Journal of Electronic Voltage and Application Vol. 4 No. 1 (2023) 21-29

JEVA

Journal homepage: http://publisher.uthm.edu.my/ojs/index.php/jeva
e-ISSN : 2716-6074

Journal of Electronic Voltage and Application

Electric Field Analysis of HDPE/NR Biocomposite Due to Moisture Content Condition

Ahmad Farid Aziz[1], Nor Akmal Mohd Jamail[1*], Qamarul Ezani Kamarudin[2]

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

[2]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jeva.2023.04.01.003
Received 09 January 2023; Accepted 19 March 2023; Available online 29 June 2023

Abstract: It is critical to develop new insulating materials that can improve the performance of next-generation high-voltage cables used in the construction of future electrical networks. The high electric field reduces solid insulation resistance and causes partial discharge through imperfections in a dielectric, causing the dielectric to age and eventually fail. Moisture is one of the most serious factors the effect the high voltage insulation status of High-Density Polyethylene (HDPE) composites. The main goal of this project is to investigate the electric field intensity of HDPE due to moisture content condition when mixed with 10g, 20g, and 30g of various bio-fillers such as coconut coir fibre, pineapple leaves fibre, and oil palm empty fruit bunch. This can be accomplished by using the Finite Element Method Magnetics (FEMM) 4.2 software to create a two-dimensional (2D) axisymmetric electrostatic model. When compared to unfilled HDPE, the inclusion of bio-filler in HDPE increased the maximum electric field intensity due to moisture content condition. The intensity of the electric field varied with the different percentages of biocomposite loading and their permittivity due to moisture content condition. The results showed, due to moisture content condition, the maximum electric field intensity was significantly lower when HDPE was added with a 10% loading of the oil palm empty fruit bunch (EFB). As a result, EFB bio-filler was the best composition because it tends to improve dielectric properties by having a lower maximum electric field intensity which is 4.214Mv/m due to moisture content condition at the top sphere electrode when compared to other compositions.

Keywords: High-Density Polyethylene (HDPE), electric field, moisture, Finite Element Method (FEMM)

1. Introduction

Electrical transmission is the process of transporting generated power to the distribution grid located in densely populated areas, typically over considerable distances. Transformers are a critical component of this process since they enhance voltage levels to enable long distance transmission. The electrical transmission system is comprised of power plants, distribution systems, and substations [1]. Collectively, these components comprise what is referred to as the electrical grid. The grid serves society's electricity demands and is responsible for transporting electrical energy from its source to its final destination. Due to the fact that power plants are frequently located in sparsely inhabited locations, the transmission system must be rather big. A high-voltage cable (HV cable) is a cable that is used to transmit electricity at a high voltage. A cable is made up of two components: a conductor and insulation. Cables that are completely insulated are regarded to be fully insulated. By decreasing the current, power losses can be avoided. Thus,

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

while distributing energy via high voltage transmission, one of the critical elements to consider is the use of adequate cable insulating materials [2][3]. Each type of insulating material has a unique electric field that varies according to the material used and its permittivity value. At every point in space, there is an electric field. Because it contains both direction and magnitude, it is theoretically described as a vector quantity. Furthermore, when a unit positive test charge is established at a certain position, the electric field explains the force acting on it [4].

An insulating material's dielectric strength is described as its ability to endure a certain electric field without deterioration or breakdown, enabling the flow of electricity. Generally, a good dielectric is a material that has high mechanical strength, is resistant to thermal and chemical deterioration, has low dielectric loss, and is devoid of gaseous inclusions and water. It has better mechanical and bonding properties than liquids and gases, making solid dielectrics a better dielectric [5]. Solids were irreversibly destroyed by this electrical failure, whereas liquids and gases recovered their dielectric strength partially and totally after the applied electric field was withdrawn [6]. Furthermore, water migration into the insulation causes electrical treeing to expand in polymeric cables without impermeable water barriers. The greatest electric stress point has the most impact on the penetration of water tree development inside the polymer [7]. Water trees grow and convert to electrical trees when cables are run in a humid environment, resulting in partial discharge and eventual collapse. Water trees can cause a reduction in the breakdown strength of solid insulation by lowering insulation resistance and slightly increasing leakage current [8].

