World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:6, No:12, 2012

Space Charge Distribution in 22 kV XLPE Insulated Cable by using Pulse Electroacoustic Measurement Technique

N. Ruangkajonmathee, R. Thiamsri, and B. Marungsri

Abstract—This paper presents the experimental results on space charge distribution in cross-linked polyethylene (XLPE) insulating material for 22 kV power distribution system cable by using pulse electroacoustic measurement technique (PEA). Numbers of XLPE insulating material ribbon having thickness 60 µm taken from unused 22 kV high voltage cable were used as specimen in this study. DC electric field stress was applied to test specimen at room temperature (25°C). Four levels of electric field stress, 25 kV/mm, 50 kV/mm, 75 kV/mm and 100 kV/mm, were used. In order to investigate space charge distribution characteristic, space charge distribution characteristics were measured after applying electric field stress 15 min, 30 min and 60 min, respectively. The results show that applied time and magnitude of dc electric field stress play an important role to the formation of space charge.

Keywords—Space charge distribution, pulsed electroacoustic (PEA) technique, cross-linked polyethylene (XLPE), DC electrical fields stress.

I. Introduction

NOWADAYS, XLPE is used an insulating material in high voltage power cable. The advantages of XLPE are high dielectric strength and electrical resistivity combined with good physical properties such as resistance to cracking and moisture penetration[1-2]. However, under certain operating conditions, their good electrical insulation properties may become degraded. For example, trapped or low mobility electrically charged species within the bulk can give rise to space charge, resulting in localized electric stress enhancement. This can cause further concentration of charge and lead to premature failure of the material [3-4].

In a solid dielectric medium, space charge and electric displacement are related by the Maxwell-Gauss equation. In situations where quantities depending on only one spatial coordinate, z, this equation is expressed as[5]:

$$\frac{\partial D(z)}{\partial z} = \rho(z) = \rho_c(z) + \rho_p(z) \tag{1}$$

where:

$D(z)$ is the electric displacement,

$\rho(z)$ is the total charge density,

$\rho_c(z)$ is the volume density of space charges, defined as real charges, being positive or negative, including surface and bulk charge,

$\rho_p(z)$ is the volume density of bound charges, defined in respect to material polarization P as:

$$\rho_p(z) = -\frac{\partial P(z)}{\partial z} \tag{2}$$

If the polarization is uniform along the z direction, the total charge is the space charge.

Space charge effects have been widely recognized as one of the major components of the electrical aging processes in polymeric insulation, because it may raise the electric field locally and hence initiate a degradation mechanism in insulator [3, 6-7]. Therefore, it is very important to understand space charge effects to polymer insulation.

PEA technique is a nondestructive method, which has been developed to measure dynamically net charge density as a function of distance through solid insulating materials under an applied voltage. The principle of space charge measurement using the PEA technique is well known and reported elsewhere [5-6,8-9].

Kwang et al. [10] studied effects of constituents of XLPE on the formation of space charge by PEA technique, cross-linked part of low density polyethylene (LDPE) encourages antioxidant and residual byproducts on the formation of space charge in XLPE have been investigated.

Montanari et al. [11] reported results the effect of humidity on space charge accumulation in XLPE at room temperature and humidity concentration from 5 to 95%. Space charge measurements were performed by using the PEA technique. Different levels of DC constant poling field were considered, ranging from 5 kV/mm to 185 kV/mm.

Chen et al. [12] report the effect of mechanical deformation on space charge dynamics in XLPE. Thin films were peeled from a66 kV commercial XLPE cable. Space charge measurements under DC electric fields have been monitored using the PEA technique.

Chong et al. [13] reports on space charge evolution in XLPE planar specimens approximately 1.20 mm thick subjected to electric stress level of 30 kV_{dc}/mm at four temperatures 25, 50, 70 and 90^{o}C for 24 h. Space charge distributions are dominated by positive charge when tested at high temperatures regardless of specimens treatment and

N. Ruangkajommathee and R. Thiamsri aremaster degree students with Suranaree University of Technology, Nakhonratchasima, 30000, Thailand.
B. Marungsri is with Suranaree University of Technology, NakhonRatchasima, 30000, Thailand (corresponding author, phone: +66 44224366; fax: +66 4422 4601; e-mail: bmshvee@ sut.ac.th).

positive charge propagation enhances as testing temperature increases. This can be a major cause of concern as positive charge propagation has been reported to be related to insulation breakdown.

