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Electric Field Analysis of Linear Low-Density Polyethylene (LLDPE)-NR Biocomposite Using FEMM Software

Muhammad Ariff Izuddin Ghazalee[1], **Nor Akmal Mohd Jamail**[1]*

[1,2]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: In the development of future electrical networks, it is crucial to develop new alternative insulating materials that can improve the performance of the next-generation high-voltage cables. The high electric field reduces the resistance of solid insulation and causes partial discharge that occurs through the impurities in a dielectric where this phenomenon causes ageing of the dielectric and ultimately leads to breakdown. Thus, this project seeks to analyze the electric field intensity of Low Linear Density Polyethylene (LLDPE) when added with 2.5%, 5.0%, 7.5% and 10.0% of different types of bio-filler such as pineapple leaves fibre, and oil palm empty fruit bunch. This can be achieved by creating a two-dimensional (2D) axisymmetric electrostatic model by using the Finite Element Method Magnetics (FEMM) 4.2 software. The results showed that the inclusion of bio-filler in LLDPE increased the maximum electric field intensity when compared with unfilled LLDPE. The electric field intensity also varied with the different weight percentages of biocomposite and their permittivity. As a result, the maximum electric field intensity was much lower for LLDPE added with a 2.5% loading of the pineapple leaves fibre. As an outcome, pineapple leaf fibre was the best composition because at the top sphere electrode than other compositions it has a lower electric field intensity, which tends to improve dielectric properties.

Keywords: Electric Field, Low Linear Density Polyethylene (LLDPE), Bio-filler, Finite Element Method (FEMM) Software, Permittivity

1. Introduction

High voltage (HV) insulator is an essential part of electrical power transmission and distribution systems, these insulators avoid excessive leakage of current to the earth from their supporting points. The actions and performance of insulators were investigated because of local conditions such as contamination, stress as well and broken or damaged structures.

**Corresponding author: norakmal@uthm.edu.my*

A material that prevents or slows the flow of electrical current is known as an insulator. Overhead insulators or outdoor insulators have dual functions, particularly for outdoor applications, support conductors mechanically and provide electrical protection to the power system network [1]. Depending on the materials used and their permittivity levels, each type of insulating material has a different electric field. Due to various electrical breakdown properties, electrical insulators made of glass, ceramic, and porcelain often fail to perform in large electrical fields. Thus, due to rising demands for greater voltage levels and improved insulation characteristics, it is crucial to build new electrical insulation material options.

Polymer biocomposites are made of a polymer and a bio-filler that give the matrix new properties. The most frequently used polymer in commercial and industrial products is Linear low-density polyethylene (LLDPE). LLDPE is one of the basic types of Polyethylene (PE) polymer. It is a thermoplastic polymer, which means that it can be melted to a liquid and remolded to a solid state. It is tough, relatively inexpensive and has excellent processability. Composite insulators have been proposed as a cost-effective replacement for ceramic and glass insulators. Furthermore, LLDPE is frequently utilized in the construction sector for pipe manufacturing and as an insulator in electrical equipment [2][3].

The objective was to gain a solid understanding of the electrical field strength of polymer LLDPE biocomposites due to normal conditions, which is the same process that causes pure polymers to malfunction. It is very important to use Finite Element Method Magnetics (FEMM) software to determine the electric field strength of the LLDPE-biocomposites insulator to ensure the credibility of polymer biocomposites' electrical field strength. Using FEMM-based software, the simulation results are used to investigate the electrical field characteristics of LLDPE-NR biocomposite under normal conditions

2. Methodology

The methodology of the project focuses on the analysis of the electric field intensity in relation to different percentages of biocomposite loading and permittivity. To simulate the results of electric field intensity, the FEMM 4.2 software is used. The section has covered the project framework and software development.

