

# Characteristic of Electric Field for XLPE Under Normal and Moisture Condition Using COMSOL Multiphysics

Fikry Hariez Spawie<sup>1</sup>, Nor Akmal Mohd Jamail<sup>1\*</sup>, Qamarul Ezani Kamarudin<sup>2</sup>

<sup>1</sup> Faculty of Electrical and Electronic Engineering  
Universiti Tun Hessein Onn Malaysia, 86400, Batu Pahat, Johor, MALAYSIA

<sup>2</sup> Faculty of Mechanical and Manufacturing Engineering,  
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

\*Corresponding Author: [norakmal@uthm.edu.my](mailto:norakmal@uthm.edu.my)  
DOI: <https://doi.org/10.30880/jeva.2024.05.01.003>

## Article Info

Received: 23 October 2023  
Accepted: 15 April 2024  
Available online: 30 June 2024

## Keywords

XLPE, moisture absorption, electric field, relative permittivity, COMSOL multiphysics

## Abstract

Cross-linked polyethylene cables (XLPE cables) have gained significant popularity in transmission lines for urban pipeline corridors due to their exceptional electrical and mechanical properties. However, prolonged usage of XLPE cables can result in degradation and eventual disintegration. This research aims to investigate the characteristics of XLPE under normal and moisture absorption conditions to address the prevalent insulation and corrosion faults observed in Malaysia, particularly during the annual flooding caused by the northeast monsoon. An experiment is conducted on an 11 kV XLPE-insulated underground cable to examine the changes in XLPE's conditions and the intensity of its electric field. Four moisture conditions are examined, including virgin XLPE, XLPE effect of distilled water absorption, XLPE with effect of distilled water and peat soil, and XLPE with effect of distilled water and clay. The relative permittivity of each sample is measured using the Keysight 16451B dielectric test fixture, and an electrostatic model of XLPE is developed using COMSOL Multiphysics for analyzing the electric field properties. Comparative simulation results reveal varying electric field intensities for each sample, with Sample 1 (virgin XLPE) exhibiting maximum and minimum electric field intensities of 10.0718 MV/m and 4.2380 MV/m, respectively, and Sample 4 (XLPE with effect of distilled water and clay) displaying maximum and minimum intensities of 10.0920 MV/m and 4.2353 MV/m, respectively. These findings contribute to a better understanding of XLPE's performance in moisture-rich environments and facilitate the development of more robust insulation materials for electrical applications.

## 1. Introduction

High-voltage (HV) insulators are essential parts of electrical power transmission and distribution networks because they limit the amount of current that can leak from their supporting points to the ground. Local factors such as contamination, stress, and damaged or broken structures were looked into in order to assess the actions and performance of insulators.

An insulator was a substance that, as its name implies, prevented or slowed the transmission of electrical current. In outdoor applications, overhead insulators, also known as outdoor insulators, serve two purposes: they support wires mechanically and offer electrical protection for the power supply network [1]. Each type of

insulating material has a different electric field depending on the substance used and the permittivity values. Due to the surroundings of the applied insulator, such as an underground cable, electric fields of this size often have some mistakes and errors.

Due to their excellent electrical and mechanical properties, cross-linked polyethylene cables (XLPE cables) have been used extensively in transmission lines for urban pipeline corridors [1][2]. Despite having good insulation qualities, cross-linked polyethylene inevitably dissolves after prolonged use [3]. This kind of wire is typically installed underground. It shares several characteristics with polyethylene, such as outstanding moisture resistance and good chemical resistance. Cross-linked polyethylene (XLPE) performs better than regular polyethylene because it has improved characteristics. In comparison to other insulation options like silicone rubber and even Ethylene Propylene Rubber (EPR), XLPE-insulated cables outperform them due to its exceptional insulation qualities.