In this paper, space charge distribution in XLPE insulating material for 22 kV cable under different dc electric fields ranging from 25 kV/mm to 100 kV/mm have been investigated by using the PEA measurement technique. The influence of electric field stress on space charge distribution been investigated.

II. Experimental

A. Specimens

Specimens for the experimental made from un-aged 22 kV XLPE distribution power cables 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 in underground distribution system of Provincial Electricity Authority of Thailand. Numbers of XLPE ribbon with thickness 60 µm were cut from the insulation around a cable by using a microtome. All specimens were measured precisely before testing so the thickness effect is neglected.

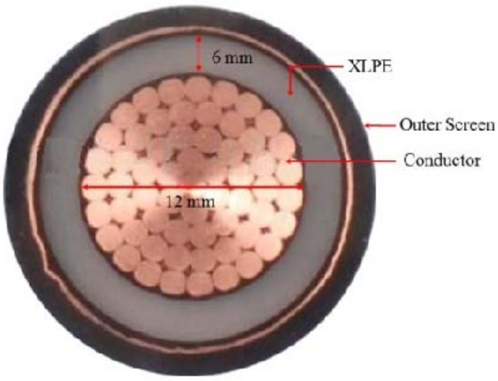

Fig. 1 Cross-section of 22 kV XLPE cable

B. Test Arrangement and Test Methods

The PEA technique was chosen to detect space charge in specimens due to its simplicity in structure, low cost and easy to implement. A high voltage pulse with 5 ns length is applied to the specimens sandwiched between the two electrodes. The pulse electric field produced interacts with charge layers, generating an electric force which displays charge. The consequence is the formation of pulsed acoustic waves in correspondence of each charge layer with respect to neutrality. The resultant acoustic signals are detected by a piezoelectric transducer (PVDF) so that the charge distribution in the specimens under test can be obtained from the output voltage profile of the transducer. The electric signal obtained in time domain represents the charge distribution. The analysis of space charge profiles is restricted to one dimension

The schematic diagram for the PEA system used for this experiment is shown in Figure 2. The electric signal obtained in time domain represents the charge distribution. To obtained quantitative charge distribution, a proper calibration is required [14].

Electrodes and specimens were immersed in transformer oil in order to avoid surface flashover in air. The experimental layout is shown in Fig. 3. To observe space charge dynamics, the electric fields ranging from 25 kV/mm to 100 kV/mm were applied to specimens. The experimental conditions are shown in Table I.

TABLE I
Test Conditions

PEA system	Conditions
Electric Field	25-100 kV/mm
Pulse Voltage	400 V, 5ns, 1kHz
Specimens thickness	60µm
High voltage Amplifier	1:2000

