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Analysis of Electric Field for HDPE-NR Biocomposite using Finite Element Method

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Abstract: In developing future electrical networks, it is crucial to develop new alternatives insulating materials which 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 occurs through the impurities in a dielectric where this phenomenon causes ageing to the dielectric and ultimately leads to breakdown. Thus, this paper seeks to analyse the electric field intensity of High Density Polyethylene (HDPE) when added with 10%, 20% and 30% of different types of bio-filler such as coconut coir fibre, 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 HDPE increased the maximum electric field intensity when compared with unfilled HDPE. The electric field intensity also varied with the different percentages loading of biocomposite and their permittivity. As a result, the maximum electric field intensity was much lower for HDPE added with a 10% loading of the oil palm empty fruit bunch. Hence, oil palm empty fruit bunch was the best composition as it tends to improve the dielectric properties since it has a lower electric field intensity at the top sphere electrode as compared to other compositions.

Keywords: Electric Field, High Density Polyethylene (HDPE), Bio-filler, Finite Element Method (FEMM) Software, Permittivity

1. Introduction

High voltage transmission is needed to transmit power over long distances. The need for a high transmission voltage as the current is reduced for a given transmitted power. Power losses can be minimized by reducing the current. Therefore, one of the essential factors that should be considered is using proper cable insulating materials when delivering electricity through high voltage transmission. An insulator is a material that is a poor conductor of electricity [1]. Every type of insulating material

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has a different electric field depending on the different material used and their permittivity values. Electrical insulators made up of glass, ceramic, and porcelain often failed to operate under large electrical fields due to electrical breakdown properties. Thus, it is crucial to develop new alternatives for electrical insulation material due to increased demands for higher voltage levels and to provide better insulation properties.

Polymer composites are combining one or more materials with different characteristics into a polymer matrix, producing new features in the polymer in term of chemical and physical properties of the polymer [2]. Polymer biocomposites are the combination of polymer and bio-filler, producing new properties of the matrix. The rise in demand for natural fibre composites or biocomposites is due to the growth of awareness of global environmental problems and health hazards. Hence, many researchers across the globe actively studied biocomposites due to their low cost and environmentally friendly such as renewability, recyclability, biodegradable, and carbon dioxide neutral as compared with synthetic fibres [3].

Nevertheless, polymer biocomposites also exhibit breakdown failures, which is the same process that causes pure polymers to malfunction. With the aim to clearly understand the electrical field strength of polymer biocomposites, it is vital to analyse the electric field intensity of the HDPE-NR biocomposites insulator by using Finite Element Method Magnetics (FEMM) software. The result obtained from the simulation is used to evaluate the best composition of bio-filler as solid insulation.

2. Methodology

The project methodology focusses on the analysis of the electric field intensity in relation to different percentages loading of biocomposite and their permittivity. FEMM 4.2 software is used to simulate the results of electric field intensity. Research framework and software development have been discussed in the section.

2.1 Research framework

Figure 1 illustrated the flowchart for the whole project planning. This project starts with doing the literature review to gain some related information on the previous researches about the electric field analysis and the characteristic of the materials. An axisymmetric model was built using FEMM 4.2 software to obtain the electric field intensity in different percentages loading of biocomposite. The steps are repeated by varying the sample according to respective relative permittivity. If the result obtained does not meet the expected result, simulate again, and check the simulation properties until the verified results are achieved. Next, the data collected is analysed using the graphical method and summarized in a table. Lastly, the results obtained are discussed by comparing the different biocomposites used in order to find out the best composition of bio-filler as solid insulation.