In comparison to other polyethylenes, XLPE unquestionably has few flaws given all of its advantages. By 1991, more than 90% of all cables installed in Japan were XLPE-insulated cables, a milestone in the history of underground cable XLPE [4]. In Malaysia, XLPE cable is a type of electrical cable that is frequently used for underground power transmission and distribution. One of the reasons why XLPE cable is so widely used is that it comes in a variety of diameters and may be used for a number of different applications, including subterranean power transmission, distribution, and industrial power supply. It has a lot of benefits over other types of cable, but it also has some limitations. There are several types of faults that can occur on XLPE cable, including insulation faults, mechanical faults, thermal faults, corrosion faults, and overload faults. Insulation and corrosion faults are the most probable to occur in Malaysia. It is because of the floods that often occur there every year. In Malaysia, flooding is a frequent natural disaster that occurs during the northeast monsoon. Late December 2014 to early January 2015 saw one of the worst floods, with damage costs reaching RM 1 billion [5]. These severe floods are caused by an increase in rainfall frequency, which alters flood volume and duration in particular with respect to urbanization and deforestation [6]. Indirectly, this natural disaster puts underground XLPE cables at risk of being harmed by outside forces, which could cause an electrical power failure or a short circuit. These faults are also caused by an electric field on an XLPE cable that exceeds the dielectric strength of the cable. The research is carried out on an 11 kV XLPE-insulated underground cable [7].

## 2. Methodology

This section discusses the methodology applied in completing this work.

### 2.1 Research Flowchart

This study utilized an experiment to determine the relative permittivity of the main material under various conditions. Using COMSOL Multiphysics software, an axisymmetric model was designed to analyze the electric field in XLPE with different weights due to moisture conditions. The simulation was iterated, adjusting the sample's relative permittivity as necessary. If the obtained results did not align with expectations, further analysis and simulations were performed. The findings were discussed in terms of the different moisture conditions. Fig. 1 presents the flowchart outlining the comprehensive research planning process.

The relative permittivity analysis of cross-linked polyethylene (XLPE) was conducted using the Keysight 16451B dielectric test fixture in the laboratory. The testing procedure, as illustrated in Fig. 2 depicting the actual testing process of the Keysight 16451B dielectric test fixture. To ensure successful testing without any air gaps, it is crucial that the sample used in the test meets certain conditions. The sample should have a flat shape with a radius of 25mm and a thickness below 3mm. Adhering to these conditions is essential for obtaining accurate results and precise measurements.

The assessment of the relationship between electrical field intensity and XLPE under various moisture conditions and their acceptability necessitated software development. The electrostatic problem was solved in different phases using the simulation program COMSOL Multiphysics. Fig. 3 shows the methodology employed for modeling two-dimensional axisymmetric problems in electrostatics.

