

## Research on Effect of Modified Semi Conductive Material on the Space Charge Behaviour in XLPE

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**Abstract.** The semi conductive shield material was prepared by mixing a variety of copolymer and carbon black (CB) with LDPE by melt blending method. In order to study the suppression of semi-conductive shield materials on space charge injection, inorganic nano fillers with different properties were added respectively, and the space charge distribution of double-layer sample which was composed of a semi conductive shield layer and a XPLE insulation layer was measured by using pulse electro-acoustic (PEA) method. The results indicate that when various semiconductive shield materials are used, the space charge distributions of XLPE are different. Moreover, the space charge injection from the surface of XLPE can be suppressed by adding nano-MgO and nano-SiC into semi-conductive shield materials.

### 1. Introduction

With the rapid development of economy and the continuous expansion of the scale of city, the demand for power is increasing, and long distance, safety and high efficiency have become the main development direction of power transmission. Compared with HVAC transmission, HVDC transmission has the advantages of low loss, low transmission cost, good stability, and ability to interconnect asynchronous communication systems. The application of HVDC has a great advantage in both cost and technique<sup>[1]</sup>. HVDC cable usually employs XLPE or oil-impregnated paper as insulation. Under DC voltage, the electric field can be distorted by the space charge accumulated in XLPE insulation. And then insulation breakdown will possibly occur, especially when the polarity is reversed<sup>[2]</sup>. To some extent, the development of XLPE insulated HVDC power cable is restricted by space charge.

Generally speaking, the space charge in XLPE insulation is mainly composed of two parts: One is the space charge injected in high field strength from the electrode which is in contact with the medium. This part of space charge is known as homo charge. The other is known as hetero charge which is caused by the dissociation or ionization of the impurities inside the insulation under high electric field<sup>[3]</sup>. Therefore, there are two methods to inhibit the accumulation of space charge in XLPE. One focuses on the disposal of the specimen surface of the electrode materials in contact with the sample in order to inhibit homo space charge. The other focuses on the modifications of the insulation material in order to inhibit hetero space charge. Some research has proved that the semi conductive shielding layer of HVDC cable plays an important role in the homogenizing of electric field distribution, and the semi-conductive shielding layer can restrain the injection of space charge in a certain extent. Liu et al.<sup>[4]</sup> reported that the space charge distributions of MgO/XLPE composite material were different when test electrodes with different semi conductive materials were employed. Zhang et al.<sup>[5]</sup> reported that when Ethylene vinyl acetate copolymer (EVA) containing carbon black was used as semi conductive electrode, the larger volume fraction of carbon black was, and the lower maximum field intensity of the particles was, and the less the amount of space charge was. Our research also showed that the HVDC cable XLPE insulation produced by Borealis could suppress the

space charge accumulation only if the dedicated semiconductive shielding material was employed together.

At present, the application of nano materials has become a hot spot worldwide. Nano particles have a series of special physical properties, such as small size effect, surface effect, macro quantum tunnel effect and quantum size effect, and nano composite materials have more excellent properties than other ordinary materials. For example, adding nano-MgO,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$  and carbon black into PE or XLPE can effectively inhibit the accumulation of space charge. So the semi conductive material containing inorganic nano materials with specific properties are expected to improve the ability to suppress charge injection<sup>[6-12]</sup>. In this paper, four kinds of copolymers were used as matrix resin to prepare semi conductive material, and CCTO with high permittivity, SiC with nonlinear conductivity, and 2 kinds of nano oxides ( $\text{SiO}_2$ , MgO) were added into the semi conducting materials. The effects of the type of matrix and the addition of nano materials on the charge injection of the semi conducting materials were investigated.

## **2. Experimental Method**

### **2.1 Specimen Preparation**

EVA and three kinds of ethylene acrylic ester (EEA) were blended with LDPE according to the mass ratio of 70:30, respectively. After appropriate amount of carbon black and crosslinking agent were added, four kinds of cross-linkable semi conductive materials were obtained.