Polyethylene is a common material that is widely used as an electrical insulation material for power cables and wire applications within high voltage insulation systems. There are expected to have high reliability for a long time because of its high dielectric strength and very low conductivity [9]. A composite material is one that is composed of two or more constituent materials that have considerably diverse physical or chemical properties and when combined, form a material with characteristics distinct from the individual components. A polymer composite is a multi-phase material composed of reinforcing fillers and a polymer matrix that exhibits synergistic mechanical qualities that neither component can attain alone [10]. 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 [11].

With the objective of gaining a comprehensive understanding of the electrical field strength of polymer biocomposites due to moisture content condition, which is the same process that causes pure polymers to malfunction. It is critical to analyse the electric field intensity of the HDPE/NR biocomposites insulator utilising Finite Element Method Magnetics (FEMM) software in order to fully comprehend the electrical field strength of polymer biocomposites. The result obtained from the simulation is used to investigate the electrical field characteristic of HDPE/NR biocomposite due to moisture condition by using FEMM-based software.

2. Methodology

Finite Element Approach Magnetics (FEMM) is a free and open-source software tool that uses the finite element method to solve electromagnetic problems. The program's goals are to solve 2D and 3D linear and nonlinear harmonic low-frequency magnetostatic issues, as well as linear electrostatic problems. The interactive shell programme in FEMM is split into two parts: a pre-processor and a post-processor. Drawing geometry issues, determining material attributes, and defining boundary conditions are all functions performed by the pre-processor. A postprocessor is used in FEMM to give findings in the form of a contour and graph. Because of its user-friendly interface, simplicity yet accuracy, and short training time, FEMM 4.2 software was chosen to address the electric field problem in this study.

2.1 Geometry of Electrode Configuration

The electrostatic model was created using the electrode arrangement that was employed in the lab, as shown in Fig. 1. The diameter of the spherical electrode that is really used in the laboratory is used to determine the size of the electrode, which is 5 cm. The sample is placed in the middle of the two spherical electrodes, which each measure 8 cm long and 0.3 cm in thickness. Because the power distribution cable is the primary focus of this project, the voltage at the top spherical electrode has been maintained at 11 kV throughout. Because of the axisymmetric shape, the only half model was employed in the simulation.

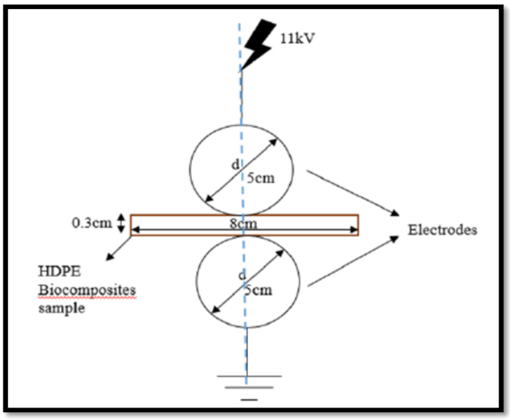

Fig. 1 - Geometry of electrode configuration

2.2 Research Framework

The flowchart for the entire project planning process is depicted in Fig. 2. This study begins with a literature review to gather pertinent information regarding prior works on electric field analysis and material characteristics. To determine the electric field intensity in various biocomposite weights due to moisture content condition, an axisymmetric model was constructed using the FEMM 4.2 programme. The procedure is repeated by altering the sample's relative permittivity. If the obtained result does not match the intended value, repeat the simulation and inspect the simulation properties until the verified values are obtained. Following that, the data is analysed graphically and summarised in a table. Finally, the results are reviewed in terms of the various biocomposites due to moisture content condition that were employed to determine the optimal composition of bio-filler for solid insulation.