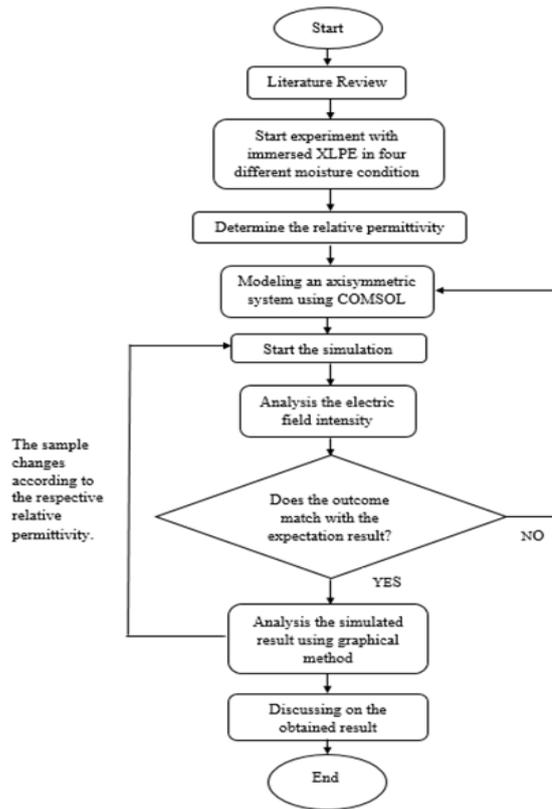


Fig. 1 Research flowchart

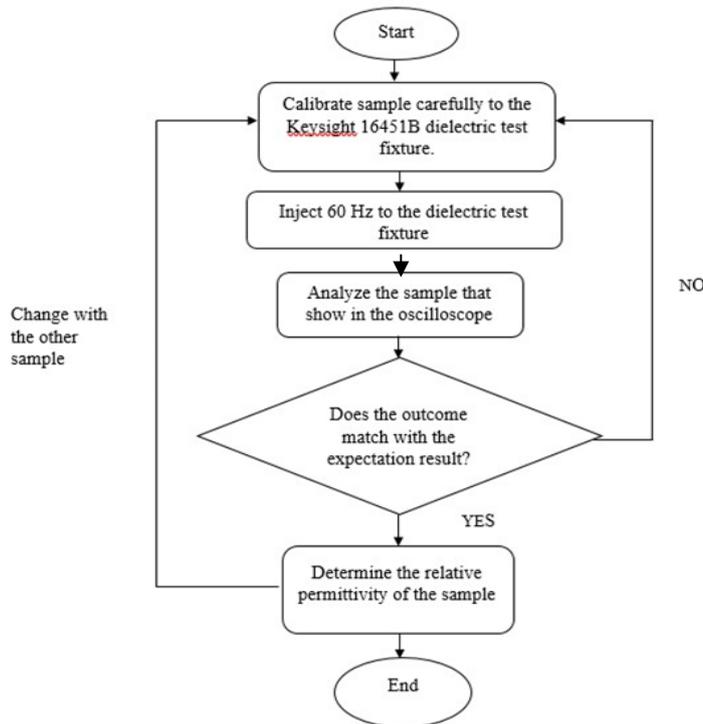


Fig. 2 Testing flowchart

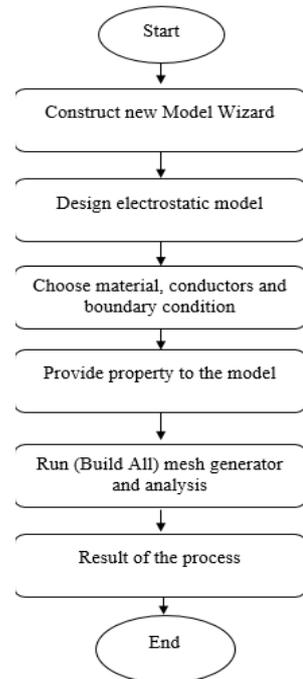


Fig. 3 Modelling two-dimensional axisymmetric flowchart

## 2.2 Characteristics of the XLPE Sample

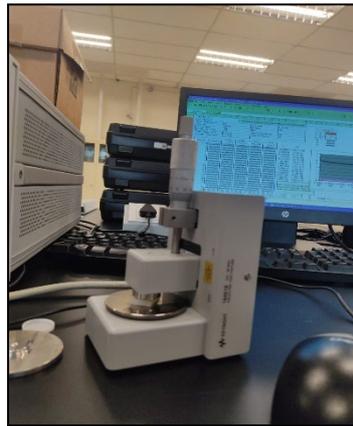
There were four samples in this experiment Table 1 shows the designation and condition of the XLPE in normal condition and with moisture absorption effect.

**Table 1** Designation of samples

Sample	Condition of the sample
Sample 1	XLPE (Did not immersed)
Sample 2	XLPE + Distilled water
Sample 3	XLPE + Distilled water + Peat Soil
Sample 4	XLPE + Distilled water + Clay

## 2.3 Relative Permittivity Test

The sample should possess a flat shape with a radius of 25mm and a thickness less than 3mm, thereby eliminating any air gaps. Fig. 4 shows the successful execution of the Keysight 16451B dielectric test fixture.

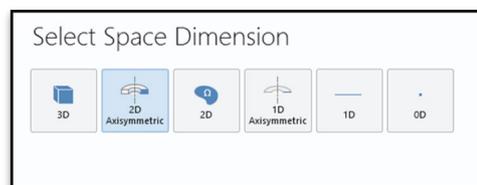


**Fig. 4** Keysight 16451B dielectric test fixture

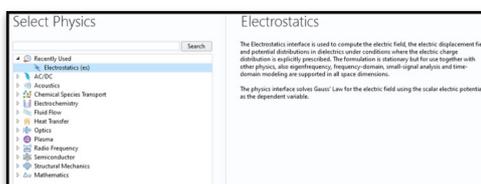
## 2.4 Selection of Electrostatic Model



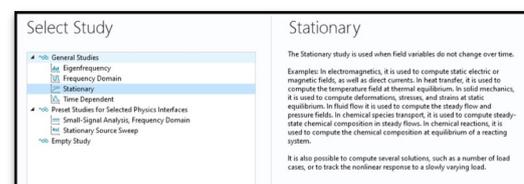
**Fig. 5** Selection for the model



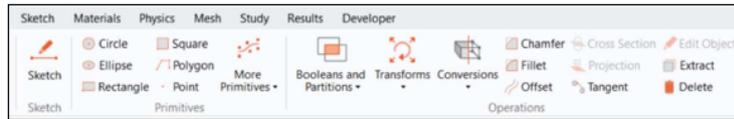
**Fig. 6** List of COMSOL multiphysics model space dimensions