2.1 Research Framework

Figure 1 shows the flowchart of the planning process to compete for this project. This study begins with a literature review to gather important information regarding prior works on electric field analysis and material characteristics of biocomposite. To investigate the electric field intensity in various biocomposite weights due to normal conditions, the FEMM 4.2 program was used to create an axisymmetric model. The method was repeated by changing the relative permittivity of the sample. Repeat the simulation and analyze the simulation's properties until they are approved. values are obtained if the produced result does not match the specified value. Following that, the data is graphically analyzed and summarized in a table. Finally, the results are discussed in terms of the various biocomposites that were used to determine the optimal composition of bio-filler for solid insulation under normal conditions.

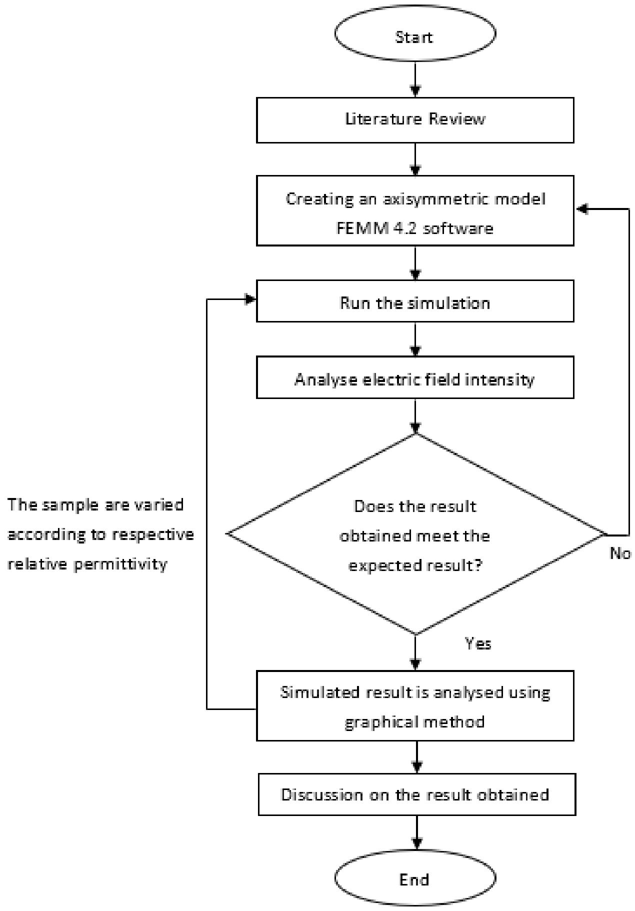

Figure 1: Flowchart of the planning process

2.1.1 Geometry of Electrode Configuration

The electrostatic model was created using the electrode arrangement that was employed in the lab, as shown in Figure 2. The electrode's size is based on the laboratory's actual length of the diameter sphere electrode is 5 cm. The sample is put between the two sphere electrodes are 8 cm long and 0.3 cm thick. The main objective of this project is to develop a power distribution cable that has been applied the voltage at the upper sphere electrode is fixed at 11 kV because the. According to IEC 60502-2, the 11 kV power line that follows British Standard BS 6622 is good for system installations such as distribution networks [4][5]. Because of the axisymmetric shape only half model was employed in the simulation.

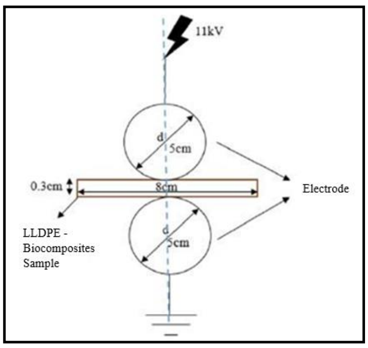

Figure 2: Geometry of electrode configuration

2.2 Relative permittivity of materials

The material characteristic to be considered for the electric field in the model is relative permittivity. There are differences in each LLDPE-NR biocomposite relative permittivity. To determine the dielectric constant of solid dielectric materials, a dielectric test apparatus is utilized. Table 1 summarizes the LLDPE-NR biocomposites sample that has been used for the relative permittivity in the software. The dialogue to enter the relative permittivity of each sample in the software.

