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Effects of Voids Towards Electric Field in High Voltage Cable

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Abstract: This paper presents a study and analysis of the effects of voids on electric fields in high voltage cables. The main objectives were to determine the electric field distribution at contaminated XLPE cable by designing the model of the cable using simulation software and to evaluate the effect of the location of voids using different materials of voids toward the electric field in the cable. The goal of this research is to explore the electric field in insulation containing a void as it is affected by the position of the void and the type of material utilised. The investigation of electric field gives a view on the performance of XLPE as an insulator as its existence may shorten the life span of cable. As the result, Other than using different materials of a void, each material has been tested on its different distance of void from the conductor at 12mm, 14mm and 16mm. Consequently, the relationship of a different material of void with the effects of the electrical field is set up such that is random. All of the different materials used in the cable, aluminium oxide (Al_2O_3) showed the least electric field. Decrement of electric field gives a view that this material can be used as nanofillers at optimum size.

Keywords: Electric Field, Voids, High Voltage Cable, COMSOL Multiphysics

1. Introduction

The technology of high voltage transmission and distribution has improved to ensure efficiency and benefit both producers and consumers. Because of its low losses for high voltage transmission, high voltage direct current (HVDC) is chosen for long-distance underground transmission. A variety of factors impact transmission performance, including high voltage cable performance. A range of internal and external variables, including insulator performance, impact high voltage cable performance. Insulators are used in cables to isolate the electrical conductor and prevent electricity from passing through it [1] .

A good characteristic of the cable must be considered to ensure there are no breakdowns that occur during the power transmission and distribution process [2]. The existence of voids of air and water

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inside the insulating material of the cables is one of the key difficulties that shortens the life of the cables. Partial discharge occurs as a consequence of vacancies, bubbles, or defects, which is result in a shorter life for the cable [3]. The void might occur during the manufacturing, fabrication, installation, energisation, or operating processes. Voids can occur in the insulation of power cables such as paper oil insulation, cross linked polyethylene (XLPE), and ethylene propylene rubber (EPR).

The objectives of this project is to determine the effects of voids at contaminated XLPE insulator cable. Besides, to evaluate the effects of location of voids using different material of voids towards distribution of electric field in cable. Other than that, to obtain the electric field characteristics inside various voids in the cable.

Paper cables are less susceptible to partial discharge activity than XLPE cables[4]. So, XLPE cables are more concern for this effect. In this study, the effects of voids towards electric field will be analyzed. This project considers electric field analysis with different size of the void, shape of the void, and the effect of distance of void from conductor surface. Therefore, a model geometry of a 275 kV XLPE cable termination was simulated in this work utilising COMSOL Multiphysics software. Through simulation, the model was utilised to derive the electric field distribution in the model with containing of void at cable termination

2. Simulation Techniques on Suspension Insulator Modelling

The simulation of string insulator on 132kV insulation power distribution system was conducted by using COMSOL Multiphysics as a tool of Finite Element Method (FEM) software.

2.1 Process Flow

Figure 1 shows the process flow for this project.

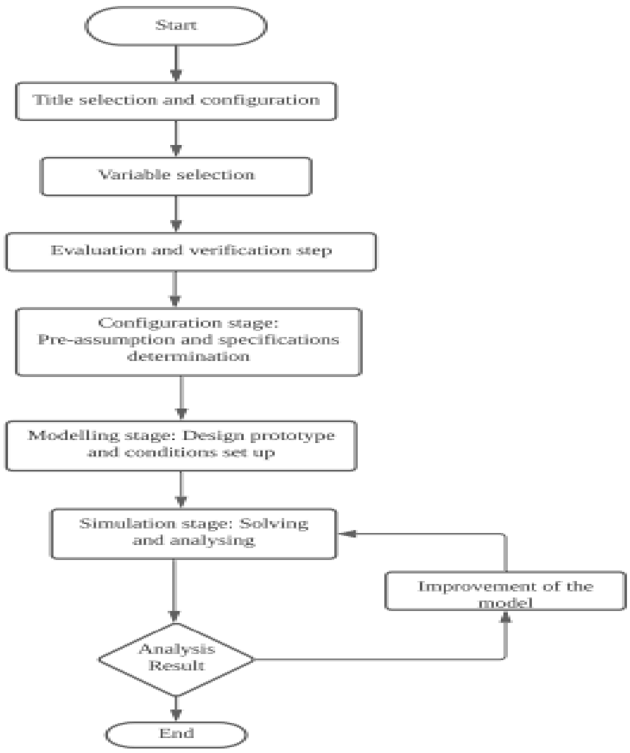


Figure 1: Process flow

2.2 Parameter of Insulator

Table 1 shows the parameter of the XLPE insulator. In this project, the cable designed follow this parameter.

