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Analysis of Electric Field and Current Density Characteristics of HVDC XLPE Insulator with Effect of Arsenic

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Abstract: An insulator is one of the important things in high voltage technology. The insulator quality should be a top priority when choosing an insulator for cable either overhead or underground because an unsuitable insulator can lead to insulator breakdown and other big problems. XLPE insulator cable is the most popular insulator in high voltage technology because it has high-temperature resistance and aging resistance compared to other insulators. Besides, electric field and current density are very important characteristics in the insulation process. Flashover can occur if the electric field and current density are increasing and cause expediting the insulator premature aging process. Arsenic is known as soil and underground contaminants. This research is to identify the effect of arsenic on electric field and current density by using FEMM Software. The software is used to simulate the XLPE insulator cable model with different thicknesses of arsenic. The result showed that the electric field strength and current density are inversely proportional to the thickness of arsenic. As a conclusion, the electric field strength and current density are decreased when the thickness of arsenic is increased.

Keywords: Electric Field, Current Density, Arsenic, XLPE

1. Introduction

Nowadays electricity is very important on a daily basis. Almost 90% of houses need an electrical source. For example, washing machines, blenders, television, and others. Therefore, if a power outage occurs many people face a big problem especially when it takes time to solve the problem like two or three days. Residential, shop lots, and small industries will be affected by that. So, the electricity supply is the number one priority to humans now. An insulator is one of the important things in high voltage technology. It is a material that cannot conduct electricity and is liable to hold the weight of conductors [1] . There are many types of popular insulators used in high voltage technology such as XLPE, silicone rubber, glass cap and pin [2] and others. The insulator quality should be a top priority when choosing an insulator for cable either overhead or underground because an unsuitable insulator can lead to

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insulator breakdown and other big problems. One of the problems faced by underground insulator application is contaminating insulators by the natural component in the soil. Arsenic is one of the soil contaminants. It brings a lot of harm to nature.

Arsenic is a naturally occurring element in the earth's and is extensively spread in the environment in the air, water, and land. If it is inorganic form, it is so poisonous. There are many factors the way this element can spread into the land because most of the industries used arsenic in inorganic compounds[3] .For example, glass, wood and paper factories. In soil, arsenic is present in a solid form which is silver-gray or white metallic solid [4]. This element is known as soil [5] and underwater arsenics[6]. This research is to investigate the behaviors of arsenic to the underground XLPE insulated cable through the electric field strength and the current density. Electric field and current density are very important characteristics in the insulation process. Flashover can occur if the electric field and current density are increasing and cause expediting the insulator premature aging process [7]. The behavior of arsenic toward the electric field and current density needs to be identified to ensure the safety of HVDC XLPE insulated cable.

The purposes of this paper are to determine analyse the behavior of arsenic in different thickness toward the electric field and current density on underground XLPE high voltage insulator cable. Besides that, to determine the relationship between electric field and current density toward HVDC XLPE insulated cable.

2.0 Methodology

The project methodology focusses on the development of the HVDC XLPE insulator cable with different thickness of arsenic. The first step is set up the type of problem, design the XLPD cable on FEMM Software, set up the material properties specification, define the electric field potential energy cable, and simulate the cable model.

2.1 Set up the type of problem

This model is based on a previous research paper [8]. Thus, in this project, designed the XLPE insulator cable was also done by using FEMM software with the accurate specifications from the cable catalogue and the research paper. So, the first step was creating a problem by choosing the "electromagnetics".

2.2 Design the XLPE cable

The model had been designed on the worksheet provided in the FEMM software. Set up the parameter on the problem definition box. Next, the way to draw the model was inserted the coordinates of each layer of cable by pressed the button "Tab" at the keyboard and to form the circle structure, the arc button from the toolbar had been clicked. After inserting the all coordinates, a set of cross-area cables had been formed. This insulator cable model had three layers consists conductor (copper), XLPE insulator and arsenic layer. Table 1 shows detail and description of theisulator cable model. Figure 1 shows the layers of XLPE insulator cable model with material specification.

