Space Charge and Electric Field Analysis on Contaminated XLPE Insulator

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ABSTRACT

Nowadays, XLPE cable has been widely used because it has better resistance than other cables. XLPE insulation has unique features including a high dielectric strength and high insulation resistance. A lot of researches based on hardware and software have been conducted to prove the effectiveness of XLPE cable such as AC and DC applications and Space Charge Distribution measurement under HVDC at High Temperature. This research focused on analysis of space charge and electric field on XLPE cable with effect of non-uniform contamination layer by using Quickfield Software. Non-uniform contaminations have been applied along XLPE cable using Arsenic Tribromide (AsBr₃), Boron Bromide (BBr₃), Ethylene Dichloride (CH₂Cl₂), Formic Acid (CH₁O₂), Formamide (CH₃NO) and Alcohol element. Presence of these contamination elements represent of underground contamination. The size and layer of the contamination were non-uniform type. From the results, it is shown that lower dielectric constant of contamination will affect more on charge of XLPE insulation. As a conclusion, it can be seen lower dielectric constant value of contamination element greatly affecting the performance of XLPE insulation. Furthermore, size of contamination also influences the content of charge in contamination where the bigger the contamination size, the more charge contained in the contamination.

Keywords: Quickfield, XLPE cable, Space Charge, Electric Field, Dielectric Constant

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1. INTRODUCTION

XLPE has begun to develop since 1963. There are Underground Power Cable, Distribution Cable, Overhead Transmission Line and Industrial Cable [1]. Researches have been done on Electric field Calculations for AC and DC Applications of Water Controlled Cable Termination [2] and Simultaneous Measurement of Space Charge Distribution and External Circuit Current in XLPE under HVDC at High Temperature [3] and contamination [4-5]. Nowadays, XLPE cable has been widely used because it has better resistance than other cables [6-8]. The improvement of the XLPE cable has made from time to time under extensive research in order to prove XLPE cable is safe to use. This improvement will increase the demand of international market. In addition, XLPE cable has been classified into several use such as transmission and
distribution cable, aerial cable, underground cable, control cable, low voltage cable and high voltage drop wire [8].

One of the interesting characteristics of XLPE cable is maximum conductor temperature which is 90°C in normal continuous operation. Furthermore, XLPE cable has a good heat resistance, moisture resistance and good resistance to chemicals and atmosphere. XLPE cable is easy to control because it has a smaller overall diameter, lighter weight, easy to be installed and easy in joining and termination [6], [9].

An underground HV cable may exposed to various pollutants carried by water flow either on the surface or in the soil. Water content that we see are not only water, but it is contaminated as a result of human activities. Due to the contamination, this is likely lead to erosion of the cable including a reduction in life expectancy and also performance of the cable. Based on this factor, this research were done to determine effects might have on the XLPE insulation through a non-uniform layer contamination reaction from selected and differences dielectric constant held by elements of the contamination. The results were focused on space charge and electric field strength [10].

A lot of research based on hardware and software has been conducted to prove the effectiveness of XLPE cable. Effect of temperature and current density were one of the results by using XLPE cable. Therefore, this research was used Quickfield Software to identify the effect of an electric field and also to identify the space charge in XLPE cable insulator when expose to non-uniform contamination [11].

2. RESEARCH METHOD

Underground cables were used in this study and this cable was tested against contamination of groundwater contamination, this can be identified by the permittivity value represented by groundwater contaminations and it is evident that there is groundwater contaminations as a result of the research conducted [12]. This research used Software Quickfield to examine the space charge, electric field and its effect on XLPE insulator [13]. Non-uniform contaminations have been used in this research. In addition, to confirm the presence of charge, the electric field was used as a measurement. Arsenic Tribromide (AsBr3), Boron Bromide (BBr3), Ethylene Dichloride (CH2Cl), Formic Acid (CH1O2), Formamide (CH3NO) and Alcohol were used in this research [14].