The cross-linkable semi conductive layer with the thickness of 200  $\mu\text{m}$  and the cross-linkable polyethylene layer with the thickness of 300  $\mu\text{m}$  were separately molded by the plate vulcanization machine at 110 °C. After the semi-conductive layer and insulation layer were stacked together and molded by the flat plate vulcanization machine at 110 °C, the specimen were cross-linked under the condition of 175 °C and 15 MPa. After cooling, the samples were short-circuited for 24 hours in a vacuum oven at 80 °C to eliminate the influence of residual crosslinking byproducts and charge for space charge measurement.

The nano semi-conductive materials were prepared by blending obtained semi conductive materials with SiC,  $\text{SiO}_2$ , MgO, and CCTO, separately. The preparation processing of sample for space charge measurement was the same as above.

### **2.2 Space Charge Measurement**

In the experiment, PEA method was used to measure the space charge distribution in the sample, and the space charge measurement system was shown in Fig. 1. The maximum output voltage of the pulse power supply was 1 kV, the pulse width was 10 ns, and the output voltage range of the high voltage DC power supply was -20 kV~20 kV. Flat electrodes were used in the test, the upper electrode was in contact with the semi conductive material, and the lower electrode was in contact with the aluminum electrode which was evaporated on the sample with silicone oil as acoustic coupling agent. The data storage and analysis of the real-time communication of the computer were acquired by the digital oscilloscope. In the experiment, electric field of 40 kV/mm was applied to the sample, and the space charge distribution of 1 min, 10 min, 20 min, 30 min and 40 min were tested, respectively. Then the sample was short-circuited, and the space charge distribution of 5s, 60 s and 30 min were recorded.

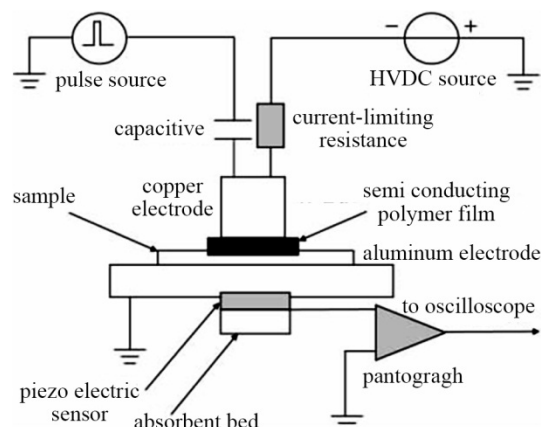


Fig. 1. Schematic diagram of PEA space charge measurement system.

### 3. Results and Discussion

#### 3.1 Effect of the matrix resin of semi conductive on the space charge distribution in XLPE

In the experiment, the semi conductive materials with different copolymers were recorded as CB/LDPE/EVA, CB/LDPE/EEA1, CB/LDPE/EEA2, CB/LDPE/EEA3, respectively. The space charge distribution in the XLPE was shown in Fig. 2, 3, 4 and 5 when four semi conductive materials were used as the electrode.

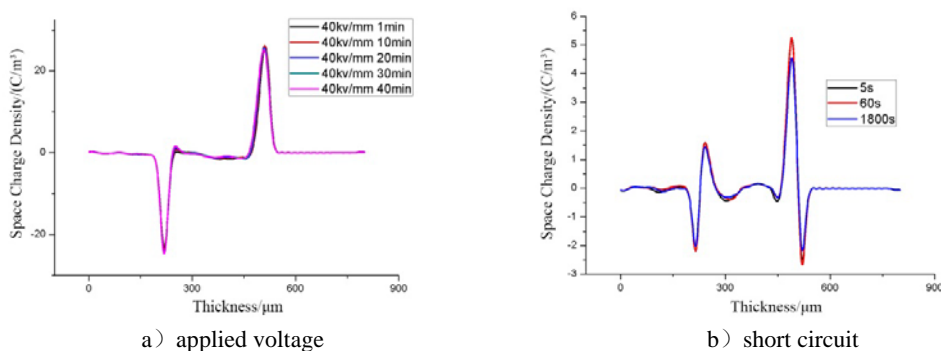


Fig. 2. The space charge distribution in XLPE when CB/LDPE/EVA was used as the electrode.