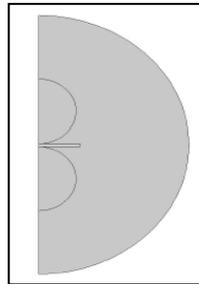
**Fig. 7** List of physics that COMSOL Multiphysics can simulate



**Fig. 8** List of study that COMSOL Multiphysics can be use



**Fig. 9** Geometry tools for design



**Fig. 10** Completed model of sphere to sphere

## 2.5 Relative Permittivity for Material

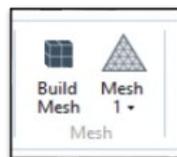
The dialogue box for entering the relative permittivity for each sample was depicted in Fig. 11.

Material Contents					
Property	Variable	Value	Unit	Property	
<input checked="" type="checkbox"/>	Relative permittivity	epsilo...	2.31	1	Basic

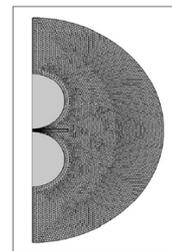
**Fig. 11** Dialogue box for entering the relative permittivity for each sample

## 2.6 Build Mesh and Post Result

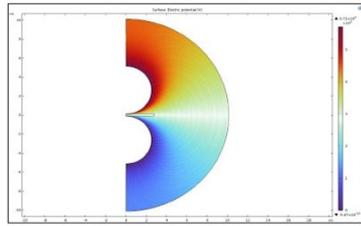
By pressing the corresponding buttons on the toolbar shown in Fig. 12, analysis techniques, such as meshing the model, can be carried out. Fig. 13 depicts the predict electrostatic model following meshing. The voltage distribution and electric field strength of the model are to be ascertained using this method. The results could be represented using graphs and contour lines with vivid colors as seen in Fig. 14. As seen in Fig. 15, we can create a new 2D Plot Group for the electric field result by right-clicking the result icon.



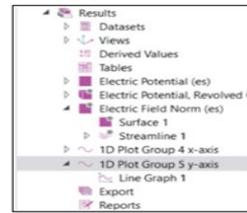
**Fig. 12** Tools for mesh



**Fig. 13** Prediction of electrostatic model of sphere to sphere after meshing process



**Fig. 14** Prediction electrostatic post-processor-rendered color density plot of voltage



**Fig. 15** Tools from the model builder

### 3. Result and Discussion

This section presents the testing results for relative permittivity, along with a comprehensive analysis of the electric field characteristics observed in each sample.

#### 3.1 Relative Permittivity of the Sample

In this section, the influence of various conditions on the relative permittivity of XLPE was presented, which has a base value of 2.3 [8]. There were four samples with different conditions. The relative permittivity of each sample had been determined accurately by employing the Keysight 16451B dielectric test fixture. The obtained results depicted in Table 2 shows the measured relative permittivity values for each tested sample, providing valuable insights for this research.

**Table 2** Relative permittivity values for each sample after testing

Sample	Condition of the sample	Relative permittivity, $\epsilon_r$
Sample 1	Pure XLPE	2.27
Sample 2	XLPE + Distilled water	2.28
Sample 3	XLPE + Distilled water + Peat Soil	2.30
Sample 4	XLPE + Distilled water + Clay	2.31

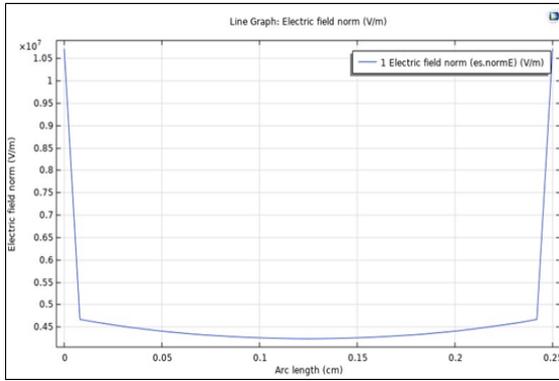
### 3.2 Simulation Results of Electric Field Distribution

