World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:5, No:12, 2011

Effect of Applied Voltage Frequency on Electrical Treeing in 22 kV Cross-linked Polyethylene Insulated Cable

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International Science Index, Electrical and Computer Engineering Vol:5, No:12, 2011 waset.org/Publication/4110

***Abstract*—**This paper presents the experimental results on effect of applied voltage stress frequency to the occurrence of electrical treeing in 22 kV cross linked polyethylene (XLPE) insulated cable.Hallow disk of XLPE insulating material with thickness 5 mm taken from unused high voltage cable was used as the specimen in this study. Stainless steel needle was inserted gradually into the specimen to give a tip to earth plane electrode separation of 2.5±0.2 mm at elevated temperature 105-110°C. The specimen was then annealed for 5 minute to minimize any mechanical stress build up around the needle-plane region before it was cooled down to room temperature. Each specimen were subjected to the same applied voltage stress level at 8 kV AC rms, with various frequency, 50, 100, 500, 1000 and 2000 Hz. Initiation time, propagation speed and pattern of electrical treeing were examined in order to study the effect of applied voltage stress frequency. By the experimental results, initial time of visible treeing decreases with increasing in applied voltage frequency. Also, obviously, propagation speed of electrical treeing increases with increasing in applied voltage frequency.Furthermore, two types of electrical treeing, bush-like and branch-like treeing were observed.The experimental results confirmed the effect of voltage stress frequency as well.

***Keywords*—**Voltage stress frequency, cross-linked polyethylene, electrical treeing, treeing propagation, treeing pattern

I. Introduction

RECENTLY, cross linked polyethylene (XLPE) material is widely used as insulating material in high voltage cable for electrical transmission and distribution systems because of its excellent physical, chemical and dielectric properties. However, under multi-stress, i.e. electrical, thermal and mechanical stresses, and over a period of time, its chemical composition and physical morphology may change without avoidable. In consequence, its properties may alter, i.e. increasing of conductivity and dielectric loss and reduction of mechanical, electrical and thermal strengths. Finally, ageing deterioration of XLPE material may occur. Many phenomena can induce ageing of XLPE material. Partial discharge is one of those phenomena. Electrical treeing is one of partial discharge in an insulation system of XLPE insulated cable. Electrical treeing is not only the main factor affecting the reliability of cable insulation, but also the final destructive formof cable insulation operating in the long run. Electrical trees can be initiated from various defects in cable insulation, such as impurity or local high electric field due to the protuberance of semi-conducting shielded layer. It is found that the factors responsible for initiating and propagating of electrical trees in cable insulation depend upon not only the cable manufacturing technique, physical morphology of insulation material but also depending on the frequency of applying voltage[1-5].

Rawangpai et al. [6] reported the experimental results on artificial ageing test of 22 kV XLPE cable for distribution system application in Thailand. XLPE insulating material of 22 kV cable was sliced to 60-70 μm in thick and was subjected to ac high voltage at 23°C, 60°C and 75°C. Testing voltage was constantly applied to the specimen until breakdown. Breakdown voltage and time to breakdown were used to evaluate life time of insulating material. The physical model by J.P. Crine for predicts life time of XLPE insulation material was adopted as life time model and was calculated in order to compare the experimental results.

Hozumi et al. [7] studied influence of morphology on electrical tree initiation in polyethylene and insulation of the XLPE cables under ac and impulse voltages.

Zheng et al. [8]studied the electrical tree growing characteristics. The relationship between electrical tree propagation and the material morphology in XLPE cable insulation has been elucidated.

Xie et al. [9] found the statistical initiation and propagation characteristics of electrical trees in XLPE cables with different voltage ratings from 66 to 500 kV.They investigated electrical treeing under a constant test voltage of 50 Hz/7 kV (the 66 kV rating cable is from UK, the others from China). They found that the characteristics of electrical trees in the inner region of 66 kV cable insulation differed considerably from those in the outer region under the same test conditions.

Yoshimura et al. [10] reported results on the influence of interfacial pressure on treeing deterioration in XLPE. However, they did not find any clear change in the breakdown time with increasing interfacial pressure.

