flowchart

Figure 3.1 shows the flowchart of this study.

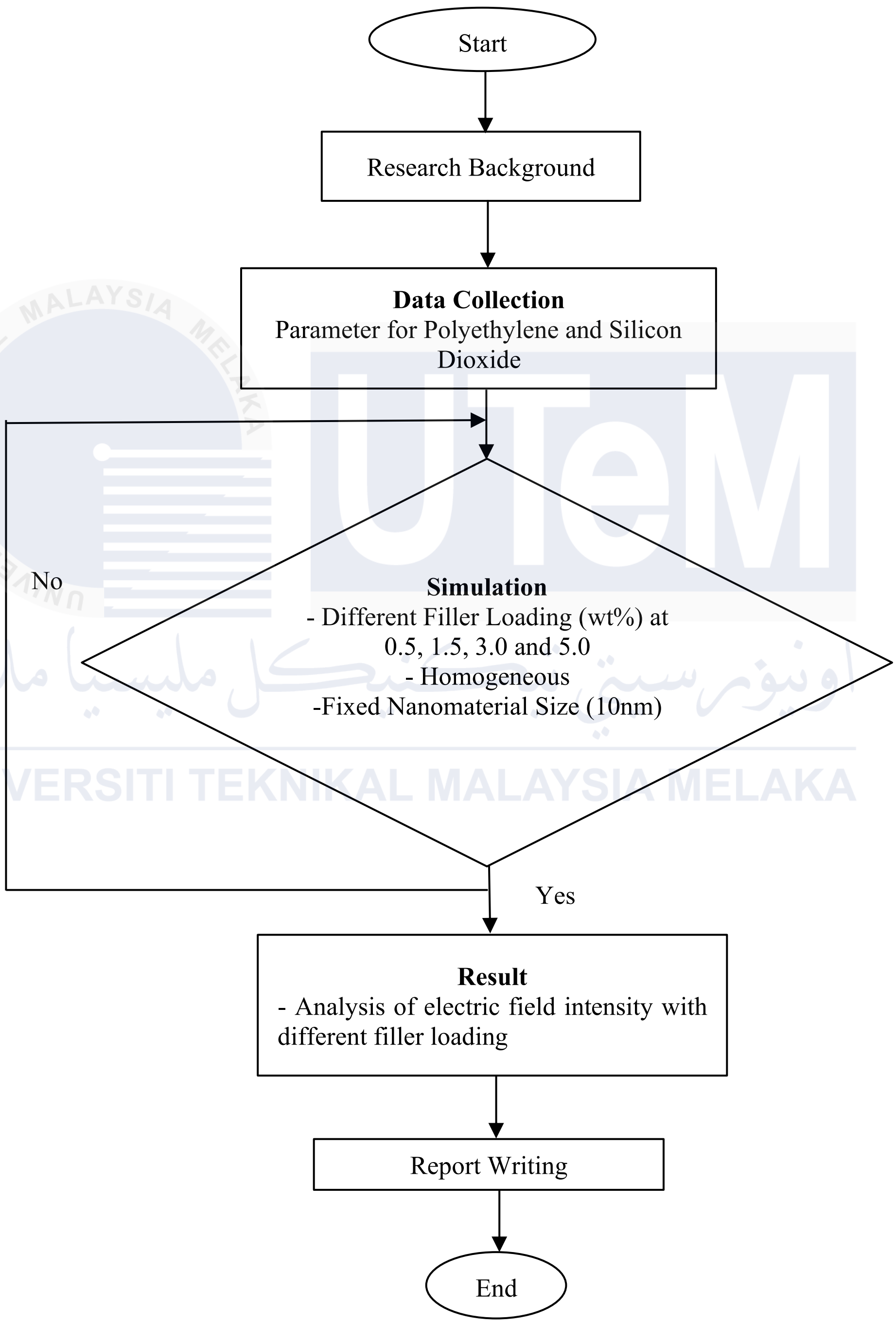

Figure 3.1 Flowchart of the study

3.2.2 Gantt Chart

Table 3.1 shows the Gantt Chart of this study.

Table 3.1 Gantt Chart of the study

PROJECT PLANNING (GANTT CHART)																																				
TITLE: ELECTRIC FIELD ANALYSIS FOR POLYMER NANOCOMPOSITES UNDER DIFFERENT FILLER LOADING PARTICLES USING FEMM 4.2 SOFTWARE																																				
	SEM 1															SEM BREAK				SEM 2																
Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Project Briefing with Supervisor	X											SEMINAR PSM I				SEMESTER BREAK																		SEMINAR PSM II		
Background Research	X	X	X	X	X	X	X	X	X	X	X		X	X	X																					
Literature Review	X	X	X	X	X	X	X	X	X	X	X		X	X	X																					
Design modeling using FEMM 4.2				X	X	X	X	X																												
Simulation on FEMM 4.2				X	X	X	X	X												X	X	X	X	X	X	X	X	X	X	X						
Result					X	X	X	X	X											X	X	X	X	X	X	X	X	X	X	X						
Data Analysis							X	X	X	X	X		X	X	X					X	X	X	X	X	X	X	X	X	X	X						
Preparation of progress report				X	X	X	X	X	X	X	X		X	X						X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
Thesis draft submission to supervisor													X	X																X	X	X	X			
Thesis submission															X																				X	X

3.2.3 K-Chart

Figure 3.2 shows the K-Chart of this study.

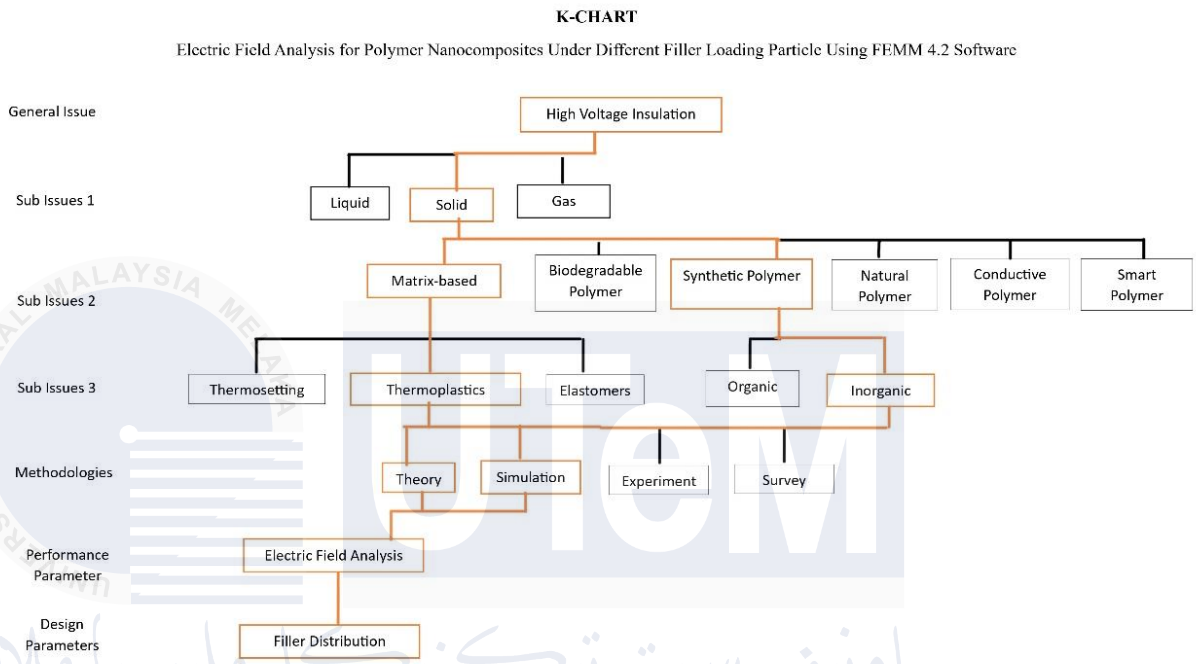

Figure 3.2 K-Chart of the project

3.3 Finite Element Method Magnetics (FEMM) 4.2 Software

FEMM 4.2 Software is one of the freely-available software that users can access that is good in problem-solving such as Magnetostatic, Electrostatic, Heat Flow, and Current Flow Problems. In this project, the electric field analysis will only be developed using 2D symmetric analysis. Lau et al. [1] previously used Finite Element Method Magnetics (FEMM) 4.2 software to model nano dielectrics made of polyethylene and nano-silica particles.

The investigation revealed that nanoparticles that have a greater permittivity than polymers alter the electric field intensity around them. The presence of interphase reduces the fluctuation in electric field strength between the nanoparticle and polymer regions when the interphase permittivity value is between the two. Furthermore, when the separation distance between nearby nanoparticles increased (indicating a lower concentration of nanoparticles), the electric field became less distorted [9].

3.3.1 Simulation using FEMM 4.2 Software

Electric Field Analysis can be generated by using the Electrostatic Problem on FEMM 4.2 Software. The program also known as software that can solve difficulties that are connected to electrostatic fields and is used to investigate the behavior such as electric fields, potentials, and charges in electrostatic systems. The steps of simulating by using the FEMM 4.2 software are as follows:

Once the FEMM 4.2 software is open, a new problem dialog as in Figure 3.3 will pop up and the Electrostatic Problem is selected to study the Electric Field Intensity of this research. Next is as in Figure 3.4 where the user needs to choose the Problem Definition Dialog to define the problem type to Planar type. Furthermore, as shown in Figure 3.5, to start the nanocomposite modeling, there are several tools to use such as point, segment, arc segment, block, and group. The tools can be accessed and modeled as in Figure 3.7.

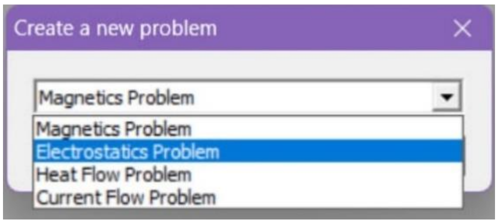

Figure 3.3 New Problem Dialog

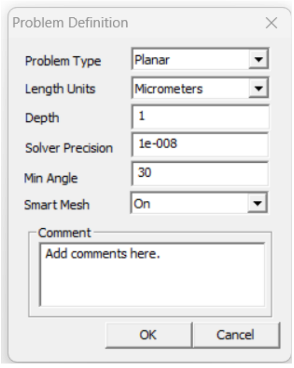

Figure 3.4 Problem Definition Dialog

Figure 3.5 Modelling Design Toolbar

Figure 3.6 Analysis Task Toolbar

From Figure 3.7 the modeling starts off with inserting the 4 nodes at each corner of the slab. The nodes represents in the form of coordinate (x,y). Figure 3.8 shows where users need to add the coordinate for each filler based on the calculations that have been made before. Next, the line were connected using the segment shown in Figure 3.5. Before running the simulation on Figure 3.7, the chosen material for this project was added from the materials library. As for a certain material that has not been available on FEMM 4.2 software, it allows users to add it manually as in Figure 3.9. Figures 3.10, 3.11, 3.12 and 3.13 show the materials that will be used throughout this study.