Table 1: Permittivity for electric filed computation due to moisture content condition

Sample	Bio-filler content	Permittivity value
LLDPE	0	2.31
LLDPE + NR	0	3.60
LLDPE + NR + oil palm empty fruit bunch	2.5%	4.29
	5.0%	9.96
	7.5%	8.23
	10.0%	11.9
LLDPE + NR + pineapple leaves fibre	2.5%	7.60
	5.0%	10.10
	7.5%	6.57
	10.0%	13.60

2.3 Software development

The development of software is critical for the project of electrical field intensity with different biocomposite materials as a function of normal conditions and allow ability. The electrostatic problem is solved in multiple steps using the FEMM 4.2 software simulation. The method for modeling two-dimensional axisymmetric issues in electrostatics is illustrated in Figure 3 [6].

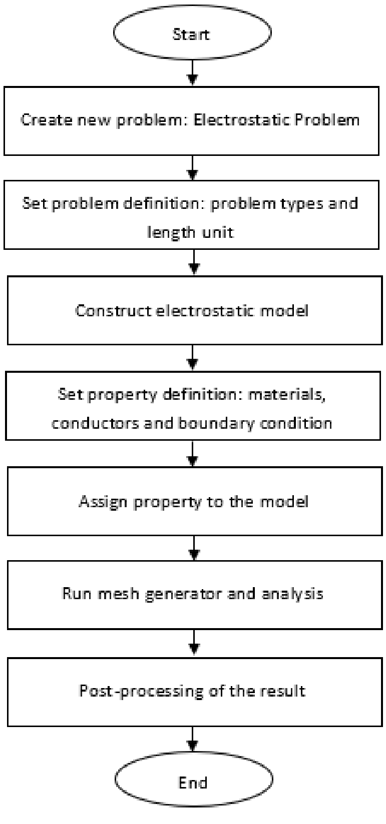

Figure 3: Flowchart of design 2D axisymmetric problems in electrostatics in software FEMM 4.2

3. Results and Discussion

This section discusses the results of the electric field intensity of the LLDPE-NR biocomposites. The results are obtained by simulating the electrostatic model in the FEMM software. All the data collected have been tabulated in tables and analyzed in the graph by using Microsoft Excel. The comparison between the electric field intensity for different percentages of biocomposite is also considered in this section. Then, this section explains which bio-filler is suitable for use as solid insulation.

3.1 Simulation Result of Electric Field

The electric field intensity will be affected differently depending on the permittivity value and voltage in normal conditions of LLDPE-NR biocomposites. Permittivity values vary depending on the weight of biocomposites. As a result, the aim of the study was to investigate the intensity of the electric field strength concerning different biocomposite weights and permittivity with voltage.

3.1.1 LLDPE Polymer Matrix with Bio-filler

The electric field strength intensity simulation result for the LLDPE-NR biocomposite filled with various values of OPEFB in the weight percentage of 2.5%, 5.0%, 7.5% and 10.0% was obtained using FEMM software and is presented in Table 2. In comparison to other LLDPE samples, including the bio-filler, the maximum electric field intensity of the unfilled LLDPE was the lowest. The maximum electric field produced by 5.0% of OPEFB was higher than that produced by 2.5%, 7.5% and 10.0% of OPEFB. The result shows 5.0% of OPEFB is the maximum electrical field produced by 10.0% of OPEFB is 2.948 MV/m, while the highest maximum electric field is 4.679 MV/m, this is considerably higher than the electrical field produced by 10.0% but significantly less than the electrical field produced by 2.5% and 7.5% of the sample. Additionally, the maximum intensity of the electric field changed according to the permittivity and voltage of the filler in normal conditions.