Table 1: The detail and description of the insulator cable model

Specification	Value	
Potential	11kV	
Ground	0V	
	Layer	Diameter (mm)
Size/ Dimension	Conductor	5.00
	Insulator	20.00
Arsenic layers	Clean	0.00
	Light	+3.00
	Moderate	+9.00
	Heavy	+ 15.00

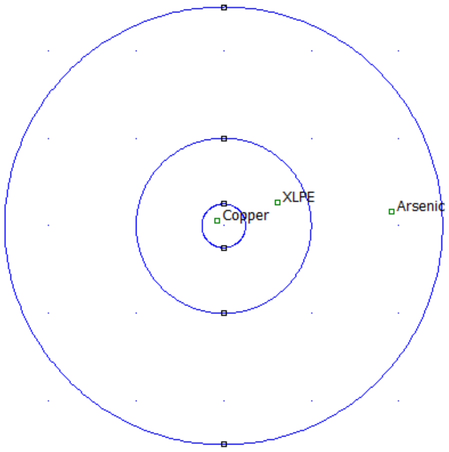

Figure 1: The layers of XLPE insulator cable model

2.2 Set up the material properties specification

Materials for each layer component are being added into FEMM software. Each material was being added into FEMM software using the "Properties" window on the toolbar. The information inserted into the material properties specification were the value of conductivity of each material. The window to insert the information was called "Block Property". Next, the insulator cable model consists of three layers. There were three materials had been inserted into the FEMM software like copper, XLPE and arsenic.

2.3 Define the Boundaries and Electric Field Potential Energy Cable

The electric potential energy was set at 11kV that goes through the conductor layer. So, to set up the boundaries of all cable model layers, "Properties" window had been selected and under "Boundary" selection the electrical potential energy had been inserted. The function to define the boundaries into both cable models was to distinguish one layer from another, for example, separate the conductor layer and the insulator layer because both were different materials. There were three materials in the insulator cable model boundaries, it was the same materials inside the material properties. After defining the boundaries to all layers, the next step was definite the electric potential energy values to all layers of both cable models. There were two types of electric potential energy: high voltage (11kV) and low voltage (0V). High voltage for conductor only and low voltage for the rest of layers. The electric potential energy values had been definite in the "Circuit Property" box under the "Conductor" selection.

2.3 Simulate the model

Figure 2 shows the steps of design and simulate the XLPE insulator cable using FEMM software. The process of simulated cable model required selecting the "Mesh" button on the toolbar to build the mesh. After that, "Run Analysis" button had been clicked to analysis the mesh and clicked the "View Result" button, a contour cable image popped up.

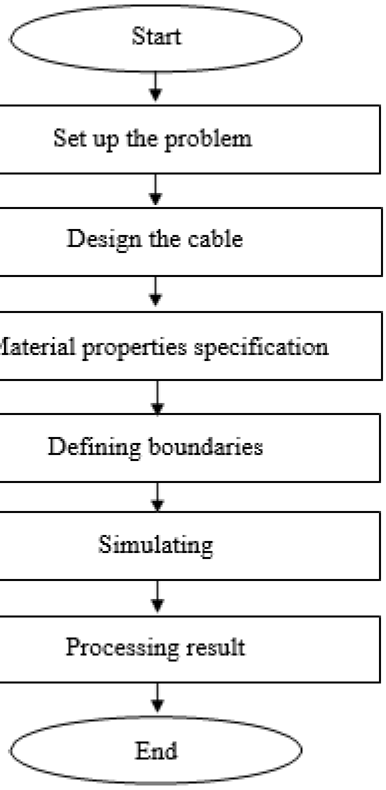

Figure 2: Steps of design and simulate the XLPE insulator cable using FEMM software

3. Results and Discussion

This chapter describes the acquired results, which are indicative of the electrical field and current density of XLPE insulated cable. To examine the behaviour of current density and electric field, four thicknesses of arsenic are utilised. There is a XLPE insulator cable model drawn in the FEMM Software.

