SEGMENTATION OF VENTED WATER TREES IN MICROSCOPIC IMAGES USING IMAGE PROCESSING TECHNIQUES

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Abstract
In this study, vented water trees in XLPE samples were initiated and grown in laboratory environment. After aging, vented type water treeing images were obtained by using light microscope. An image segmentation based on morphological image processing and color image processing has been applied to clean dye residues and/or other spots and insignificant regions in the image. Component analysis was performed for RGB and HSV color spaces of images before morphological image processing. Appropriate components were selected to recognize the areas with the vented water treeing. Thresholding has been applied for selected components. Finally, thresholded images were segmented using morphological image processing.

Keywords: Vented water treeing, image segmentation, morphological image processing, color image processing, microscope image

1. INTRODUCTION

XLPE (crosslinked polyethylene) cables, which play active role in power transmission and distribution, are tested in terms of quality of insulation. Thus, it would be quite beneficial to review and analyze the parameters, which cause degradation of the cable insulation. Qualities of polymeric insulators, which are used in the transmission and distribution may vary [1], [2]. In this study, XLPE (cross-linked polyethylene) was chosen as polymeric insulator. XLPE is widely used in power transmission and distribution [3], which is made by crosslinking polyethylene molecules. It has good dielectric, chemical and physical properties, therefore it is preferred for medium and high voltage applications as insulator of cable [4], [5]. Crosslinking usually is obtained adding a catalyst. There are many ways of crosslinking, however dicumyl peroxide curing agent is generally used [6]–[9]. The behaviors of polymeric insulators against the applied AC signal amplitude, frequency and experimental environment parameters can be analyzed in the aging tests. XLPE insulated single core medium voltage cable is shown in Fig.1. Insulator sample taken from XLPE insulated single core medium voltage cable shown in Fig.2.

Fig. 1. *XLPE insulated single core medium voltage cable*

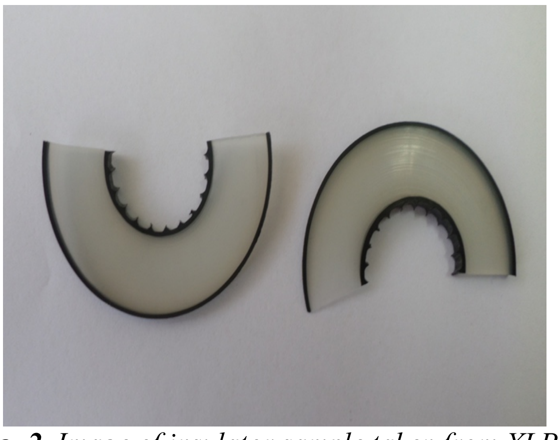

Fig. 2. *Image of insulator sample taken from XLPE insulated single core medium voltage cable*

2. WATER TREEING

Water treeing plays an active role in medium and high voltage XLPE cables throughout their service life [10]. Water treeing is a dominant phenomenon, which occurs as an early failure in the underground XLPE distribution cables. Water trees vary from a few microns to 1 mm and they usually have a branched, widespread and hydrophilic structure. Water trees are observed under electric field. Water treeing can lead to electrical treeing and hence insulator degradation after a certain time [11]. There are two types of water treeing, either bow-tie or vented type. Bow tie water treeing occurs in the insulator, however vented water treeing occurs inner and/or outer conductor's screen of cable and it spreads towards the conductor. Bow tie and vented type water treeing images are shown in Fig.3. and Fig.5. respectively. Factors affecting the initiation and growth of the water treeing can be listed as follows;

- Electric field
- Frequency
- Temperature
- Relative humidity
- Ionic content
- Polymer morphology
- Mechanical pressure
- Additives, contaminants, and treeing retardants [4], [6]–[8], [12], [13].