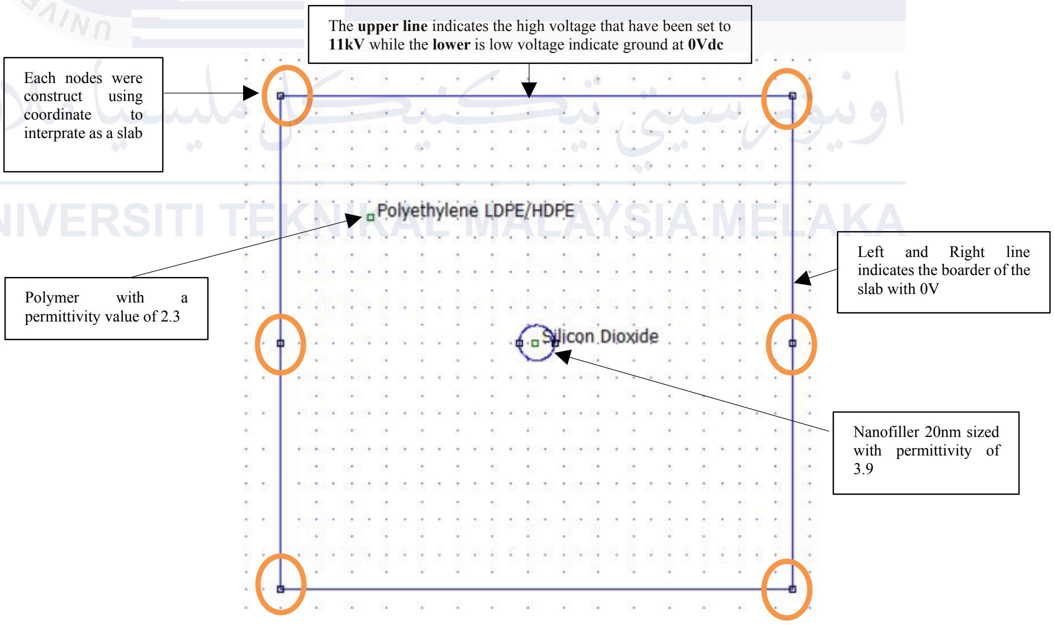

Figure 3.7 Polymer and Filler Modelling

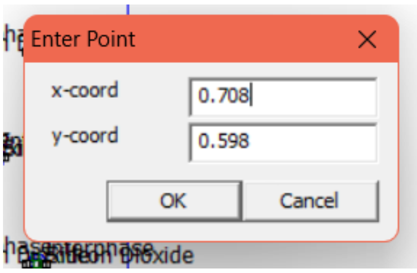

Figure 3.8 Coordinate Point Dialog

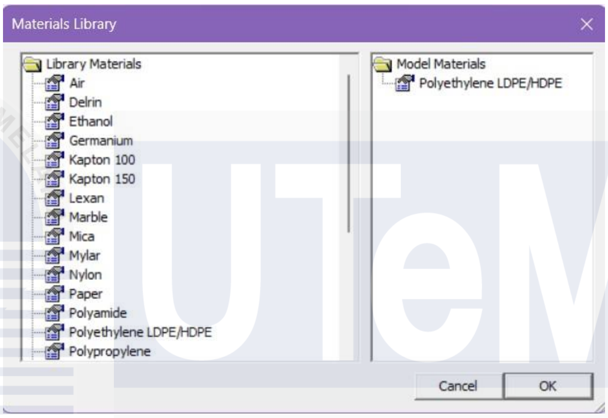

Figure 3.9 Materials Library

Figure 3.10 New Material Dialog

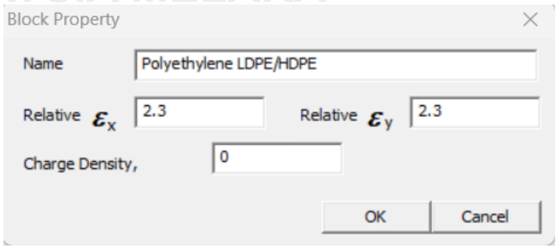

Figure 3.11 Polyethylene Material Dialog

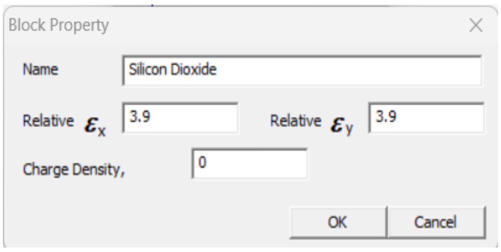

Figure 3.12 Silicon Dioxide Material Dialog

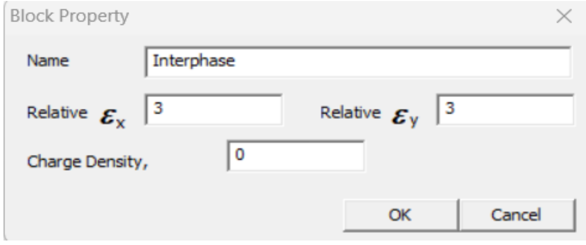

Figure 3.13 Interphase Material Dialog

There are another two steps that declare the slab of the model where the upper is the High Voltage of 11kV and the lower is Ground at 0Vdc as in Figures 3.14 and 3.15. Before the simulation can be run, the user needs to access the tools in Figure 3.6 so that Figure 3.16 will show the Electric Field Intensity Modelling that has been running. As in Figure 3.17 is the legend of electric field intensity that will be analyze.

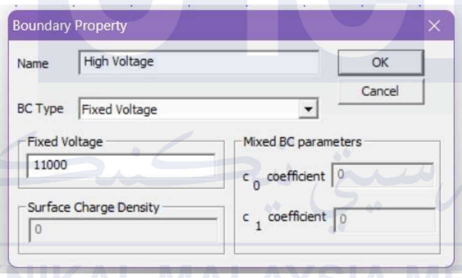

Figure 3.14 High Voltage Boundary Property

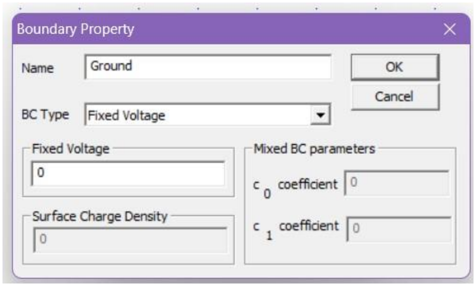

Figure 3.15 Ground Boundary Property

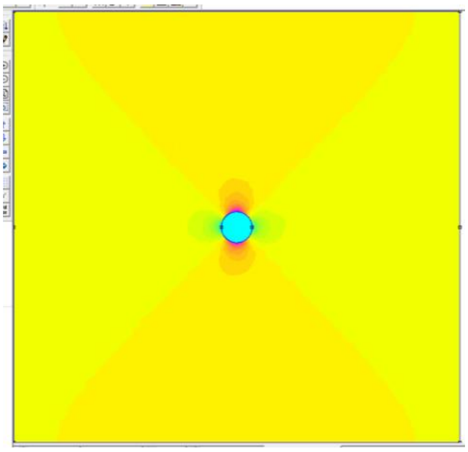

Figure 3.16 Electric Field Intensity of Polymer and Filler Modelling

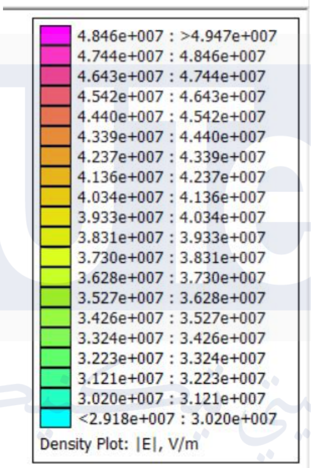

Figure 3.17 Legend for Simulation Result

3.4 Parameters for Polymer Nanocomposites Modelling

Table 3.2 shows the details of modelling parameters for polymer and nanofiller. As shown below in Table 3.2, there are four different filler loading used in this study which are 0.5wt%, 1.5wt%, 3.0wt% and 5.0wt%. The base polymer that was used in this study is Polyethylene with a permittivity of 2.3. Besides, the nanofiller that was chosen is a Silicon Dioxide (SiO_2) with a value of 3.9 as a permittivity and also with an interphase of 3.0 permittivity with three different sizes which are 5nm, 15nm and 30nm. For this study, the size of the nanofiller was 10nm.

Table 3.2 Modelling Parameters for Polymer and Nanofiller

wt (%)	Interphase Size	Polymer - Filler	Permittivity
0.5	5nm	PE – SiO_2	Interphase : 3.0 Polymer : 2.3 Filler : 3.9
1.5			
3.0			
5.0			
0.5	15nm		
1.5			
3.0			
5.0			
0.5	30nm		
1.5			
3.0			
5.0			

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the results obtained from FEMM 4.2 software. From the results, the electric field intensity and distribution of polymer nanocomposites analysis were analyzed. Based on the scope of work mentioned in Chapter 1, this study uses a different size of interphase at 5nm, 15nm and 30nm, as well as a fixed size of Silicon Dioxide (SiO_2) at 10nm size. The distribution of this research is focusing on the homogenous type. The main purpose is to study the polymer nanocomposite under different filler loading (wt%).

4.2 Polymer Nanocomposites with Different Weight Percentage(wt%)

Several advantageous phenomena have been identified in the dielectric and electrical insulation characteristics of developing polymer nanocomposites. Polymer nanocomposites are composed of a polymer matrix with multiple weight percent nano-fillers that are homogeneously spread. Nano-fillers in polymer nanocomposites are so small that they measure less than 100nm [13]. Research has shown that when filler size decreases from the microscale to the nanoscale, the interphase layer becomes more prominent. As filler size decreases, the effective surface area between the filler and polymer matrix increases. At some point, the interphase volume fraction exceeds both the filler and polymer matrix volume fractions [13].