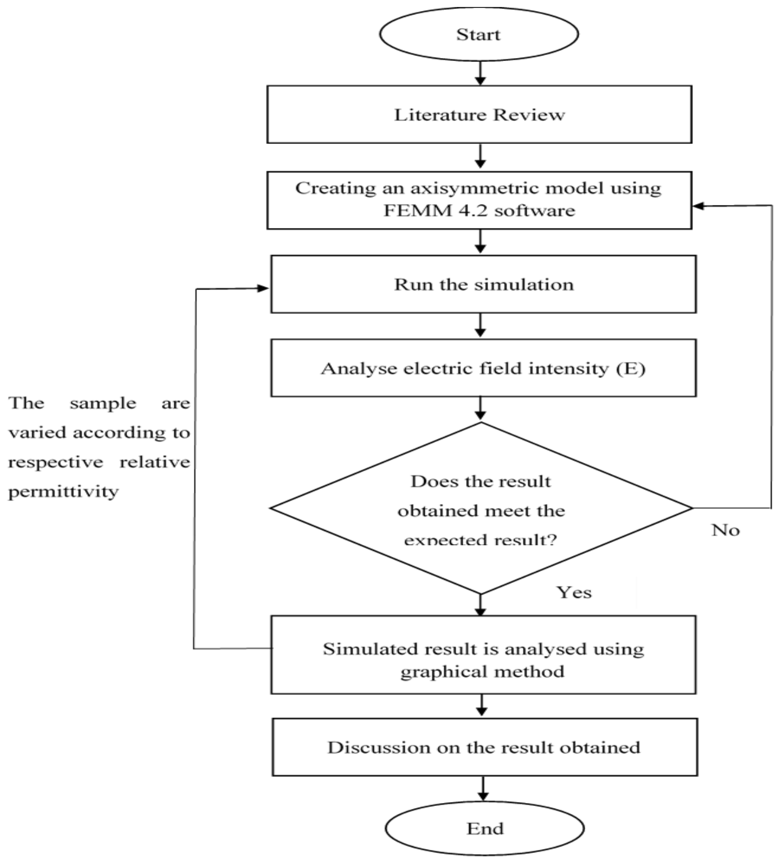

Figure 1: Research framework

2.1.1 Geometry of electrode configuration

The electrostatic model has been designed based on the electrode configuration used in the laboratory, as pictured in Figure 2. The size of the electrode is based on the actual diameter sphere electrode used in the laboratory, which is 5 cm. The sample inserted between the two sphere electrodes, which have a length of 8 cm and a thickness of 0.3 cm. The voltage at the upper sphere electrode is fixed at 11 kV, as this project is mainly focused on power distribution cable. The British Standard BS 6622 11 kV power cable, according to IEC 60502-2 is suitable for fixed installations such as distribution networks [4-5]. The only half model has been used in the simulation due to the axisymmetric geometry.

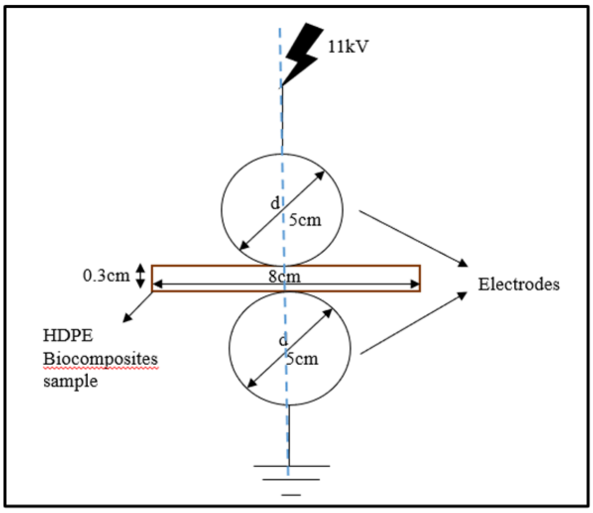

Figure 2: Geometry of electrode configuration

2.2 Relative permittivity of materials

The material property to be considered for the electric field of the model is relative permittivity. Each of the HDPE-NR biocomposites is different from the relative permittivity. The dielectric test fixture is used to assess the dielectric constant of solid dielectric materials. HDPE is used as the base matrix and mixed with NR grade SMR CV 10 along with the bio-filler. HDPE-NR biocomposite is comprised of 80% HDPE and 20% NR with the ratio composition of 80:20 and an additional of different amounts of bio-filler weightage percentage in the range of 10%, 20%, and 30%. The HDPE-NR biocomposites sample and its permittivity used for the simulation are summarized in Table 1.