The contamination that has been used for this research are shown in Table 1 and Table 2 below. The simulation was run based on these properties. The dielectric constant of the contamination was inserted in the material properties. Different value of dielectric constant has represent.

| Chemical Formula | State | Dielectric Constant |
|------------------|-------|---------------------|
| Boron Bromide    | BBr3  | Liquid              | 2.58   |
| Arsenic Tribromide | AsBr3 | Liquid              | 9      |
| Ethylene Dichloride | CH2Cl | Liquid              | 15     |
| Alcohol          |       | Liquid              | 31     |
| Formic Acid      | CH1O2 | Liquid              | 57     |
| Formamide        | CH3NO | Liquid              | 84     |

| Properties Used in the designated model [9], [19-20] |
|---------------------------------------------------|
| Properties                                      | Parameter | Dielectric Constant |
| XLPE Insulator                                  | 2.3       |
| Size of conductor                               | Radius = 4.72035 mm |
| Tickness of XLPE Insulator                      | 3.4 mm    |
| High Voltage                                    | 11kV      |
| Ground                                          | 0V        |
| Size of Contamination (mm²)                     | 0.1819, 0.6787, 0.7637, 1.3105, 1.7879, 1.8142, 2.5496, 2.7026, 2.7171, 3.8484 |

Figure 1 shows the beginning of model painting methods. In this research, the method of inserting the shape was used where the diameter of the conductor is 9.44 mm and insulator thickness is 3.4 mm. The contaminations also have been used based on two conditions which are hydrophilic and hydrophobic [20]. To find hotspot area, click “Mesh” and the green line will appear randomly. The maximum mesh is 255 nodes and in this research, the node has been set to maximum of 214 nodes.
3. RESULTS AND ANALYSIS

This part will discuss about the space charge and the electric field effect on XLPE insulator with effect of non-uniform layer contamination as shown in Figure 2. It consists of 2D panel-parallel models made by Quickfield Student Version software. Based on the analysis, there have been changes between normal condition of XLPE insulation and ten (10) different size of contamination that randomly designed. For this research, only four (4) from ten (10) has been pickup to analyze the space charge and the electric field strength effect on XLPE insulator.

The results of the simulation of XLPE insulator through normal condition or without contamination shows the uniform reading of electric field strength on each thickness of 3.4 mm. Figure 2 shows the color map of normal condition XLPE insulator. From the colour contour map which was obtained, the reading of electric field strength for XLPE insulator under normal condition has been generated. Figure 3 shows a graph that has been formed through contour reading method. X-axis was labeled as the thickness of XLPE insulator, while the Y-axis is the reading of electric field strength. From the graph, it can be concluded that the further insulator from the conductor, the less electric field strength.

Figure 2. Colour map contour Electric Field Strength for XLPE insulation cable

Figure 3. Graph thickness of XLPE insulator against Electric field strength
Figure 4 shows the charge contained in XLPE insulation under normal condition. Under normal condition, charge in XLPE insulator shows the positive number and the charge changed when contaminations were inserted. Based on Figure 4, the reading of the charge $Q_s = 5.5195 \times 10^{-8}$ C.

![Colour map for charge at XLPE insulator without contamination](image)

**3.1. Contour Map on with Different Contamination**

Table 3 shows different of overall colour contour map based on different contamination. There were six (6) contamination selected and each has different dielectric constant values. By referring to table 3 (a) where the XLPE insulator is in a state without the effects of contamination, have shown a good performance. After effect with contamination, the XLPE insulator performance changed according to the type of contamination which was determined. On table 3 (b), an effect that applies to XLPE is very significant because BBr3 have the dielectric constant lower value than dielectric constant values for the XLPE insulator which is 2.58. Unlike table 3 (g), where CH3CO have been approached and seemed unimpressed XLPE insulation or only slightly affected and are in a better situation in terms of performance.

![Table 3](image)

Meanwhile Table 4 shows the different charge on XLPE insulator based on selected contamination. XLPE insulation has a full charge if in normal condition with the $5.5195 \times 10^{-8}$ C. The charge value decreases if contamination that has a different dielectric constant value of BBr3 to CH3NO.

![Table 5](image)
3.2. Electric Field Strength with Different Contamination Size

Table 6(a) shows the selected contamination which is Boron Bromide (BBr3) that has the lowest dielectric constant of 2.58. From Table 6, it can be concluded that the smaller size of contamination has no effect on XLPE insulator compared to the bigger size of contamination. It can be shown at a contamination size of 0.1819mm2, where the effect on electric field strength and charge has no significant difference.