Table 1: Parameter of insulator [6]

Item	Parameter Name	Variable Value	Unit or Dimension
1	System voltage	275	kV
2	Conductor	16.85	mm
3	XLPE	49	mm
4	Aluminium sheath	50.2	mm
5	High Density Polyethylene (HDPE)	66	mm

2.3 Model of XLPE Insulator Cable

Four layers of a circle are formed in graphics using required standard. The model is shown in Figure 2. It consists of four layers which are the inner circle is the conductor core, the next circle layer is the XLPE insulator, the circle for the aluminum sheath, and the last circle is High Density Polyethylene (HDPE). Note that the position of void is varied in study.

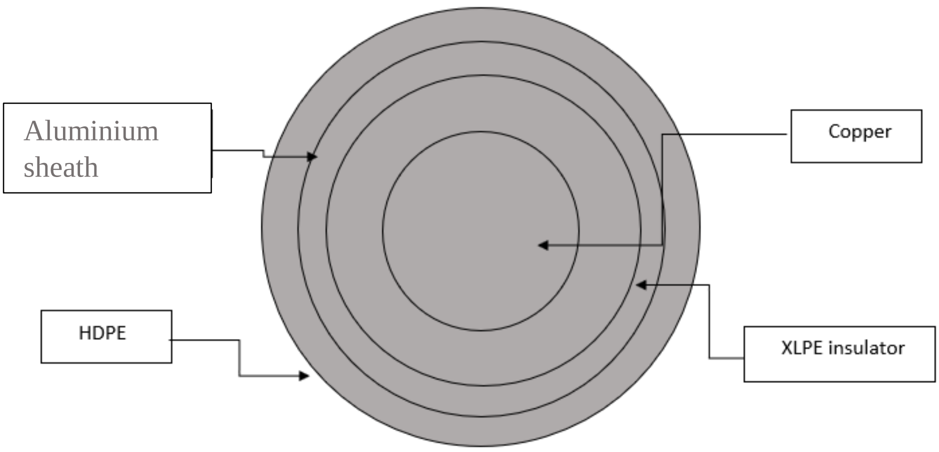


Figure 2: Model of clean design of 275 kV power cable

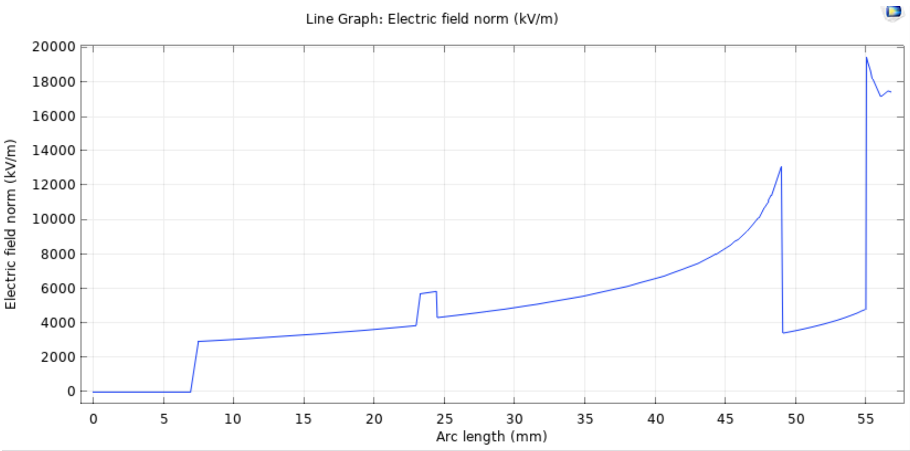
2.4 Model of Cable with and without void

Error! Reference source not found. and 3.7 Aluminium Oxide

Aluminum Oxide characteristics is discussed. Simulation through COMSOL Multiphysics give electric field behavior in in Table 5. In general, pattern of electric field is same as other material such that it increases until it reaches maximum and decreases at minimum value before it raise again. At 14 mm and 16 mm distance of voids from conductor, decrement happens in between 45mm and 50 mm compared to the first graph. The graph shown the maximum value that has been reach by 12mm is