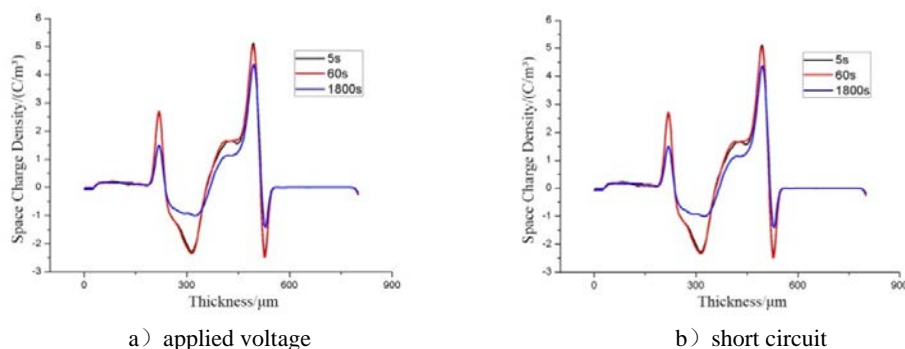


Fig. 3. The space charge distribution in XLPE when CB/LDPE/EEA1 was used as the electrode

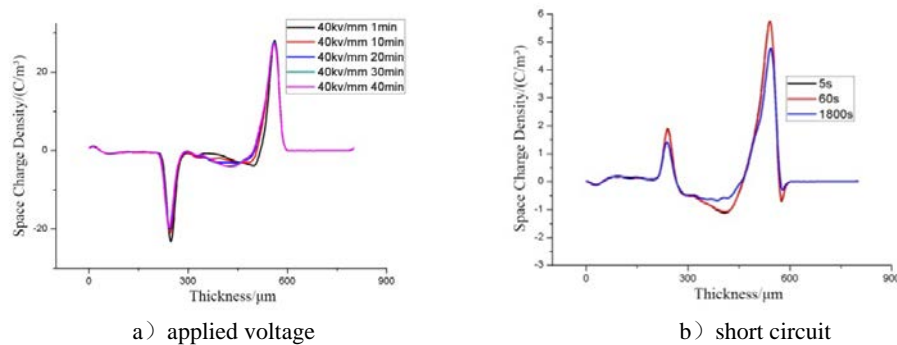


Fig. 4. The space charge distribution in XLPE when CB/LDPE/EEA2 was used as the electrode

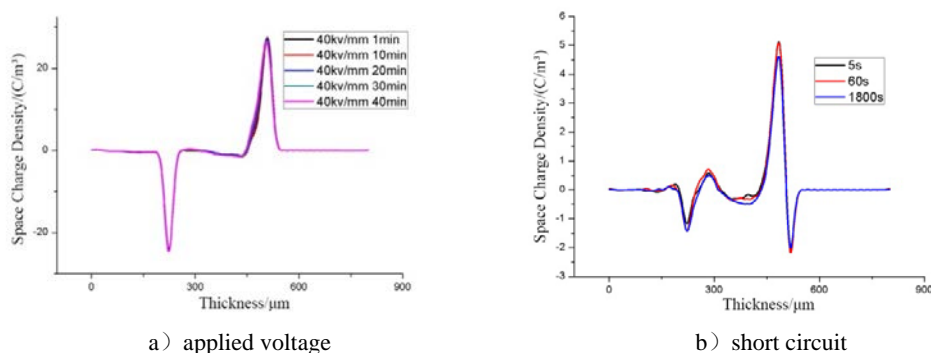


Fig. 5. The space charge distribution in XLPE when CB/LDPE/EEA3 was used as the electrode.

