# A Comparison Study of Electric Field Propagation in Water Treeing Types for XLPE Insulated Underground Cable of Distribution System in Thailand

P. Narupon, B. Terapong, and M. Boonruang*

***Abstract—*** *Water treeing has been the problem for XLPE insulated underground cable. However, this issue is still not known well which the humidity can damage to XLPE insulated cable quickly. This study was a focus on the electric field of water treeing types based on 22kV distribution system of Thailand. The electrical field distribution was simulated in ANSYS Maxwell 2D software. The results showed that electric fields of bush and vented type are more as the large radius of water treeing, but electric field of bow-type is more as the small radius of water treeing only. Therefore, in this study the XLPE insulated cable applied with the voltage of 22kV for a long time, the bush and vented type become dangerous in XLPE insulated underground cable more than bow-type. Moreover, in this study XLPE with ionic solutions tested to confirm simulation results by realistic experiment. The experiment was tested in the environmental model include NaCl and* $CuSO_4$ *0.1 mol/L with the temperatures at room and* $50^oC$*. The simulation also validated the result of the experiment.*

***Keywords—*** **XLPE underground cable, water treeing, electric field, ANSYS MAXWELL, lonic solution.**

## 1. INTRODUCTION

The penetration of different ionic solutions in underground XLPE cable form tracks or tree structure in XLPE layer which is known as "Water Treeing." Water treeing is an electrochemical tree process in the presence of water, moisture or ionic solutions which distort the polymeric materials due to partial discharges through layers under electric stress in extremely non-uniform fields [1]. The XLPE that used in the underground distribution system has excellent electrical properties, but it faces the environmental problem. This problem relates to the ingress of moisture or other solutions that reduce the performance of XLPE in high electric fields. Moisture or other solutions can penetrate into XLPE cable through small cracks and weak points. Applied voltage as a source of external forces (electric fields) that cause this ingress is shown through small cracks of the XLPE cable [2]. In [3]-[6], the damaging phenomenon took place inside the material with continued exposure to moisture and electrical stress was proved and discussed as water treeing. It is a significant source that causes aging of polymeric cable insulation apart from thermal degradation, partial discharges, aggression by environment and losses [7]. The study of the inception and extent of the growth of water treeing to electrical treeing have been examined and analyzed in [8].

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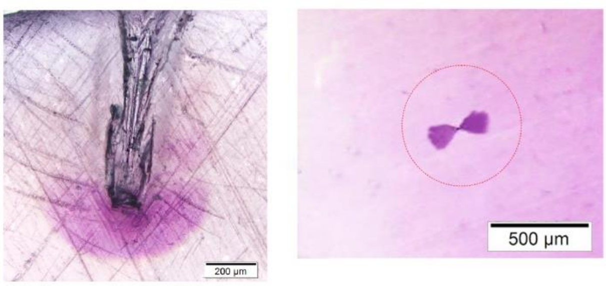
When a high voltage was applied to a copper conductor of an XLPE cable in the absence of water treeing, electric fields were equally distributed across the surface of all insulation layers. In the presence of water treeing, this behavior did not exist. Unequally distributed behavior exists with localization of electric fields. If localized electric fields exceed the minimum acceptable value, the breakdown will be expected. In the underground level, different ionic solutions exist on which power cables pass were laid. The presence of ionic solutions in the water treeing can cause different stressing in XLPE insulation. This phenomenon accelerates unequal distribution of electric fields.

Water treeing was separated into three types that are vented type, bush type, and bow-type. However, the morphology of vented and bush type is quite similar. Vented type grows from the edge of XLPE insulator to conductor. The direction of the vented type usually belongs to the electric field line. Bow-type grows inside of XLPE insulator. The direction of bow-type distributes opposite belong electric field line [9]. Vented type and bow-type is shown in Fig. 1.




(a) (b)

**Fig.1. (a) Vented type and (b) Bow-type.**

Many published papers of researchers were studied about water treeing. Fast propagation of water treeing occurred at high temperature [10], whereas others research paper revealed that fast propagation of water treeing occurred at low temperature [11]. However, the previously published paper was not considered parameters of the ionic solutions well. In this paper at the experiment, we considered parameters of ionic solution that includes electrical properties, pH, and temperature. Before the experiment, the simulation was done by ANSYS Maxwell 2D software about the behavior of electric fields which form water treeing in XLPE insulator underneath water solution. The simulation compared the electric field of bow-type and other types including the bush type and vented type published in [12].

The rest of the paper organized as follows; Simulation in the second section which includes Modeling of the electric field of ANSYS Maxwell, Underground cable, Modeling of underground cable, the Non-uniform electric field of XLPE cable layers, and Simulation procedure. The third section depicts Simulation results and discussion which includes Distribution of electric fields in layers of XLPE cable, Comparison between bow-type, bush type, and vented type. The fourth section depicts Experimental results and discussion which include Type of water treeing, Time aging to XLPE cable degradation, Effect of pH on XLPE cable, Effect of temperature on XLPE cable, and Effect of ionic solutions on XLPE cable. Lastly, it is the Conclusion of the paper.

## 2. SIMULATION

### *Modeling of Electric Field of ANSYS Maxwell*

ANSYS Maxwell 2D is a high-performance interactive software package that applies finite element analysis (FEA) to solve electric field and magnetic field problems. However, this study used 2D in the simulation, because water treeing shape belonged to the cross-section area of sliced water treeing.