Table 2: The sample of LLDPE biocomposite to show the electric field

Sample	Bio-filler content (wt%)	Relative Permittivity	Minimum electric field, Emin (MV/m)	Maximum electric field, Emax (MV/m)
LLDPE	0	2.31	3.688	3.904
LLDPE + NR	0	3.60	3.516	4.219
LLDPE + NR + oil palm empty fruit bunch	2.5%	4.29	3.422	4.278
	5.0%	9.96	3.516	4.679
	7.5%	8.23	3.684	4.605
	10.0%	11.9	2.948	4.422
LLDPE + NR + pineapples leaves fibre	2.5%	7.60	3.341	4.176
	5.0%	10.10	3.573	4.764
	7.5%	6.57	3.505	4.906
	10.0%	13.60	3.525	5.287

The electric field intensity for LLDPE and various weights of empty fruit bunches from oil palms are compared in Figure 4. The electric field is gauged from the sample layer that is closest to the positive conductor before the sample reaches its endpoint. The surface of the sample, which is closest to the electrodes, has the strongest electric field intensity, as seen in the graph. The electric field weakens with increasing distance from the conductor surface. Additionally, the results indicate that 5.0% of OPEFB has a greater electric field than 2.5% of OPEFB. Additionally, the maximum intensity of the electric field changed according to the permittivity and voltage of the filler in normal conditions. The electric field intensity is greatest at the sample's surface, which is closest to the electrodes. As the distance from the conductor surface increases, the electric field decreases. The result also shows that 2.5% of OPEFB has a lower electric field while 5.0% of OPEFB has a higher electric field.

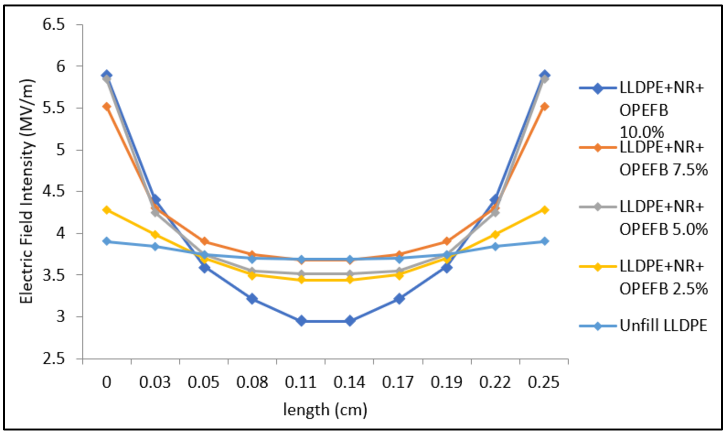

Figure 4: Graph of Electric field intensity for LLDPE-NR with OPEFB 2.5%, 5.0%, 7.5% and 10% with unfilled LLDPE as standard

The sample LLDPE-NR biocomposite electric field intensity with different weights of PALF in percentages of 2.5%, 5.0%, 7.5% and 10.0% is shown in Table 2, which is produced on FEMM simulations. For reference, the maximum electric field intensity of the unfilled LLDPE was the highest when compared to other LLDPE samples including the bio-filler PALF. The maximum electric field produced by 10.0% of PALF to LLDPE was higher than that produced by 2.5%, 5.0%, and 7.5% of PALF. The introduction of 10.0% of PALF results in the highest maximum electric field is 5.287 (MV/m). Under normal conditions, the maximum electric field intensity varied depending on the relative permittivity and the voltage of the filler. The comparison of the electric field intensity for LLDPE and various weights of pineapple leaves fibre is shown in Figure 5. From the layer of the sample that is closest to the positive conductor to the sample's endpoint, the electric field is measured. The graph shows that the sample's surface, which is closest to the top sphere electrode, has the strongest electric field. The final result also revealed that 5.0% of PALF has a smaller electric field than 7.5% of PALF.