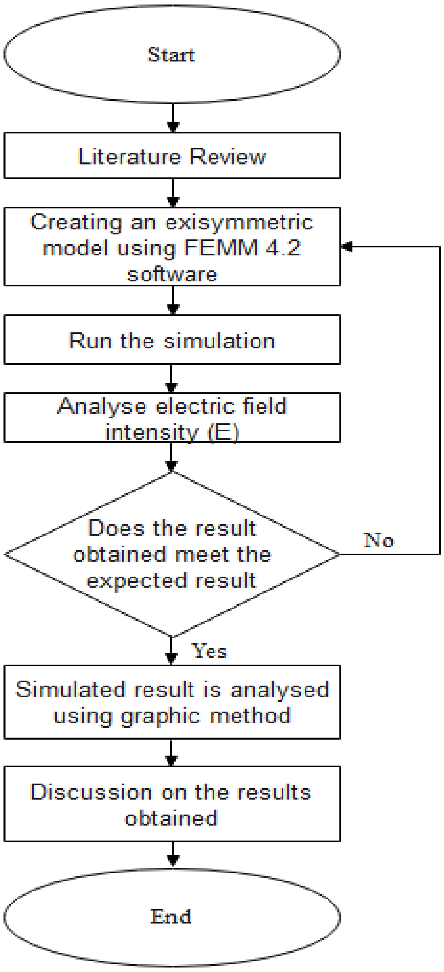

Fig. 2 - Research framework

2.3 Software Development

The development of software is important for the investigation of electrical field intensity in relation to various biocomposite materials due to moisture content condition and their allowability. The electrostatic problem is solved in multiple steps using the FEMM 4.2 software simulation. The method for modelling two-dimensional axisymmetric issues in electrostatics is illustrated in Fig. 3.

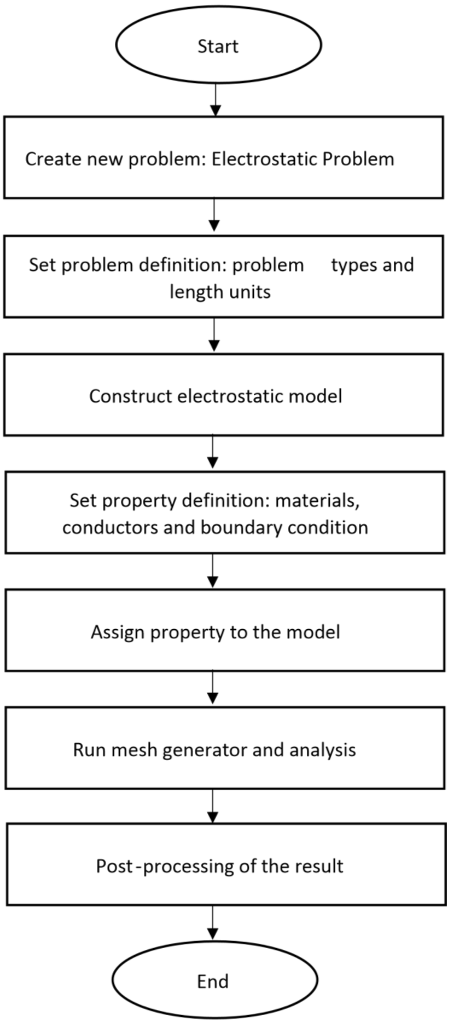

Fig. 3 - Step for designing 2D axisymmetric problems in electrostatics

2.4 Design Model

As illustrated in Fig. 4, the model was created using model tools in the FEMM 4.2 software. Figure 2.4 shows a vertical arrangement with three half-circles with diameters of 5 cm and 8 cm representing the two electrodes sphere and outer boundary, and a horizontal layout with a sample with 0.3 cm width and 4 cm length.

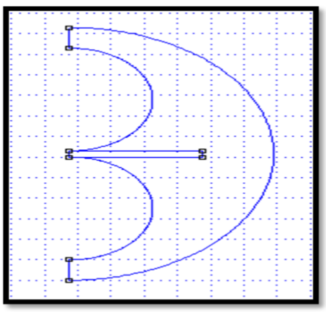

Fig. 4 - Created model

2.5 Relative Permittivity of Materials

Relative permittivity is the material property to consider for the model's electric field. The relative permittivity of each HDPE-NR biocomposite is varied. To determine the dielectric constant of solid dielectric materials, a dielectric test apparatus is utilized. Table 1 summaries the HDPE-NR biocomposite sample and permittivity used in the simulation.

Table 1 - Permittivity for electric field computation due to moisture content condition

Sample	Bio-filler content (g)	Permittivity value
Unfilled HDPE	0	2.31
HDPE + NR + EFB	10	2.60
HDPE + NR + EFB	20	2.82
HDPE + NR + EFB	30	2.84
HDPE + NR + PAL	10	2.70
HDPE + NR + PAL	20	3.04
HDPE + NR + PAL	30	3.29
HDPE + NR + CC	10	2.66
HDPE + NR + CC	20	2.91
HDPE + NR + CC	30	3.10

2.6 Post Processing of the Result

The overall purpose of this technique is to obtain the result of the model's voltage distribution and electric field intensity. To see the solution provided by the solver, the electrostatics post-processing in FEMM 4.2 is employed. The results are presented visually in the form of contours and graphs. Once the post-processor is started, as illustrated in Fig. 5, a voltage colour density plot is displayed. Manually defined contours can be created by defining the sample's start and end points.