#### 3.2.1 Comparing Electric Field Intensity: Sample 1 vs. Sample 2

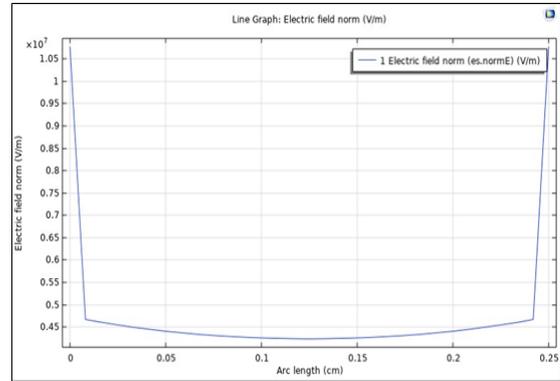
Table 3 presents the simulation results of the electric field intensity for two distinct samples: virgin XLPE (Sample 1) and XLPE immersed with distilled water (Sample 2), obtained using the COMSOL Multiphysics software. Notably, Sample 1 exhibited a lower maximum electric field intensity compared to Sample 2. The maximum electric field intensities for the two samples were recorded as 10.0718 MV/m and 10.0769 MV/m, respectively. It was worth mentioning that the difference in the minimum electric field intensity values between the two samples was negligible, with values of 4.2380 MV/m and 4.2374 MV/m, respectively. Fig. 16 and Fig.17 illustrate the relationship between the electric field intensity and length for Sample 1 and Sample 2, respectively. Both graphs have been zoomed in to accurately determine the maximum and minimum electric field intensity values such as show in Fig.18 and Fig. 20 for Sample 1, and Fig. 19 and Fig. 21 for Sample 2 respectively.

**Table 3** Electric field intensity of sample 1 and sample 2

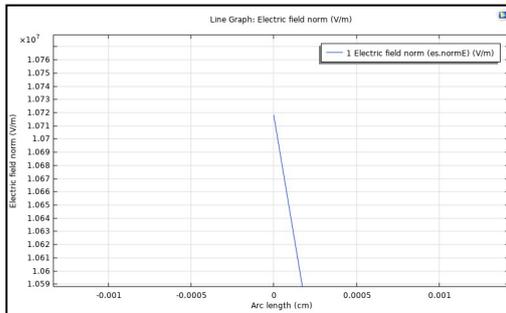
Sample	Relative permittivity, $\epsilon_r$	Minimum Electric Field, $E_{min}$ (MV/m)	Maximum Electric Field, $E_{max}$ (MV/m)
Sample 1	2.27	4.2380	10.0718
Sample 2	2.28	4.2374	10.0769



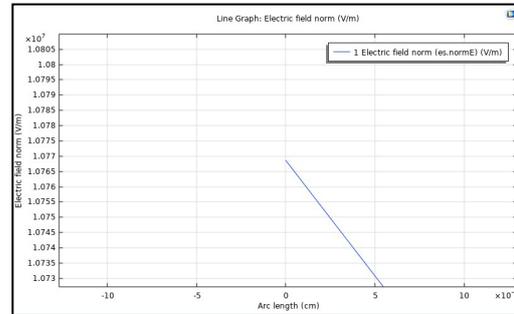
**Fig. 16** Relationship between electric field intensity and length for sample 1



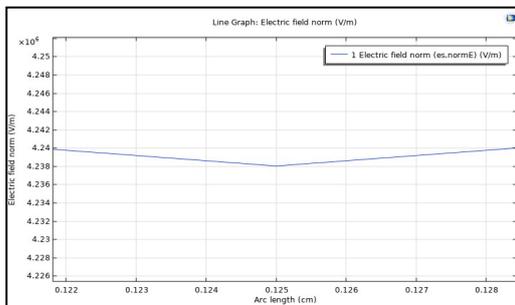
**Fig. 17** Relationship between electric field intensity and length for sample 2



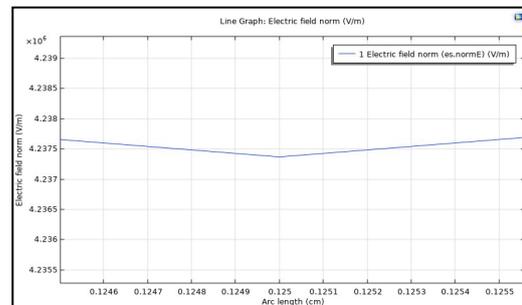
**Fig. 18** Maximum value of electric field intensity for sample 1