Meanwhile, at a contamination size of 3.8484mm2, the effect was obvious on electric field and the charge. Based on Figure 6(b) until Figure 6(f), Arsenic Tribromide (AsBr3), Ethylene Dichloride (CH2C1), Alcohol, Formic Acid (CH1O2) and Formamide (CH3NO) with dielectric constant of 9, 15, 31, 57 and 84 respectively has been used. It’s clearly seen where the electric field strength of XLPE insulator is not affected by the selected contamination and the charge was increased in each contamination.

| Table 6. Difference contour on XLPE insulation and contamination |
|---|---|
| no | (i) | (ii) |
| (a) | Boron Bromide (BBr3) with dielectric constant 2.58 |
| (b) | Arsenic Tribromide (AsBr3) with dielectric constant 9 |
| (c) | Ethylene Dichloride (CH2C1) with dielectric constant 15 |
| (d) | Alcohol with dielectric constant 31 |
| (e) | Formic Acid (CH1O2) with dielectric constant 57 |
| (f) | Formamide (CH3NO) with dielectric constant 84 |

Figure 5 till Figure 8 show the changes in electric field on XLPE insulator when there was non-contamination layer on insulator surface. The changes happened due to the different dielectric constant that affect XLPE condition as an insulator. This situation was caused by smaller value of dielectric constant where the higher value of dielectric constant of contamination, the severe condition of the insulator. The electric field strength also was affected by this situation.
Based on Figure 5, the smaller size of contamination gave a small effect on XLPE insulator. The significant difference was observed on the surface of XLPE towards difference contamination with different dielectric constant. Contamination formed from 0.1819mm² size did not have much impact on the XLPE insulation near the conductor. At the end of the XLPE insulator has visible effects caused by contamination on XLPE insulation. Boron Bromide (BBr₃) is the most significant element that affects XLPE insulation starting at a distance of 3.0 mm - 3.4 mm.

Figure 5. Electric field strength on XLPE insulator with contamination size of 0.1819 mm²

Based on Figure 6, Boron Bromide (BBr₃) with dielectric constant of 2.58 has greatly affects the electric field strength on XLPE insulator compared to other contaminations. Boron Bromide (BBr₃) has shown that the effects of contamination is greater than others. This could cause XLPE insulation performance on the wane. This sudden effect began to occur at a distance of about 1.6 mm-1.8 mm and thereafter, reading of electric field strength decreases. 1.7879 mm² sized contamination is seen much influence performance XLPE insulation itself.

Based on Figure 7, difference contaminations with different dielectric constant has shown significant changes on XLPE insulator. The significant difference of electric field strength has been shown starting from Boron Bromide (BBr₃) to Formamide (CH₃NO). Not too much difference in the size of the measuring contamination 2.7171 mm² and 1.7879 mm². Each contamination has significant differences value from the electric field strength readings start at a distance of 1.6 mm - 1.8 mm from the conductor and continued to fall sharply until the end of XLPE insulation.

Figure 6. Electric field strength on XLPE insulator through contamination size of 1.7879 mm²

Based on Figure 8, it can be concluded that the bigger the size of contamination, the larger effect of electric field strength on XLPE insulator mainly of contamination with lower dielectric constant from XLPE insulator. The most significant impact came on Boron Bromide (BBr₃), which at a distance of 3.2 mm from the conductor, electric field strength readings fall sharply compared with the reading of other contamination. This situation will result in deteriorating performance of the XLPE insulation.
3.3. Difference Charge on Different Size of Contamination of Non-uniform Layer

Figure 9 shows the difference charge on four different size of contamination which are 0.6787 mm², 1.7879 mm², 2.7171 mm² and 3.8484 mm². Contamination that has lower dielectric charge had higher charge compared to high dielectric. It has been proven through this analysis where Boron Bromide (BBr₃) which has a dielectric constant of 2.58 has a higher charge compared to Formamide (CH₃NO) which has a dielectric constant of 84. Furthermore, size of contamination also influences the content of charge in contamination where the bigger the contamination size, the more charge contained in the contamination. Through this research, it has been proven that contamination which has a size of 3.8484 mm² has more charge compared to the mid and smaller size.
4. CONCLUSION

The main goal of this project is to design XLPE insulated cable and evaluate the electric field and space charge from normal condition to effect of non-uniform layer contamination. Furthermore, XLPE insulation has unique features including high dielectric strength and high insulation resistance. Contaminations were selected based on the value of the dielectric constant for each of the elements of contamination as well as the size of the contamination itself was chosen randomly. From the results obtained, it can be seen and identified elements of contamination which is a lower dielectric constant value greatly affecting the performance of XLPE insulation. As well as the size of the non-uniform contamination layer, the larger the size of the contamination, the more emphasized XLPE insulation.