3.1 Simulation Result of Electric Field of XLPE High Voltage Insulator Cable

The simulation results of the 11kV voltage XLPE insulator cable shown the concentration of electric field at each layer of the cable. The colour map depicted the amount of concentration of the electric field as described in the legend. The simulation was carried out with four different thicknesses of arsenic: 0mm, 3mm, 9mm, and 15mm. From the result, there were different amounts of concentration of the electric field for each arsenic's thickness. Figure 3 was the clean cable models which mean there was no arsenic powder on the insulator cable. From the legend in Figure 3, the purple colour indicates the highest electric field and blue colour indicate the lowest electric field. According to the contoured cable images, the insulator cable had the highest concentration of the electric field on the whole conductor area and entered the XLPE insulator area. Figure 3 shows the contoured image of insulator cable with no arsenic powder.

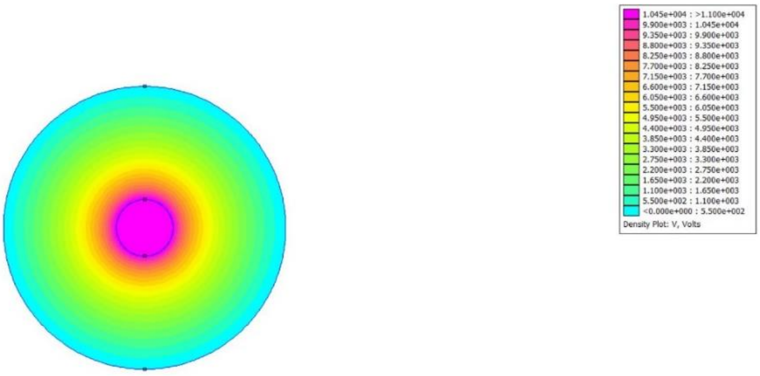

Figure 3: The contoured image of insulator cable with no arsenic powder

Figure 4 shows the contoured cable image of the insulator cable with the presence of arsenic powder in thickness light (3mm). Based on the figure, the concentration of the electric field was highest and reduced slowly along the cable.

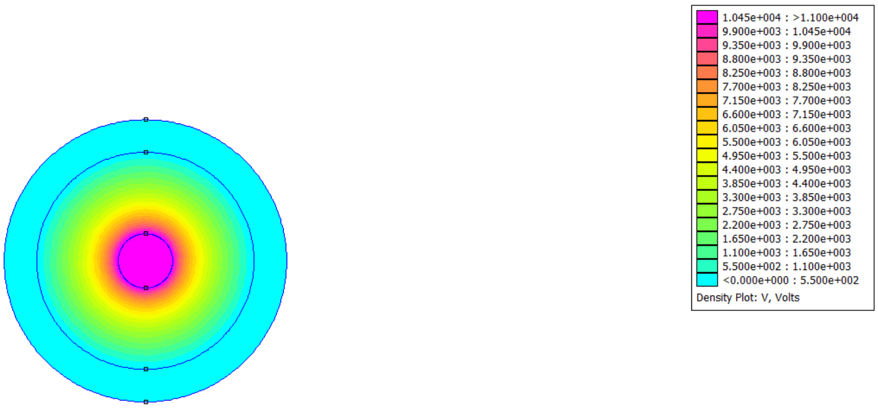

Figure 4: The contoured cable image of the insulator cable with 3mm arsenic powder

Figure 5 shows the contoured cable image of the insulator cable model with the presence of arsenic powder in thickness moderate (9mm). Figure 5 shows the concentration of the electric field on the complete cable model was lower at the arsenic layer compared to the conductor layer. Besides, for the simple cable model the concentration of the electric field was decrease and reduces slowly along the cable.