Table 1: Permittivity for electric field computation

Sample	Bio-filler content (%)	Permittivity value
Unfilled HDPE	0	2.17
HDPE + NR +oil palm empty fruit bunch	10	2.78
	20	3.18
	30	3.45
HDPE + NR + coconut coir fibre	10	2.98
	20	4.87
	30	5.18
HDPE + NR + pineapple leaves fibre	10	3.37
	20	5.48
	30	5.51

2.3 Software development

Software development is essential for the analysis of electric field intensity in relation to different percentages loading of biocomposite and their permittivity. The simulation in FEMM 4.2 software is demonstrated in several steps to solve the electrostatic problem. Figure 3 shows the process of designing 2D axisymmetric problems in electrostatics [6].

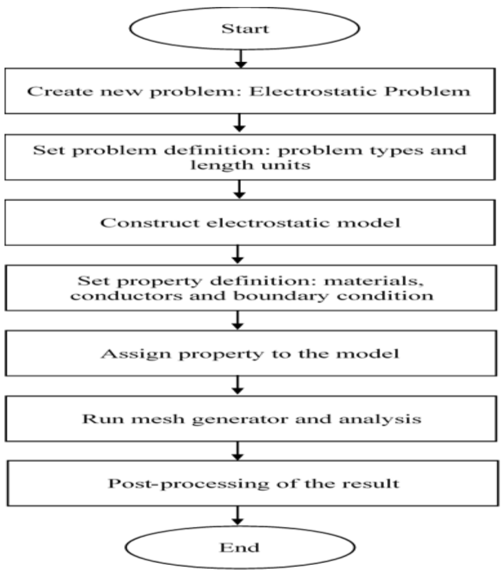

Figure 3: Steps for designing 2D axisymmetric problems in electrostatics

3. Results and Discussion

This section discusses the results of the electric field intensity of the HDPE-NR biocomposites. The results are obtained by simulating the electrostatic model in the FEMM software. All the data collected that have been tabulated in tables and anlysed 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 in which bio-filler is suitable used as solid insulation.

3.1 Simulation Result of Electric Field

The permittivity value of HDPE-NR biocomposites will result in a different effect on the electric field intensity. The different percentages loading of biocomposites has different permittivity values. Hence, the analysis was done to observe the electric field intensity in relation to different percentages loading of biocomposite and their permittivity.

3.1.1 HDPE Polymer Matrix with Bio-filler

Table 2 represents the simulation result of electric field intensity for the HDPE-NR compound filled with different amounts loading of bio-filler in a range of 10%, 20%, and 30% was recorded by using FEMM software. For reference purposes, the maximum electric field intensity of the unfilled HDPE showed the lowest among other HDPE samples with the inclusion of the bio-filler. By adding 30% of bio-filler to HDPE, the maximum electric field became higher than 10% and 20% of bio-filler. It is shown that the inclusion of 30% of PALF has the highest maximum electric field, which is 5.120 MV/m. Whereas, the inclusion of 10% of EFB shown the lowest maximum electric field, which is 4.368 MV/m, even lower compared to both 20% and 30% loading sample. Besides, the maximum electric field intensity varied depending on the filler permittivity. The higher the permittivity value of the sample, the higher the maximum electric field. The results mean that the inclusion of bio-filler can increase the maximum electric field intensity.