As shown in Fig. 2 a), when CB/LDPE/EVA is used as the electrode, the inner space charge of XLPE is less, and there is a small amount of positive charge near the cathode. Fig. 2 b) shows that after short circuit, there is some positive charge near the two electrodes. This indicates that in the process of applying DC voltage, homo charge was injected from the anode. Seen from Fig. 3a), using the CB/LDPE/EEA1 as the electrode, there is a lot of space charge in XLPE, and there is more homo space charge near the two electrodes. Fig. 3b) shows that after short circuit, there is still a lot of homo charge near the two electrodes. It is further confirmed that the charge are largely injected from the electrode. Fig. 4 shows that when CB/LDPE/EEA2 was used as the electrode, in the early stage of the applied voltage, there is mainly hetero charge near the electrode. The hetero charge may be derived from the dissociation or ionization of the low molecular by-products and impurities from the crosslinking reaction. With the increase of time, the negative charge inside the XLPE obviously increased and moved to the anode fast. After short circuit, homo charge is assembled around the two electrodes, but the quantity of negative charge is more than positive charge in the material. It indicates that the cathode is easier for charge to inject than the anode. As shown in Fig. 5, when CB/LDPE/EEA3 was used as the electrode, whether during the applied voltage or in the process of short circuit, the quantity of space charge in XLPE was relatively small. Above all, the results show that the properties of the matrix resin of semi conductive electrode materials have obvious influence on the charge injection behavior in XLPE. The reason may be that there is a difference in the proportion of polar groups in different copolymers. Due to the difference of type and proportion of polar groups in various copolymers, the compatibility of the matrix resin and carbon black is different, and then the aggregation and dispersion of carbon black particles in the matrix resin are influenced. All of these result in the difference of the interface states between semi-conductive electrode and XLPE.

### 3.2 Effect of inorganic nano particles on the space charge distribution in XLPE

1.54 wt% SiO<sub>2</sub>, 1.54 wt% CCTO, 2.31 wt% MgO and 1.54 wt% SiC were respectively added into CB/LDPE/EEA3. These materials were respectively recorded as CB/SiO<sub>2</sub>/LDPE/EEA3, CB/CCTO/LDPE/EEA3, CB/MgO/LDPE/EEA3, CB/SiC/LDPE/EEA3. The materials above are

used as semi conductive electrodes, and the space charge distribution in XLPE is shown in Fig. 6, 7, 8 and 9.

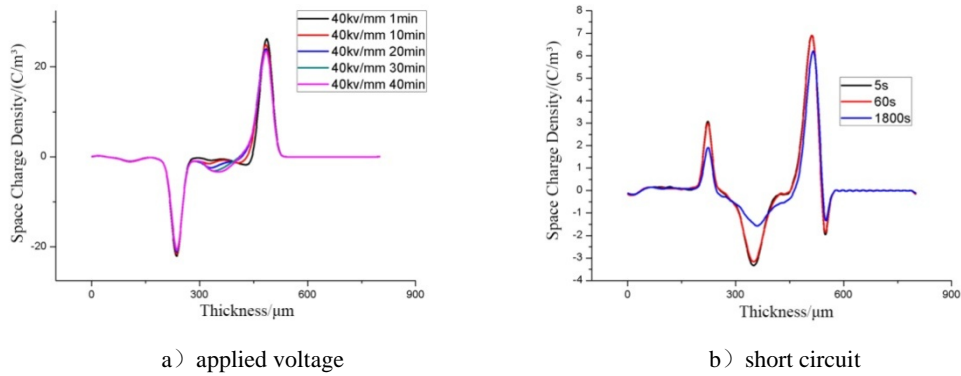


Fig. 6. The space charge distribution in XLPE when CB/SiO<sub>2</sub>/LDPE/EEA3 was used as electrode.

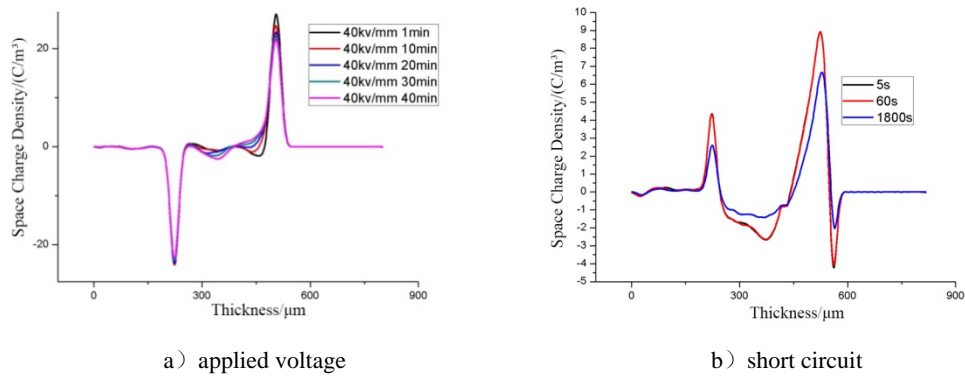


Fig. 7. The space charge distribution in XLPE when CB/CCTO/LDPE/EEA3 was used as electrode.

