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Electric field and temperature analysis of high-voltage XLPE cable insulation bubbles based on COMSOL simulation

Yu Zhang

School of Electrical Engineering, Anhui Polytechnic University, Wuhu, Anhui, 241000, China

Abstract: *Compared with ordinary PVC cables, crosslinked polyethylene insulated cables have been used widely because of their high load capacity, strong overload capacity and long service life.However, in cable production process, small bubbles may appear in XLPE layer, and the bubble defects can cause distortion to the electric field distribution and temperature distribution of the cable.This article simulates electric field and temperature distribution characteristics of bubbles in different sizes and locations in 110kV XLPE cables by COMSOL.The simulation results show that when the bubble appears in the XLPE layer, the electric field intensity near the interface between the bubble and XLPE decreases sharply, and in comparison with the condition that there is no bubble, the electric field intensity is greater.Meanwhile, the closer bubble get to the outside of the XLPE layer, the smaller the maximum field intensity will be.Also,the internal temperature of the bubble in the XLPE layer shows a linear ting trend.*

Keywords: *crosslinked polyethylene cable, bubbles, finite element software, electric field intensity, temperature*

1. Introduction

High voltage cable can be divided into oil-filled cable, sticky soaked paper cable and plastic insulated cable.At present, in the process of high-voltage cable production, the main materials in China are still cross-linked polyethylene (XLPE) insulation material and PVC insulation material.Cross-linked polyethylene insulated cable has the advantages comparing to PVC insulated cable.It has a simple structure, light weight, good heat resistance, strong load capacity, no melting, chemical corrosion resistance, high mechanical strength, and these are what other cables do not have.Therefore, the application of XLPE cable in the power grid has been very widely used, and has gradually replaced the traditional cable.

The extrusion of XLPE insulation can not be made without absolute dust and moisture.So cable insulation may contain a small amount of impurities, bubbles and moisture.When the cable keep running for a long time, impurities, bubbles and moisture will make small discharge phenomenon in the inner insulation, which is known as local discharge phenomenon.Local discharge phenomenon will make the temperature rise, insulation branches, expedite aging till breakdown. So it is a great potential safety hazard[1][2].

This article establish the model of 110kV XLPE cables with the bubbles of different positions and sizes,and simulate the changes of its electric field intensity and temperature by COMSOL.By using COMSOL ,we can clearly see the distribution of electric field intensity and temperature in XLPE layer.At the same time, the distribution and change trend of field intensity and temperature under different bubble existence conditions can also be shown by constructing two-dimensional curves[3][4]. The electric field intensity and temperature distribution in XLPE cable under different conditions have certain reference value for ensuring the stability of cable operation and the reliability of power supply.

2. Cable model establishment

2.1 Cross-linked polyethylene (XLPE) cable model

Single-core cross-linked polyethylene cable is generally made of copper core, conductor shielding layer, XLPE insulation layer, insulation shielding layer, water-blocking belt, air gap, corrugated aluminum sheath, asphalt anticorrosive layer, polyethylene outer sheath[5]. A simulation model of cross-

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linked polyethylene cable with two-dimensional coaxial structure is established in COMSOL to study the electric field intensity and temperature of its steady state in the electrostatic field.The two-dimensional model is shown in Figure 1, and the material and relative dielectric permitants of each layer are shown in Table 1.

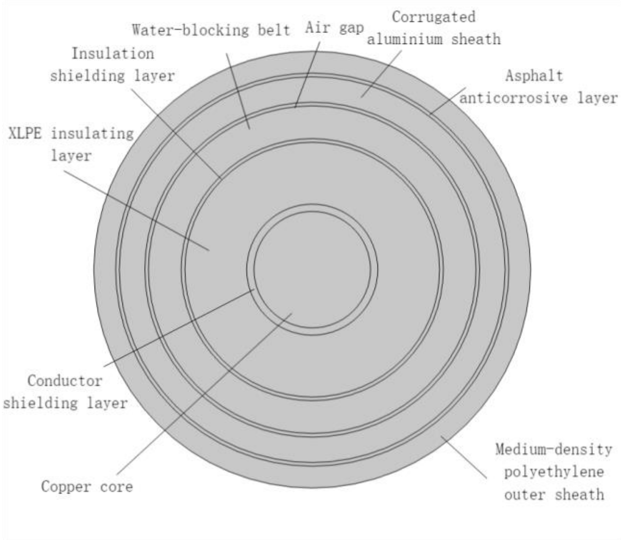

Figure 1: A crosslinked polyethylene cross-section model

Table 1: Materials and Parameters of each layer

tructure	material	relative dielectric constant
Copper core	copper	10000
Conductor shielding layer	Ultra-smooth semiconductor cross-linked polyethylene	2.35
XLPE insulating layer	Ultra-net crosslinked polyethylene	2.35
Insulation shielding layer	silastic	8
Water-blocking belt	polyacrylic ester	3.5
Air gap	air	1
Corrugated aluminium sheath	aluminium	10000
Asphalt anticorrosive layer	pitch	3
Medium-density polyethylene outer sheath	polytene	2.3