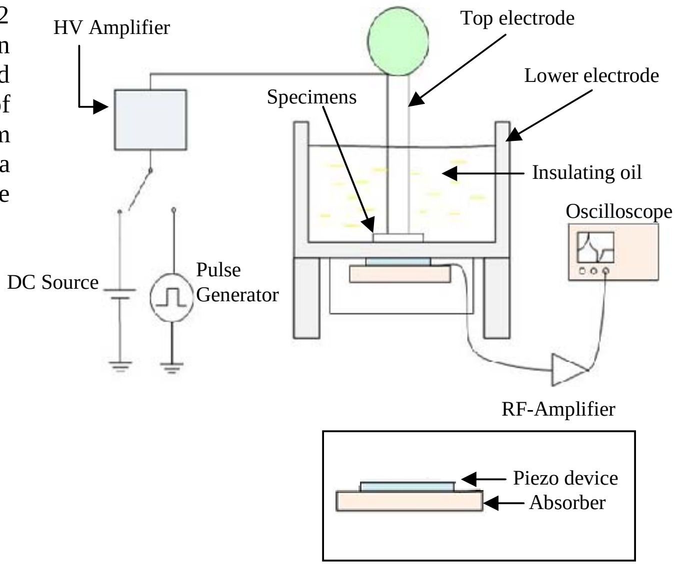

Fig. 2 Test arrangement

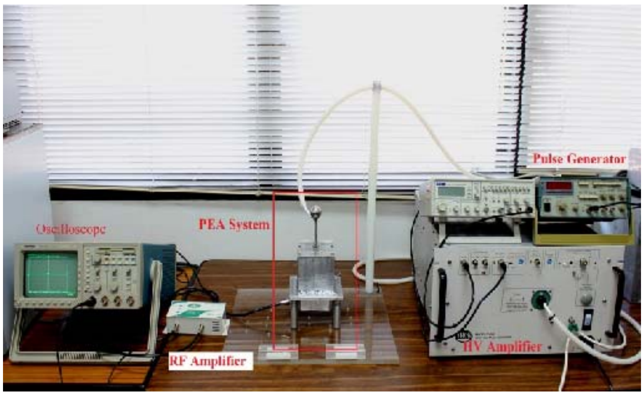

Fig. 3 Test chamber

III. Test Results and Discussion

The PEA measurements were performed at room temperature after applying DC field stress for15 min, 30 min and 60 min, respectively. The experimental were carefully conducted in order to obtain the precisely results. Measurement results for each electric field stress level are illustrated in Fig. 4, Fig. 5, Fig. 6 and Fig. 7, respectively.

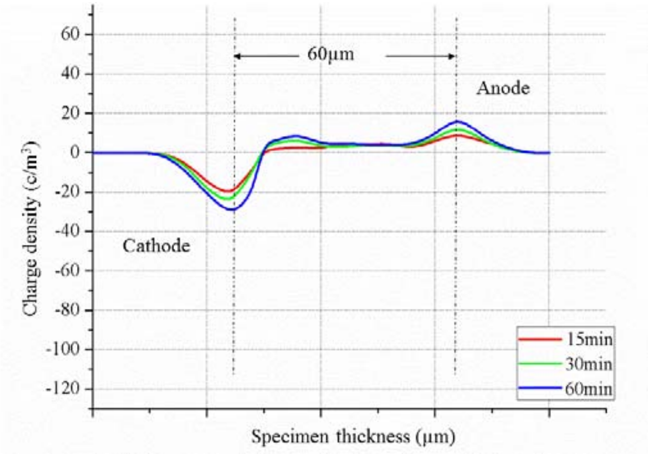

Fig. 4 Space charge distribution in the presence of the applied electric field 25 kV/mm

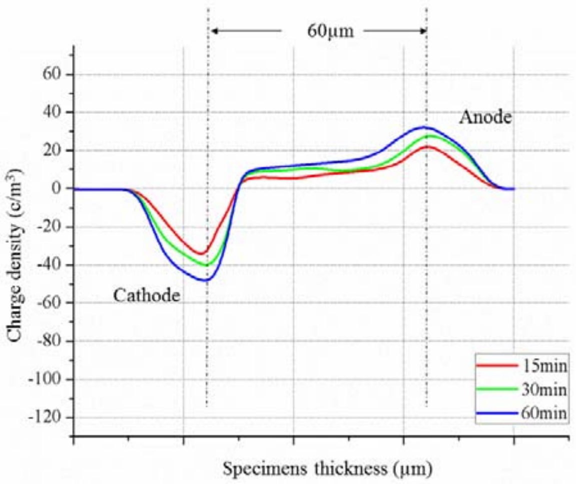

Fig. 5 Space charge distribution in the presence of the applied electric field50 kV/mm

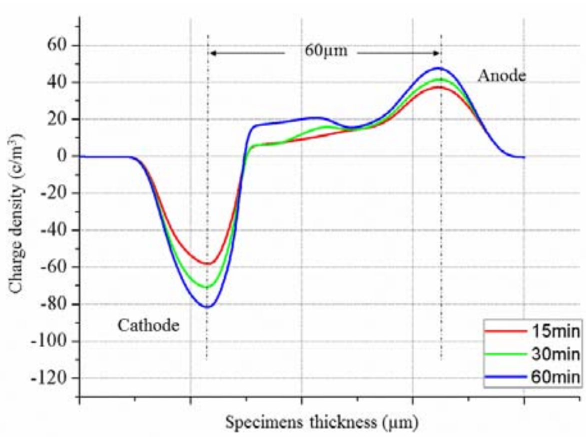

Fig. 6 Space charge distribution in the presence of the applied electric field75kV/mm