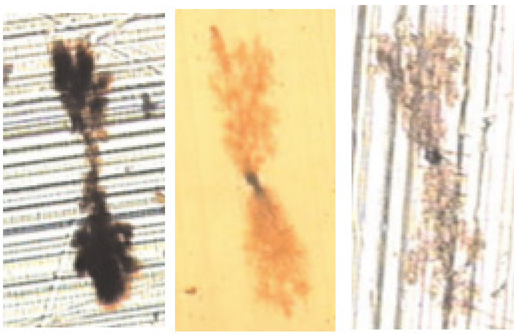

Fig. 3. *Bow-tie water tree* [14]

2.1. WATER TREE TEST AND OBSERVATION

Water treeing tests were performed in the laboratory environment. Polyamide reservoir is filled with ionic solution and aluminum electrodes, which are connected to high voltage output terminals of transformer, together with insulator samples, taken from XLPE insulated single core cable, are placed on it. The prepared test setups used to initiate and grow the water trees in laboratory conditions are generally similar. The parameters such as length and number of water needles on XLPE, LDPE (Low Density Polyethylene) samples can vary. The material of the electrodes may vary as well. In some studies, Pt, Cu, Fe and Pb electrodes were used. [6]–[8]. Salted water is generally used as a solution in water treeing test, however at the same time different ionic solutions (Na_2SO_4, $CuSO_4$, $FeSO_4$, K_2SO_4, KBr, $CuSO_4$, $Cu(NO_3)_2$, $CuCl_2$, $AgNO_3$) may also be used. The lengths and widths of water trees are observed and analyzed for different ionic solutions. [4], [12], [15], [16].

In this study, 1M NaCl solution was prepared to age XLPE samples. The pH level of solution is 6,21 and conductivity of solution is measured as 84,2 mS/cm. Ultrapure water Milli Q was used in NaCl solution. Water treeing test setup is shown in Fig.4. The duration of the experiment is set as 24 hours, applied voltage and frequency levels are selected as 24 kV_{PP}, and 3 kHz respectively.

100μm thick slices were taken from aged XLPE samples and dyed with methylen blue [17]. Water treeing images (Fig. 5.) were taken from dyed slices by Olympus CX41 light microscope.

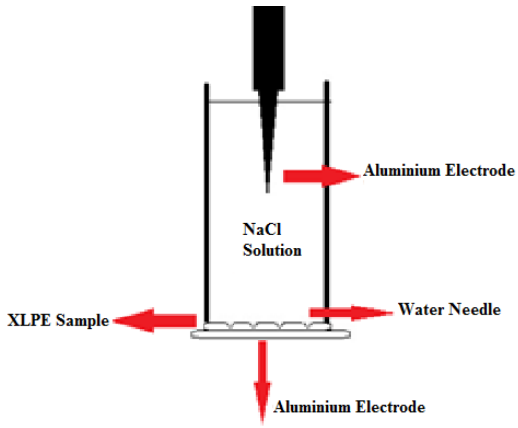

Fig. 4. *Water treeing test setup*

- Aging Duration: 24 hours
- Applied voltage and frequency: 24 kV_{pp} – 3 kHz
- Relative Humidity: % 43 RH
- Environment Temperature: 22.5˚C
- Pressure: 929,93 hPa

- Solution type, molarity, conductivity: NaCl, 1 M- 84,2 mS/cm

Fig. 5. *Microscope images of vented water trees (1M, 24 kV$_{PP}$, 3 kHz, 24 hours, 84.2 mS/cm)*

2.2. OBSERVATION OF WATER TREES

3. IMAGE PROCESSING

In the image processing section, images of vented water trees taken using a light microscope were separated into RGB and HSV color space components. The most suitable components were selected for segmentation in both color spaces. Both the Hue and Green component (selected components) of the image were filtered using the median filter. Enhanced images were thresholded and then converted to binary images. Thresholded images were segmented using morphological image processing. In morphological image processing method, erosion, dilation and opening stages were applied. The steps of segmentation of vented water trees are shown Fig. 6.