Figure 5: The contoured cable image of the insulator cable with 3mm arsenic powder

Figure 6 shows the contoured cable image of insulator cable model with the presence of arsenic powder in thickness heavy (15mm). Figure 6 shows the insulator cable model the concentration of the electric field was decrease at the conductor area and reduces slowly along the cable.

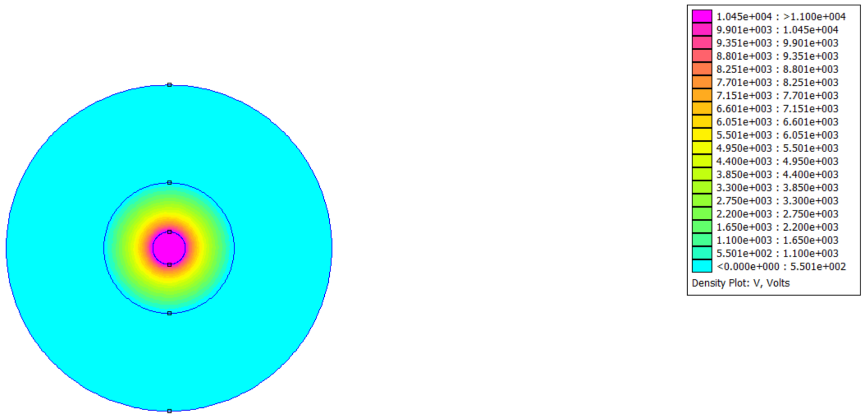

Figure 6: The contoured cable image of insulator cable model with 15mm arsenic powder

3.2 Graph of electric field and current density of XLPE High Voltage Insulator Cable

Based on Figure 7 and Figure 8 show the graph of electric field and current density of clean XLPE insulated cable. The electric field and current density graphs decreased gradually. The measurement was obtained from the starting of the conductor layer to the XLPE insulator layer.