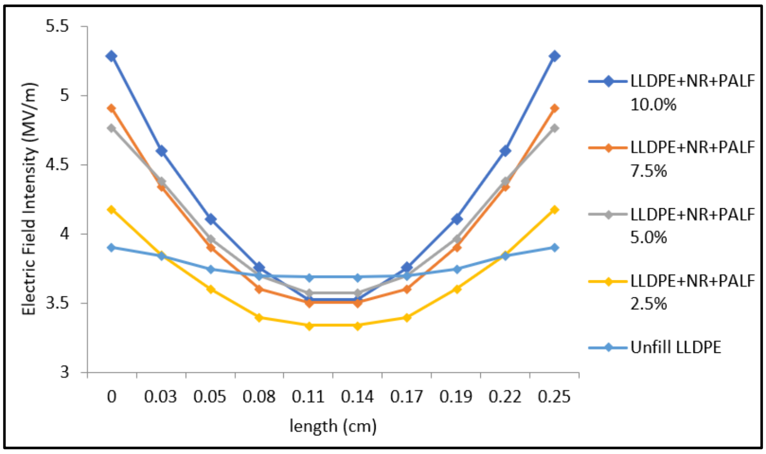

Figure 5: Graph of Electric field intensity for LLDPE-NR with PALF 2.5%, 5.0%, 7.5% and 10% with unfilled LLDPE as standard

3.1.2 Comparison between 2.5% of biocomposites

Throughout to determine the best composition of oil palm empty fruit bunch and pineapple leaves fibre bio-filler as solid insulation. Thus, the electric field intensity of LLDPE was compared to that of 2.5% of biocomposites. The electric field intensity for a sample LLDPE containing 2.5% biocomposites has been shown in Figure 6. The analysis found that the electric field intensity is the largest on the part of the sample closest to the top electrode. The electric field becomes lower as a moves away from the conductor surface. For reference, the electric field intensity was highest in the LLDPE sample compared to the unfilled LLDPE samples. When the sample length is smaller than 0.03 cm, OPEFB bio-filler has the highest electric field from the surface, while PALF bio-filler, which makes up 2.5% of biocomposites, has the lowest electric field. The results demonstrate that OPEFB bio-fillers continue to have a greater electric field intensity whereas PALF bio-fillers have the lowest electric field intensity for lengths ranging from 0.03 cm to 0.22 cm.

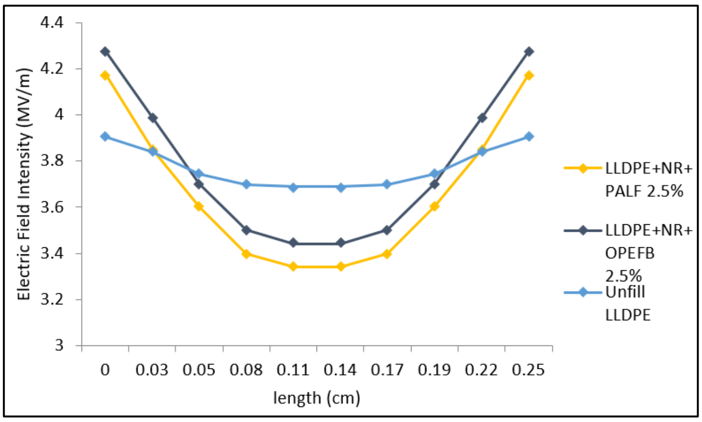

Figure 6: Electric field intensity comparison for LLDPE sample with 2.5% biocomposites

4. Discussion

Based on the results, varying biocomposite weights with voltage produce varying electric field strengths in the resulting LLDPE-NR biocomposites. In the LLDPE-NR biocomposite samples, if one goes from the conductor area, the electric field weakens. When compared to the bottom electrode, the top electrode appears to have a higher electric field intensity. All samples have the highest electric field intensity at their surface, closest to the top electrode, according to the analysis. This is related to the top electrode obtaining a high voltage, which produces the strongest electric field. When an electric field is applied to a sample, electrons and positive ions migrate towards the electrode with the opposite polarity, positively charged ions move towards the cathode and negatively charged ions go towards the anode. As a result, the field accumulates at both electrodes, resulting in a decrease in insulation thickness in the central region. [7].