Table 2: Electric field intensity of HDPE polymer matrix with bio-filler

Sample	Bio-filler content (%)	Relative Permittivity	Minimum electric field, Emax (MV/m)	Maximum electric field, Emin (MV/m)
Unfilled HDPE	0	2.17	3.534	4.208
HDPE + NR + oil palm empty fruit bunch	10	2.78	3.499	4.368
	20	3.18	3.477	4.474
	30	3.45	3.462	4.547
HDPE + NR + coconut coir fibre	10	2.98	3.488	4.421
	20	4.87	3.387	4.938
	30	5.18	3.371	5.026
HDPE + NR + pineapple leaves fibre	10	3.37	3.466	4.525
	20	5.48	3.356	5.111
	30	5.51	3.355	5.120

The graph shows in Figure 4 is the comparison of the electric field intensity for HDPE with different percentage loading of oil palm empty fruit bunch. The measurement of the electric field is obtained from the layer of the sample near to the positive conductor until the end point of the sample. From the graph, the electric field intensity is the highest at the surface of the sample, which is closest to the top sphere electrode. As the distance increases from the conductor sphere surface, the electric field decreases. Besides, the result shows that when the length of the sample is within 0.07 cm from the surface of the sample, 10% of EFB loading has a lower electric field, while 30% of EFB loading has a higher electric field. However, the data shows the opposite result in the range of length between 0.07 cm and 0.23 cm, where 10% of EFB loading shows higher electric field intensity, whereas 30% of EFB loading shows the lowest electric field intensity. Hence, as the percentage loading of EFB increases, the minimum electric field became lower.

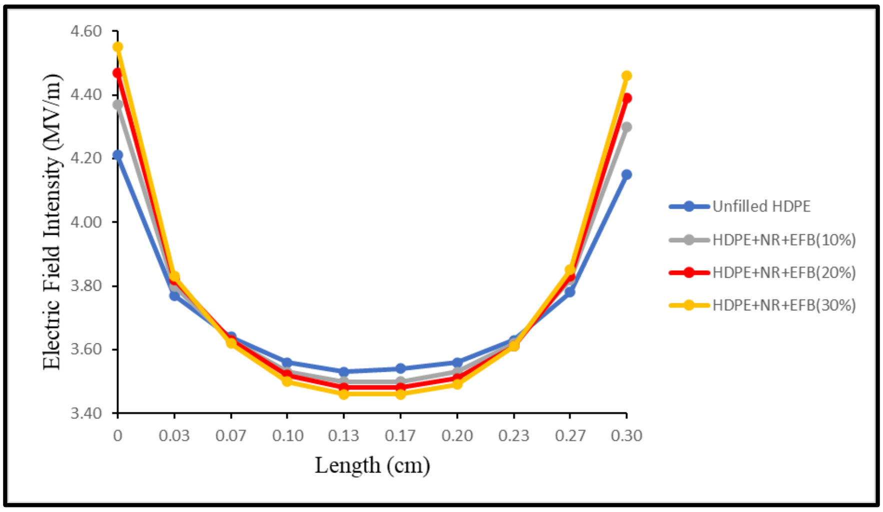

Figure 4: Electric field intensity for HDPE with 10%, 20%, and 30% of oil palm empty fruit bunch with unfilled HDPE as a reference

The comparison of the electric field intensity for HDPE with different percentage loading of CCF and PALF are illustrated in Figure 5 and Figure 6, respectively. The measurement of the electric field is obtained from the layer of the sample near to the positive conductor until the end point of the sample. The electric field intensity of HDPE with CCF or PALF show a similar trend as HDPE with EFB, where the electric field decreases as the distance increases from the conductor sphere surface. From the both graphs, the electric field intensity is the highest at the surface of the sample, which is closest to the top sphere electrode. The results also show that 10% of CCF or PALF loading has a lower electric field, while 30% of CCF or PALF loading has the largest electric field when the length of the sample is within 0.07 cm from the surface of the sample. In contrast, the results show the opposite outcome in the range of length between 0.07 cm and 0.23 cm, where 10% of CCF or PALF loading shows the highest electric field intensity, whereas 30% of CCF or PALF loading shows the lowest electric field intensity among CCF or PALF bio-filler. Hence, as the percentage loading of bio-filler increases, the minimum electric field became lower. By comparing to different percentage loading of bio-filler, the change of the electric field against the length of the samples can be clearly seen. As less filler loading is added to the HDPE, the separation distance between the particles increases results in less distorted electric field in the HDPE-NR biocomposites.