While there have been several studies on the interphase layer of nanocomposites, there is still limited research on their electric field intensity. The impact of electric field intensity on the interphase layer remains unclear. For this chapter there are several analysis were made. The first analysis was the simulation upon unfilled Polyethylene to study the electric field intensity when there is no filler and interphase added based on Figure 4.1. Secondly, the modelling without interphase and thirdly Polyethylene nanocomposite at different weight percentage(wt%) and lastly different value of interphase.

4.2.1 Unfilled Polyethylene (PE)

Simulations are used to analyze the impact of filler orientations and content on the electric field of nanodielectrics. It was analyzed at 1 μm thick and 1 μm wide of polyethylene samples with various electric field distribution scenarios. After several simulations were simulated, it is proven that during unfilled conditions in Figure 4.2, the voltage is larger near the high voltage at 11kV direct voltage and lower at the ground where it is a 0Vdc. As in Figure 4.3 shows that the electric field intensity for Unfilled PE is at 964.9 x 10^6 V/m.

Figure 4.1 Unfilled PE Modelling

Based on Figure 4.3 shows that there are no electric field distribution upon unfilled PE due to no other nanoparticles added in this polymer. Therefore, the value of electric field was found at 0V/m.

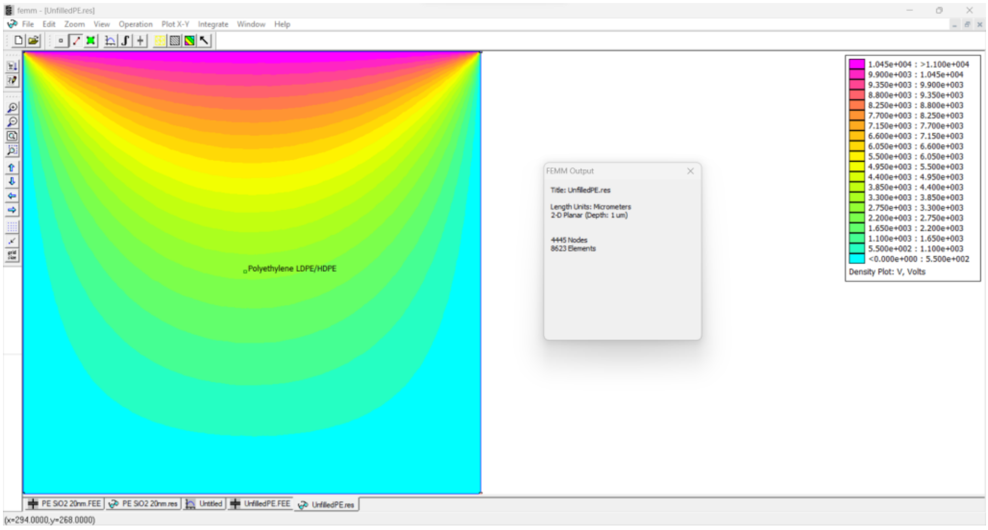

Figure 4.2 Voltage of Unfilled PE

Figure 4.3 Electric Field Intensity of Unfilled PE

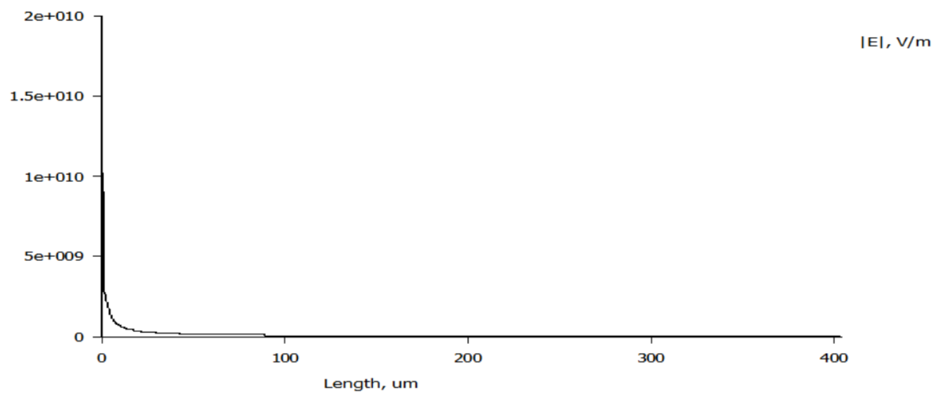

Figure 4.4 Electric Field Intensity of Unfilled PE Graph

4.2.2 Modelling of PE and SiO_2 without Interphase

In this simulation, Figure 4.4 is a modelling of Silicon Dioxide (SiO_2) when added as a filler. Figure 4.5 and 4.6 shows that the peak of electric field intensity is at 48.46 x 10^6 V/m to 49.47 x 10^6 V/m.

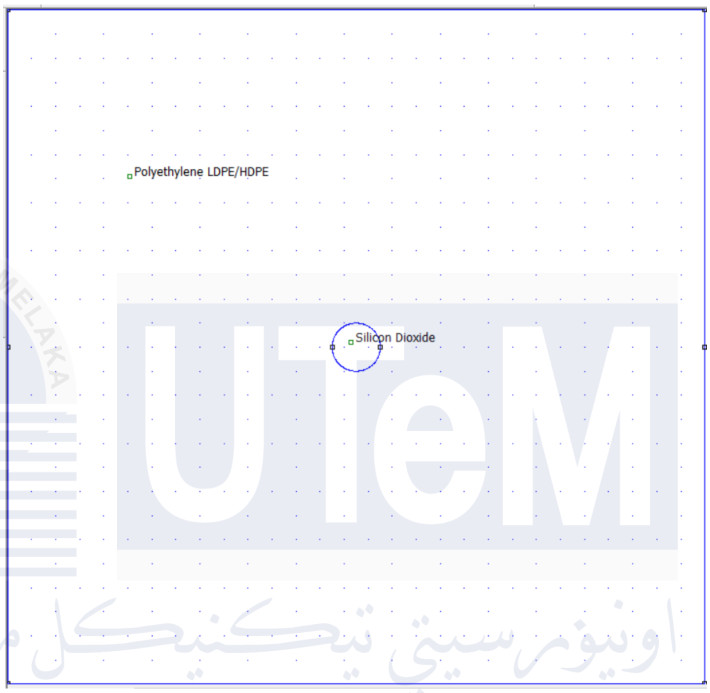

Figure 4.5 PE and SiO_2 Modelling without Interphase

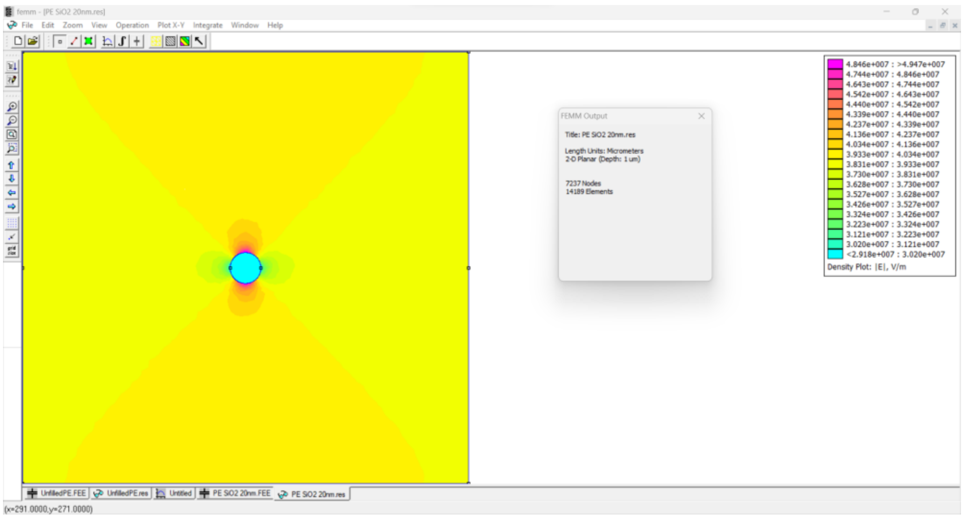

Figure 4.6 Electric Field Intensity without Interphase

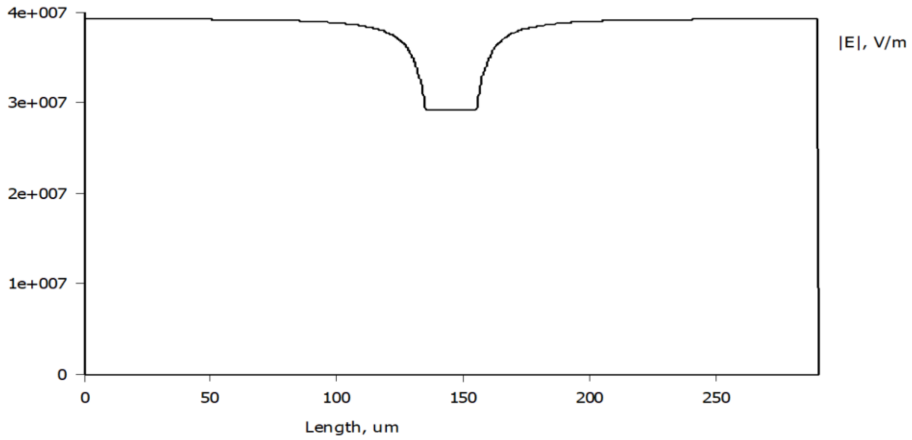

Figure 4.7 Electric Field Intensity without Interphase Graph

4.2.3 PE and SiO_2 at 5nm Interphase with Different Filler Loading

This section discussed the PE and SiO_2 at 5nm interphase with different filler loading(wt%) which are at 0.5wt%, 1.5wt%, 3.0wt% and 5.0wt%. According to the Volume Model, the thickness of the interphase layer is determined by the distance between fillers as well as the filler loading percentage (wt.%). Nanofillers agglomerate at larger concentrations because of the high surface energy and strong van der Waals forces.

This aggregation can cause uneven distribution and localized stress locations, compromising the composite's electrical properties. Maintaining a uniform dispersion of nanofillers inside the polymer matrix becomes difficult with larger loadings. Therefore, at a maximum of 10.0wt%, it is often easier to establish and maintain a uniform distribution, which is essential for the composite's improved qualities. Using nanofillers at less than 10.0wt% in polymer nanocomposites finds a compromise between improving material characteristics and retaining processability, mechanical performance, and economic feasibility.

4.2.3.1 Filler Loading at 0.5wt%

Figure 4.8 shows a total of 0.5wt% nanoparticles that can fit in a slab of 1µ x 1µ. It can be seen on the legend from the right corner of the simulations, the dispersion of the electric field intensity started to appear around 10.71 x 10^{10} V/m to 10.96 x 10^{10} V/m. Figure 4.9 illustrates the waveform of the nanomaterial when 0.5wt% of filler loading were added.