When compared to an unfilled polymer matrix, the electric field's intensity is impacted by the presence of bio-filler in a polymer matrix. Using simulation, it was determined the different biocomposites between weights and permittivity affected the voltage of the final LLDPE-NR biocomposites. The results show that unfilled LLDPE biocomposites have a low electric field intensity than 2.5%, 5.0%, 7.5% and 10.0% biocomposites. This means that the intensity of the minimum electric field varies with the relative permittivity and normal voltage of the bio-filler.

Biocomposite LLDPE-NR of The electric field intensity is impacted by the difference in polarity between natural fibres and the polymer matrix. The majority of biofillers are hydrophilic, whereas LLDPE is a hydrophobic material. When hydrophilic bio-filler is added to hydrophobic LLDPE, during the reinforcing process, the final LLDPE -NR biocomposite material has the potential to absorb water from the surroundings. Additionally, it was hard to achieve sufficient homogeneity, particularly when there was a mismatch between the polyethylene and the biobased reinforcement and there was a high filler content. The overall performance of LLDPE -NR biocomposites is reduced due to minimal surface interaction, limited interfacial 50 bonding, and a lack of compatibility between highly polar bio-filler and non-polar LLDPE matrix [8].

Alaa Abd Mohammed [9] has established that the formation of an accumulation of water molecules can occur in the presence of a bio-filler-matrix interface. Due to the difficulties in establishing a homogenous filler dispersion at high filler contents, the formation of agglomerations increases as filler content rises.

According to N.A.M. Jamail [10], the composite sample's filler agglomeration tends to boost the migration of charges, which may lead to better conductivity. Because it had the lowest maximum electric field and conductivity values in contrast to the other samples in the same group, the sample containing 2.5% biocomposites was the best sample.

The electric field intensity of sample LLDPE was compared to the electric field intensity of 2.5% of biocomposites to determine the optimal composition of oil palm empty fruit bunch and pineapple leaves fibre bio-filler as solid insulation. The simulation results clearly illustrate that when the PALF bio-filler is combined with LLDPE, the maximum electric field intensity is the lowest when compared to the OPEFB bio-filler.

Furthermore, electrical voltage occurs in a high field region dependent on the material's electric field intensity, resulting in a reduced electric field strength. As a result, PALF bio-filler was the best composition because the top electrode has lower electrical field intensity than other compositions, which enhances dielectric characteristics.

5. Conclusion

In conclusion, all of the project's objectives were reached with the assistance of modeling using FEMM software. The project was the creation of a biocomposite LLDPE -NR electrostatic model. The Finite Element Magnetics approach, an axisymmetric electrostatic design with two electrodes, and one LLDPE-NR biocomposite sample were used to successfully model a version of the FEMM software version 4.2. The simulation can be used to analyze the voltage, distribution, and strength of the electric field for various biocomposite weights. In comparison to LLDPE that isn't filled, the electric field intensity is generally greatly reduced when LLDPE is combined with bio-filler. Employing FEMM-based software, the project was accomplished by examining the electrical field properties of LLDPE-biocomposite under normal conditions. The simulation findings show that compared to 2.5%, 5.0%, 7.5%, and 10.0% biocomposites, unfilled LLDPE biocomposites have a lower electric field intensity. This shows that under typical circumstances, the maximum electric field strength varies in accordance with the permittivity and voltage of the bio-filler. This project was finding the ideal ratio of bio-filler made from empty fruit bunches from oil palms and pineapple leaves for solid insulation. The findings demonstrated a connection between the voltage, permittivity value, and electric field strength under standard conditions. The best composition in this regard was PALF bio-filler because, compared to other compositions, it has a lower electric field intensity at the top electrode, which tends to improve dielectric characteristics.

Acknowledgement

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