A mathematical model of electric fields (*E*) spreading around an XLPE power cable is presented by the wave equation (Helmholtz's equation) derived from a differential form of Maxwell equations which are Faraday's law and Ampere's law as defined in equations (1) to (9) as given in [12] and [13]. The first equation is Faraday's law as shown in equation (1).

$$\nabla \times \vec{E} = \frac{\partial \vec{B}}{\partial t} \tag{1}$$

Take the curl ($\nabla$) of both side, equation (1) become

$$\nabla \times \left(\nabla \times \vec{E}\right) = -\frac{\partial}{\partial t}\left(\nabla \times \vec{B}\right) \tag{2}$$

Since *B* and *H* are related by the constitutive equation.

$$\vec{B} = \mu \vec{H} \tag{3}$$

Then take equation (3) in equation (2)

$$\nabla \times \left(\nabla \times \vec{E}\right) = -\mu \frac{\partial}{\partial t}\left(\nabla \times \vec{H}\right) \tag{4}$$

Use Ampere's law in equation (5) to replace equation (4); then it became equation (6).

$$\left(\nabla \times \vec{H}\right) = \vec{J} + \frac{\partial \vec{D}}{\partial t} \tag{5}$$

Then

$$\nabla \times \left(\nabla \times \vec{E}\right) = -\mu \frac{\partial}{\partial t}\vec{J} - \mu \frac{\partial^2 \vec{D}}{\partial t^2} \tag{6}$$

For isotropic materials, we can use the constitutive equation, Since :

$$\vec{J} = \sigma \vec{E} \text{ and } \vec{D} = \varepsilon \vec{E} \tag{7}$$

Then equation (6) becomes

$$\nabla \times \left(\nabla \times \vec{E}\right) = -\mu\sigma \frac{\partial}{\partial t}\vec{E} - \mu\varepsilon \frac{\partial^2 \vec{E}}{\partial t^2} \tag{8}$$

Using a vector identity for the curl-curl operator, Equation 8 becomes

$$\nabla \times \left(\nabla \times \vec{E}\right) = \nabla\left(\nabla \cdot \vec{E}\right) - \nabla^2 \vec{E} \tag{9}$$

Because the divergence of the electric field is zero on the homogeneous material, then equation (8) becomes

$$\nabla^2 \vec{E} = -\mu\sigma \frac{\partial}{\partial t}\vec{E} - \mu\varepsilon \frac{\partial^2 \vec{E}}{\partial t^2} = 0 \tag{10}$$

Where $\varepsilon$ is the dielectric constant of media, $\mu$ and $\sigma$ are the magnetic permeability and the conductivity of conductors, respectively. Then the equation (10) was used in ANSYS MAXWELL 2D to analyze electric fields.

### *Underground Cable*

Dimensions of a commercial underground cable 12/20(24) kV (50 $mm^2$ cross-section area) single core XLPE cable were used in this study with the cross-section shown in Fig. 2 (by T = thickness size). More information has been given in [14]. This power cable is mostly used in underground distribution systems in Thailand.

### *Modeling of Underground Cable*

Bow-type with radius $r_0$ of 0.1 mm, 0.5 mm, 1.0 mm, and 1.5 mm was considered for electric field simulations. The modeled water treeing with radius $r_0$ is shown in Fig. 3. The radius of water treeing was assigned water solutions in the simulation. The region beyond outer was assigned as vacuum linked with the ground. Since bow-type occurs anywhere in the XLPE layer, it was set in the middle of XLPE layer.

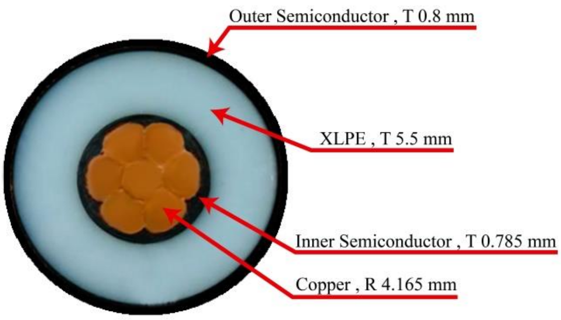



**Fig.2. Cross-section of 22 kV XLPE underground cable.**

For simulation, the electric properties of this chamber with XLPE cable was shown in Table 1. The Electric properties of the outer semiconductor were a same inner semiconductor.

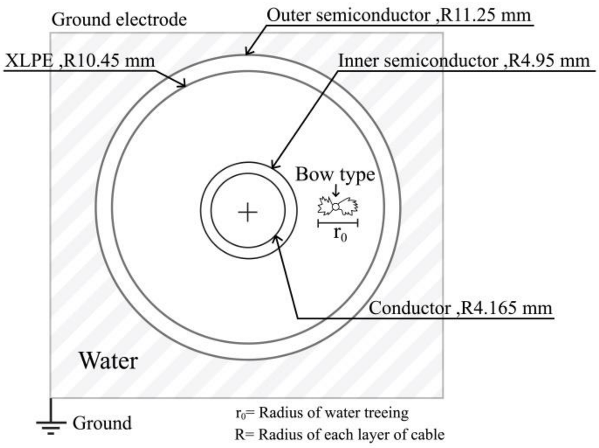



**Fig.3. Modeling of underground cable for simulation.**

**Table 1. Electric properties of the chamber and XLPE cable**

| List | Dielectric constant | Conductivity (S/m) |
|---|---|---|
| Semiconductor | 100 | $2 \times 10^{-3}$ |
| XLPE | 2.3 | $1 \times 10^{-17}$ |
| Conductor | 1 | $5.8 \times 10^{7}$ |
| Distilled water | 81 | $2 \times 10^{-4}$ |
| Ground | 1 | $2 \times 10^{6}$ |
| Vacuum | 1 | 0 |

### *Non-Uniform Electric Field of XLPE Cable layers*

In ANSYS Maxwell 2D, the geometry of XLPE cable can be discretized into small elements in 2D to obtain solving by the algebraic equation shown in equation (11). The desired field in each element is approximated with a second order quadratic polynomial expressed as in equation (11). The field quantities inside the triangles are calculated using a second-order quadratic interpolation scheme. The discretized model of XLPE cable was shown in Fig. 4.

$$A_Z(x,y)=a_0+a_1x+a_2y+a_3x^2+a_4xy+a_5y^2 \quad (11)$$

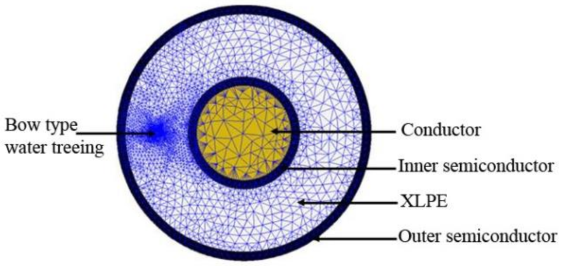



**Fig.4. Discretized water treed XLPE cable.**

### *Simulation Procedure*

Bow-type with radius $r_0$ = 0.1mm, 0.5mm, 1.0 mm, and 1.5mm was initiated at the center of XLPE layer whereby each radius was set in one simulation. Unchanged 24kV voltage at 50Hz was applied at copper conductor with water solution that assigned to the water treeing. The conditions of the simulation procedure were shown in Table 2. For simulation, the boundary conditions of the chamber with XLPE cable include applied voltage 24kV, 50Hz at the copper conductor and applied voltage 0kV at the ground electrode as shown in Fig. 5.