Figure 4.8 Electric Field Intensity at 5nm Interphase with 0.5wt% Filler Loading

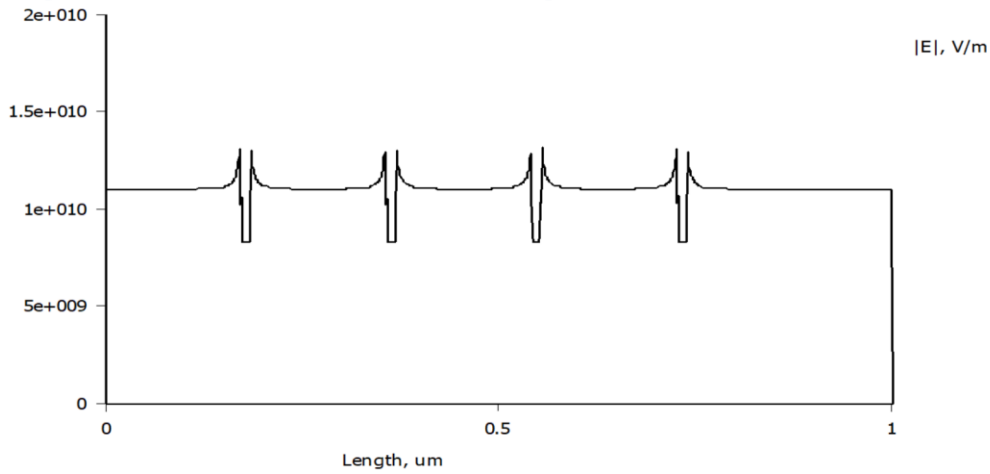

Figure 4.9 Electric Field Intensity at 5nm Interphase with 0.5wt% Filler Loading Graph

4.2.3.2 Filler Loading at 1.5wt%

Figure 4.10 shows a total of 1.5wt% nanoparticles and can be seen on the legend that the dispersion of the electric field intensity started to increase around 1.104 x 10^{10} V/m to 1.131 x 10^{10} V/m. Higher filler loading has increased the value of electric field intensity of the nanoparticles. Figure 4.11 illustrates the waveform of the nanomaterial when 1.5wt% of filler loading were added.

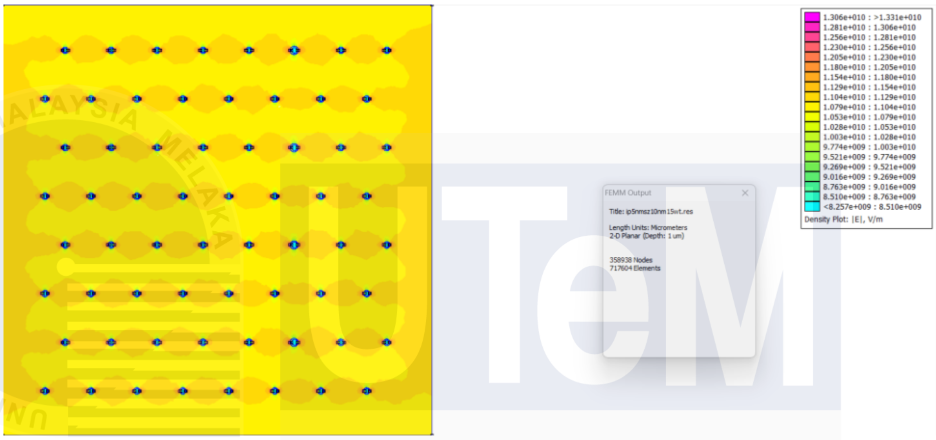

Figure 4.10 Figure 4.11 Electric Field Intensity at 5nm Interphase with 1.5wt% Filler Loading

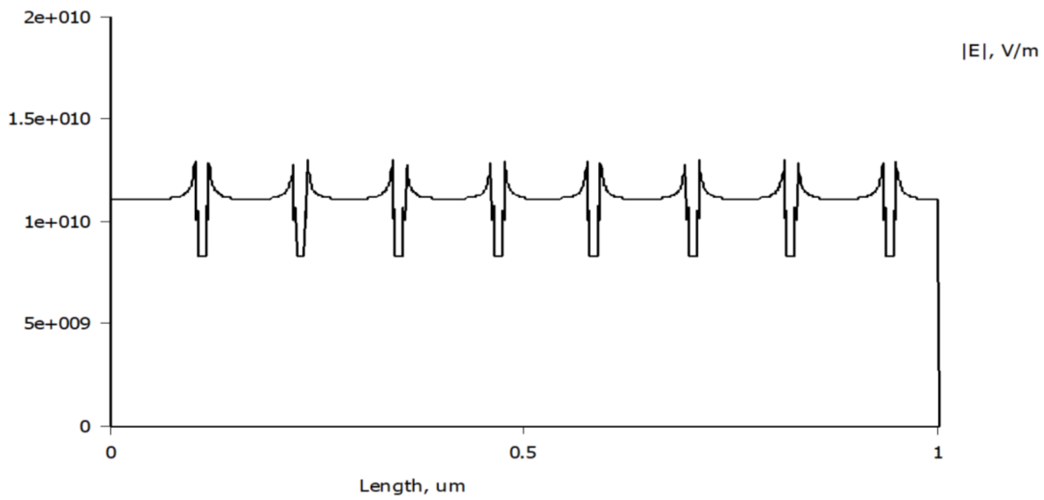

Figure 4.12 Electric Field Intensity at 5nm Interphase with 1.5wt% Filler Loading Graph

4.2.3.3 Filler Loading at 3.0wt%

Figure 4.12 shows the dispersion of the electric field intensity has increase when the higher value of filler loading added. The electric field intensity at around 1.141 x 10^{10} V/m to 1.165 x 10^{10} V/m. Figure 4.13 illustrates the waveform of the nanomaterial when 3.0wt% of filler loading were added.

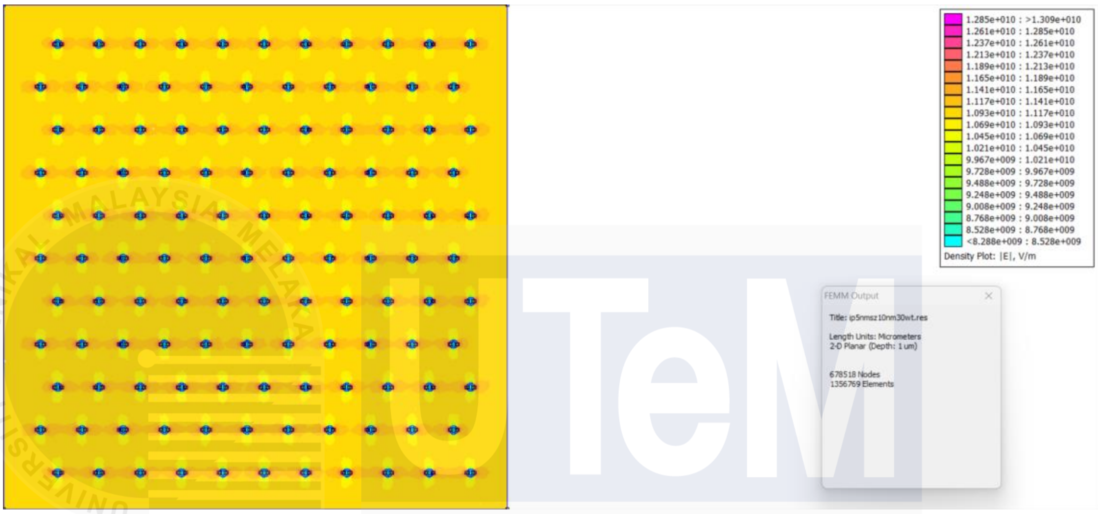

Figure 4.13 Electric Field Intensity at 5nm Interphase with 3.0wt% Filler Loading

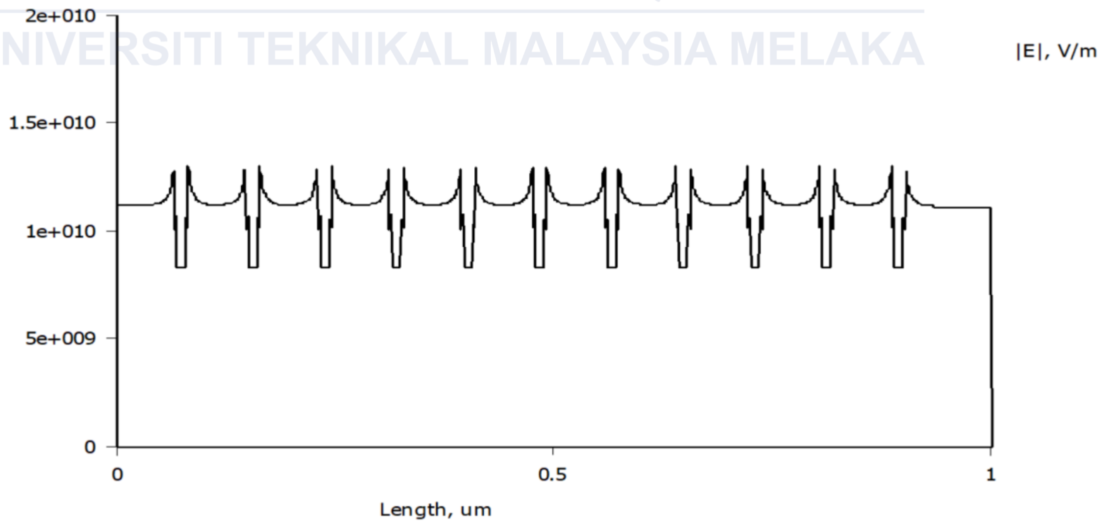

Figure 4.14 Electric Field Intensity at 5nm Interphase with 3.0wt% Filler Loading Graph

4.2.3.4 Filler Loading at 5.0wt%

At this part, it can be seen in Figure 4.14 that the value of nanoparticles is increasing to 5.0wt% and the dispersion of the electric field intensity has increase around 1.169 x 10^{10} V/m to 1.193 x 10^{10} V/m. It is shown that the peak electric field intensity is around 1.29 x 10^{10} V/m to 1.314 x 10^{10} V/m. Figure 4.15 illustrates the waveform of the nanomaterials when 5.0wt% of filler loading were added.