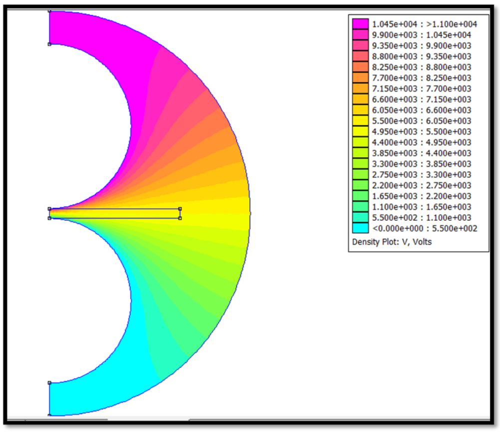

Fig. 5 - Color density plot of voltage rendered in the electrostatic post-processor

3. Result and Discussion

This chapter presents the findings of an investigation into the effect that the moisture content condition has on the electric field intensity of HDPE-NR biocomposites. The results are acquired by running simulations in the FEMM programme based on an electrostatic model. In this section, the voltage as well as the electric field distribution of the sample have been covered. The information that was obtained was organised into tables, and then the data were analysed using a graph that was created in Microsoft Excel. In addition to that, a comparison of the electric field intensity for varying percentages of biocomposite as a result of the condition of the moisture content is also taken into consideration in this chapter. The following chapter will discuss the many types of bio-fillers that may be utilised successfully as solid insulation.

3.1 HDPE Polymer Matrix with EFB Bio-Filler Due to Moisture Content Condition

The graph showed in Fig. 6 is the comparison of the electric field intensity for HDPE with varying percentage loading of oil palm empty fruit bunch due to moisture content condition. The electric field is measured from the sample layer nearest to the positive conductor until it reaches the sample's end point. The electric field intensity is highest at the sample's surface, which is closest to the top spherical electrode, as seen in the graph. The electric field reduces as the distance from the conductor spherical surface rises. Besides, the result shows that when the length of the sample is within 0.05 cm from the surface of the sample, 10% of EFB loading has a smaller electric field, while 30% of EFB loading has a greater electric field due to moisture content condition. Hence, when the percentage loading of EFB rises, the minimum electric field became lower at length 0.15cm.

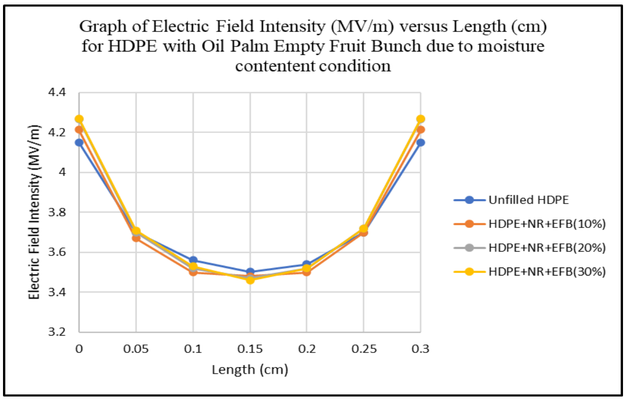

Fig 6 - Electric field intensity for HDPE with 10%, 20%, and 30% of oil palm empty fruit bunch with unfilled HDPE as a reference due to moisture content condition

3.2 HDPE Polymer Matrix with CCF Bio-Filler Due to Moisture Content Condition

Fig. 7 shows a comparison of electric field intensity for HDPE with various percentage loadings of coconut coir fibre due to moisture content condition. From the sample layer near the positive conductor to the sample end point, the electric field is measured. The electric field intensity of HDPE with CCF due to moisture content condition follows the same pattern as HDPE with EFB in that it decreases as distance from the conductor sphere surface increases. The electric field intensity is highest at the sample's surface, which is closest to the top sphere electrode, as shown in the graph. When the length of the sample is within 0.05 cm of the surface of the sample, the result also shows that 10% of CCF loading has a lower electric field, while 30% of CCF loading has the largest electric field. In the range of length between 0.05 cm and 0.25 cm, with 10% of CCF loading showing the highest electric field intensity and 30% of CCF loading showing the lowest electric field intensity among CCF bio-filler due to moisture content condition. As a result, the minimum electric field decreased as the percentage loading of CCF increased.