2.2 Establishment of cable air gap defect model

When making the XLPE cable insulation layer, because the cable conductor is partially damp or cross-linked by-product impurities, bubbles will remain in the insulation extrusion link in the insulation layer, which is called a typical "air gap defect", as shown in Figure 2.The size of bubbles is generally between a few micrometers and a few hundred micrometers. In order to make the experimental results more obvious, bubbles with diameter sizes of 0.1mm and 0.2mm were set as experimental variables to observe the changes of electric field intensity and temperature.

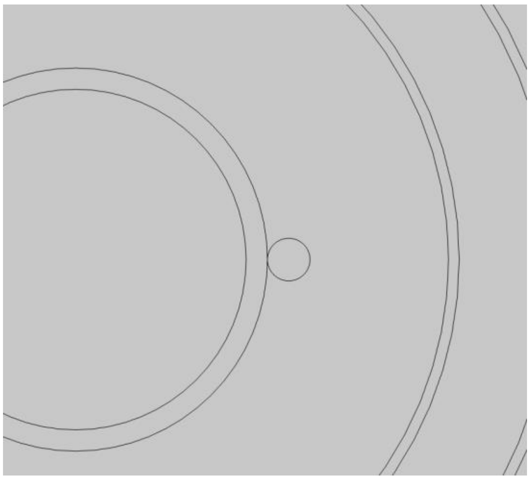

Figure 2: Bubble model

In FIG. 3, select one diameter bubble,bubble models were built d_1=0mm 、d_2=1mm 、d_3=2mm 、d_4=3mm 、d_5=4mm 、d_6=5mm 、d_7=6.5mm away from here,and make a 2d transect,which start form the innermost layer of XLPE and ended from the outermost layer of XLPE and passed vertically through the center of the bubble.The results of seven simulation experiments were observed.

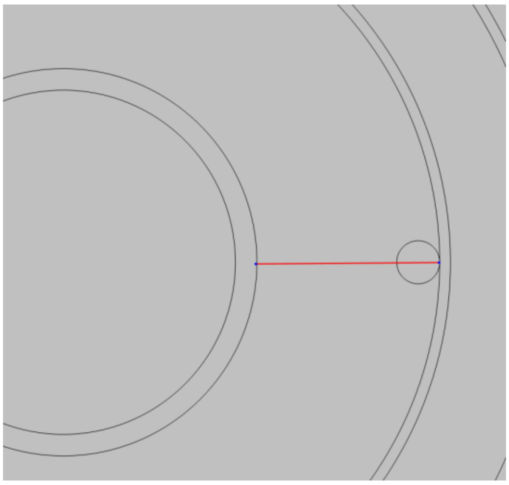

Figure 3: 2D line lines

3. Simulation results and analysis

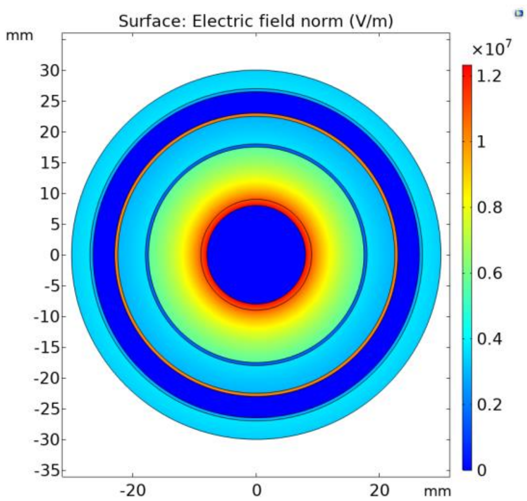

Figure 4: Electric field intensity distribution diagram

ISSN 2522-3488 Vol. 6, Issue 2: 50-55, DOI: 10.25236/IJNDES.2022.060209

Using finite element software COMSOL, the 2D distribution diagram of electric field intensity and temperature of the cable in XLPE layer is shown in Figure 4 and 5.

It is clearly seen in the figure:When getting closer to the copper core,electric field intensity is getting bigger, and the electric field intensity of the copper core in this model is maximum ,about 1.2×10^{7} V / m, the copper cores is the minimum, about 0V/m.