**Fig. 19** Maximum value of electric field intensity for sample 2



**Fig. 20** Minimum value of electric field intensity for sample 1



**Fig. 21** Minimum value of electric field intensity for sample 2

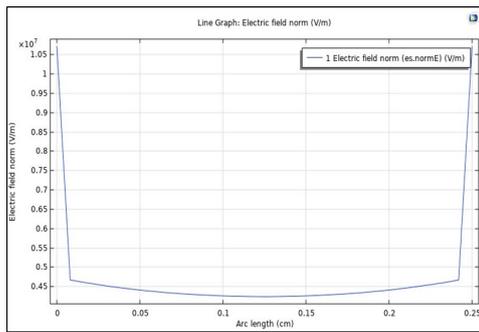
### 3.2.2 Comparing Electric Field Intensity: Sample 1 vs. Sample 3

Remarkably, the simulation results obtained using the COMSOL Multiphysics software as presented in Table 4 demonstrate contrasting electric field intensities for two distinct samples: virgin XLPE (Sample 1) and XLPE immersed with distilled water and peat soil (Sample 3). Sample 1 displayed a lower maximum electric field

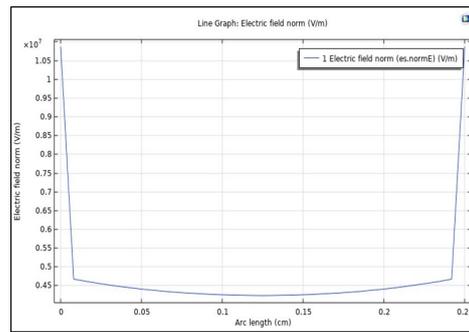
intensity compared to Sample 3, with recorded values of 10.0718 MV/m and 10.0870 MV/m, respectively. It was worth highlighting that the difference in the minimum electric field intensity values between the two samples was negligible, as they stand at 4.2380 MV/m and 4.2360 MV/m, respectively. Fig. 22 and Fig. 23 depict the correlation between the length and electric field intensity for Sample 1 and Sample 3, respectively. In order to accurately determine the maximum and minimum values of electric field intensity, the graphs have been carefully adjusted to allow for a precise analysis of the maximum and minimum values of electric field intensity, as depicted in Fig. 24 and Fig. 26 for Sample 1, and Fig. 25 and Fig. 27 for Sample 3, respectively.

**Table 4** Electric field intensity of sample 1 and sample 3

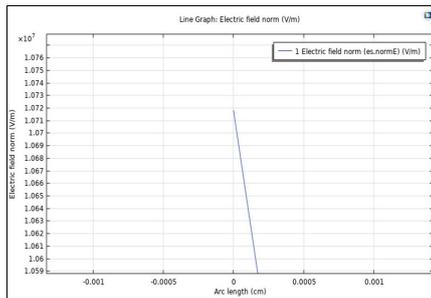
Sample	Relative permittivity, $\epsilon_r$	Minimum Electric Field, $E_{min}$ (MV/m)	Maximum Electric Field, $E_{max}$ (MV/m)
Sample 1	2.27	4.2380	10.0718
Sample 3	2.30	4.2360	10.0870



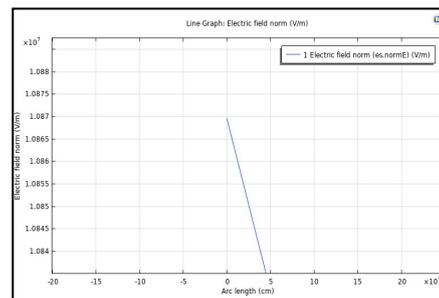
**Fig. 22** Relationship between electric field intensity and length for sample 1



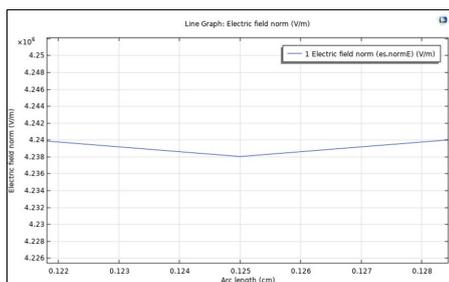
**Fig. 23** Relationship between electric field intensity and length for sample 3



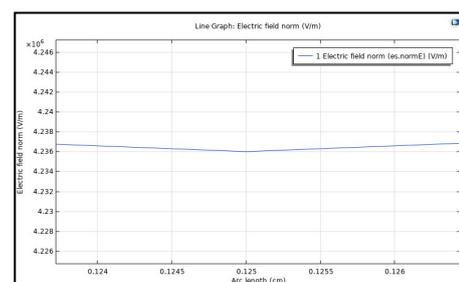
**Fig. 24** Maximum value of electric field intensity for sample 1