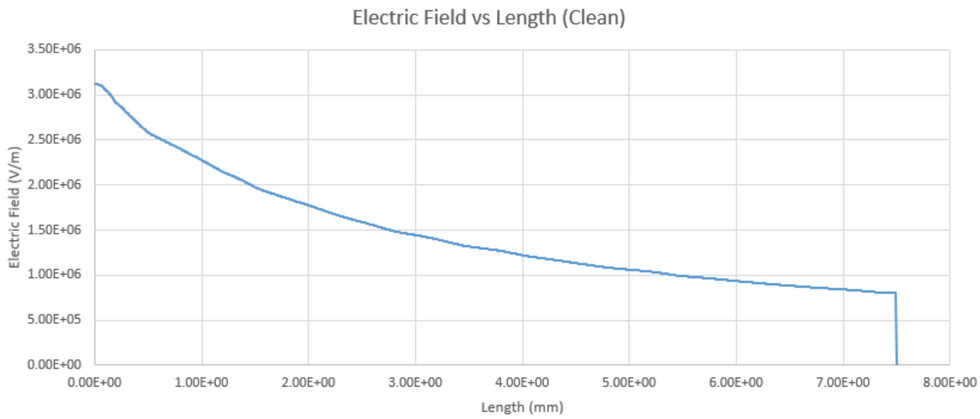

Figure 7: The graph of electric field of clean XLPE insulator cable

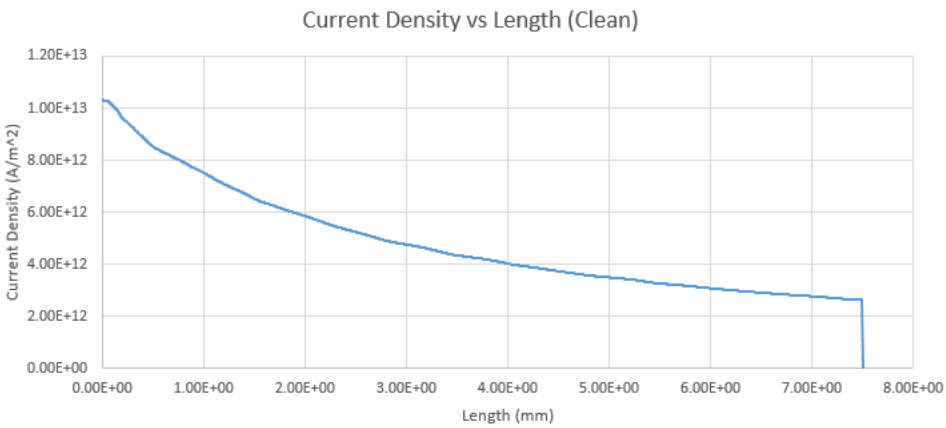

Figure 8: The graph of current density of clean XLPE insulator cable

Next, based on Figure 9 and Figure 10 show the graphs of electric field and current density of XLPE insulated cable with the thickness of arsenic powder was 3mm. The electric field and current density graphs decreased gradually. Both graphs had the highest values when it was nearest to the conductor layer and dropped gradually at the XLPE insulator layer. The electric field and current density turned to zero when it passed the arsenic layer.