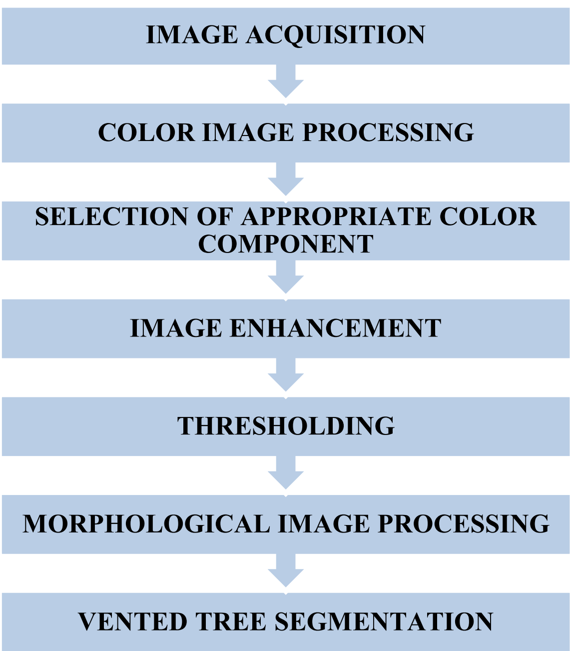

Fig. 6. *The steps of segmentation of vented water trees.*

3.1. COLOR IMAGE PROCESSING

The use of colors in image processing has the ability to provide effective information about the image. Color image processing is divided into full color and pseudo color image processing. Full color image processing is about images obtained with full color sensors. Pseudo color image processing is about color assignment to intensity variations [18], [19].

In color image processing, color information and color space are the most basic issues that need to be known. The fact that the human eye can distinguish thousands of colors and the important role of color in object recognition has led to the use of color image processing. [19]

3.1.1. RGB Color Space

The RGB color space is a color space that takes its name from the initials of the words 'Red', 'Green', and 'Blue'. The RGB color space is designed to define colors within a unit cube by means of a The RGB color space is designed to define colors within a unit cube by means of a combined color mixing method (Fig. 7.). Three basic colors (red (R), green (G), blue (B)) can be mixed. The other colors are obtained from a mixture of these three basic colors. RGB color space is used in computer monitors, scanners, televisions, etc. [20], [21], [22].

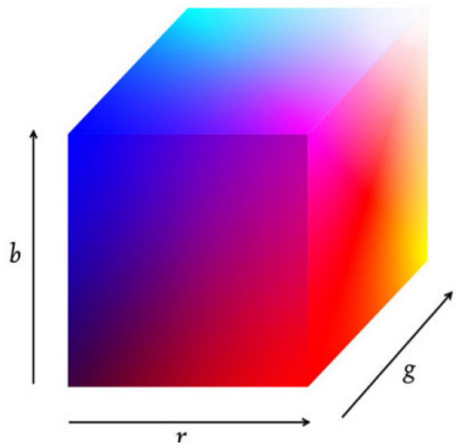

Fig. 7. *RGB color space*

3.1.2. HSV Color Space

The HSV color space is a color space that takes its name from the initials of the words 'Hue', 'Saturation' and 'Value'. The HSV color space allows for easier color selection. It is ideal when the colors need to be shown manually and users need to see their colors and choose. The HSV color space is used to adjust the color intensity or color intensity as the dynamic range is wide in terms of color saturation [22], [23]. HSV color space in hexagonal funnel form is shown Fig. 8.

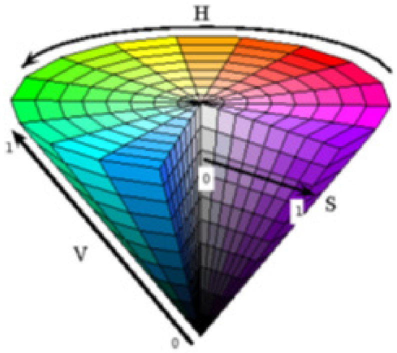

Fig. 8. *HSV color space*

Conversion of RGB - HSV color space (Equation 1. and Table 1.) are shown below.

$$h = \begin{cases} 0\ , \text{if max=min} \\ \left(60^\circ \text{ x } \frac{g-b}{max-min} + 360^\circ\right) \text{mod } 360^\circ\ , \text{if max} = \text{r} \\ 60^\circ \text{ x } \frac{b-r}{max-min} + 120^\circ\ , \text{if max} = \text{g} \\ 60^\circ \text{ x } \frac{r-g}{max-min} + 240^\circ\ , \text{if max} = \text{b} \end{cases}$$

$$s = \begin{cases} 0\ , \text{if max=0} \\ \frac{max-min}{max} = 1 - \frac{min}{max}\ , \text{otherwise} \end{cases}$$

$$v = \text{max}$$

Table 1. *Conversion of RGB - HSV color space*

RGB	HSV	RESULT
(1, 0, 0)	(0°, 1, 1)	
(0.5, 1, 0.5)	(120°, 0.5, 1)	
(0, 0, 0.5)	(240°, 1, 0.5)	

3.2. MORPHOLOGICAL IMAGE PROCESSING

The branch of biology, which deals with the shapes and structures of living things, is called morphology. Mathematical morphology is a necessary tool based on basic set operations for extracting image components that are useful in representation and description. In image processing, it is often used as pre- or post-processing, such as morphological filtering, thinning, pruning [18].