19000 kV/m while the maximum value reaches by 14 mm and 16 mm is about 15000 kV/m and 13000 kV/m respectively

Table 5: Aluminum oxide at different location of void and its effect towards electric field

<table>
<tr><th>Location of void at x-axis</th><th>Electric field distribution vs x-coordinate</th></tr>
<tr><td>12 mm</td><td>
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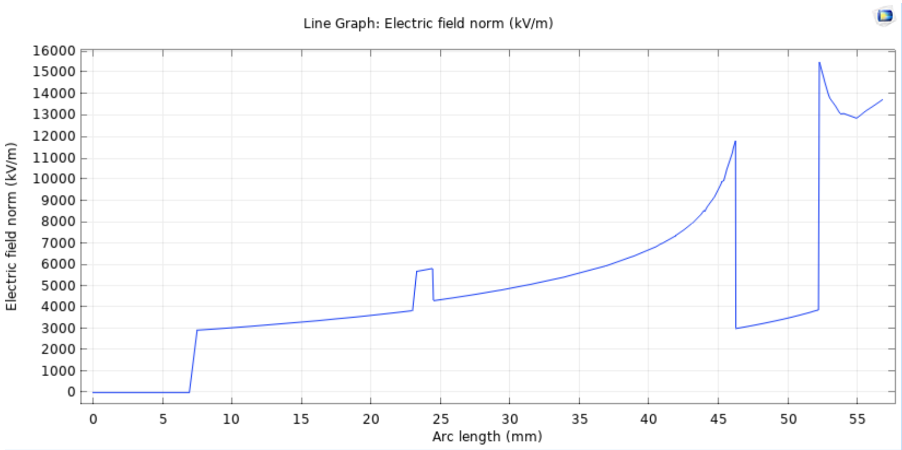
<tr><td>14 mm</td><td>
</td></tr>
</table>

4.0 Conclusion

From the result obtained, the electric field in cable with void installed had a lower value of maximum electric field than when without voids was installed. Besides, the higher the distance of voids from conductor, the higher the decrement of electric field. There were various recommendations for future work can be made to improve the outcomes, such as investigating space charge density in the context of contamination voids in high voltage cable and using Multiple core simulation using COMSOL Multiphysiscs and third Simulation of 500 kV cable. This is because it can transmit large amounts of electricity at relatively low currents. It also can reduce power lost in the transmission line.

Acknowledgement

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References

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[6] M. Yagi *et al.*, "Design and evaluation of 275 kV-3 kA HTS power cable," *Phys. Procedia*, vol. 45, no. May, pp. 277–280, 2014, doi: 10.1016/j.phpro.2013.05.021. show the design of the cable without and with a void. The cable consists of four layer. This cable is supply for 275 kV. Next, the existence of different material of voids is designed to investigated the electric field distribution.