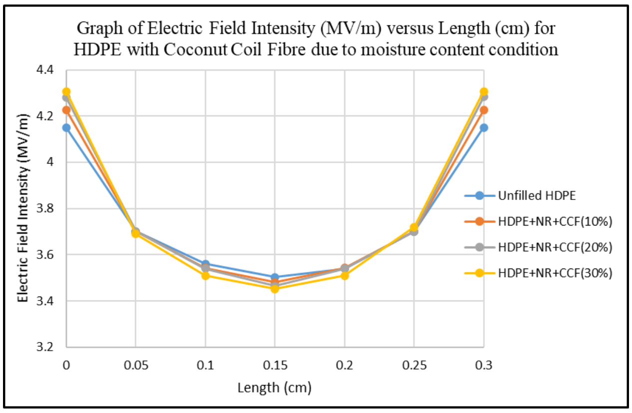

Fig. 7 - Electric field intensity for HDPE with 10%, 20%, and 30% of coconut coir fibre with unfilled HDPE as a reference due to moisture content condition

3.3 HDPE Polymer Matrix with PALF Bio-Filler Due to Moisture Content Condition

Fig. 8 illustrates a comparison of the electric field intensity for HDPE with varied percentage loadings of pineapple leaves fibre due to moisture content condition. The electric field is measured from the sample layer nearest to the positive conductor until it reaches the sample's end point. The electric field intensity of HDPE with PALF follows the same pattern as HDPE with EFB or CCF where the electric field diminishes as the distance rise from the conductor spherical surface due to moisture content condition. According to the graph, the electric field intensity is the highest near the surface of the sample, which is closest to the top spherical electrode. The result also reveals that 10% of PALF loading has a lesser electric field, while 30% of PALF loading has the maximum electric field when the length of the sample is within 0.05 cm from the surface of the sample due to moisture content condition. In contrast, the result reveals the opposite outcome in the range of length between 0.05 cm and 0.25 cm, where 10% of PALF loading shows higher electric field intensity, whereas 30% of PALF loading shows the lowest electric field intensity among PALF bio-filler due to moisture content condition. As noted from Figure 4.6, the electric field intensity for HDPE with 20% of PALF is slightly lower than 30% of PALF loading. Hence, when the percentage loading of PALF grows, the minimum electric field got smaller due to moisture content condition. By comparing to varied % loading of bio-filler owing to moisture content condition, the change of the electric field against the length of the samples can be clearly noticed. As less filler loading is added to the HDPE, the separation distance between the particles rises results in less distorted electric field in the HDPE-NR biocomposite due to moisture content condition.

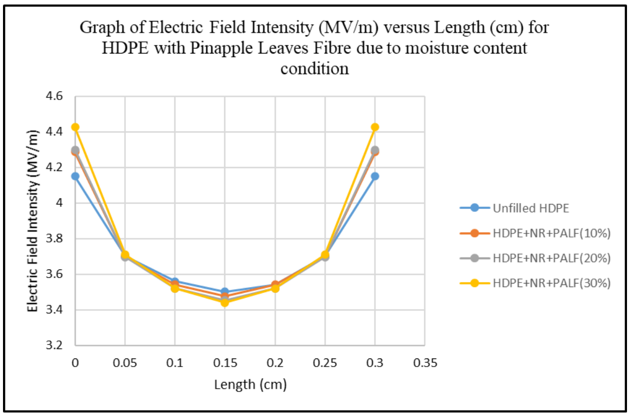

Fig. 8 - Electric field intensity for HDPE with 10%, 20%, and 30% of pineapple leaves fibre with unfilled HDPE as a reference due to moisture content condition

3.4 Comparison Between Different Bio-filler Due to Moisture Content Condition

Fig. 9 depicts the electric field intensity of an HDPE sample under a 10% biocomposites loading based on the moisture content condition. According to the study, the surface of the sample closest to the top spherical electrode had the maximum electric field intensity. As the distance from the surface of the conductor sphere grows, the strength of the electric field diminishes. Due to the moisture content condition, the unfilled HDPE sample had the lowest electric field intensity among other HDPE samples containing 10% bio-filler for comparative reasons. PALF bio-filler has the largest electric field when the length of the sample is within 0.05 cm of the sample's surface, whereas EFB bio-filler has the lowest electric field among 10% loading biocomposites. In the length range of 0.05 cm to 0.25 cm, the EFB bio-filler has a greater electric field intensity than the PALF bio-filler, which has the lowest electric field intensity due to its higher moisture content.