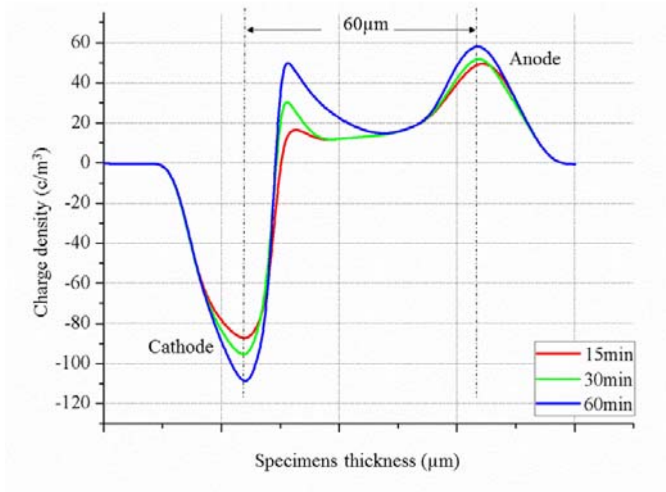

Fig. 7 Space charge distribution in the presence of the applied electric field100kV/mm

As illustrated in Figs. 4-7, magnitude of space charge increases with increasing magnitude of electric field stress. Higher formation rate of space charge obtained when applying higher electric field stress. Furthermore, the relation between charging time and the charge density at different applied DC voltage can be seen. Under same electric field stress, magnitude of space charge increases with increasing charged time.

Fig. 8 and Fig. 9 show the relation between charging time and the charge density at cathode and anode, respectively.

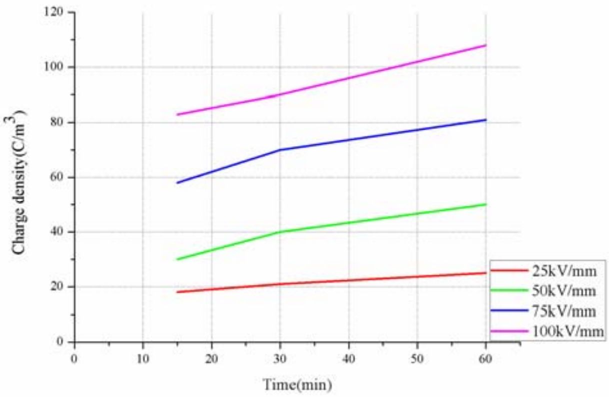

Fig. 8 The relation between charging time and the charge density at cathode

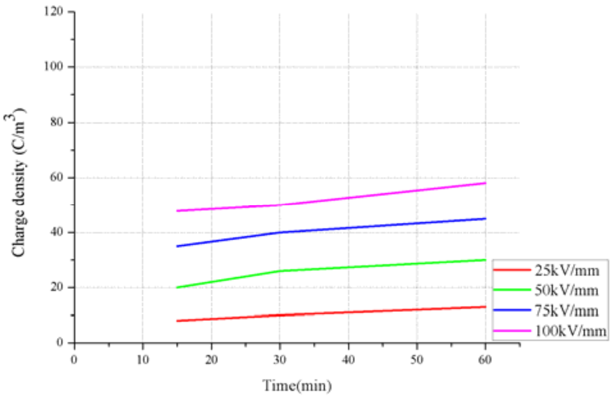

Fig. 9 The relation between charging time and the charge density at anode

IV. Conclusion

Space charge distribution characteristics in XLPE ribbon at the applied electric fields ranging from 25 to 100 kV/mm have been observed over a period of 15 min, 30 min and 60 min., respectively using the PEA technique. The following conclusions are given.

(1) The characteristics of space charge formation at the two electrodes after applying different magnitude of DC electric field stress were obtained.

(2) Magnitude of DC electric field stress and time applying DC field stress has an important role to space charge distribution in XLPE material.

Acknowledgment

The authors would like acknowledge Suranaree University of Technology for financial support.

References

[1] R. Arrighi, "From Impregnated Paper to Polymeric Insulating Material in Power Cables", *IEEE Trans. Electr. Insul.*, Vol. 21, 1986, pp.7-18.

[2] T. L. Hanley, R. P. Burford, R. J. Fleming and K. W. Barber, "A General Review of Polymeric Insulation for Use in HVDC Cables", *IEEE Electr. Insul. Mag.*, Vol. 19, No. 1, 2003, pp. 13-24.