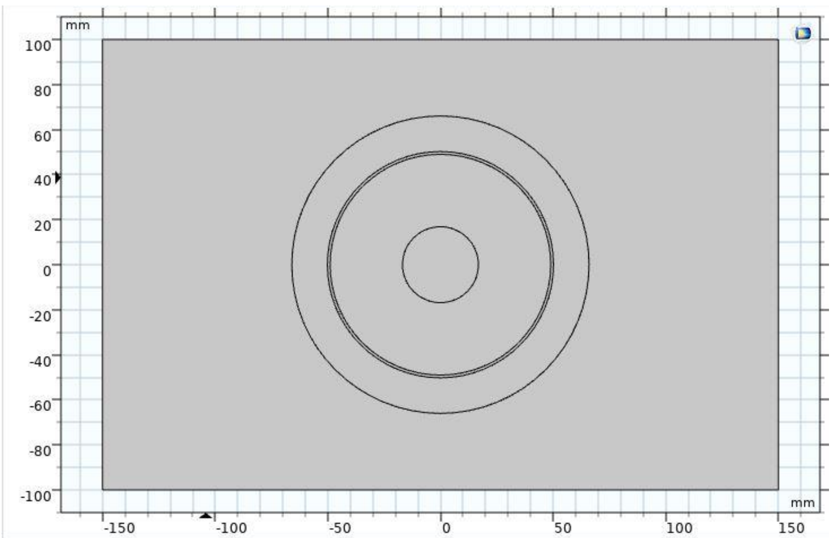


Figure 2: Design of cable without void

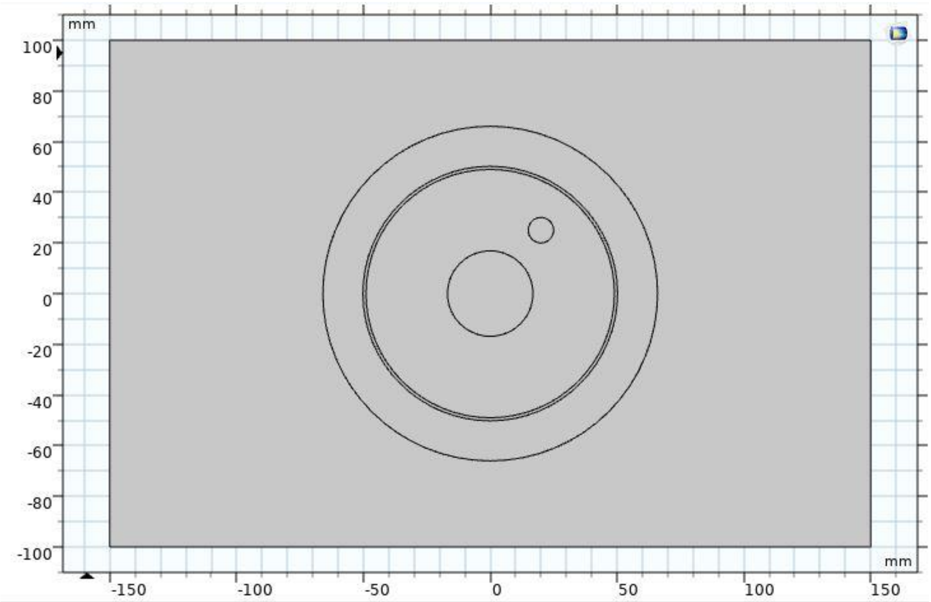


Figure 3: Design of cable void

2.5 Material Properties

It was essential to assign material and boundary properties to solve mathematical calculation. In COMSOL Multiphysics software, a material library was provided. But material properties can be added in the simulation to complete all the necessary materials. In this project, relative permittivity was the input needed to declare a material to find the electric field. **Error! Reference source not found.** shows the relative permittivity of material in this project.

Table 2: Relative permittivity of the material [5][6]

Item	Material	Relative Permittivity, εr
1	Air	1.0005
2	XLPE	2.3
3	HDPE	2.5
4	Silicon Dioxide	3.9
5	Titanium Dioxide	85
6	Aluminium Oxide	9.4

2.6 Solver Study

AC/DC module was used in this simulation project using COMSOL Multiphysics software. Next, for the study in this project, stationary was selected. The stationary study was chosen because this project does not involve changes due to time and frequency

3. Results and Discussion

The cable in various conditions was observed. There were two main results, including designing a cable without a void and with a void. Furthermore, the electric potential and electric field distribution were also obtained with their graph.

3.1 Electric Field Distribution without and with void

Figure 5 shows the electric field distribution without void and Figure 6 the electric field distribution with void.