Auckland et al. [11] focus on a mechanical approach to the understanding of electrical treeing. In their view, treeing initiation is believed to arise from fatigue forces induced by the applied voltage. During the growth microscopic explosions within the dielectric due to localized intrinsic breakdown will create chock waves which lead to fatigue failure and fracture. It is verified by experiments that tree growth may be

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controlled by the fracture toughness of the polymer as well as by its modulus of elasticity.

Noto and Yoshimura [12] examined polyethylene under various frequencies of ac electric stress. It was found that tree does not follow a linear growth relationship with the frequency. Under various applied voltages, tree exhibits different growth characteristics with various frequencies.

Many researchers have studied the effects of morphology of semi-crystalline material on the initiation and propagation of electrical trees in the past decades, but little attention was paid to the influence of frequency voltage on electrical tree in XLPE cable insulation [7-12].In this study, initiation time, propagation speed and pattern of electrical treeing in 22 kV XLPE insulated cable subjected to sinusoidal waveform voltage stress with various frequency from 50-2,000 Hz were examined. The effects of applied voltage stress frequency to the occurrence electrical treeing were studied and elucidated.

II. Test Arrangement

A. Specimen

In this study, all specimens were taken from a commercial 22 kV XLPE distribution power cable having copper conductors 12 mm in diameter and XLPE insulation 6 mm thick, as shown in Fig. 1. This type of power cable is used for underground distribution system of Provincial Electricity Authority (PEA) of Thailand. Unused cable was cut intohollow disc with a thickness of 5 mm. Cable cover and semiconducting layer wereremoved before the experimental.Stainless steel needle was inserted gradually into the specimen to give a tip to earth-plane electrode separation of 2.5±0.2mm at elevated temperature of 105-110°C.The specimen was then annealed for approximately 5 minutes to minimize any mechanical stress build up around the needle-plane region before it was cooled down to room temperature. A typical specimen with an inserted needle is shown in Fig. 2.

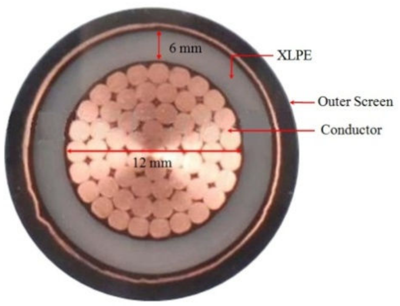

Fig. 1 Cross-section of 22 kV XLPE cable

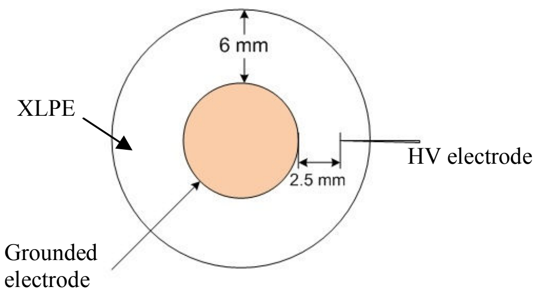

Fig. 2 Schematic diagram of specimen

B. Test Method

During the experimental, thespecimen was immersed in insulating bath oil to prevent external discharges or flashover. Testvoltage was applied from high voltage amplifier (8 kV AC rms) with various frequencies at 50, 100, 500, 1000 and2000 Hz, respectively. The experimental was conducted at room temperature (25°C).For each frequency of voltage stress, the occurrence of electrical treeing was enlarged by using digital microscope (5-500X)andwas continuously recorded until electrical treeing cover ≈ 90% of needle-plane gap spacing. Electrical failure or breakdown of XLPE insulating material was avoided. Schematic diagram of experimental setup is illustrated in Fig.3 and actual experimental layout is illustrated in Fig.4.