3.2.1. Erosion

It is the basic morphological operator for shrinking or thinning an object in a binary image. Erosion operation is given in Equation 2 and 3. [18].

$$A \ominus B = \{z|(B)_z \subseteq A\} \quad (2)$$

$$A \ominus B = \{z|(B)_z \cap A^c = \emptyset\} \quad (3)$$

3.2.2. Dilation

It is the basic morphological operator for expanding or thickening an object in a binary image. Dilation operation is given in Equation 4 and 5. [18].

$$(1) \quad \oplus B = \left\{z\middle|(\hat{B})_z \cap A \neq \emptyset\right\} \quad (4)$$

$$A \oplus B = \left\{z\middle|\left[(\hat{B})_z \cap A\right] \subseteq A\right\} \quad (5)$$

3.2.3. Opening

The opening operation is to apply erosion operation and dilation operation to the image successively. Opening operation is given in Equation 6. [18].

$$A \circ B = (A \ominus B) \oplus B \quad (6)$$

Original image, dilated image, eroded image and opened image are shown in Fig.9, Fig.10, Fig. 11, and Fig.12 respectively.

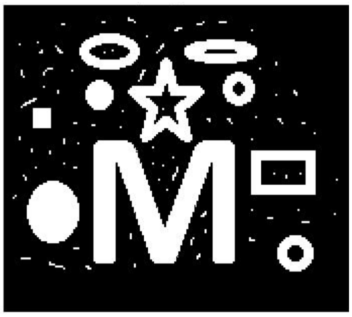

Fig. 8. *Original Image*

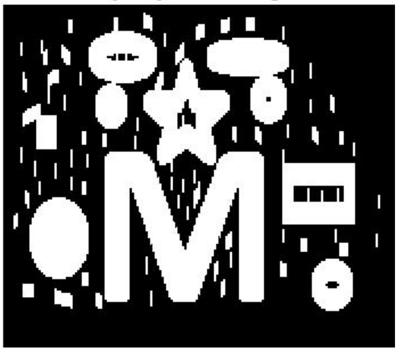

Fig. 9. *Dilated image*

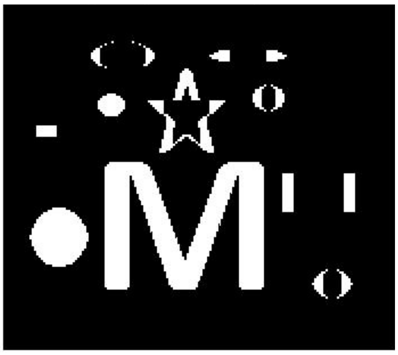

Fig. 10. *Eroded image*

Fig. 11. *Opened image*

3.3. IMAGE SEGMENTATION RESULTS

Microscope images of vented type water trees (1M, 24 kV_{PP}, 3 kHz, 24 hours, 84.2 mS/cm) are shown in Fig.13. and Fig. 17.

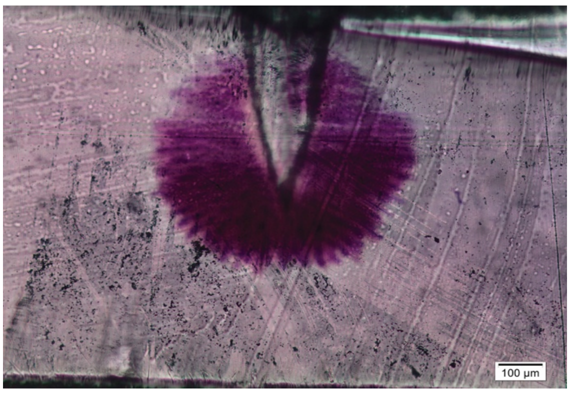

Fig. 12. *Microscope image of vented type water tree (1M, 24 kV_{PP}, 3 kHz, 24 hours, 84.2 mS/cm)*

Segmented images of vented type water trees are shown in Fig.14. and Fig.16.