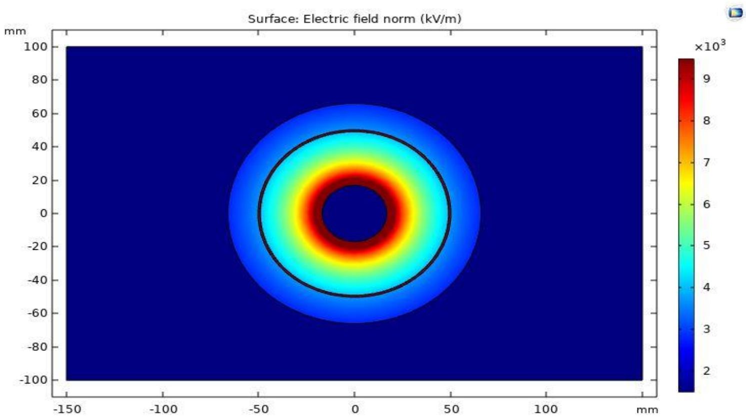


Figure 4: The electric field distribution without void

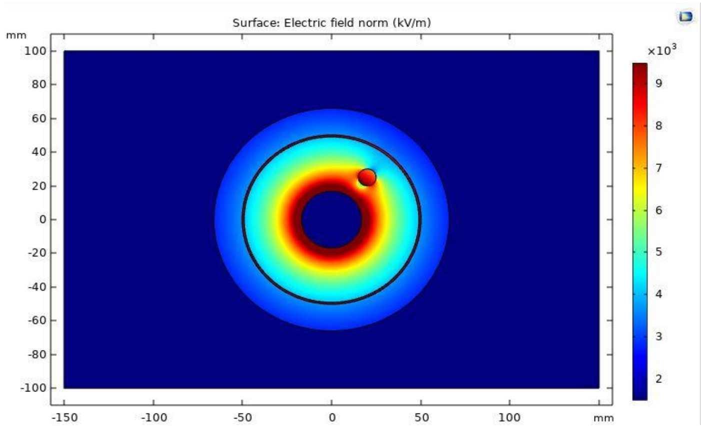


Figure 6: The electric field distribution with void

3.2 Cutline for Graph Electric Field in High Voltage Cable with Void

Figure 7 shows the cut line for graph electric field in high voltage cable with and without voids. The cut line was in this cable from end to the end of the layer sheath of cable.

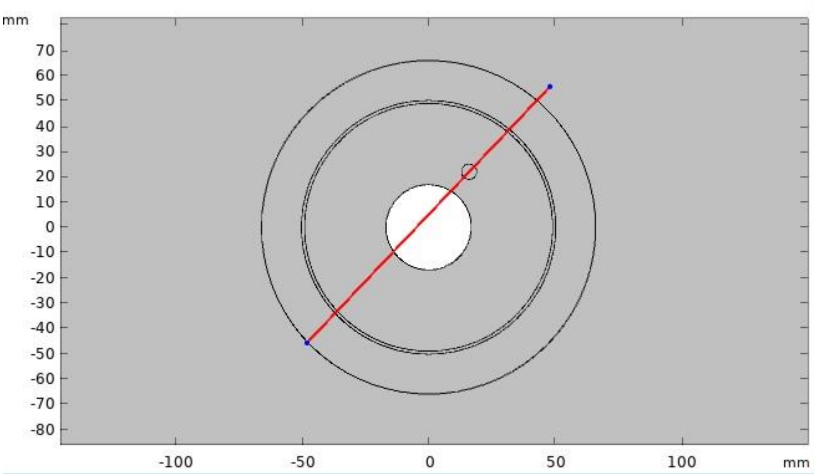


Figure 7: Cut line for graph electric field in the high voltage cable

3.3 Graph Electric Field with and without Void

Figure 8 and Figure 9 shows the graph of electric field distribution on high voltage cable with or without void.