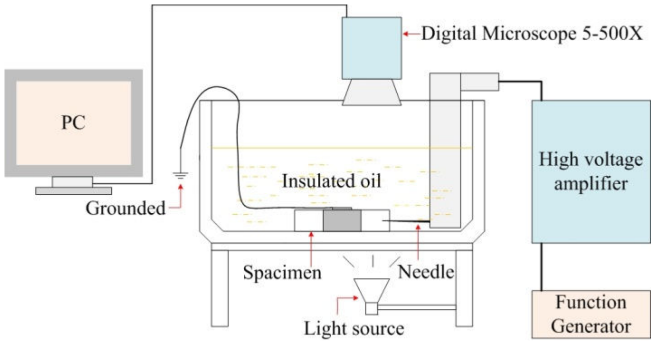

Fig. 3 Schematic diagram of experimental setup

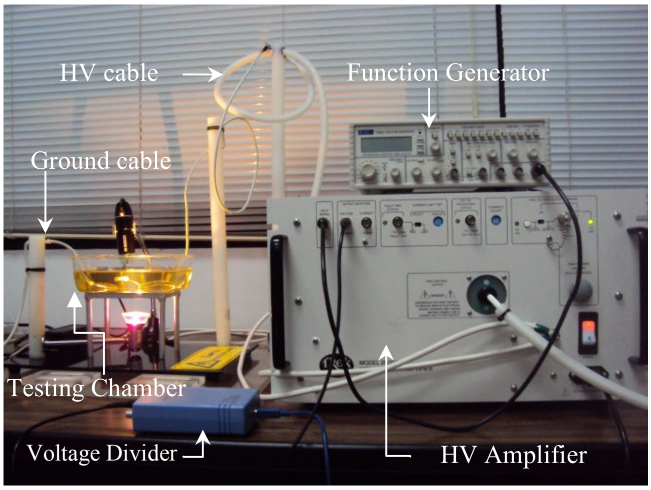

Fig. 4 Experimental Layout

III. Test Results and Discussions

From the experimental results, significant differences in the occurrence of electricaltreeing at each voltage stress frequency were observed. Three characteristics of electrical treeing, i.e. time of first visible treeing, treeing pattern and treeing propagation time, were analyzed and were discussed for each voltage stress frequency. Video capture software is useful tool for analyses the recorded video.

Incaseof applied voltage stress frequency at 50 Hz, first of visible treeing having 0.4 mm in length was observed after applying voltage stress for 31 minute. Electrical treeing initiated from tip of the needle electrode and expanded to the plane electrode. After applying voltage stress for 90 minute, the expansion of electrical treeing reached 1.01 mm. Branch like treeing expansion with slowly speed propagation was observed for this voltage stress frequency. Caption picture of electrical treeing from recorded video are illustrated in Fig.5.

In case of applied voltage stress frequency at 100 Hz, first of visible treeing having 0.28 mm in length was observed after applying voltage stress for 22 minute. Electrical treeing initiated from tip of the needle electrode and expanded to the plan electrode. Unlike previous frequency, brush-like treeing was observed for this voltage stress frequency. The expansion of bush-like treeing reached 1.07 mm after applying voltage stress for 66 minute. Propagation speed of bush-like treeing at frequency 100 Hz is faster than that of frequency 50 Hz. Caption pictures of bush-like treeing are illustrated in Fig.6.

In case of applied voltage stress frequency at 500 Hz (ten times of power frequency), first of visible electrical treeing having 0.37 mm in length was observed after applying voltage stress for 15 minute. Electrical treeing initiated from tip of the needle electrode and expanded to the plane electrode same as those two previous frequencies.However, propagation and expansion speeds are faster than those of the two previous frequencies. The expansion of branch-like treeing reached 1.52 mm in length after applying voltage stress for 80 minute. Caption pictures of branch-like treeing are illustrated in Fig.7.

In case of applied voltage stress frequency at 1000 Hz (twenty times of power frequency), first visible electrical treeing having 0.43 mm in length was observed after applying voltage stress for 9 minute. Also, electrical treeing initiated from tip of the needle electrode same as the previous three frequencies, 50 Hz, 100 Hz, and 500 Hz, respectively. The expansion of electrical treeing reached 1.98 mm in length after applying voltage stress 62 minute. Such treeing occurrence indicates higher propagation speed when comparing with the other frequency. Caption picture of branch-like treeing are illustrated in Fig.8.