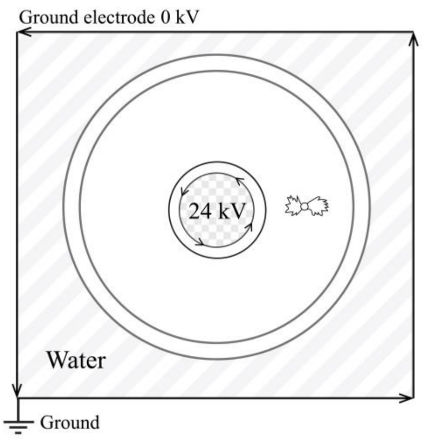



**Fig.5. Boundary conditions of the chamber and XLPE cable.**

**Table 2. Conditions of Simulation Procedure**

| Parameter | Value |
|---|---|
| Voltage (V) | 24kV, 50Hz |
| Radius of water treeing ($r_0$) | 0.1mm, 0.5mm, 1.0mm, and 1.5mm |

## 3. SIMULATION RESULTS AND DISCUSSION

The results of electric fields distributions in bow-type with radius, $r_0$=0.1mm, 0.5mm, 1.0mm, and 1.5mm with water solutions, were shown in Fig. 7. The simulation was done. The considered area is around water treeing as shown in Fig. 6. And, distances from the inner semiconductor to outer semiconductor were given in x-axis. In Fig. 7, the level of the electric field was plotted and shown in its corresponding layer as arranged in Fig. 6. The electric field of an inner semiconductor at a distance of 0.785mm was 0kV/mm. The maximum electric field was 80kV/mm around XLPE layer, and outer semiconductor at a distance of 0.8 mm was 0kV/mm.

The electric fields distribution in bow-type was also compared with bush and vented type from the published paper of [12]. Electric field distribution of water treeing with water solutions was shown in Fig. 8, Fig. 9, and Fig. 10. From Fig. 11 showed the comparison of the electric field distribution of bow-type, bush type, and vented type. The levels of electric fields in the bow-type, bush type, and vented type as shown in Table 3.

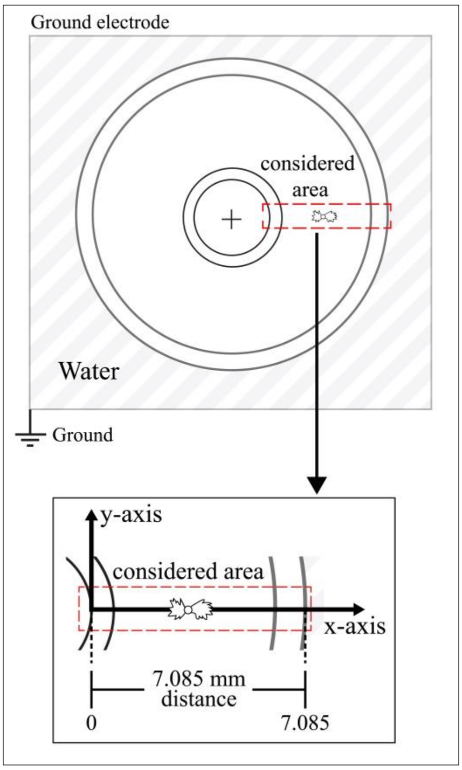



**Fig.6. Considered area of electric field for Bow-type.**

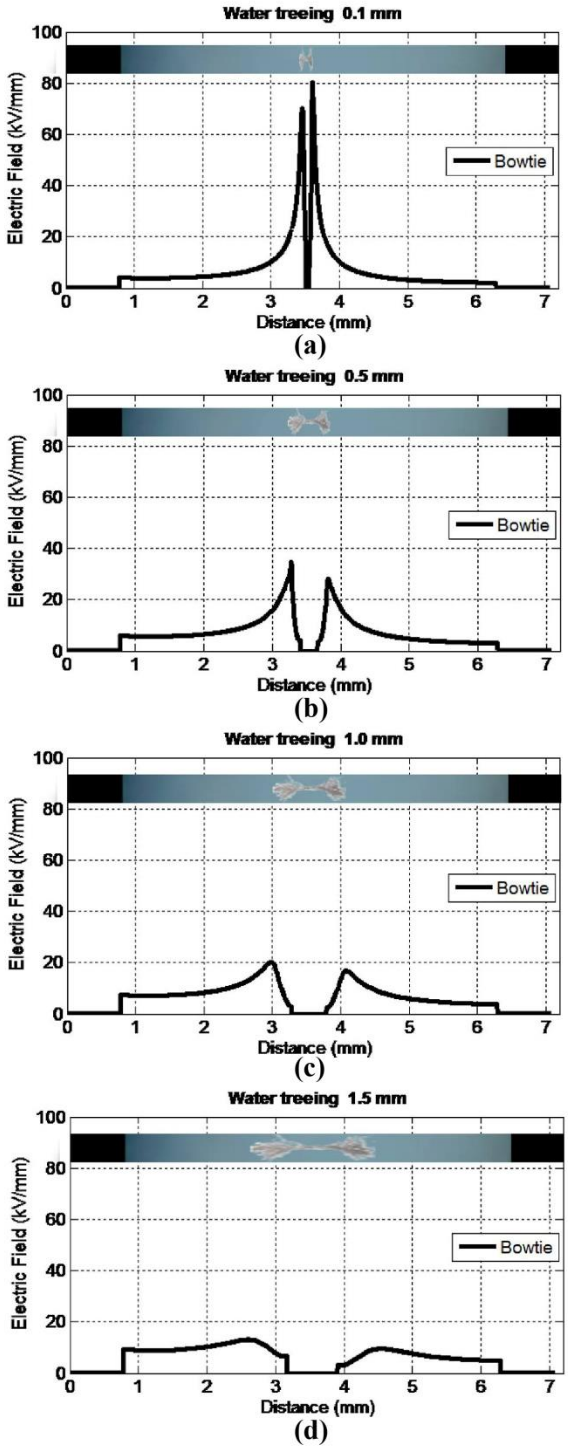



**Fig.7. Relationship of Electric Field and Considered Area for Bow-Type with Water Solution includes (a) $r_0$=0.1mm (b) $r_0$=0.5mm, (c) $r_0$=1.0mm, and (d) $r_0$=1.5mm.**