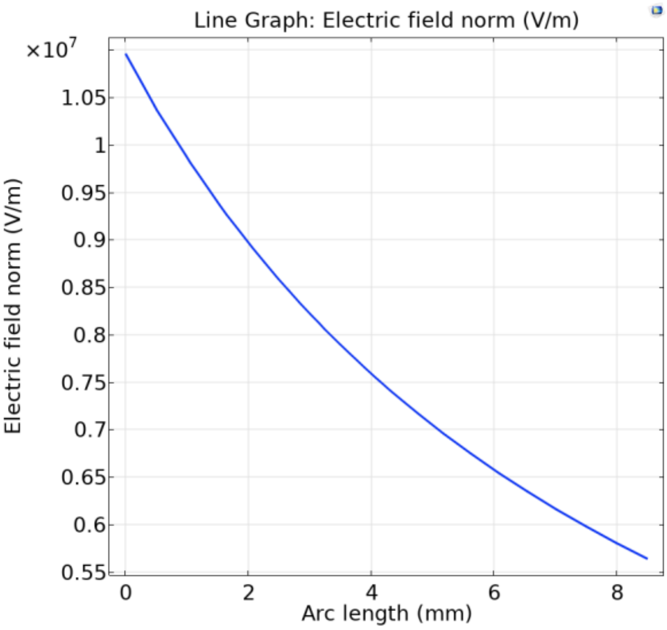

Figure 5: Electric field intensity curve of the XLP Elayer

Figure 5 is obtained as a 2D intercept in the XLPE layer. It can be seen from the figure that the electric field intensity curve shows a smooth downward trend, and the biggest innermost field intensity of XLPE is 1.09×10^{7}V / m; the smallest lateral field strength, approximately 5.7×10^{6}V/m.

Similarly,as we analyze the two-dimensional temperature distribution map of the model (Figure 6), we know that the temperature inside the cable is high inside and low outside. The temperature of copper core is the highest, and the temperature of aluminum wrinkle sheath, asphalt anticorrosion layer and outer sheath is the lowest, about 285K.

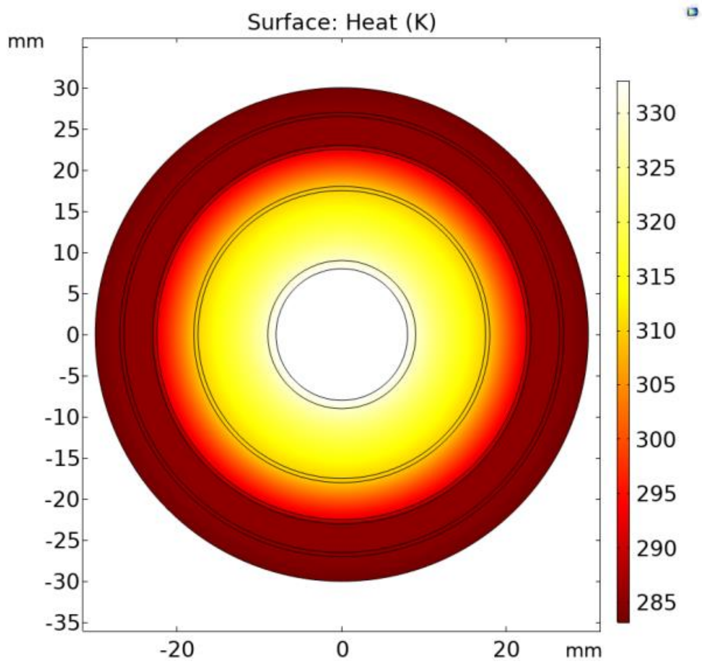

Figure 6: Temperature distribution diagram

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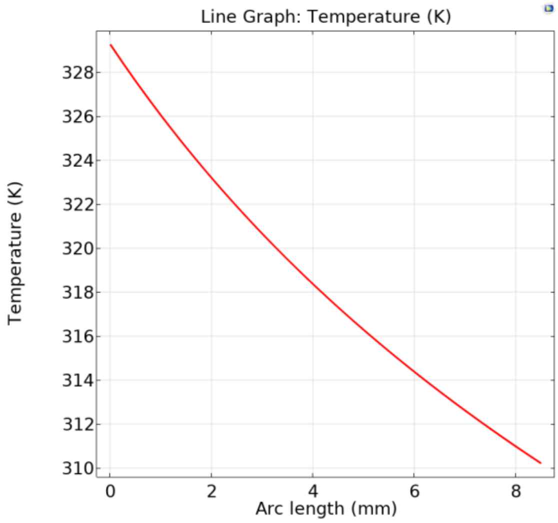

Figure 7: XLPE layer temperature curve

The temperature curve within the XLPE layer is shown in Figure 7, which also shows a smooth decline from the inner layer to the outer layer.The innermost temperature is the highest and the outermost temperature is the lowest.

