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]:

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

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:

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

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/mm at four temperatures 25, 50, 70 and 90°C for 24 h. Space charge distributions are dominated by positive charge when tested at high temperatures regardless of specimens treatment and

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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](image)

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.

![Fig. 2 Test arrangement](image)

### Table I

<table>
<thead>
<tr>
<th>PEA system Conditions</th>
<th>Test Conditions</th>
</tr>
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<tbody>
<tr>
<td>Electric Field</td>
<td>25-100 kV/mm</td>
</tr>
<tr>
<td>Pulse Voltage</td>
<td>400 V, 5ns, 1kHz</td>
</tr>
<tr>
<td>Specimens thickness</td>
<td>60μm</td>
</tr>
<tr>
<td>High voltage Amplifier</td>
<td>1:2000</td>
</tr>
</tbody>
</table>

![Fig. 3 Test chamber](image)

III. TEST RESULTS AND DISCUSSION

The PEA measurements were performed at room temperature after applying DC field stress for 15 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.
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.
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.

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REFERENCES


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