**Fig. 25** Maximum value of electric field intensity for sample 3



**Fig. 26** Minimum value of electric field intensity for sample 1



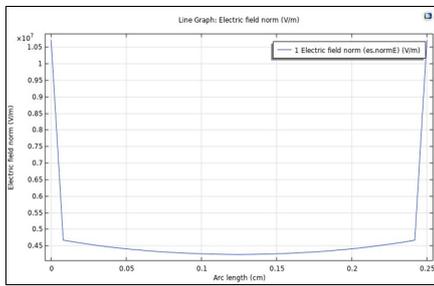
**Fig. 27** Minimum value of electric field intensity for sample 3

### 3.2.3 Comparing Electric Field Intensity: Sample 1 vs. Sample 4

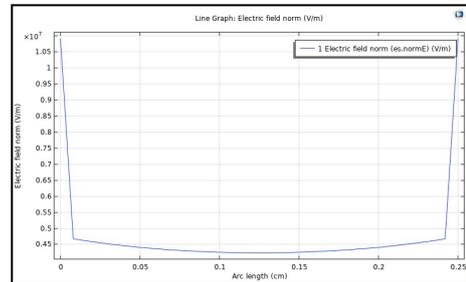
Notably, the simulation results obtained using the COMSOL Multiphysics software as presented in Table 5 reveal a striking disparity in electric field intensities between two distinct samples: virgin XLPE (Sample 1) and XLPE immersed in distilled water and clay (Sample 4). Remarkably, Sample 1 exhibits a lower maximum electric field intensity of 10.0718 MV/m, while Sample 4 demonstrates a higher intensity of 10.0920 MV/m. This discrepancy was noteworthy and highlights the significant impact of the immersion medium on the electric field behavior. Equally noteworthy was the substantial difference in the minimum electric field intensities between these two samples, surpassing the variations observed in previous comparisons with other samples which are 4.2380 MV/m for Sample 1 and 4.2353 MV/m for Sample 4. Fig. 28 and Fig. 29 showcase the relationship between length and electric field intensity for Sample 1 and Sample 4, respectively. In order to accurately determine the maximum and minimum electric field intensity values, both graphs have undergone a zoomed-in transformation. This adjustment is clearly depicted in Figure 30 and Fig. 32 for Sample 1, as well as Fig. 31 and Fig. 33 for Sample 4.

**Table 5** Electric field intensity of sample 1 and sample 4

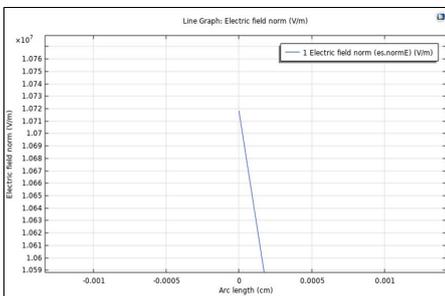
Sample	Relative permittivity, $\epsilon_r$	Minimum Electric Field, $E_{min}$ (MV/m)	Maximum Electric Field, $E_{max}$ (MV/m)
Sample 1	2.27	4.2380	10.0718
Sample 4	2.31	4.2353	10.0920



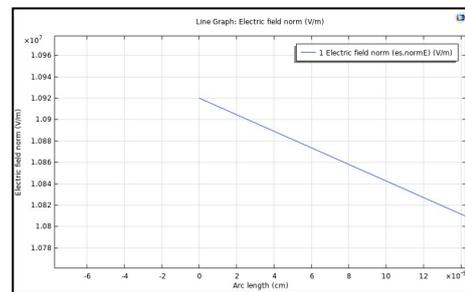
**Fig. 28** Relationship between electric field intensity and length for sample 1



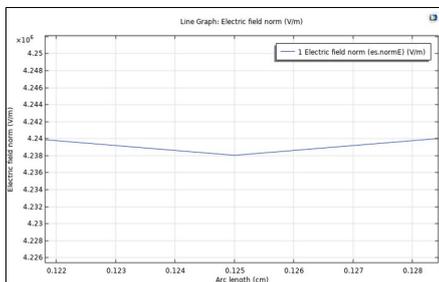
**Fig. 29** Relationship between electric field intensity and length for sample 4