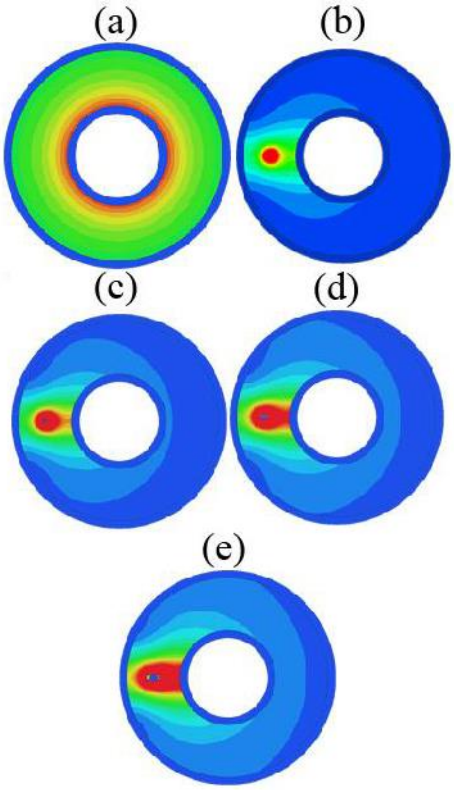



**Fig.8. Electric Field Distribution in Bow-Type with Water Solution includes (a) No Water Treeing (b) $r_0$=0.1mm, (c) $r_0$=0.5mm, (d) $r_0$=1.0mm, and (e) $r_0$=1.5mm.**

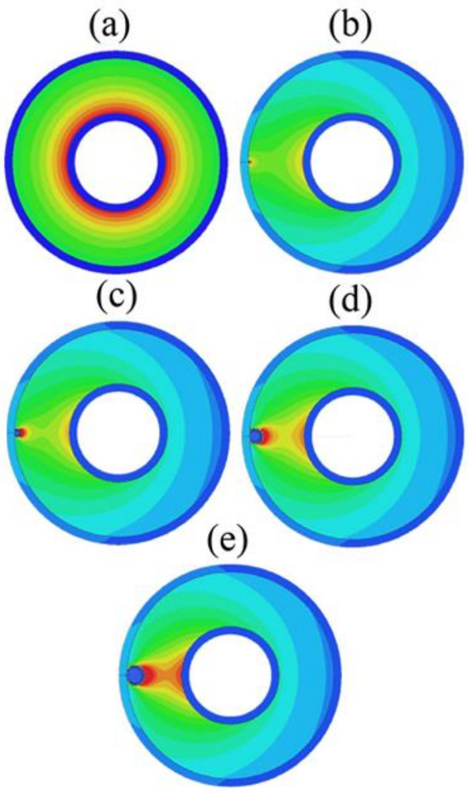



**Fig.9. Electric Field Distribution in Bush Type with Water Solution includes (a) No Water Treeing (b) $r_0$=0.1mm, (c) $r_0$=0.5mm, (d) $r_0$=1.0mm, and (e) $r_0$=1.5mm.**

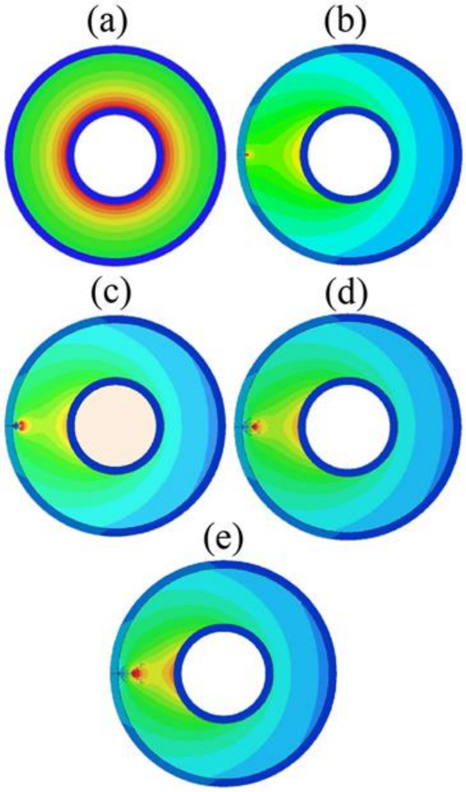



**Fig.10. Electric Field Distribution in Vented Type with Water Solution includes (a) No Water Treeing (b) $r_0$=0.1mm, (c) $r_0$=0.5mm, (d) $r_0$=1.0mm, and (e) $r_0$=1.5mm.**

**Table 3. Maximum of electric fields for Bow-type, Bush type, and Vented type**

| Type | *$r_0$ | Electric Field (kV/mm) | | |
|---|---|---|---|---|
| | | Layer | | |
| | | *Inner | XLPE | *Outer |
| Bow | 0.1 | 0.100738 | 80.200995 | 0.046685 |
| | 0.5 | 0.146180 | 34.744676 | 0.067641 |
| | 1.0 | 0.181288 | 20.032492 | 0.083771 |
| | 1.5 | 0.224712 | 13.074819 | 0.107515 |
| Bush | 0.1 | 0.146438 | 16.395072 | 0 |
| | 0.5 | 0.150517 | 15.502039 | 0 |
| | 1.0 | 0.161777 | 19.166656 | 0 |
| | 1.5 | 0.173035 | 20.809467 | 0 |
| Vent | 0.1 | 0.145410 | 9.796613 | 0 |
| | 0.5 | 0.150416 | 6.762211 | 0 |
| | 1.0 | 0.153302 | 21.374130 | 0 |
| | 1.5 | 0.162293 | 25.284099 | 0 |