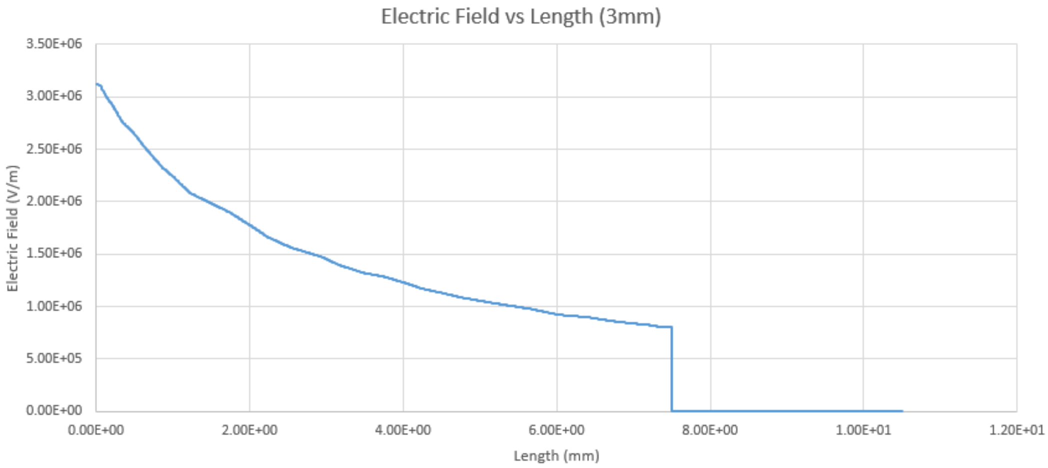

Figure 9: The graph of electric field with 3mm arsenic powder

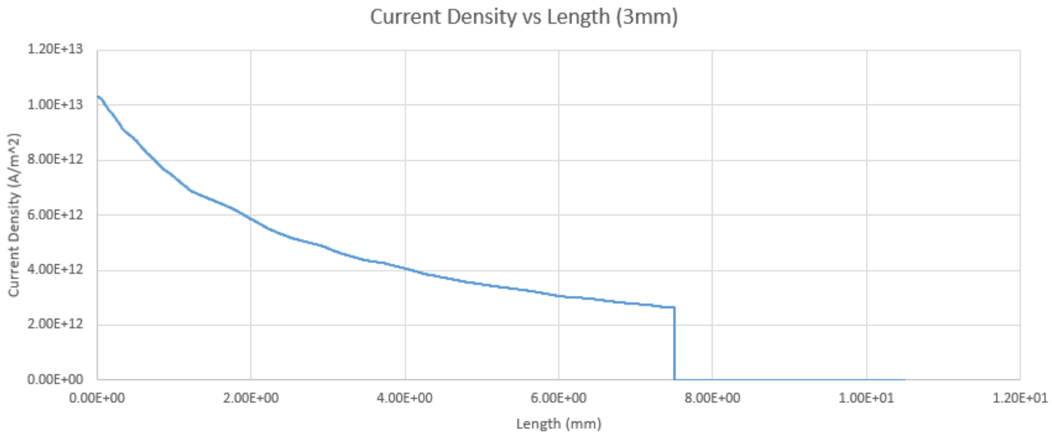

Figure 10: The graph of current density with 3mm arsenic powder

Besides that, based on Figure 11 and Figure 12 show the graphs of electric field and current density of XLPE insulated cable with the thickness of arsenic powder was 9mm. The electric field and current density graphs decreased gradually. Both graphs had the highest values when it was nearest to the conductor layer and dropped gradually at the XLPE insulator layer. The electric field and current density turned to zero when it passed the arsenic layer.

Finally, based on Figure 13 and Figure 14 show the graphs of electric field and current density of XLPE insulated cable with the thickness of arsenic was 15mm. The electric field and current density graphs decreased gradually. Both graphs had the highest values when it was nearest to the conductor layer and dropped gradually at the XLPE insulator layer. The electric field and current density turned to zero when it passed the arsenic layer.