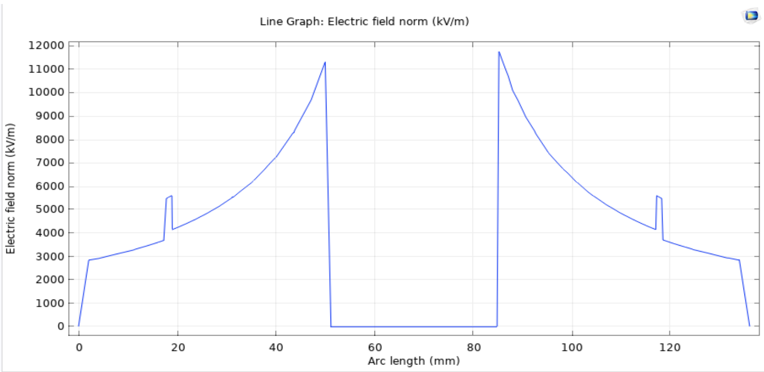


Figure 8: Graph electric field without void

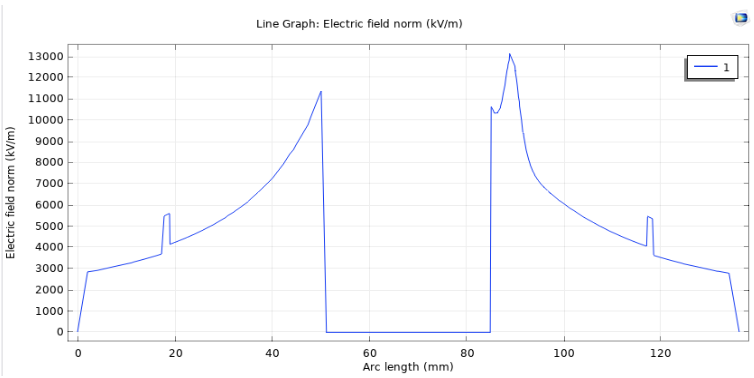


Figure 9: Graph electric field with void

As mentioned, the size and location of void also plays important role in the field distribution of a cable. Firstly, for the cable without void, it shows that the electric field is increasing until it dramatically increases at aluminum part before become stable. The graph also continuously increases until maximum electric field achieve. When there is a void in the insulation, the electric field of the void increases, as indicated in the picture above. Because the electric field at the void is larger due to the lower permittivity of the insulation material, the insulation material must endure more stress at the void position. Because of its lower permittivity, void (air) has a lower breakdown strength than insulating material. As a result of the void within the insulating material, its breakdown strength reduced [4].

3.4 Different Material of Voids

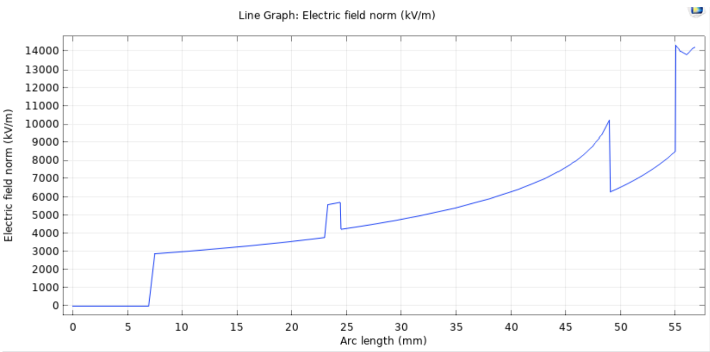
Silicon Dioxide (SiO_2), Aluminum Oxide (Al_2O_3), or Titanium Oxide (TiO_2) are the materials utilised in this experiment. All of these materials are being studied for their electrical fields at distance of voids from conductor. This behavior is being known through a graph of electrical field distribution where the value of electrical field represents of electrical field at cable layer of points. Different material of voids consists differently due to its permittivity value and there are three location of voids which are 12 mm, 14 mm and 16 mm at x-axis are being done with this COMSOL software. Analysis is discussed in every different type of material.

3.5 Silicon Dioxide

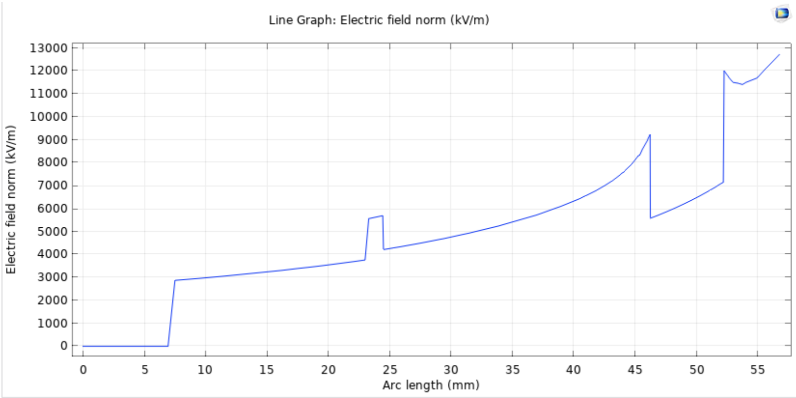
Table 3 shows the SiO_2 at different location of void and its effect towards electric field. It has been demonstrated that in the presence of SiO2, electric field behaviour differs from that of a perfect cable that is free of defects in both behaviour and value. These findings are depicted in the figure above as a line graph generated from COMSOL Multiphysics analysis. Graph shown is electric field distribution vs x-coordinate arc length of a cable represented by mm. This graph starting at 0 mm until average 55 mm of arc length. Analysis on electric field is done to investigate the behavior of electric field on each different location of voids.