*Inner = Inner semiconductor
*Outer = Outer semiconductor
*$r_0$ = radius of water treeing

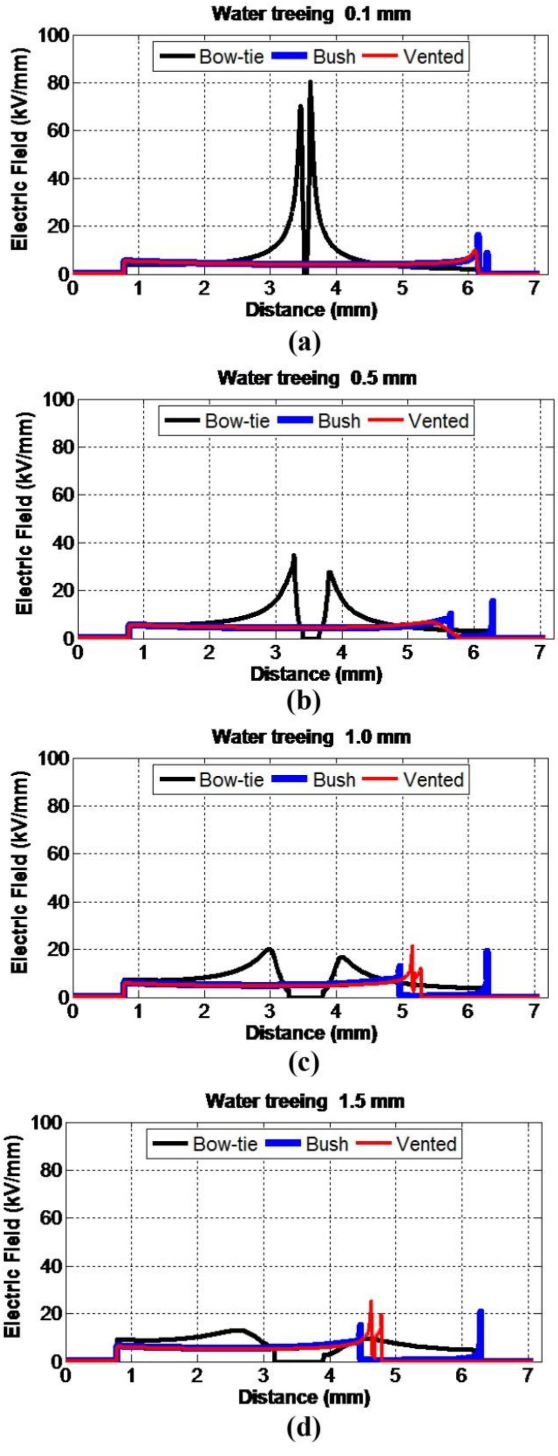



**Fig.11. Comparison of Electric Field in Bow-Type, Bush Type, and Vented Type with Water Solution includes (a) $r_0$=0.1mm (b) $r_0$=0.5mm, (c) $r_0$=1.0mm, and (d) $r_0$=1.5mm.**

From Fig. 7, 8, 9, 10, 11 and Table 3, the following have been observed when performing the study of the electric field distribution. The amounts of electric fields for the breakdown voltage of XLPE insulation from [15] has been used for comparison in this study. In [15] electric field of breakdown voltage for XLPE was ranged from 30 – 50 kV/mm. And, it will be used in assessing the health of XLPE layer.

***Distribution of Electric Fields in Layers of XLPE Cable***

Form Fig. 8 for bow-type, distribution of electric field was non-uniform from the outer surface of the copper conductor to insulation layers. Inner and outer semiconductor layers were the least electric field layers as indicated by blue colors. The highest electric field occured at XLPE layer that illustrated by red color, especially in the water treeing portion. Therefore, the presence of water treeing disturbed a uniform distribution of electric fields in layers of XLPE cable. From Fig. 7, the highest electric field of XLPE cable occured at bow-type, especially at radius 0.1 mm as shown in Fig. 7(a). So, when the radius of bow-type increase, the electric field will be decreased. At radius 1.0 mm and 1.5 mm, highest electric fields of the XLPE cable were similar in the bow, bush, and vented type. When compared to permissible values of XLPE insulation [15], the localized behavior of bow-type seemed to be able to cause damage (breakdown) at radius 0.1 and 0.5 mm.

***Comparison between Bow-Type, Bush Type, and Vented Type***

Fig. 11 and Table 3 showed that bow-type was very harmful when it had a small radius. In the opposite bush and vented type was very harmful when it had a large radius. In the results, a small radius of bow-type may cause a breakdown in XLPE cable but at large radius of bow-type may cause a breakdown, slowly. In bush and vented type, electric fields increased when the radius increased. So, if the radius of water treeing increases, propagation of bow-type may grow slower than bush and vented type. The next topic will show the propagation of these water treeing by using the experiment.

## 4. EXPERIMENT RESULT AND DISCUSSION

Since the experiments of the XLPE cable in distilled water, there had a lot of the research. This study used the solutions include NaCl and $CuSO_4$ ionic solutions.

The single core XLPE cable 12/20(24)kV with 50mm$^2$ cross-section area was cut to 200 cm. The cable was peeled cover out as shown in Fig. 2, by remaining of outer semiconductor, XLPE insulation, inner semiconductor, and copper conductor. Moreover, then the cables were pinned hole for accelerated degradation as shown in Fig. 12.

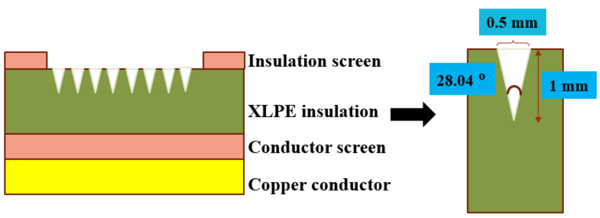



**Fig.12. Model of pinned hole in XLPE cable.**

The experiment was tested with NaCl and $CuSO_4$ ionic solution of 0.1mol/L. The XLPE cable was applied the voltage 24kV 50Hz. Independent variables included temperatures and testing periods. The cables were put in the stainless sink. The experimental setup was shown in Fig. 13 and Fig. 14. Table 4 showed the variables in this experiment.