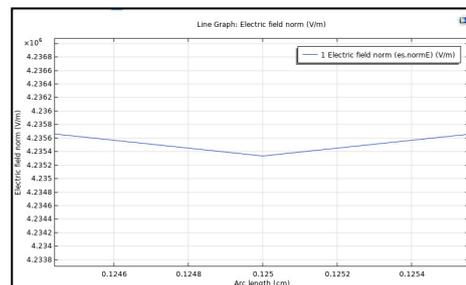
**Fig. 30** Maximum value of electric field intensity for sample 1



**Fig. 31** Maximum value of electric field intensity for sample 4



**Fig. 32** Minimum value of electric field intensity for sample 1



**Fig. 33** Minimum value of electric field intensity for sample 4

## Acknowledgement

The author would like to express their sincere appreciation to the Faculty of Electrical and Electronic Engineering at Universiti Tun Hussein Onn Malaysia for their support and the excellent facilities provided. They would also like to thank Central Cable Berhad for generously supplying the crucial XLPE material that was essential for this research.

## Conflict of Interest

The author declares that there are no conflicts of interest associated with this paper's publication. There are no any personal, business or professional ties that might influence this work. The research's neutrality and integrity are guaranteed by this transparency. The author promises to immediately disclose any future possible conflicts of interest that might surface.

## Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Fikry Hariez Spawie; **data collection:** Fikry Hariez Spawie; **analysis and interpretation of results:** Fikry Hariez Spawie; **draft manuscript preparation:** Fikry Hariez Spawie, Nor Akmal Mohd Jamail. All authors reviewed the results and approved the final version of the manuscript.

## References

- [1] Jin YH;Cai L;Cheng ZS;Cheng H;Deng T;Fan YP;Fang C;Huang D;Huang LQ;Huang Q;Han Y;Hu B;Hu F;Li BH;Li YR;Liang K;Lin LK;Luo LS;Ma J;Ma LL;Peng ZY;Pan YB;Pan ZY;Ren XQ;Sun HM;Wang Y;Wang YY;Weng H;Wei CJ;Wu DF;Xia J;Xiong Y;Xu HB;Yao XM;Yuan YF;Ye TS;Zhang . (n.d.). A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-ncov) infected pneumonia (standard version). Military Medical Research. Retrieved November 8, 2022, from <https://pubmed.ncbi.nlm.nih.gov/32029004/>
- [2] Song, W., Tang, J., Pan, C., Meng, G., & Zhang, M. (n.d.). Improvement of insulation defect identification for DC XLPE cable by considering PD aging - [scite report]. scite.ai. Retrieved November 8, 2022, from <https://scite.ai/reports/improvement-of-insulation-defect-identification-LegV91r>
- [3] Polymeric insulation for HVDC extruded cables challenges and ... (n.d.). Retrieved November 8, 2022, from Li/publication/327155251\_Polymeric\_Insulation\_for\_HVDC\_Extruded\_Cables\_Challenges\_and\_Development\_Directions/links/5baed287299bf13e6054a602/Polymeric-Insulation-for-HVDC-Extruded-Cables-Challenges-and-Development-Directions.pdf <https://www.researchgate.net/profile/Zhonglei>
- [4] T. Uematsu, "Historical review of water trees in XLPE cables," Furukawa Rev., no. 10, pp. 31–48, 1992.
- [5] Davies, Richard. 2015. Floodlist-Asia. Malaysia Floods – Kelantan Flooding Worst Recorded as Costs Rise to RM1 Billion [Online], 2019. Available: <http://floodlist.com/asia/malaysia-floods-kelantan-worst-recorded-costs>.
- [6] Nashwan, Mohamed Salem, Ismail, Tarmizi & Ahmed, Kamal. (2018). Flood Susceptibility Assessment in Kelantan River Basin Using Copula. Int. J. Eng. Technol, 7(2), 584-590.
- [7] Central Cable Bhd. Batu Berendam, Melaka, XLPE Insulated Power Cable – JKR Specification.
- [8] X. Changfu, H. Chengbo, X. Jiayuan, L. Yunpeng, Z. Kaiyuan and P. Shaotong, "Influence of deteriorated porcelain insulator on electric field and potential distribution of insulators strings in 110kV transmission lines," 2017 IEEE International Conference on Smart Grid and Smart Cities (ICSGSC), pp. 162-166, 2017.