[3] Y. Zhang, J. Lewiner, C. Alquie and N. Hampton "Evidence of strong correlation between space charge buildup and breakdown in cable insulation", *IEEE Trans. Dielectr. Electr. Insul*., Vol.4, 1997, pp 83-778.

[4] Z.Liu, R.Liu, H. Wang and W. Liu " Space charge and initiation of electrical trees", *IEEE Trans. Electr. Insul.*, Vol.24, 1989, pp.9-83.

[5] O. Gallot-Lavallée, V. Griseri, G. Teyssedre and C. Laurent, "The pulsed electro-acoustic technique in research on dielectrics for electrical engineering: Today's achievements and perspectives for the future", *RS-RIGE*, Vol. 8, No. 5, June 2005, pp. 749 – 772.

[6] L. Dissado, G. Mazzanti and G. C. Montanari, "The Role of Trapped Space Charges in the Electrical Aging of Insulating Materials", *IEEE Trans. Diel.andElectr. Insul.*, Vol. 4, 1997, pp. 496-506.

[7] C. Le Gressus and G. Blaise, "Breakdown Phenomena Related to Trappingr De-Trapping Processes in Wide Band Gap Insulators", *IEEE Trans. Electr. Insul.*, Vol. 27, No. 3, 1992, pp. 472-481.

[8] T. Maeno, H. Kushibe, T. Takada and C.M. Cooke, "Pulsed electroacoustic Method for the measurement of volume charge in e-beam irradiated PMMA", *Proc. IEEE Conf. Electr.Insul.Diel. Phenomena*,1985, pp. 389-397.

[9] T. Maeno, T. Futami, H. Kushibe, T. Takada and C.M. Cooke, "Measurement of spatial charge distribution in thick dielectrics using the pulsed electroacoustic method", *IEEE Trans. Electr.Insul.*, Vol. 23, 1988, pp.433-439.

[10] S. Suh Kwang, J. Sun Hwang, S. Noh Jin and T. Takada, "Effects of Constituents of XLPE on the Formation of Space Charge", *IEEE Trans. Diel. and Electr. Insul.*, Vol. 1, 1994, pp. 1077-1083.

[11] G. C. Moniaranari and F. Palmieri, "The effect of humidity on space charge accumulation in XLPE", *in Proc. Annual Report Conference on Electrical Insulation and Dielectric Phenomena.*, 2003, pp. 205-208.

[12] G. Chen and M.R. Kamaruzzaman, "Impact of mechanical deformation on space charge in XLPE", *in Proc. International Conference on Solid Dielectrics*, Winchester, UK, July 8-13, 2007, pp.511-513.

[13] Y.L. Chong, G. Chen and Y.F.F. Ho, "Temperature Effect on Space Charge Dynamics in XLPE Insulation", *IEEE Trans. Electr.Insul.*, Vol. 14, 2007, pp.65-76.

[14] T. Maeno, "Calibration of the pulsed electroacoustic method for measuring space charge density", *Trans. IEE Japan*, Vol. 119-A, 1999, pp.114-119.

NattawutRuangkajonmathee was born in KhonKaen Province, Thailand, in 1987. He received his B. Eng. in Electrical Engineering from Suranaree University of Technology, Nakhon Ratchsima, in 2009. Currently, He is a master degree student in school of Electrical Engineering, Institute of engineering, Suranaree University of Technology. His research topic interesting is High voltage insulation technology.

Ratthakhet Thiamsri was born in Ang Thong Province, Thailand, in 1987. He received his B. Eng. in Electrical Engineering from Suranaree University of Technology, Nakhon Ratchasima, Thailand, in 2009. Currently, He is a master degree student in school of Electrical Engineering, Institute of engineering, Suranaree University of Technology. His interesting areas arehigh voltage technology applications, high voltage insulation technology and power system technology.

Boonruang Marungsri was born in Nakhon Ratchasima Province, Thailand, in 1973. He received his B. Eng. and M. Eng. from Chulalongkorn University, Thailand in 1996 and 1999 and D. Eng. from Chubu University, Kasugai, Aichi, Japan in 2006, all in electrical engineering, respectively. Dr. Marungsri is currently an assistant professor in School of Electrical Engineering, Suranaree University of Technology, Thailand. His areas of interest are high voltage insulation technologies and electrical power system.