In general, pattern of electric field distribution vs x-coordinate for silicon dioxide start from 0 kV/m of electric field and reaches maximum and it will decrease to a certain point before it starts to raise again. Comparing maximum point for each different location of void, at 12 mm the void happens at 10000 kV/m while at 14 mm the graph effected at 9000 kV/m and at 16 mm the electric field of void reach at average 8000 kV/m. However, for all three different graph it sudden drop is seen after it reaches maximum and raise again. From that result, it can be concluded that the more the distance of voids from conductor, the less electric field will obtain.

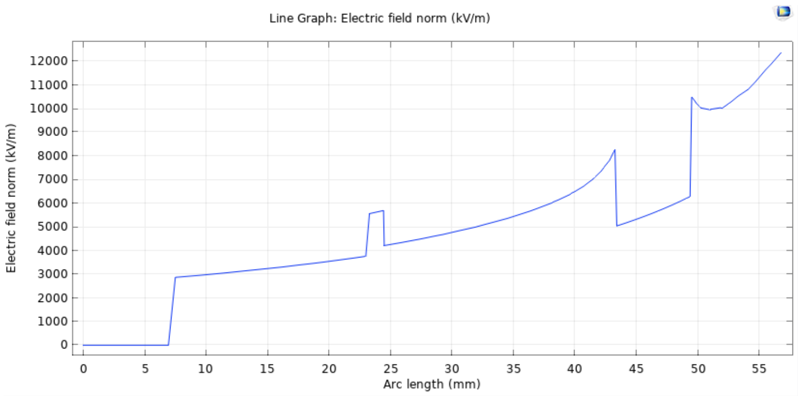
Table 3: SiO_2 at different location of void and its effect towards electric field

Location of void at x-axis	Electric field distribution vs x-coordinate
12 mm	

14 mm



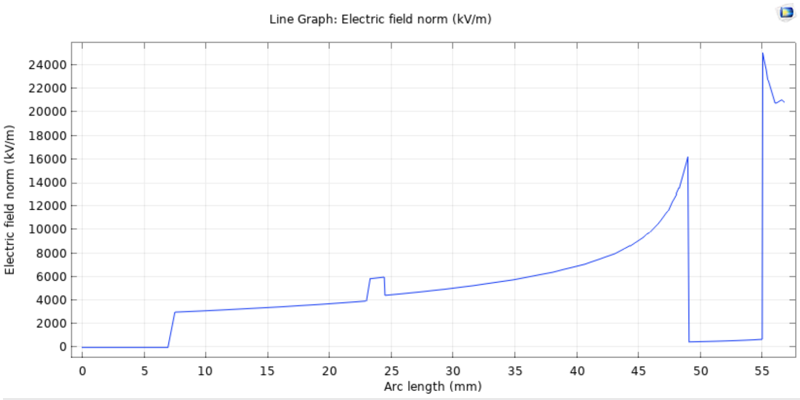
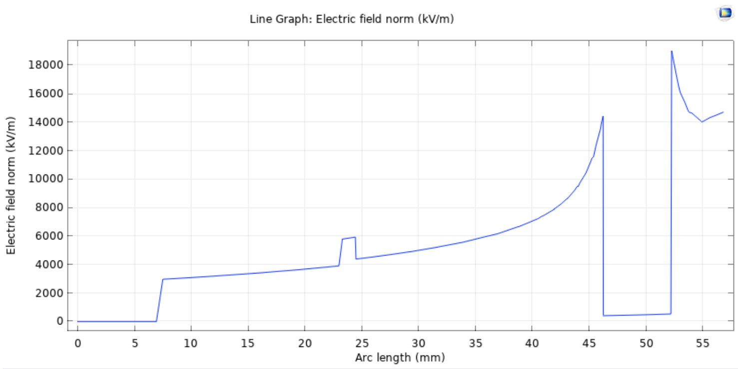
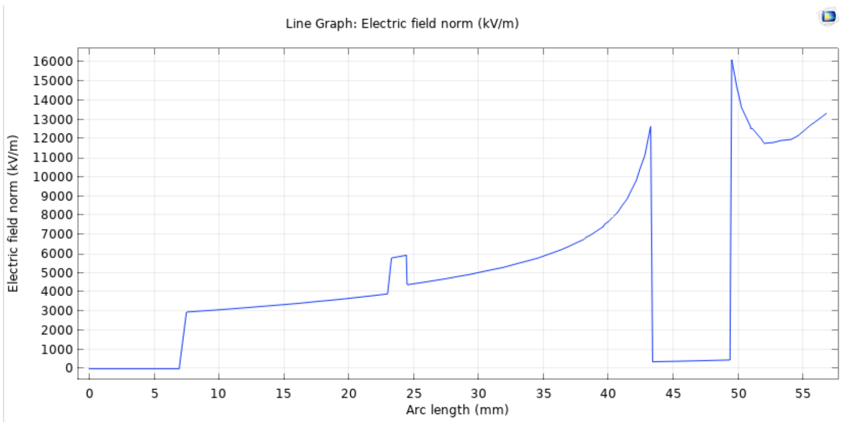
16 mm