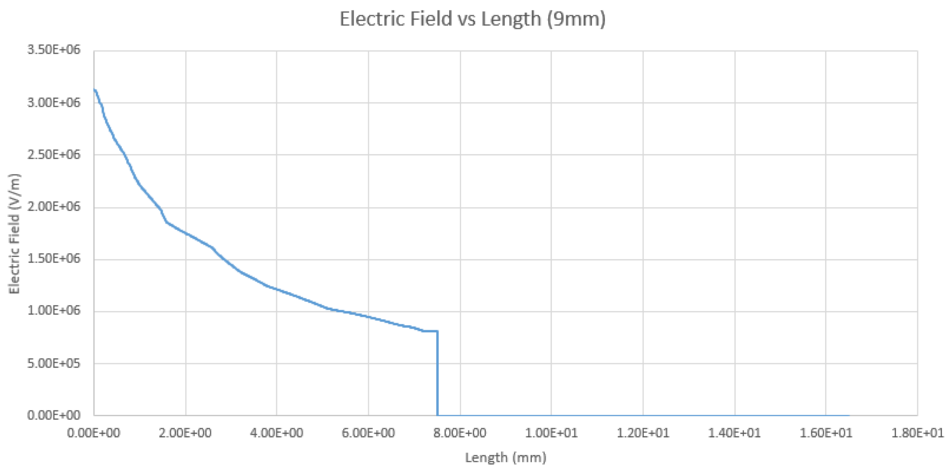

Figure 11: The graph of electric field with 9mm arsenic powder

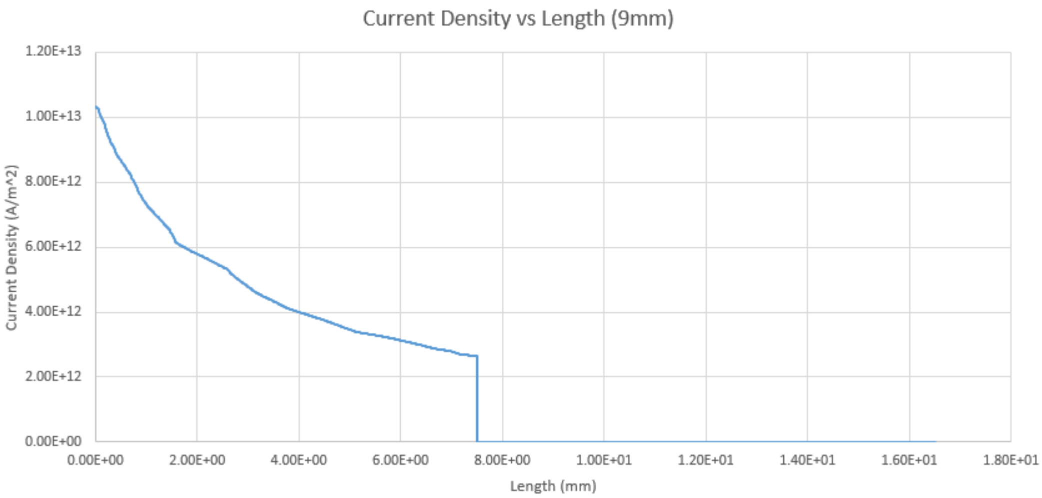

Figure 12: The graph of current density with 9mm arsenic powder

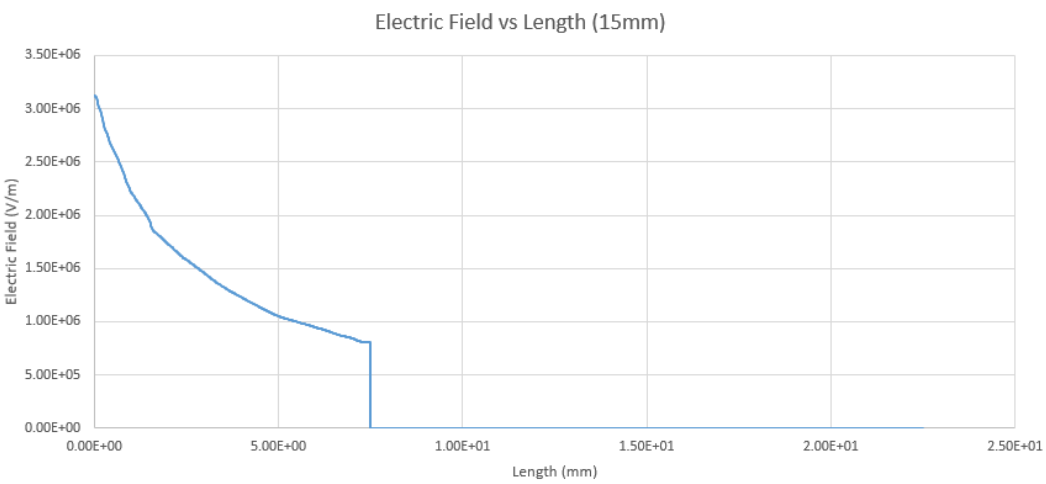

Figure 13: The graph of electric field with 15mm arsenic powder

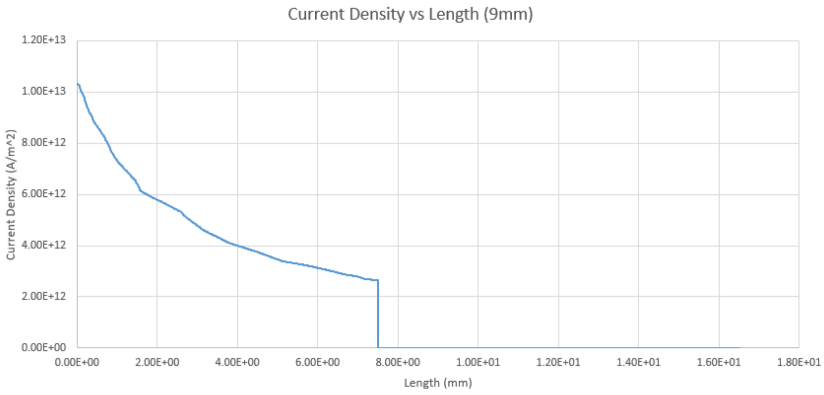

Figure 14: The graph of current density with 15mm arsenic powder

3.3 Discussion of the Electric Field and Current Density of Difference thickness of Arsenic

Figure 15 and Figure 16 show the combination graph of the electric field and current of XLPE high voltage insulator cable for all arsenic thickness. The legend clean indicates no arsenic powder cable, 3mm indicates light arsenic powder layer, 9mm indicates moderate arsenic powder layer and 15mm indicates heavy arsenic powder layer. The length for the y-axis indicates the thickness of the cable.