Figure 4.15 Electric Field Intensity at 5nm Interphase with 5.0wt% Filler Loading

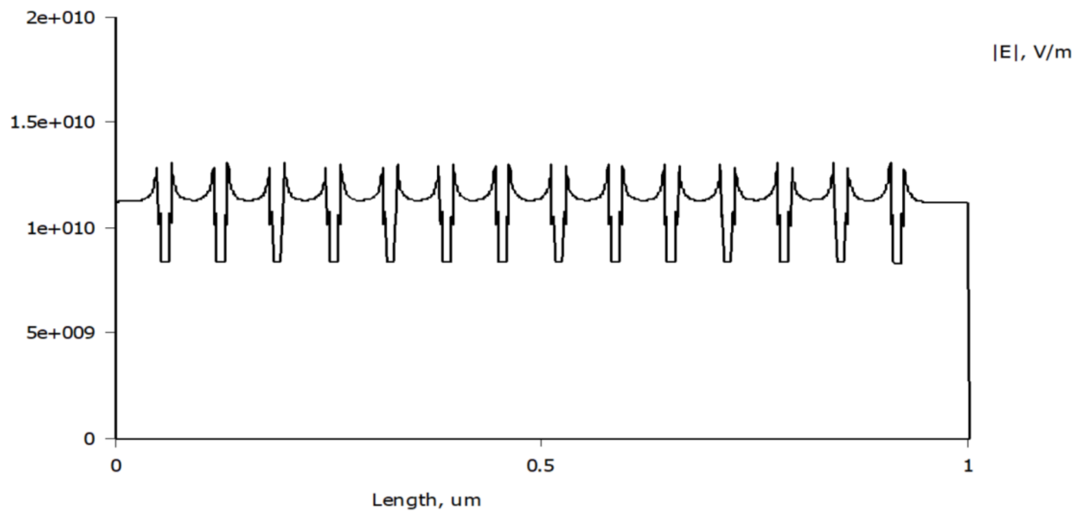

Figure 4.16 Electric Field Intensity at 5nm Interphase with 5.0wt% Filler Loading Graph

4.2.4 PE and SiO_2 at 15nm Interphase with Different Filler Loading

This section discussed the modeling of PE and SiO_2 when 15nm interphase was added at 0.5wt%, 1.5wt%, 3.0wt%, and 5.0wt% filler loading.

4.2.4.1 Filler Loading at 0.5wt%

Figure 4.16 shows a total of 0.5wt% nanoparticles that can fit in the slab. It can be seen that the dispersion of the electric field intensity is around 1.073 x 10^{10} V/m to 1.095 x 10^{10} V/m. Figure 4.17 illustrates the waveform of the nanomaterial when 0.5wt% of filler loading were added.

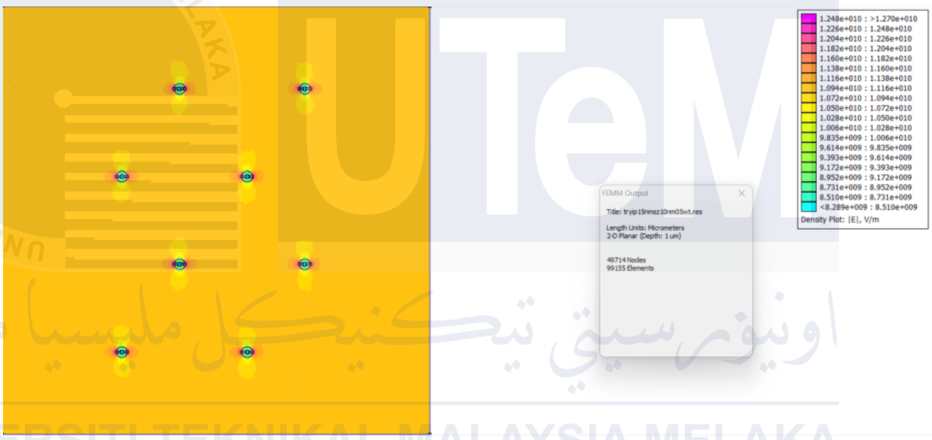

Figure 4.17 Electric Field Intensity at 15nm Interphase with 0.5wt% Filler Loading

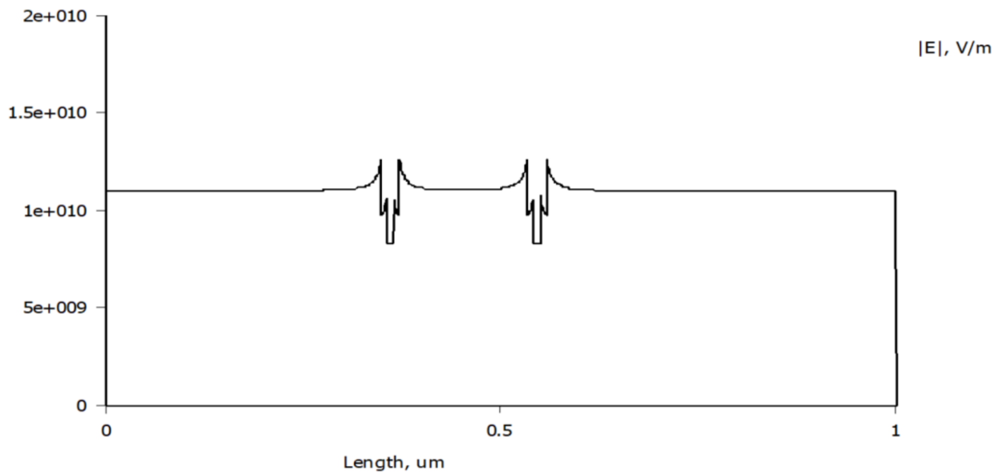

Figure 4.18 Electric Field Intensity at 15nm Interphase with 0.5wt% Filler Loading Graph

4.2.4.2 Filler Loading at 1.5wt%

Figure 4.18 shows a total of 1.5wt% nanoparticles and can be seen on the legend that the dispersion of the electric field intensity is at 1.044 x 10^{10} V/m to 1.096 x 10^{10} V/m. The dispersion at this part has started to grew bigger as the increased of interphase size from 5nm to 15nm. Figure 4.19 illustrates the waveform of the nanomaterial when 1.5wt% of filler loading were added.

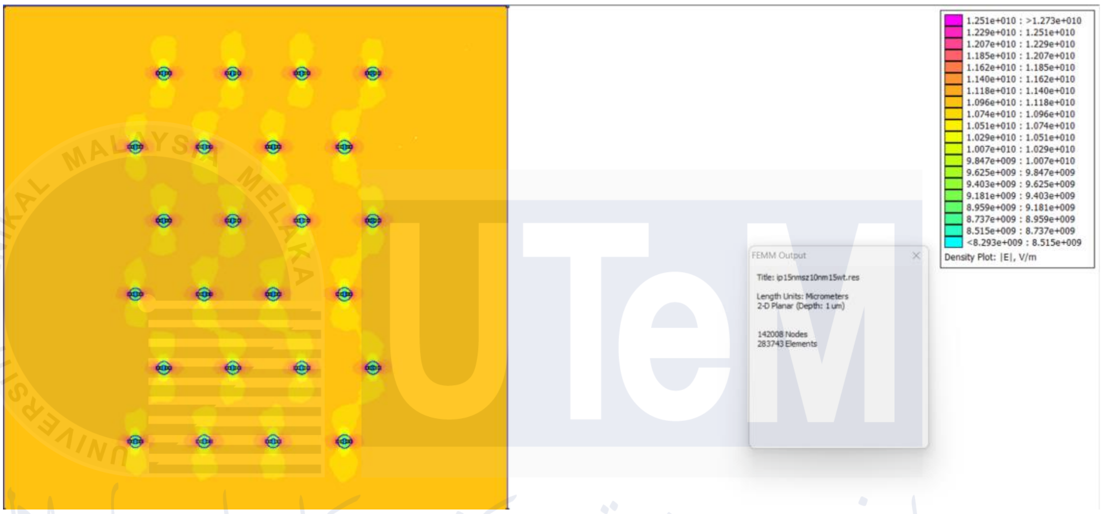

Figure 4.19 Electric Field Intensity at 15nm Interphase with 1.5wt% Filler Loading

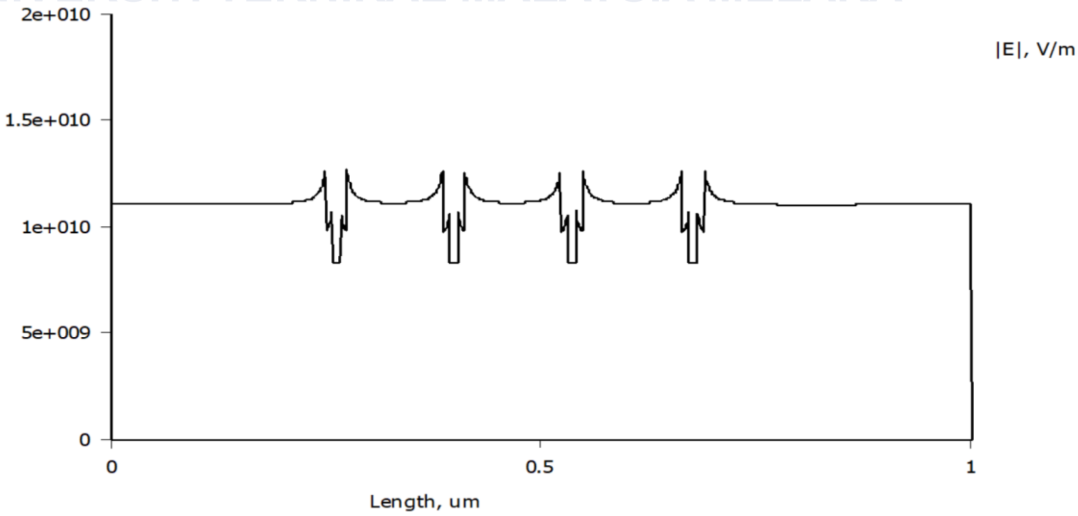

Figure 4.20 Electric Field Intensity at 15nm Interphase with 1.5wt% Filler Loading Graph

4.2.4.3 Filler Loading at 3.0wt%

Figure 4.20 shows the dispersion of the electric field intensity has increase when the higher value of filler loading added. The electric field intensity at around 1.097 x 10^{10} V/m to 1.119 x 10^{10} V/m. Figure 4.21 illustrates the waveform of the nanomaterial when 3.0wt% of filler loading were added.