In case of applied voltage stress at frequency 2000 Hz (forty times of power frequency), first of visible electrical treeing was observed after applying voltage stress 5 minute. Apparent of visible treeing is the most fastest comparing with the other frequency. Branch-like treeing, also, initiated from tip of needle electrode and reached 2.48 mm in length after applying voltage stress 40 minute. Caption picture of electrical treeing are illustrated in Fig.9.

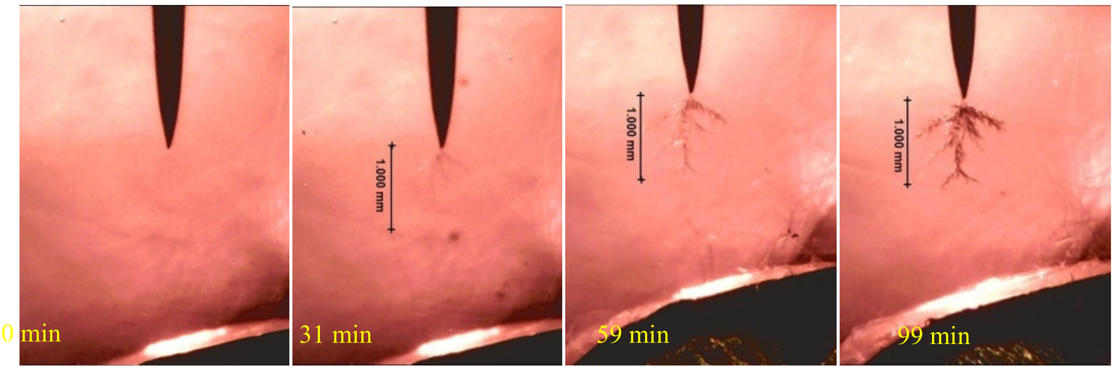

Fig. 5 Electrical treeing of applied voltage stressfrequency at 50 Hz

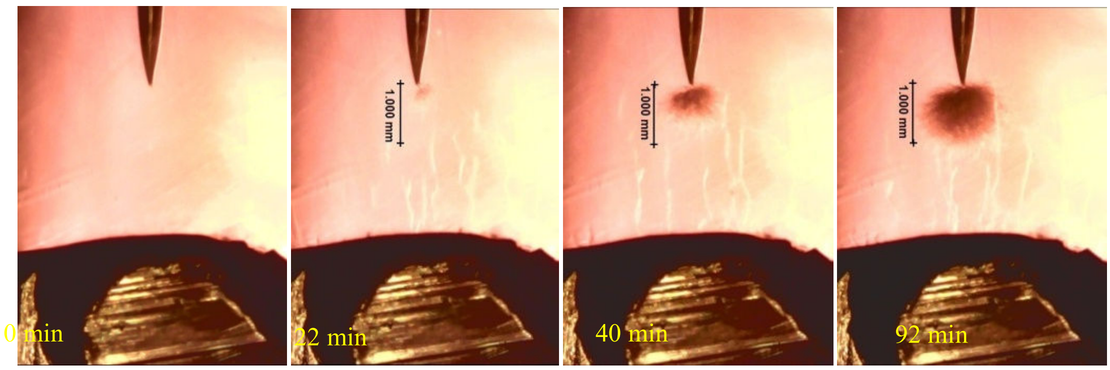

Fig. 6 Electrical treeing of applied voltage stress frequency at 100 Hz

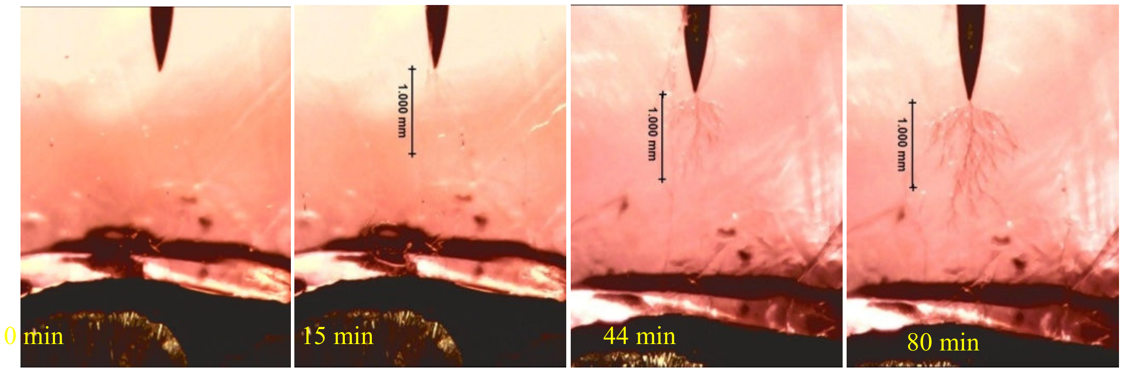

Fig.7 Electrical treeing of applied voltage stress frequency at 500 Hz

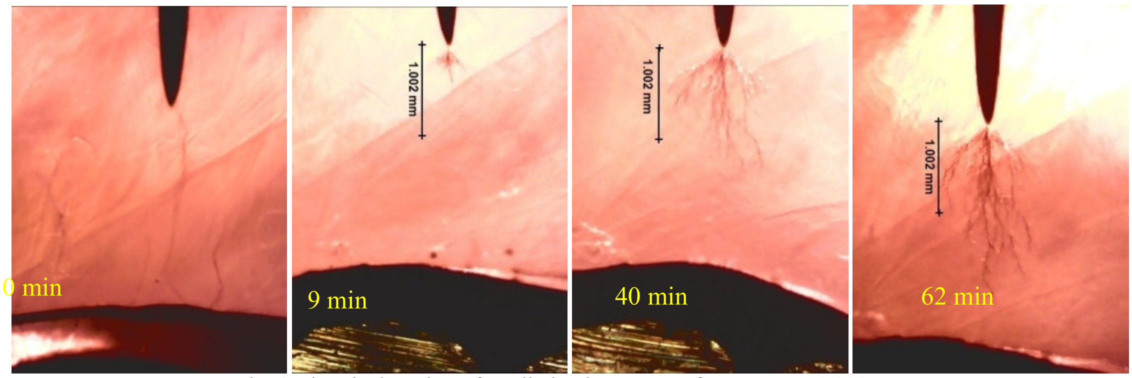

Fig. 8 Electrical treeing of applied voltage stress frequency at 1,000 Hz

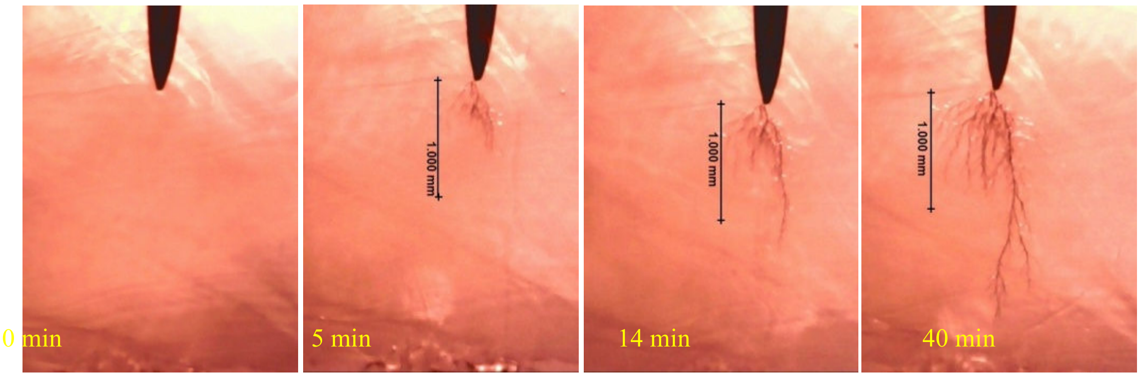

Fig. 9 Electrical treeing of applied voltage stress frequency at 2,000 Hz

TABLE I
COMPARISON PROPAGATION LENGTH AND PROPAGATION TIME OF ELECTRICAL TREEING

50 Hz		100 Hz		500 Hz		1,000 Hz		2,000 Hz	