**Table 4. Variable of experimental procedure**

| Parameter | Value |
|---|---|
| Voltage | 24kV, 50Hz |
| Temperature | Room temperature and 50$^oC$ |
| Testing period (hours) | 1000 and 4000 |
| Ionic solution | NaCl and $CuSO_4$ 0.1mol/L |

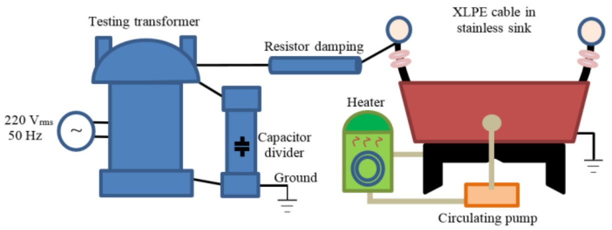



**Fig.13. Diagram for experimental setup.**

**Fig.14. Experimental setup.**

After testing, for observing of water treeing, an XLPE cable was sliced by a microtome to become a thickness of 400 - 600 µm. The slices were stained with methylene blue solution at 80$^oC$ for 2 hours. Then the slices were dried around 3 hours.

Water treeing was observed by using a stereomicroscope (Olympus BX51M) in Fig 15. Table 6 to Table 13 showed the length of water treeing with including on the Fig. 22 to Fig. 25. Morphology of water treeing showed in Fig. 18 to Fig. 21. The measuring of water treeing showed in Fig. 16 for vented type and Fig. 17 for bow-type. $L_0$ was defined as the length of water treeing. After observing, there had three water treeing types, included bow-type, bush and vented type. However, the vented type was the similar bush type. Both all just called vented type water treeing.

**Fig.15. A Stereomicroscope (Olympus BX51m).**

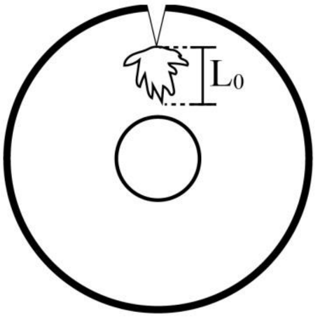



**Fig.16. Measuring direction of Vented type.**

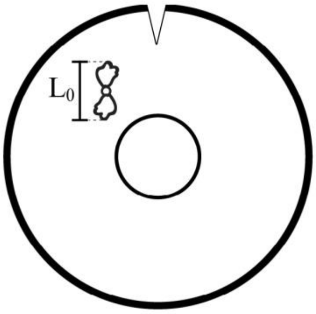



**Fig.17. Measuring direction of Bow-type.**

The average pH value of ionic solutions 0.1 mol/L were measured by a pH meter. Their parameters were measured as shown in Table 5.

**Table 5. pH of Ionic Solutions 0.1mol/L**

| Temperature | NaCl | $CuSO_4$ |
|---|---|---|
| Room | 6.49 | 4.04 |
| 50$^oC$ | 6.74 | 3.90 |

**Table 6. Length of Vented Type (µm) in XLPE Insulation for NaCl Ionic Solution 1000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 208.25 | 189.19 | 198.72 |
| 50$^oC$ | 127.49 | 100.23 | 113.86 |

**Table 7. Length of Vented Type (μm) in XLPE Insulation for NaCl Ionic Solution 4000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 336.21 | 326.29 | 331.25 |
| 50°C | 280.23 | 269.03 | 274.63 |

**Table 8. Length of Vented Type (μm) in XLPE Insulation for $CuSO_4$ Ionic Solution 1000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 1580.32 | 1535.72 | 1558.02 |
| 50°C | 1988.64 | 1875.44 | 1932.04 |

**Table 9. Length of Vented Type (μm) in XLPE Insulation for $CuSO_4$ Ionic Solution 4000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 3002.84 | 2834.58 | 2918.71 |
| 50°C | 3311.33 | 3158.65 | 3234.99 |

**Table 10. Length of Bow-Type (μm) in XLPE Insulation for NaCl Ionic Solution 1000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 140.28 | 130.36 | 135.32 |
| 50°C | 201.11 | 180.19 | 190.65 |

**Table 11. Length of Bow-Type (μm) in XLPE Insulation for NaCl Ionic Solution 4000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 280.71 | 222.57 | 251.64 |
| 50°C | 293.11 | 251.37 | 272.24 |

**Table 12. Length of Bow-Type (μm) in XLPE Insulation for $CuSO_4$ Ionic Solution 1000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 220.31 | 189.75 | 205.03 |
| 50°C | 342.82 | 328.02 | 335.42 |

**Table 13. Length of Bow-Type (μm) in XLPE Insulation for $CuSO_4$ Ionic Solution 4000hours**

| Temperature | Max | Min | Average |
|---|---|---|---|
| Room | 350.03 | 301.29 | 325.66 |
| 50°C | 400.55 | 380.07 | 390.31 |

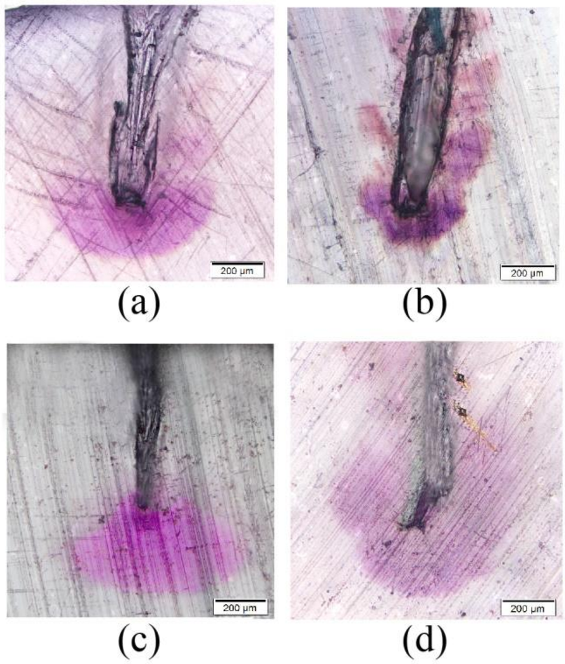



**Fig.18. Vented Water Treeing in NaCl Solution: (a) Room Temperature, 1000hours (b) 50°C, 1000hours (c) Room Temperature, 4000hours and (d) 50°C, 4000hours.**