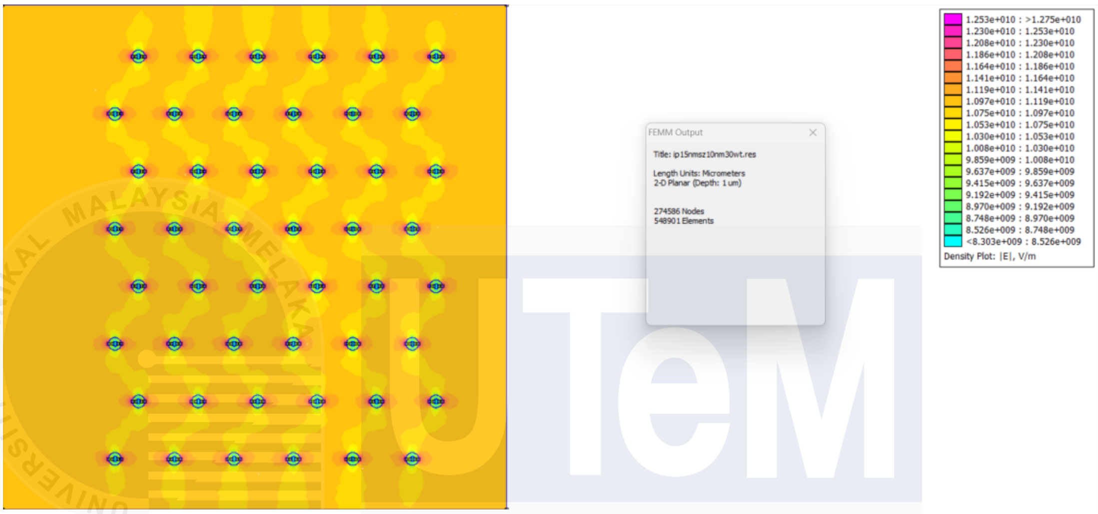

Figure 4.21 Electric Field Intensity at 15nm Interphase with 3.0wt% Filler Loading

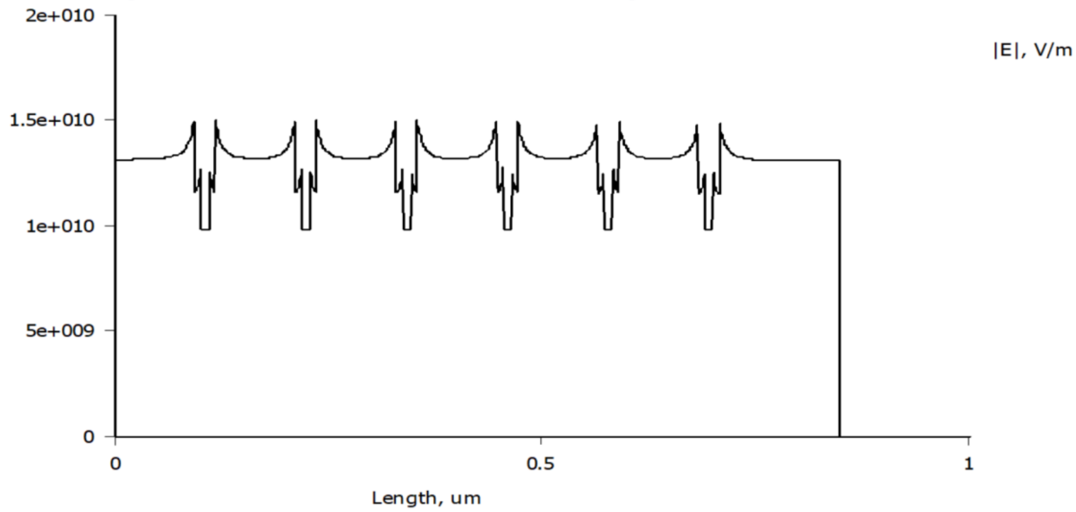

Figure 4.22 Electric Field Intensity at 15nm Interphase with 3.0wt% Filler Loading Graph

4.2.4.4 Filler Loading at 5.0wt%

At this part, it can be seen in Figure 4.22 that the value of nanoparticles is increasing to 5.0wt% and the dispersion of the electric field intensity has increase around 1.318 x 10^{10} V/m to 1.347 x 10^{10} V/m. It is shown that the peak electric field intensity is around 1.272 x 10^{10} V/m to 1.296 x 10^{10} V/m. Figure 4.23 illustrates the waveform of the nanomaterials when 5.0wt% of filler loading were added.

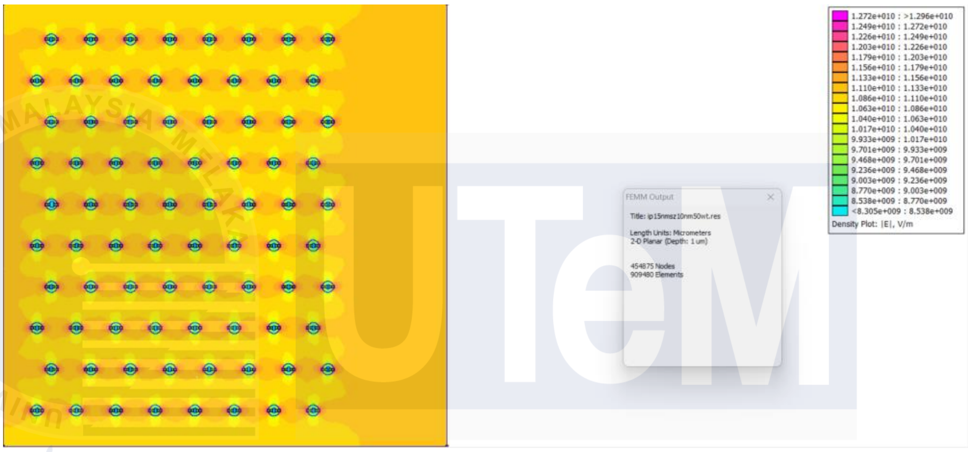

Figure 4.23 Electric Field Intensity at 15nm Interphase with 5.0wt% Filler Loading

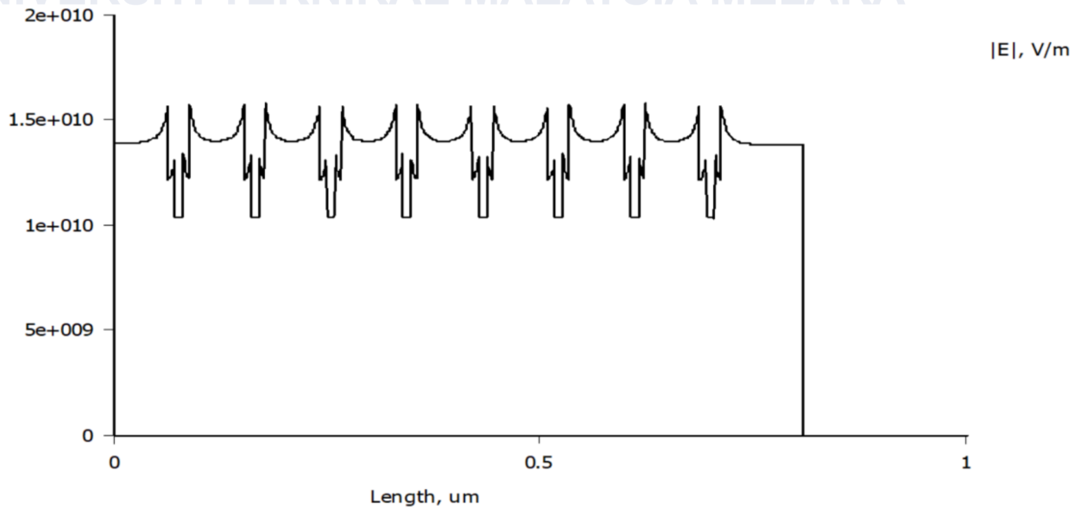

Figure 4.24 Electric Field Intensity at 15nm Interphase with 5.0wt% Filler Loading Graph

4.2.5 PE and SiO_2 at 30nm Interphase with Different Filler Loading

This section discussed the modeling of PE and SiO_2 when 30nm interphase was added at 0.5wt%, 1.5wt%, 3.0wt%, and 5.0wt% filler loading.

4.2.5.1 Filler Loading at 0.5wt%

Figure 4.24 shows a total of 0.5wt% nanoparticles that can fit in the slab. It can be seen that the dispersion of the electric field intensity is around 1.109×10^{10} V/m to 1.130×10^{10} V/m. Figure 4.25 illustrates the waveform of the nanomaterial when 0.5wt% of filler loading were added.

Figure 4.25 Electric Field Intensity at 30nm Interphase with 0.5wt% Filler Loading

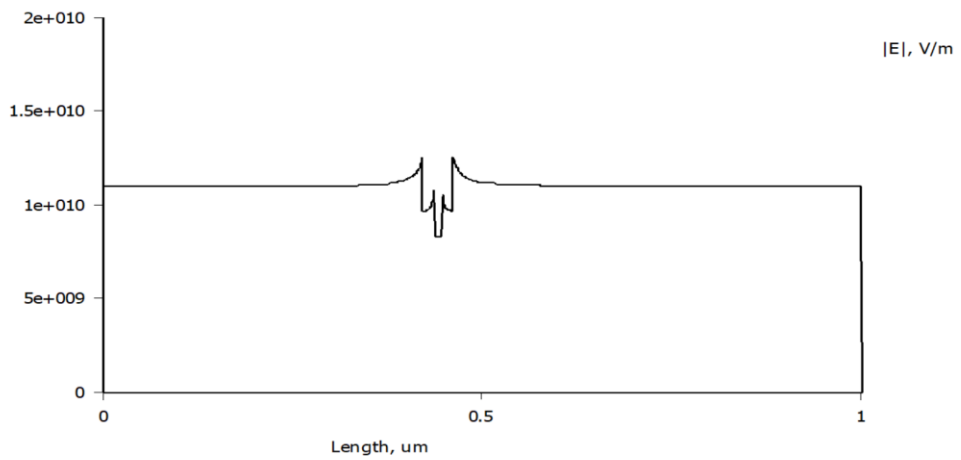

Figure 4.26 Electric Field Intensity at 30nm Interphase with 0.5wt% Filler Loading Graph

4.2.5.2 Filler Loading at 1.5wt%

Figure 4.26 shows a total of 1.5wt% nanoparticles and can be seen on the legend that the dispersion of the electric field intensity is at 1.108 x 10^{10} V/m to 1.129x 10^{10} V/m. The dispersion at this part has started to grew bigger as the increased of interphase size from 5nm and 15nm to 30nm. Figure 4.27 illustrates the waveform of the nanomaterial when 1.5wt% of filler loading were added.