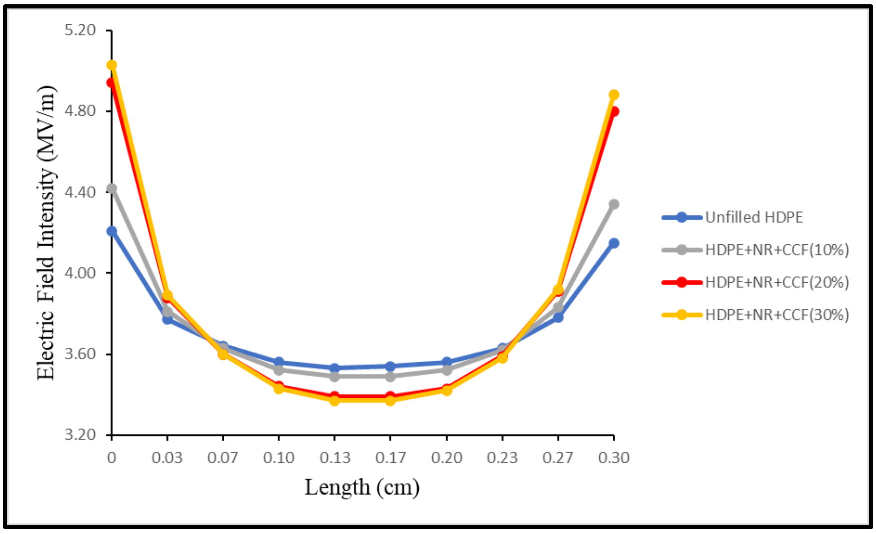

Figure 5: Electric field intensity for HDPE with 10%, 20%, and 30% of coconut coir fibre with unfilled HDPE as a reference

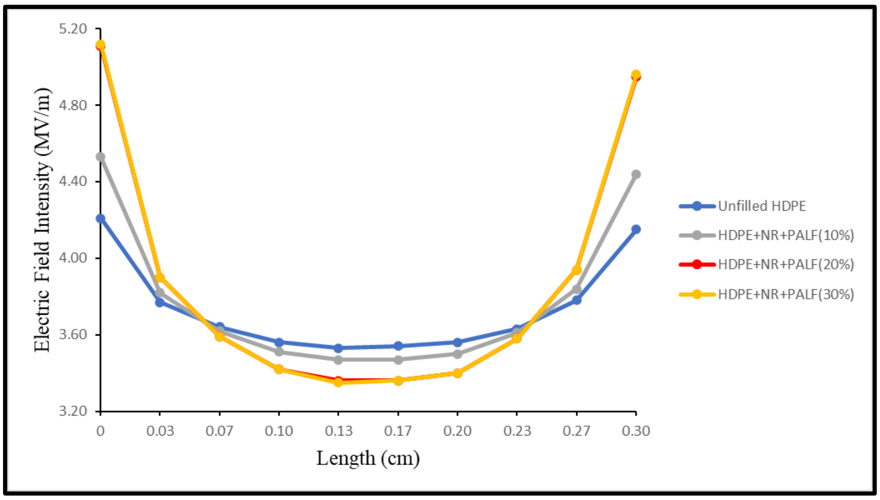

Figure 6: Electric field intensity for HDPE with 10%, 20%, and 30% of pineapple leaves fibre with unfilled HDPE as a reference

3.1.2 Comparison between 10% loading of biocomposites

As stated in section 3.1.1, when less filler loading is added to the HDPE, the separation distance between the particles increases results in less distorted electric field in the HDPE-NR biocomposites. Hence, a 10% loading of biocomposites showed a less distorted electric field as it has the lowest permittivity value as compared with 20%, and 30% of biocomposites. For the purpose of this discussion, the comparison of electric field intensity for sample HDPE with 10% loading of biocomposites was done in order to evaluate the best composition between coconut coir fibre, pineapple leaves fibre, and oil palm empty fruit bunch bio-filler as solid insulation. For the purpose of measuring the electric field intensity, the measurement is obtained from the layer of the sample near to the positive conductor until the end point of the sample.