Length (mm)	Time (min)	Length (mm)	Time (min)	Length (mm)	Time (min)	Length (mm)	Time (min)	Length (mm)	Time (min)
0.40	31	0.28	22	0.37	15	0.43	9	0.78	5
0.41	35	0.31	28	0.41	21	0.51	15	0.81	7
0.43	37	0.39	33	0.48	25	0.59	20	0.87	9
0.49	41	0.46	38	0.59	29	0.75	25	0.93	11
0.53	43	0.58	40	0.67	35	0.86	30	0.99	12
0.61	48	0.61	42	0.75	37	0.98	35	1.23	14
0.68	51	0.64	46	0.80	41	1.11	37	1.32	16
0.72	55	0.73	50	0.91	44	1.30	40	1.38	17
0.86	59	0.81	56	1.06	50	1.46	44	1.43	18
0.91	63	0.89	60	1.21	55	1.53	49	1.55	20
0.96	69	0.99	66	1.35	59	1.61	54	1.63	24
1.00	74	1.07	70	1.41	64	1.73	56	1.75	28
1.00	84	1.07	75	1.51	71	1.85	59	1.98	32
1.01	90	1.07	80	1.51	77	1.89	60	2.13	36
1.01	99	1.07	92	1.52	80	1.98	62	2.48	40

In order to examine the effect of applied voltage stress frequency, propagation length and propagation time of electrical treeing were measured by using video caption pictures. The measuring results illustrated in Table I and were plotted together, as shown in Fig. 10.As shown in Table I, initial time of visible treeing (recorded video) decreases with increasing in applied voltage frequency. Obviously, as shown in Fig. 10, propagation speed of electrical treeing increases with increasing in applied