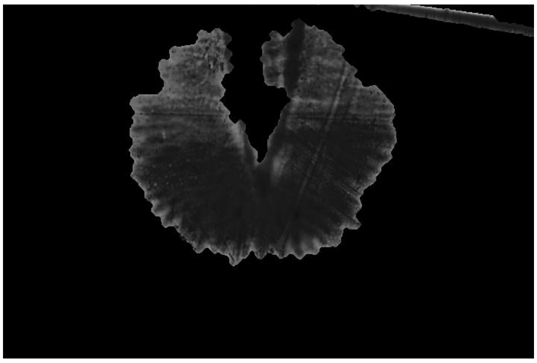

Fig. 13. *Segmented image*

Plotted boundaries images are shown in Fig.15. and Fig.18.

Fig. 14. *Plotted boundaries and segmented image*

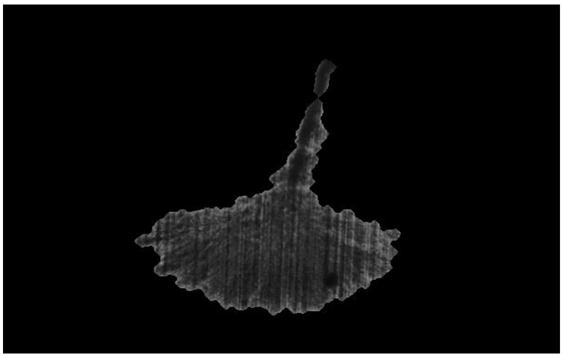

Fig. 15. *Segmented image*

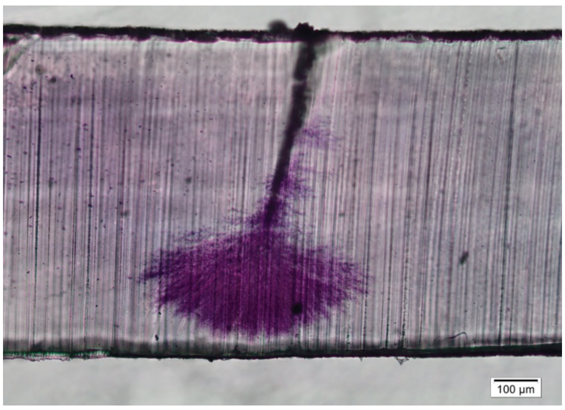

Fig. 16. *Microscope image of vented type water tree (1M, 24 kV_{PP}, 3 kHz, 24 hours, 84.2 mS/cm)*

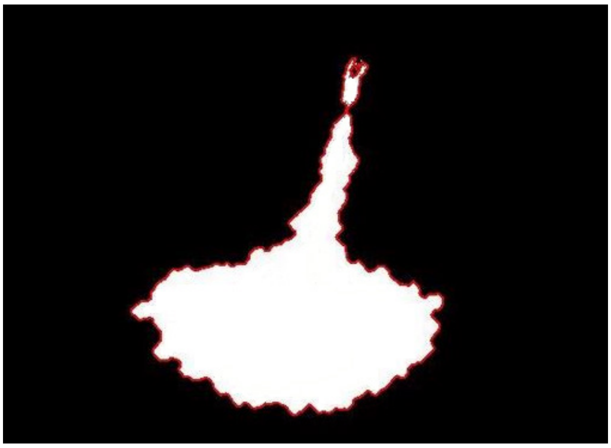

Fig. 17. *Plotted boundaries and segmented image*

4. CONCLUSIONS AND FUTURE SCOPES

In this study, vented type water trees were initiated and grown in laboratory conditions. Vented type tree segmentation based on morphological image processing was performed. Morphological image processing techniques were used for cleaning spots and insignificant regions of microscopic images of vented type water trees observed due to dye residues. This work will provide clear images in order to obtain highly accurate results in smart diagnostic systems based on image processing.

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