3.6 Titanium Dioxide

Observing the electric field properties of titanium Oxide in Table 4. A general pattern for electric field is visible in the same way as silicon dioxide, with it growing to the maximum value of electric field and then reducing until it increases again to the maximum value. The general pattern of the electric field has been compared. Starting of 0 mm arc length of cable until it reaches 7 mm, the graph increases until it reaches at maximum value which happens in between 40 mm and 45 mm location of void from conductor. An increment of electric field suddenly decreases before it raises again. Increment pattern for all the different location of voids happen gradually. The graph show starting point of increment is the same for all the different type of graph. Comparing to 14 mm and 16 mm location of voids, increment to maximum value happen is same which are in between 45 mm and 50 mm. Decrement pattern of electrical field after reaching maximum value is same for all this type of graph.

Table Error! No text of specified style in document.**: Titanium at different location of void and its effect towards electric field**

Location of void at x-axis	Electric field distribution vs x-coordinate
12 mm	
14 mm	
16 mm	

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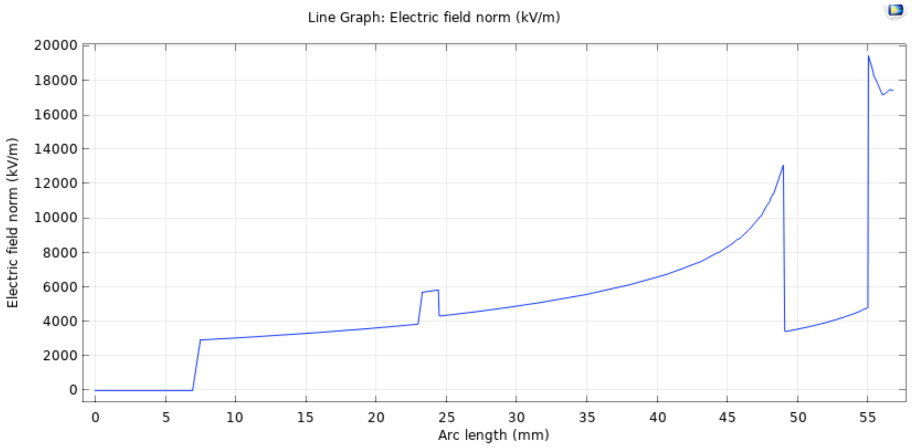
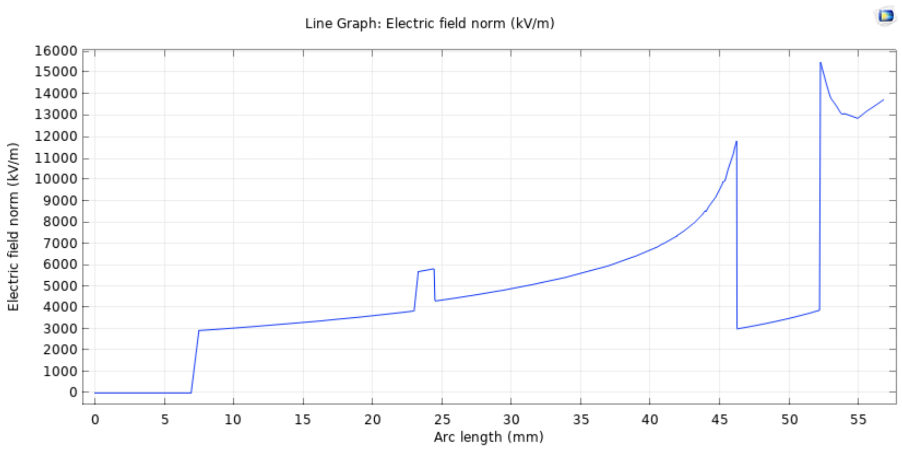
12 mm	
14 mm	

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