voltage frequency.The experimental results show that voltage stress frequency is one of dominant effect to the occurrence of electrical treeing. Furthermore, as illustrated in Table II, Two types of electrical treeing, bush-like and branch-like treeing were observed from the experimental.

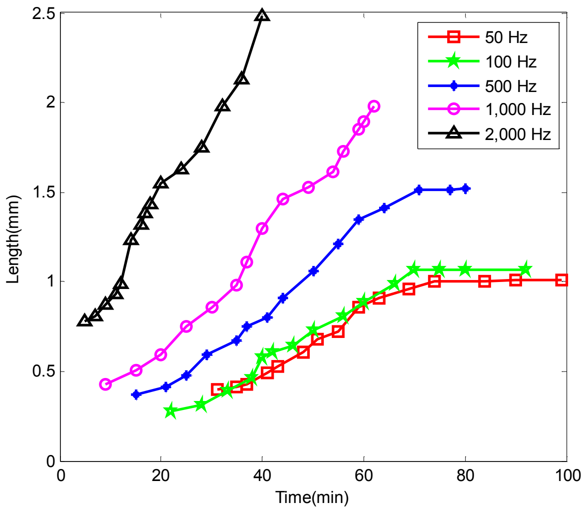

Fig. 10 Propagation characteristics of electrical trees

TABLE II
PATTERN OF ELECTRICAL TREEING

Frequency (Hz)	Time (min)	Treeing length(mm)	Treeing characteristic
50	99	1.01	Branch tree
100	92	1.07	Bush tree
500	80	1.52	Branch tree
1,000	62	1.98	Branch tree
2,000	40	2.48	Branch tree

IV. CONCLUSION

The following conclusions are given according to the experimental results.

(1) Initial time of visible electrical treeing decrease with increasing in applied voltage stress frequency.

(2)Obviously, propagation speed of electrical treeing increase with increasing in applied voltage stress frequency.

(3) Two types of electrical treeing, bush-like and branch-like treeing, were observed.

ACKNOWLEDGMENT

The Authors would like to thank you Suranaree University of Technology for financial support.

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