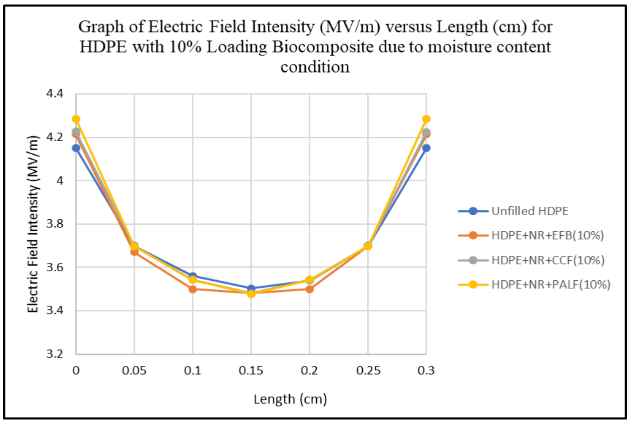

Fig. 9 - Comparison of electric field intensity for sample HDPE with 10% loading of biocomposites due to moisture content condition

Fig. 10 and Fig. 11 shows the electric field intensity for the HDPE sample due to the moisture content condition when loaded with 20% and 30% biocomposites, respectively. As mentioned in section 4.3.5, the electric field intensity displayed the same behaviour and trend in both instances as HDPE with a 10% biocomposite loading. The surface of the sample closest to the top spherical electrode has the highest electric field intensity. Intensity of the electric field lowers as distance from the conductor spherical surface rises. The electric field intensity value increases somewhat when 20% or 30% biocomposites are added to the HDPE sample due to moisture content condition.

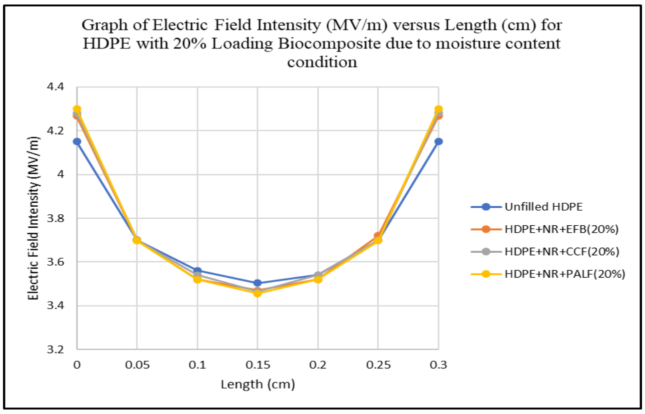

Fig. 10 - Comparison of electric field intensity for sample HDPE with 20% loading of biocomposites due to moisture content condition

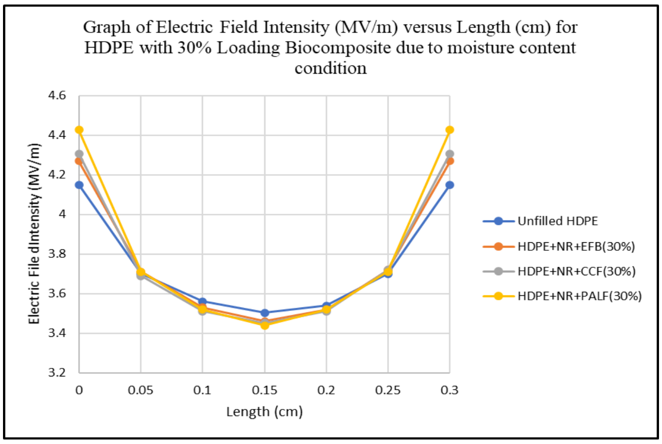

Fig. 11 - Comparison of electric field intensity for sample HDPE with 30% loading of biocomposites due to moisture content condition

4. Conclusion

In conclusion, all of objective of these project was achieved well with the help of simulation by using FEMM software due to moisture content condition sample. The project's first objective was achieved by creating an electrostatic model of HDPE-NR biocomposite. A version of the FEMM 4.2 software was successfully modelled using Finite Element Magnetics method. An axisymmetric electrostatic model contains two sphere electrodes. The voltage and electric field distribution, as well as the electric field intensity, may be calculated using the simulation with different percentages of biocomposite loading due to moisture content condition. When compared to HDPE that was not filled with anything, the electric field intensity that was produced by filled HDPE due to moisture content condition with bio-filler was significantly higher.