2.1 Effects of air bubbles on the electric field strength of the XLPE layer

For the presence of 2mm bubbles in the XLPE layer, the simulation results are shown in Figure 8,given the fact that the field intensity at the bubble apparent distortion.

Firstly, longitudinal analysis: when air bubbles are present, the electric field intensity near the junction surface of the bubble and the XLPE layer decreases sharply, but the electric field intensity at the bubble is greater than that in the presence of no bubble.

Transverse analysis: As the bubble is farther and farther away from the conductor shield layer, the maximum electric field intensity at the bubble also decreases. when d_1=0mm, electric field intensity $E_{max}=1.47\times10^7$V/m; when d_7=6.5mm, electric field intensity $E_{max}=8.7\times10^6$V/m .

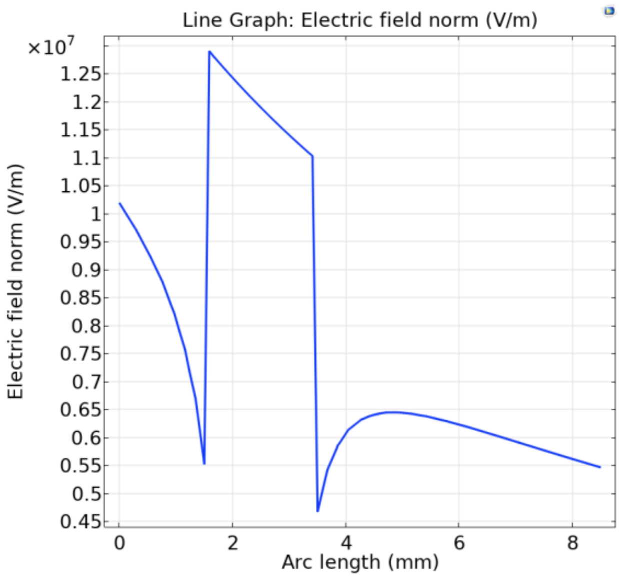

Figure 8: Field intensity curve of the XLPE layer in the presence of bubble defects

2.2 Effects of air bubbles on the temperature of the XLPE layer

Also taking the presence of 2mm bubbles in the XLPE layer as an example, the simulation results are shown in Figure 6.

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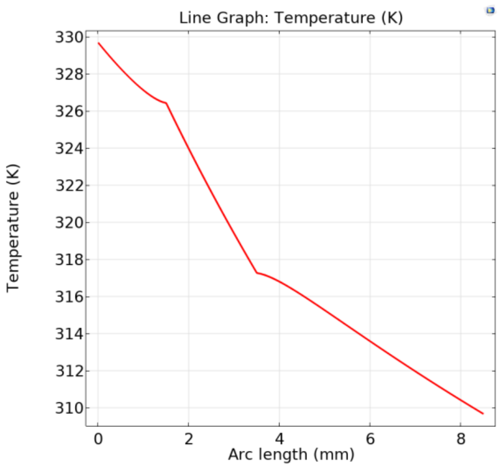

Figure 9: Temperature curve of XLPE layer in the presence of bubble defects

It can be seen from the figure that the existence position of the bubble changes the direction of the original temperature curve, and almost shows a linear downward trend.Moving the bubbles outward, the slope of the internal temperature curve decreases, indicating that the internal temperature decreases faster as the bubble gradually moves to the outside.

4. Conclusion

In order to explore the influence of typical bubble defects in XLPE layer of crosslinked polyethylene cable on field intensity and temperature distribution, COMSOL finite element software is used to adjust the position and size of the bubble defect to simulate field intensity and temperature distribution, and the following conclusions can be obtained:

(1) When there is no bubble defect in the XLPE layer, the electric field intensity and temperature in the layer tend to decrease to different degrees from inside to outside.

(2) When there are bubbles in the XLPE layer, the electric field intensity near the junction surface between the bubble and the XLPE layer decreases sharply, but the electric field strength at the bubble is greater than that when there are no bubbles.As the bubble gets further away from the conductor shield, the maximum electric field intensity at the bubble also decreases.

(3) When there are bubbles in the XLPE layer, the interior of the bubble shows a linear downward trend,and when the bubble gradually moves to the outer layer,the decrease of the internal temperature of the bubble get smaller.

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