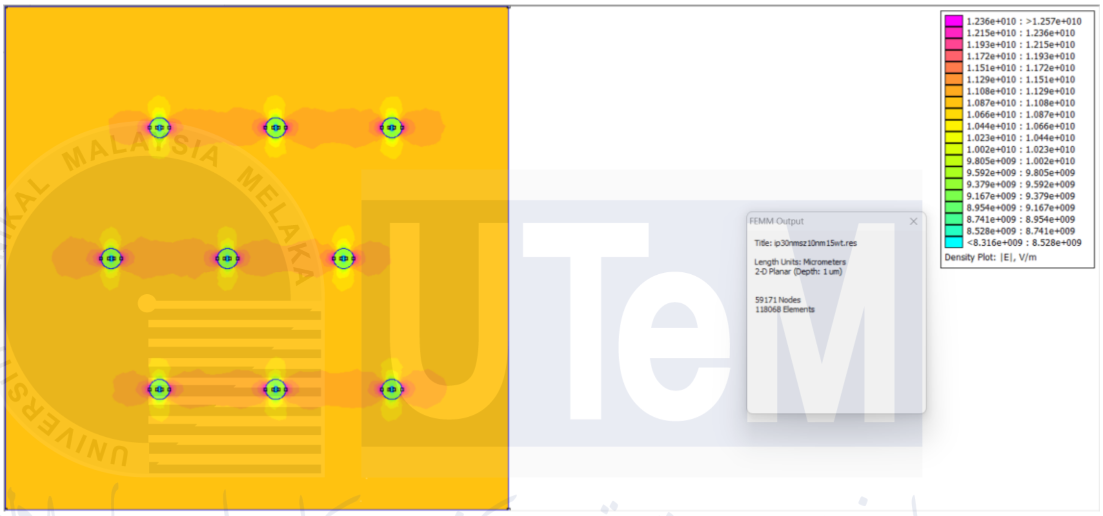

Figure 4.27 Electric Field Intensity at 30nm Interphase with 1.5wt% Filler Loading

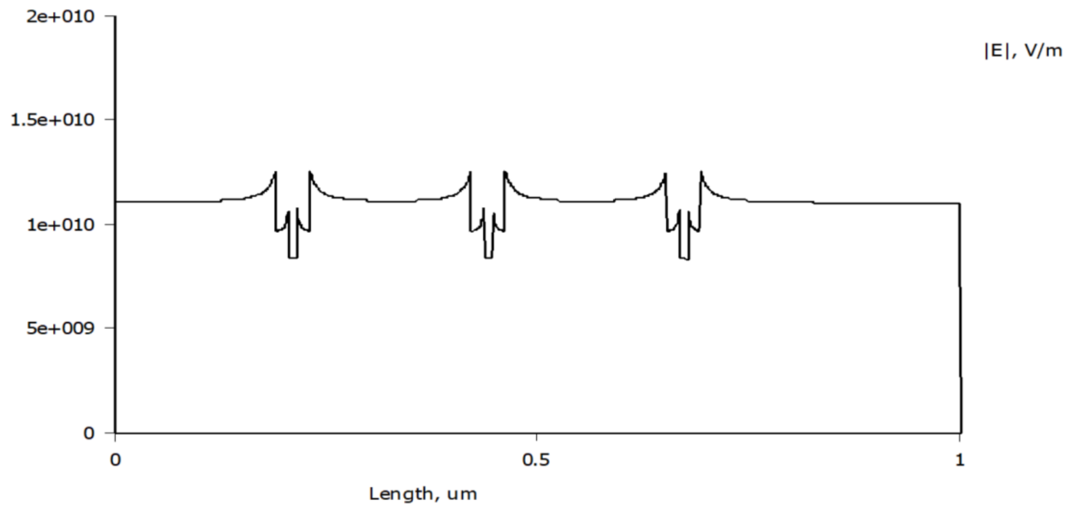

Figure 4.28 Electric Field Intensity at 30nm Interphase with 1.5wt% Filler Loading Graph

4.2.5.3 Filler Loading at 3.0wt%

Figure 4.28 shows the dispersion of the electric field intensity has increase when the higher value of filler loading added. The electric field intensity at around 1.131 x 10^{10} V/m to 1.153 x 10^{10} V/m. Figure 4.29 illustrates the waveform of the nanomaterial when 3.0wt% of filler loading were added.

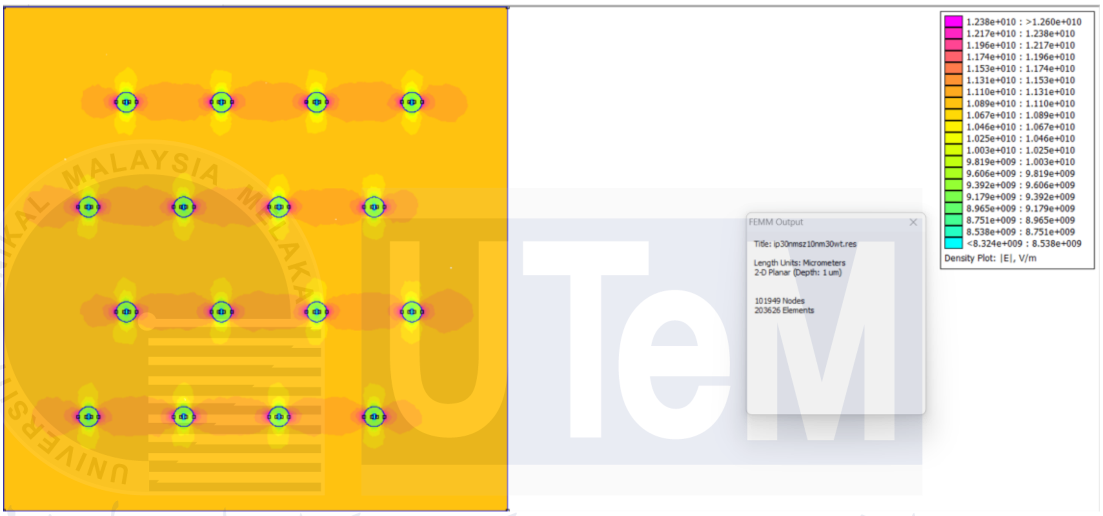

Figure 4.29 Electric Field Intensity at 30nm Interphase with 3.0wt% Filler Loading

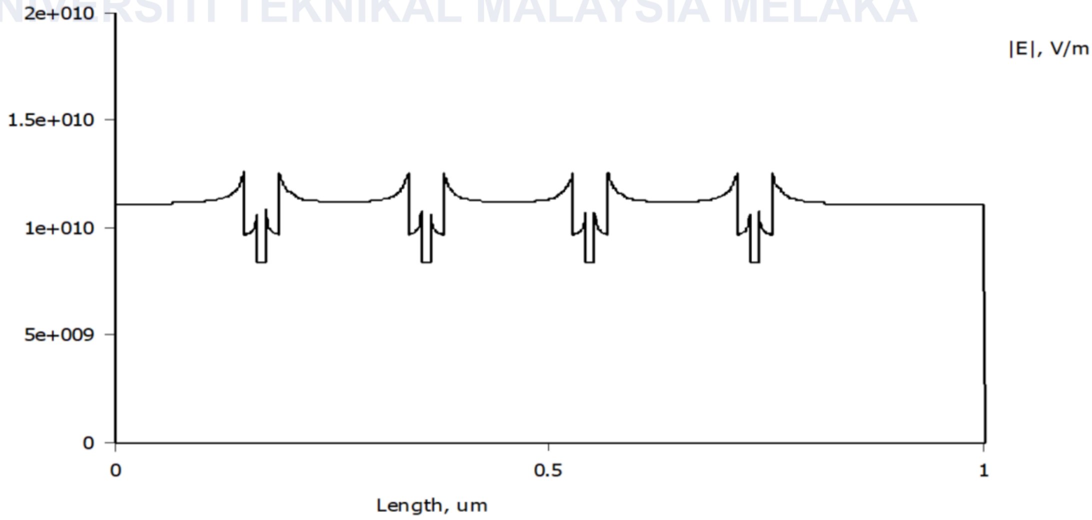

Figure 4.30 Electric Field Intensity at 30nm Interphase with 3.0wt% Filler Loading Graph

4.2.5.4 Filler Loading at 5.0wt%

At this part, it can be seen in Figure 4.30 that the value of nanoparticles is increasing to 5.0wt% and the dispersion of the electric field intensity has increase around 1.157 x 10^{10} V/m to 1.179 x 10^{10} V/m. It is shown that the peak electric field intensity is around 1.243 x 10^{10} V/m to 1.265 x 10^{10} V/m. Figure 4.31 illustrates the waveform of the nanomaterials when 5.0wt% of filler loading were added.

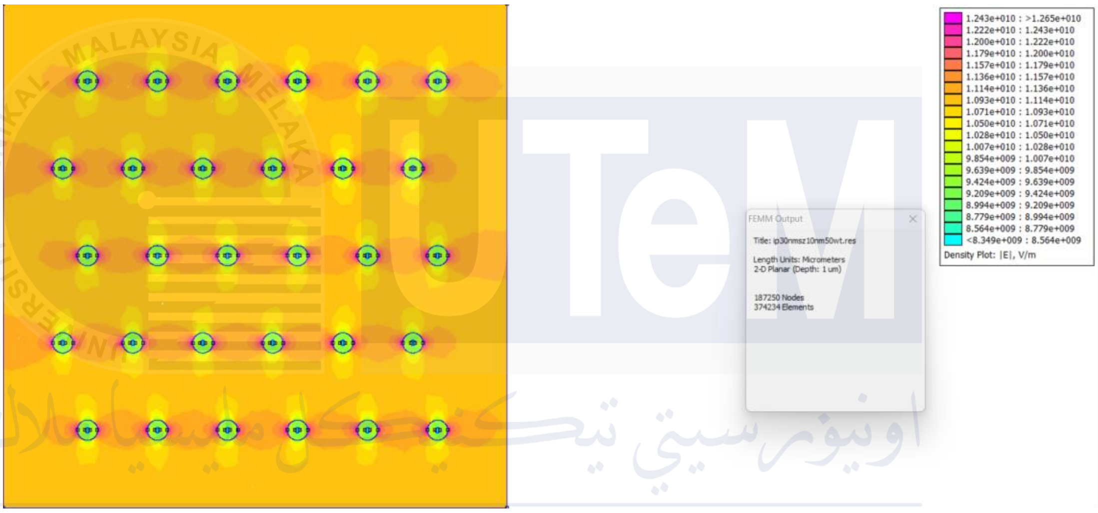

Figure 4.31 Electric Field Intensity at 30nm Interphase with 5.0wt% Filler Loading