The second objective of this project was accomplished which is to investigate the electric field intensity of HDPE/NR biocomposite due to moisture content condition. The results demonstrate that electric field intensity influenced by the percentages loading of biocomposite and their permittivity value due to moisture content condition. A high percentage loading of biocomposite having higher permittivity value, which results in higher electric field intensity. Meanwhile, when the distance between surrounding particles separates widely, the electric field intensity decreases. This feature is often associated with a polymer containing a lower percentage loading of biocomposite. As a result, the sample with a 10% biocomposite loading was the best, as it had the lowest maximum electric field intensity compared to the other samples in the same group due to moisture content condition.

The third objective is to compare the best electric field performance to get the best composition of HDPE/NR biocomposite due to moisture content condition for high voltage insulation. The sample was used in moisture content condition is oil palm empty fruit bunch, coconut coir fibre, and pineapple leaves fibre as solid insulation. The results show that the highest electric field intensity is proportional to the permittivity value of the resulting HDPE-NR biocomposite due to moisture content condition, with the maximum electric field intensity decreasing as the permittivity value of the HDPE-NR biocomposite due to moisture condition decreases. In this regard, EFB bio-filler due to moisture content condition was the best composition because it improves dielectric properties by having a lower maximum electric field intensity at the top sphere electrode which is 4.214MV/m when compared to other compositions.

Acknowledgement

The author would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for the facilities that has been provided and for its support.

References

[1] R. Paynter and B.J. Boydell, "Transmission Lines and Substations" in Introduction to Electricity, 1st ed., Upper Saddle River, NJ: Pearson, 2011, ch.25, sec.3, pp.1102-1104

[2] Andritsch, T., Vaughan, A., & Stevens, G. C. (2017). Novel insulation materials for high voltage cable systems. IEEE Electrical Insulation Magazine, 33(4), 27-33.

[3] EIA. (May 27, 2015). Electricity Losses [Online]. Available:http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3

[4] W. McAllister, "Electrostatics (Electric field)." [Online]. Available: https://www.khanacademy.org/science/electrical-engineering/eeelectrostatics/ee-electric-force-and-electric-field/a/ee-electric-field. [Accessed: 31-May-2020].

[5] Arora, R. and Mosch, W., 2011. High voltage and electrical insulation engineering (Vol. 69). John Wiley & Sons.

[6] K. Y. Lau et al., "Modeling of polymer nanocomposites: Permittivity vs. electric field intensity," Conf. Proceeding - 2014 IEEE Int. Conf. Power Energy, PECon 2014, pp. 140–145, 2014. https://ieeexplore.ieee.org/abstract/document/7062429

[7] D. Kavitha and M. Balachandran, "Influence of high permittivity nanoparticle on water tree growth in XLPE nanocomposite," Proc. IEEE Int. Conf. Circuit, Power Comput. Technol. ICCPCT 2017, 2017. https://ieeexplore.ieee.org/document/8074389

[8] Y. Z. Arief, M. Shafanizam, Z. Adzis, and M. Z. H. Makmud, "Degradation of polymeric power cable due to water treeing under AC and DC stress," PECon 2012 - 2012 IEEE Int. Conf. Power Energy, no. December, pp. 950–955, 2012. https://ieeexplore.ieee.org/abstract/document/6450355

[9] P. N. Khanam and M. A. A. AlMaadeed, "Processing and characterization of polyethylene-based composites," Adv. Manuf. Polym. Compos. Sci., vol. 1, no. 2, pp. 63–79, 2015. https://doi.org/10.3390/polym11010024

[10] "Bio-composites update: Beyond eco-branding". Composites World. Gardner Business Media, Inc. Retrieved 1 September 2015.

[11] Sanyang, M.L., Sapuan, S.M., Jawaid, M., Ishak, M.R. and Sahari, J., 2016. Recent developments in sugar palm (Arenga pinnata) based biocomposites and their potential industrial applications: A review. Renewable and Sustainable Energy Reviews, 54, pp.533-549. https://doi.org/10.1016/j.rser.2015.10.037