Figure 7 depicted the electric field intensity for sample HDPE with a 10% loading of biocomposites. From the analysis, the surface of the sample, which is closest to the top sphere electrode shows the highest electric field intensity. The electric field intensity decreases as the distance increases from the conductor sphere surface. For reference purposes, the electric field intensity of the unfilled HDPE showed the lowest among other HDPE samples with the inclusion of 10% bio-filler. As observed, when the length of the sample is within 0.07 cm from the surface of the sample, PALF bio-filler shows the highest electric field, while EFB bio-filler shows the lowest electric field among 10% loading of biocomposites. However, the data shows the opposite result in the range of length between 0.07 cm and 0.23 cm, where the EFB bio-filler shows higher electric field intensity, whereas PALF bio-filler shows the lowest electric field intensity.

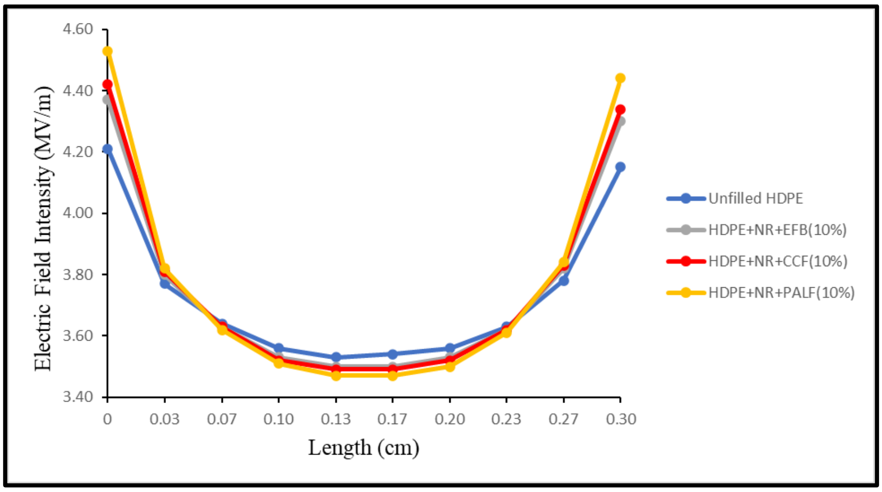

Figure 7: Comparison of electric field intensity for sample HDPE with 10% loading of biocomposites

4. Discussions

From the result obtained, the difference in electric field intensity of different percentages loading of biocomposite on the resulting HDPE-NR biocomposites can be noticed. The shape of the graphs for all the HDPE-NR biocomposite samples is in a parabolic shape, where the electric field decreases as the distance increases from the conductor sphere surface. The electric field intensity of the samples seems higher at the top sphere electrode when compared to the bottom sphere electrode. From the analysis, all the samples have the maximum electric field intensity at the surface of the sample, which is closest to the top sphere electrode. This is because a high voltage of 11 kV is applied to the top sphere electrode leading to the highest electric field intensity. When an electric field is applied to the sample, the electrons and positive ions migrate toward the electrode of opposite polarity, where the positive charge moves towards the cathode and negative charge moves toward the anode. The effect is an accumulation of the field near both electrodes and a consequent reduction in the central region of the insulation thickness [7].

It is observed that the inclusion of bio-filler in a polymer matrix affects the electric field intensity compared to the unfilled polymer. The effects of different percentages loading of biocomposites and their permittivity in the resulting HDPE-NR biocomposites was analysed by simulation. The simulation results indicated that 30% of biocomposite shows higher electric field intensity compare to 10% and 20% biocomposite. Hence, the higher the percentage loading of biocomposite in a polymer, the higher the maximum electric field intensity it is. This is because a high percentage loading of biocomposite having higher permittivity value, which results in higher electric field intensity than low percentage loading of biocomposite. This means that the maximum electric field intensity is changed depending on the bio-filler permittivity.