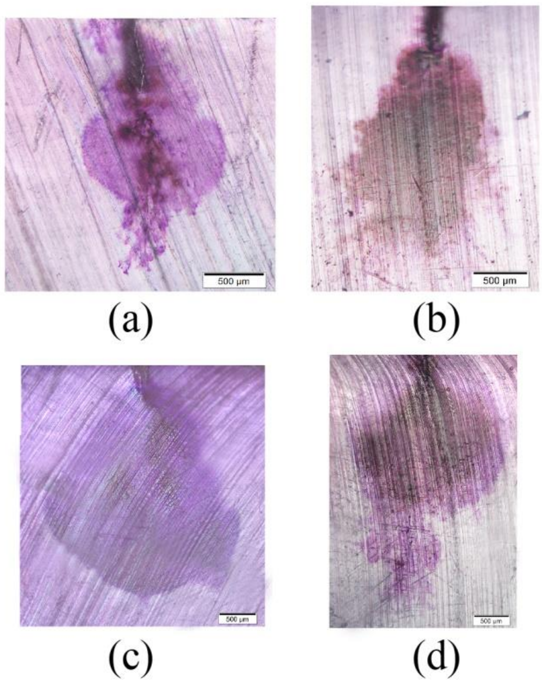



**Fig.19. Vented Water Treeing in $CuSO_4$ Solution: (a) Room Temperature, 1000hours (b) 50°C, 1000hours (c) Room Temperature, 4000hours and (d) 50°C, 4000hours.**

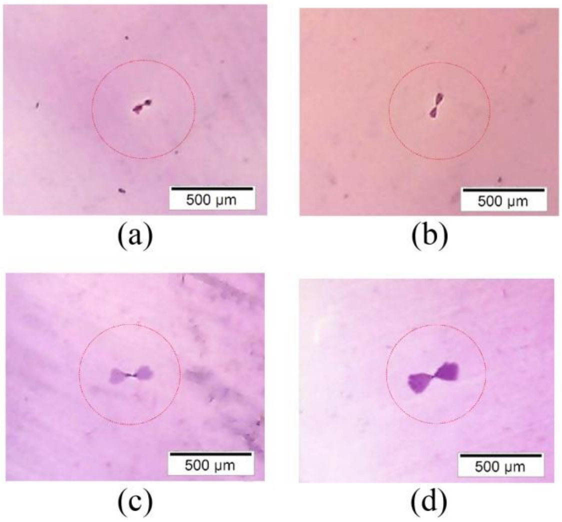



**Fig.20. Bow-Type Water Treeing in $CuSO_4$ Solution: (a) Room Temperature, 1000hours (b) 50°C, 1000hours (c) Room Temperature, 4000hours and (d) 50°C, 4000hours.**

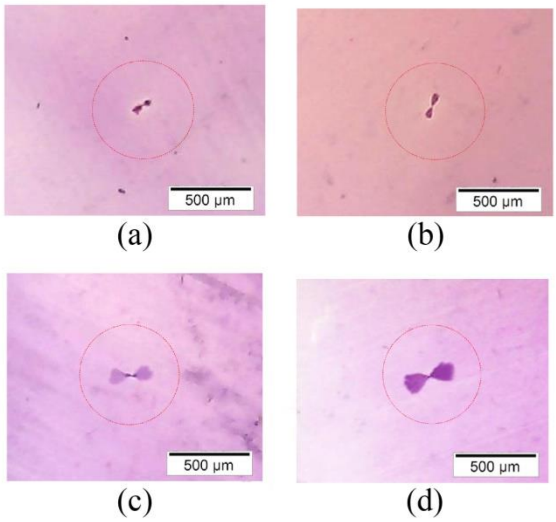



**Fig.21. Bow-Type Water Treeing in $CuSO_4$ Solution: (a) Room Temperature, 1000hours (b) 50°C, 1000hours (c) Room Temperature, 4000hours and (d) 50°C, 4000hours.**