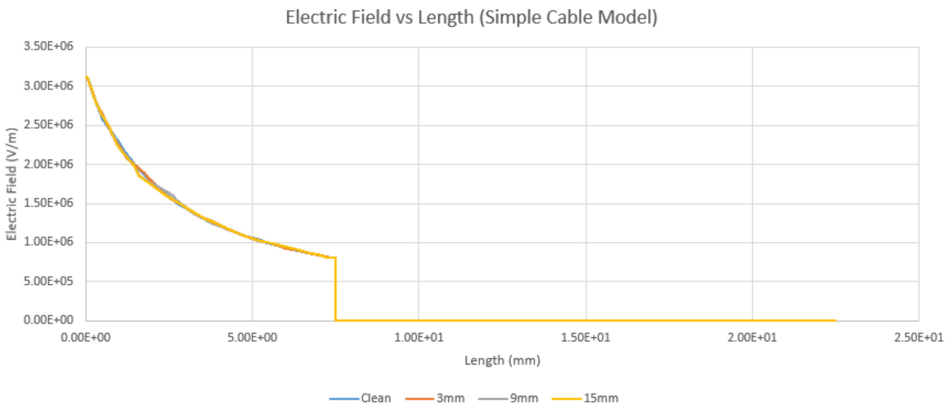

Figure 15: The combination graph of electric field for all thickness of arsenic powder

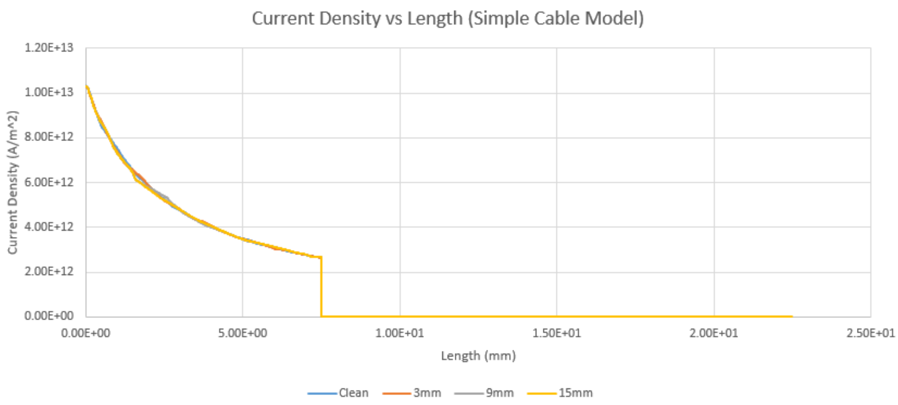

Figure 16: The combination graph of current density for all thickness of arsenic powder

From both figures, it shows that electric field and current density were directly proportional. When the electric field was high, the current density also high and vice versa. According to Ohm's Law: $J = \sigma E$, J indicates current density, σ indicates conductivity of arsenics and E indicates electric field. Since the electric field is everywhere around the insulator cable and the shape of arsenic powder is homogeneous, the current density also holds on the insulator cable [9].

Besides that, from the graphs also it can be concluded that the thickness of arsenic powder can affect the strength of the electric field. According to the Figure 15 it showed the 15mm thickness of arsenic powder had decreased the strength of electric field reading. It starts from 1.41mm to 1.97mm 15mm thickness arsenic powder had a significant impact on the performance of XLPE insulation compared to other thicknesses. It was because electric field strength depends on the location of the source like the conductor in this case. The magnitude of an electric field diminished as the distance between a point and the source increased [10].

4. Conclusion

In conclusion, the strength of the electric field is directly proportional to the current density. The highest the electric field strength reading, the highest the current density reading. Next, the 15mm thickness arsenic powder has a significant impact on the performance of XLPE insulation compared to other thicknesses. In conclusion, the largest the thickness of arsenic powder, the biggest impact on the performance of XLPE insulation. As the recommendation, use different software because FEMM software cannot support complex design and try to use variety type of study material.

Acknowledgement

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