This result agreed with the work of K.Y.Lau [8] which clarified that higher permittivity values within interphase result in more distorted electric field distribution and negatively affect the breakdown strength of the nanocomposites. As less filler loading is added to the HDPE, the separation distance between the particles increases and further away from each other which results in a less distorted electric field in the HDPE-NR biocomposites. Therefore, the 10% loading of biocomposite would seem to be preferable over 20% and 30% biocomposite counterparts, since it results in less distorted electric field in the high field region.

Besides, the polarity difference between natural fibres and polymer matrix also affects the electric field intensity of the HDPE-NR biocomposites. Most of the bio-filler are hydrophilic in nature, while HDPE is commonly hydrophobic materials. The addition of hydrophilic bio-filler to hydrophobic HDPE would provide the resulting HDPE-NR biocomposite material to become a tendency to absorb water from the surrounding during the reinforcement process. Moreover, there was difficulty in achieving good homogeneity, especially in the presence of high filler content when a mismatch of polyethylene and biobased reinforcement. This resulted in a low surface interaction, limited interfacial bonding, a lack of compatibility between highly polar bio-filler and non-polar HDPE matrix reduces the overall performance of HDPE-NR biocomposites [9].

Alaa Abd Mohammed [10] has shown that the presence of biofiller-matrix interface can cause the formation of agglomeration of water molecules. As the filler content increases, the creation of agglomerations increases due to the complexities of obtaining a homogeneous filler dispersion at high filler content. According to N.A.M. Jamail [11], agglomeration of fillers in the composite sample tends to increase the movement of charges that can cause higher conductivity. Hence, the sample with the amount of 10% loading of biocomposites was the best sample as it had the lowest maximum electric field and conductivity compared to other samples within the same group.

The comparison of the electric field intensity for sample HDPE with 10% loading of biocomposites was done in order to evaluate the best composition between coconut coir fibre, pineapple leaves fibre, and oil palm empty fruit bunch bio-filler as solid insulation. Simulation results clearly demonstrate that EFB bio-filler when added to HDPE shows the lowest maximum electric field intensity compare to CCF and PALF bio-filler. This is due to the resulting HDPE-NR EFB have lower permittivity value than HDPE-NR CCF and HDPE-NR PALF. This means that the maximum electric field intensity varied depending on the resulting HDPE-NR biocomposite permittivity. The lower permittivity it is, the lower the maximum electric field intensity.

Moreover, electrical breakdown depends on the electric field intensity of the material and happens in a high field region, this would result in a lower breakdown strength. From this study, the result obtained is focused more on the high field region which is closest to the top sphere conductor. Thus, EFB bio-filler was the best composition as it tends to improve the dielectric properties since it has a lower electric field intensity at the top sphere electrode as compared to other compositions.

4. Conclusion

In conclusion, all the objectives for this project were achieved well with the help of simulation by using FEMM software. This project was achieved by creating an electrostatic model of HDPE-NR biocomposite. An axisymmetric electrostatic model contains two sphere electrodes and one HDPE-NR biocomposite sample was successfully modelled using Finite Element Magnetics Method (FEMM) 4.2 software. The electric field intensity in relation to different percentages loading of biocomposite and their permittivity had been analysed. The results demonstrate that electric field intensity influenced by the percentages loading of biocomposites and their permittivity value. A high percentage loading of biocomposite having higher permittivity value, which results in higher electric field intensity. Meanwhile, the electric field intensity reduces when the distance between neighbouring particles separated far away from each other, this phenomenon commonly correlated with a polymer containing a lower percentage loading of biocomposite. Thus, the sample with the amount of 10% loading of biocomposites was the best sample as it had the lowest maximum electric field intensity compared to other samples within the same group. The results showed that the electric field intensity has a relationship with the permittivity value where the maximum electric field intensity will get to be lower when the permittivity value of the resulting HDPE-NR biocomposite is lesser. Along these lines, EFB bio-filler was the best composition as it tends to improve the dielectric properties since it has a lower electric field intensity at the top sphere electrode as compared to other compositions.

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