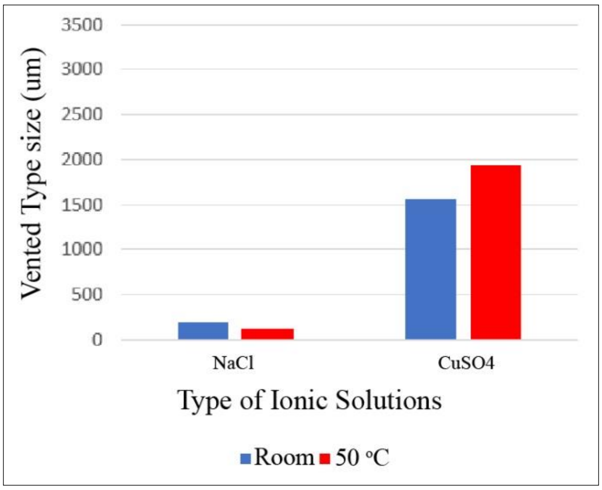



**Fig.22. Size Comparison of Vented Type in 1000hours.**

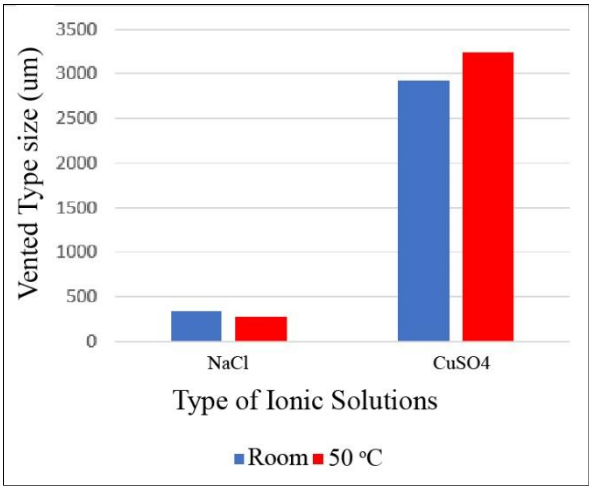



**Fig.23. Size Comparison of Vented Type in 4000hours.**

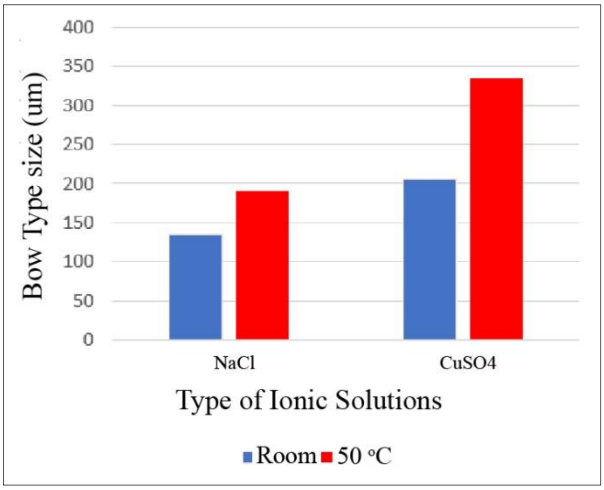



**Fig.24. Size Comparison of Bow-type in 1000hours.**

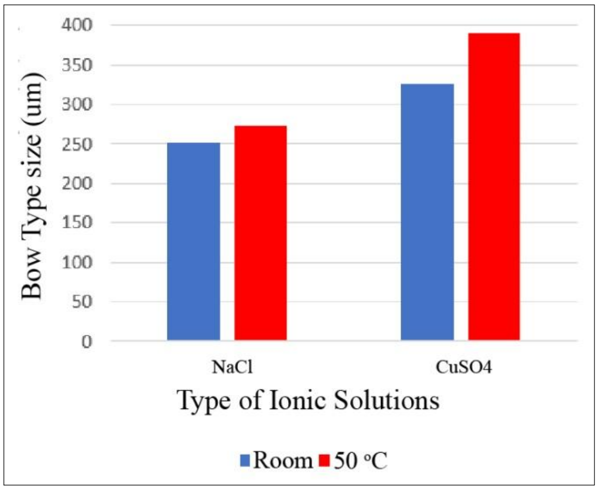



**Fig.25. Size Comparison of Bow-Type in 4000hours.**

### *Types of Water Treeing*

Water treeing type was separated in two types include bow-type and vented type. Because vented and bush was too quite similar. Characteristic of the vented type was identical to "tree or branch of a tree." Characteristic of bow-type was similar to "bow or fan." Moreover, in Fig.

26 showed the combination of electrical treeing with vented type water treeing. The vented type is the dark purple color. The electrical treeing is in the square.

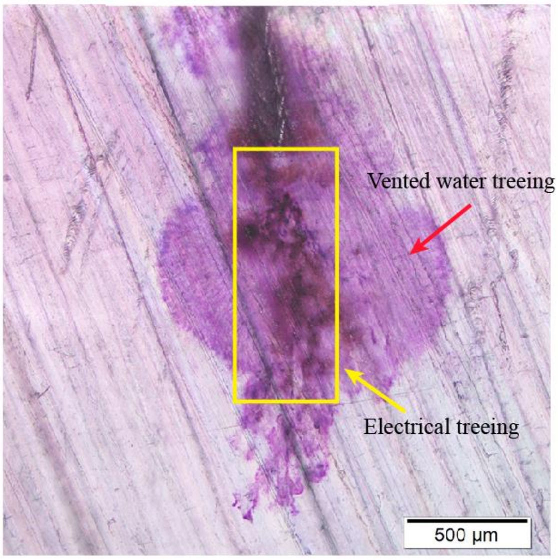



**Fig.26. Combination of Vented Type Water Treeing and Electrical Treeing.**

***Time aging to XLPE Cable Degradation***

In the simulation of this paper, the trend of water treeing showed that the electric field of vented type increased as radius increased. In the opposite, the electric field of bow-type decreased as radius increased. The experiment was compared with the simulation. In 1000 hours, the propagation trend of vented type increased slower than bow-type. However, in 4000 hours, the propagation trend of vented type increased faster than the bow-type. Therefore, the trend of water treeing belonged with the simulation results.

***Effect of pH on XLPE Cable***

From Table 5, The pH value of NaCl and $CuSO_4$ are in the range of strongly acid to pure water neutral (pH low than 7). Therefore, the characteristic of pH that smaller than 7 is rather acid [16]. The corrosion of acid can damage the XLPE insulator layer, fast.

pH of NaCl at room temperature was more moderate than NaCl solution at 50$^o$C. Water treeing size in NaCl, pH 6.49, at room temperature was longer than in NaCl, pH 6.74, at 50$^o$C. And, the pH of $CuSO_4$ solution at room temperature was higher than a $CuSO_4$ solution at 50$^o$C. Water treeing size in $CuSO_4$, pH 4.04, at room temperature was shorter than in $CuSO_4$, pH 3.70, at 50$^o$C.

***Effect of Temperature on XLPE Cable***

The size of water treeing showed in Table 6 to Table 13. For bow-type, fast propagation of water treeing occurred at room temperature more than 50$^o$C in NaCl. However, For vented type, fast propagation was opposite to bow-type. For bow and vented type in $CuSO_4$, fast propagation of water treeing occurred at 50$^o$C more than room temperature.

***Effect of Ionic Solutions on XLPE Cable***

For of all both water treeing, the propagation trend showed that $CuSO_4$ was grower than NaCl. Because $CuSO_4$ ionic solution may be acid higher than NaCl ionic solution that referred to the previous point. Maybe, $CuSO_4$ had $Cu^{+2}$ ion that high conductivity, also.

## 5. CONCLUSION

For this study, the effect of ionic solutions and temperatures to XLPE underground cable for the medium voltage distribution system was studied. This experiment found two types of water treeing that included the bow-type and vented type. For vented type, it can occur the combination of electrical treeing and vented type water treeing. The propagation trend of water treeing in $CuSO_4$ was grower than NaCl. For bow-type, propagation size of water treeing in NaCl and $CuSO_4$ solutions were quite similar, because bow-type treeing occurred in XLPE layer by impurities. The ionic solutions were difficult to pass into small voids. However, sometimes the environment cannot control such as changing room temperature all the times, some dust from outside, and an extended testing period.

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