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REFERENCES

[1] N. Ishii et al., “Underground Power Cable, Distribution Cable, Overhead Transmission Line, Industrial Cable and Their Accessories”, no. 32, 2007.

[2] H. Kasuga, T. Fujitomi, H. Miyake, and Y. Tanaka, “Simultaneous measurement of space charge distribution and external circuit current in XLPE under HVDC at high temperature,” in Proceedings of the 2016 IEEE International Conference on Dielectrics, ICD 2016, 2016, vol. 1.

[3] T. Karmokar and R. Pietsch, “Electric field Calculations for AC and DC Applications of Water Controlled Cable Termination,” pp. 0–6, 2014.

[4] E. Data, H. Ingredients, O. F. Materials, and P. Data, “Material Safety Data Sheet Formic Acid,” pp. 1–3, 2000. LabChem Inc, ”MSDS: Formamide, pp. 1–6, 2000.

[5] N. Hampton, “Historical Overview of Medium & High Voltage Cables,” Georg. Tech, 2012, pp 1-39

[6] N. Hampton, R. Hartlein, H. Lennartsson, H. Orton, and R. Ramachandran, “Long-Life XLpe Insulated Power Cable,” Jicable, 2006.

[7] A. B. Kabel, “High Voltage XLPE Cable System Technical User Guide,” Bragg Kabel AG, 2006, pp 1-20

[8] P. Mvi et al., “XLPE Insulated Power Cables,” Univers. Cable Berhad, no. 2, pp. 1-68, 1990.

[9] W. a. Thue, “Electrical Power Cable Engineering”, Third Edition, 2011, pp150

[10] I. C. Popa and A.-I. Dolan, “Numerical modeling of power cables,” in 2016 19th International Symposium on Electrical Apparatus and Technologies (SIELA), 2016, pp 1–6.

[11] A Saracino and H. Phipps, “Groundwater Contaminants and Contaminant Sources”, no. 2, pp 1-5, April, 2008

[12] QuickField, “Terra Analysis LTD”. Version 6.2 user guide 2016, pp 11-31

[13] M. N. O. Sadiku, “Numerical Techniques in Electromagnetics”. 1992, no 1887, pp 3-6

[14] M. Name and G. P. Characteristics, “Ethylene Dichloride (EDC) Material Safety Data Sheet Ethylene Dichloride (EDC) Material Safety Data Sheet,” pp. 1–11.

[15] VWR, “Safety data sheet isopropyl alcohol”, vol. 2006, no. 1907, pp 1–12, 2012.

[16] W. P. Way, “Material Safety Data Sheet Arsenic Trioxide Section 1 - Chemical Product and Company Identification Section 2 - Composition, Information on Ingredients Chemical Name: Section 3 - Hazards Identification Material Safety Data Sheet Arsenic Trioxide Section”, pp. 1–7, 2000.

[17] “Dielectric Constants Dielectric Constants”, pdf, pp. 1-42.

[18] Tenaga Cables Industries, “XLPE INSULATED CABLES”, pp. 1–43.

[19] P. H. F. Morshuis, R. Bodega, D. Fabiani, G. C. Montanari, L. A. Dissado, and J. J. Smit, “Calculation and measurement of space charge in MV-size extruded cables systems under load conditions,” in 2007 International Conference on Solid Dielectrics, ICS D, 2007, pp. 502–505.

[20] C. Sendner, D. Horinek, L. Bocquet, and R. R. Netz, “Interfacial water at hydrophobic and hydrophilic surfaces: Slip, viscosity, and diffusion,” Langmuir, vol. 25, no. 18, pp. 10768–10781, 2009.