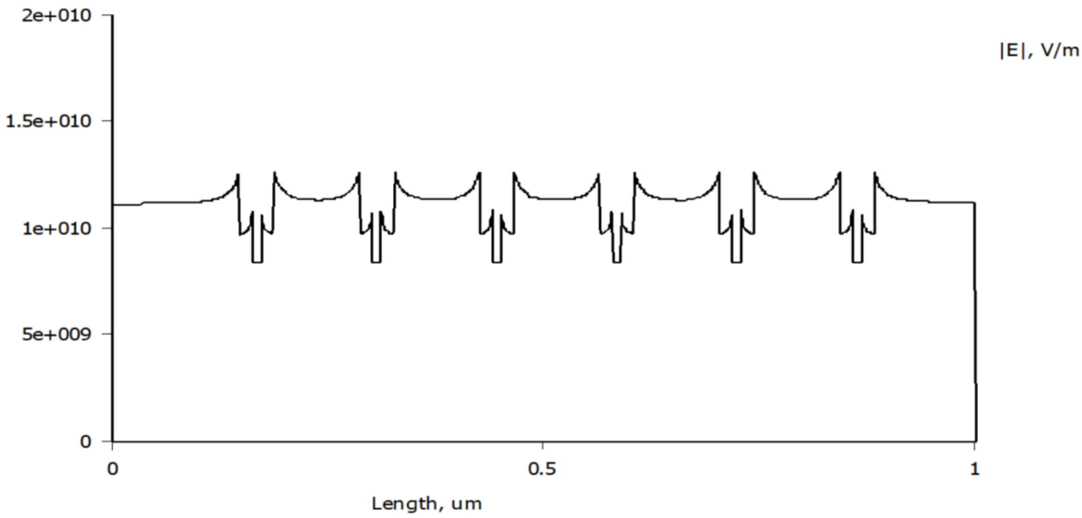

Figure 4.32 Electric Field Intensity at 30nm Interphase with 5.0wt% Filler Loading Graph

4.3 Discussion on the Effect of Different Filler Loading on Nanomaterials

Figure 4.32 shows that the electric field started to disperse and create more colour spectrum than the lower filler loading. However, it can be seen in Figure 4.33 that the dispersion of the electric field intensity started to disperse even more within each nanomaterials. It can be concluded that when the electric field is higher, the dispersion of electric field can be seen evenmore.

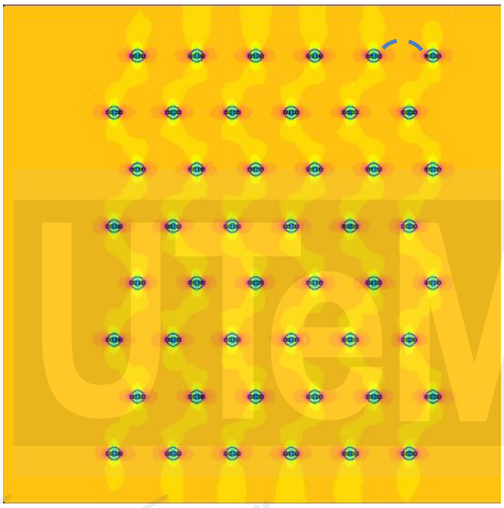

Figure 4.33 Electric Field Intensity Dispersion at 3.0wt% Filler Loading

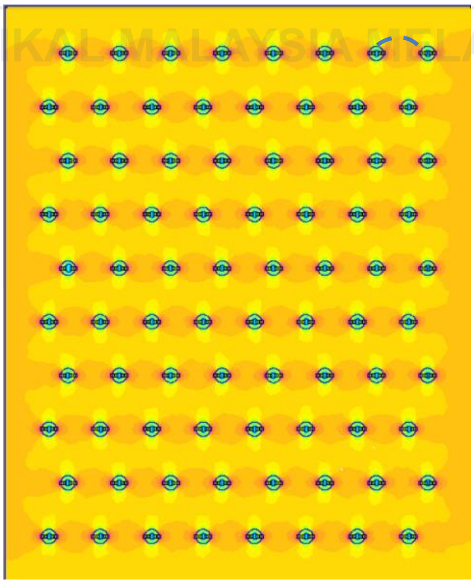

Figure 4.34 Electric Field Intensity Dispersion at 5.0wt% Filler Loading

It can be conclude that the value of electric field intensity for each filler loading is decreasing when the interphase value is bigger. Excessive filler content could affect the polymer's insulating characteristics, which may be undesirable in particular applications requiring dielectric properties. High electric field intensity can cause dielectric breakdown in insulating materials. This occurs when the material's insulating characteristics fail and it becomes conductive, causing in an unregulated flow of electricity. For example from previous researcher, nanofillers in nanocomposites such as silica (SiO2), alumina (Al2O3), and titania (TiO2) play an important role in improving the dielectric breakdown strength and partial discharge resistance of nanocomposites [14]. Table 4.1 shows the peak of electric field intensity for all parameters selected.

Table 4.1 Summary of Different Filler Loading Nanoparticles

	Interphase (nm)		
Weight Percentage (wt%)	**5**	**15**	**30**
0.5	1.294 x 10^{10} V/m to 1.318 x 10^{10} V/m	1.248 x 10^{10} V/m to 1.27 x 10^{10} V/m	1.232 x 10^{10} V/m to 1.254 x 10^{10} V/m
1.5	1.306 x 10^{10} V/m to 1.331 x 10^{10} V/m	1.251 x 10^{10} V/m to 1.273 x 10^{10} V/m	1.236 x 10^{10} V/m to 1.257 x 10^{10} V/m
3.0	1.285 x 10^{10} V/m to 1.309 x 10^{10} V/m	1.253 x 10^{10} V/m to 1.275 x 10^{10} V/m	1.238 x 10^{10} V/m to 1.260 x 10^{10} V/m
5.0	1.29 x 1010 V/m to 1.314 x 10^{10} V/m	1.272 x 10^{10} V/m to 1.296 x 10^{10} V/m	1.243 x 10^{10} V/m to 1.265 x 10^{10} V/m

Figure 4.35 shows that the Table 4.1 were tabulated by using a graph for the better analysis. Figure 4.35 shows that Table 4.1 was tabulated to a graph for better analysis and it can be seen that the smaller the nanofillers size, the higher the value of Electric Field intensity will be. As the weight percentage of filler loading rises from 0.5% to 5.0%, the electric field strength increases significantly throughout all interphase thicknesses. There is a continuous pattern that indicates that the electric field strength rises with weight %, independent of interphase thickness. In contrast, when the interphase thickness grows, the electric field intensity drops slightly with each weight percentage. The data gathered could potentially utilized to optimize filler

loading and interphase thickness in composite materials to attain the necessary electric field strengths.

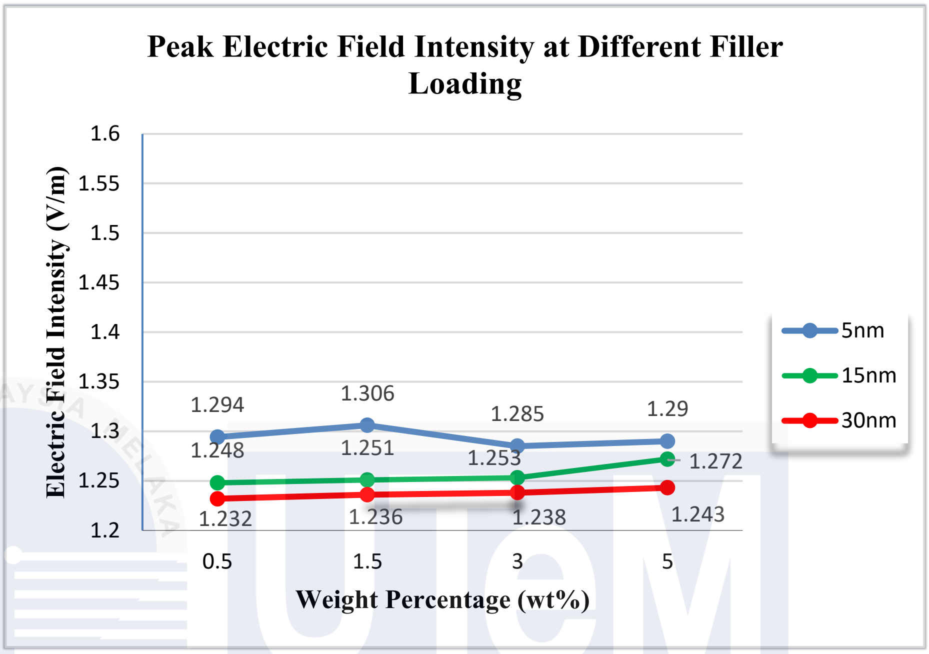

Figure 4.35 Summary of Electric Field Intensity Peak at Different Filler Loading

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the main intention of doing this research is to investigate the electric field analysis for Polymer Nanocomposites under Different Filler Loading Particles using FEMM 4.2 Software. By using the FEMM 4.2 software, the electric field intensity on certain materials was conducted and analyzed. The simulation results indicate that the filler wt% loading factor affects the electric field intensity. It indicated that the electric field intensity had a circular relationship with the filler wt%, with the peak electric field intensity decreasing as the filler wt% decreased. Thus, based on the first objective, it succeeded in modeling the polymer nanocomposite for an analysis on electric field distribution using Finite Elements Method Magnetics (FEMM) 4.2 software. The second objective where to determine the effect of electric field distribution upon different filler loading particles using Finite Elements Method Magnetics (FEMM) 4.2 software was successfully achieved. It can be concluded that when increasing the filler loading(wt%), the Electric Field intensity of the nanoparticles will be increase and this could affect the dielectric value.

5.2 Future Works

There are several recommendations for continuing research to measure electric field intensity based on different types of filler and their size. Previous papers have not explored this topic extensively. Although a simulation makes it possible to view and determine how the electric field strength is distributed concerning the interphase layer, it is still necessary to compare the simulation to the real measurement in lab work. This is because the simulation in FEMM does not account for other hidden factors that may influence the final result, such as accumulation. Accumulation occurs when many fillers adhere to each other, creating a microscale structure.

This is due to electrostatic force or dipole moment, which becomes a substantial influence as the filler reaches the nanoscale. The FEMM simulator can only replicate the perfect arrangement or configuration of the filling, not accumulation. To be confident with the conclusions of this research, the works must compare simulation results to actual measurements.

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