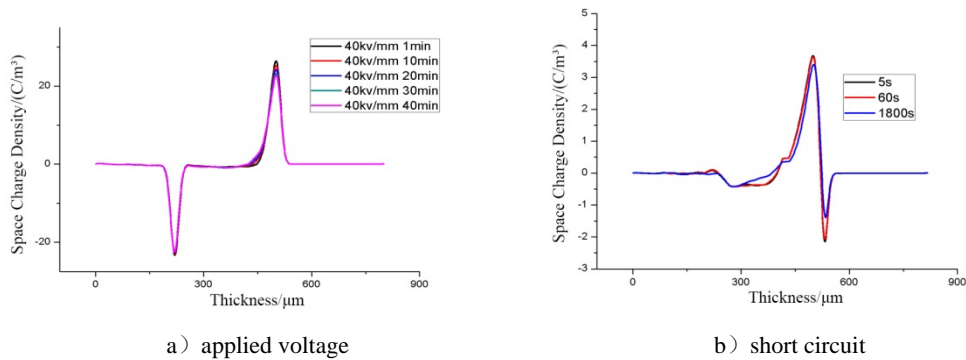


Fig. 8. The space charge distribution in XLPE when CB/MgO/LDPE/EEA3 was used as electrode.

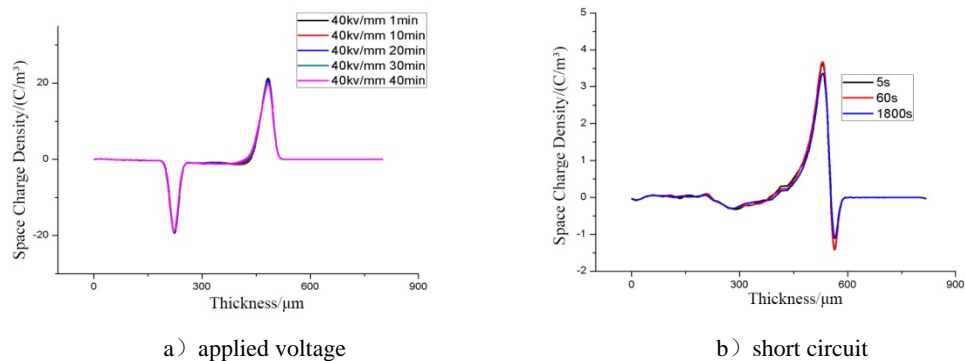


Fig. 9. The space charge distribution in XLPE when CB/SiC/LDPE/EEA3 was used as electrode.

It can be concluded by comparing Fig. 5 with Fig. 6 and Fig. 7, after adding SiO<sub>2</sub> or CCTO to the semi conductive material, the negative charge in XLPE obviously increases in the process of applying

DC voltage. The space charge distribution diagram of the short circuit period also shows that negative charge occurs in a larger area in the XLPE. In Fig. 8 a) and Fig. 9 a), when adding nano-MgO or nano-SiC to the semi conductive material as the test electrode, the space charge in the XLPE is hardly observed under DC voltage. Moreover, only a small amount of negative charge near the cathode in the short circuit period can be observed, and the positive charge near the anode is also significantly reduced compared with the semi conductive electrode without nano materials. The results shows that the addition of nano-MgO or SiC can effectively inhibit the charge injection from the electrodes to the XLPE, and the related mechanism will be further explored in the future.

#### 4. Conclusion

In this paper, the space charge distribution of XLPE was tested in the process of applying DC voltage and short circuit after a certain period of time, and the results can be concluded as followed:

(1) The properties of matrix resin used for semi conductive electrodes have great influence on the distribution of space charge in XLPE. Because various copolymers and carbon black have different compatibility, which results in different aggregation state and dispersion degree of the carbon black particles in the semi conductive material, the interface between semi conductive electrode and XLPE can be affected.

(2) Inorganic nano fillers with different characteristics in semi conductive electrodes have obvious influences on the distribution of space charge in XLPE. The semi conductive material with nano-MgO or nano-SiC can suppress the charge injection better, and whether in the pressure or in the short circuit process, the amount of charge in XLPE is very small.

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