Characteristics Investigation for Space Charge in Coaxial Cable under Temperature Gradient with Improved Measurement System

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ABSTRACT

The accumulation of space charge in a coaxial cable under high-voltage direct current (HVDC) may lead to the internal electrical field serious distortion, and thus extremely affect the long-term reliability of the cable in service. Therefore, it is significant to measure the space charge characteristic in a full-size power cable in real time. In this paper, an improved pulsed electro-acoustic (PEA) system suited for a full-size power cable under a temperature gradient was realized by designing the units of pulse injection and signal detection. Then, an induced current heating device was used to regulate the temperature of cable core conductor, therefore, the temperature gradient along the radial insulation was formed. Lastly, based on the improved space charge measurement system, the space charge of 10KV coaxial cable under 10kV/mm stress with polarity reversal and different temperature gradient (10 ℃, 20 ℃) were measured, and the space charge characteristics were analyzed. The results showed hetero-charge accumulated near the outer semi-conductive, these would affect cable's long-term reliability.

KEYWORDS

Coaxial cable, Space charge, Temperature gradient

INTRODUCTION

Compared with the high-voltage (HV) alternating current (AC) power cable, the HVDC power cable has many advantages, such as smaller insulation thickness, higher working stress, smaller outer radius, lighter weight, less dielectric and conductor losses, more load flow, and no AC magnetic stress. According to the differences in insulation materials and cable structure, HVDC power coaxial cables include oil-impregnated paper cables, oil-filled cables, inflatable cables, and extruded plastic cables. Among them, extruded plastic cables have larger transmission capacity, simpler accessory structure, and more stable operation situation[1]. However, the space charge effect in plastic cables, which causes the distortion of the local field under HVDC stress, will seriously affect the cable's long-term operation[2]. Moreover, the distributions of space charge are also closely related to many characteristics of the material's micro-structure, such as dielectric conductance, electrode injection, charge migration, charge recombination, and the variation of trap density[3]. Many electrical properties of the material's macro-structure, such as conductivity, breakdown, and aging, will be degraded gradually.

PEA technology has been considered a non destructive method whose basic principle is the propagation of acoustic waves across the insulation bulk generated by the electrostatic force origination from the pulsed electric stress and charges (internal charge and induced charges on the electrodes) when a pulsed electric stress is applied to a sample. Then the acoustic waves are detected by piezoelectric sensor made with polyvinylidene fluoride (PVDF) attached to the electrode, and observed by an oscilloscope. Recently, PEA technology is widely used for space charge measurement in the world[4,5], but many studies are mainly focused on flat samples because the PEA device used for flat samples is not only mature but also easily operated[6-9]. In addition, when the cable is loaded in service, a temperature gradient forming across the insulation is caused by Joule heat originating from the current in the HV cable conductor [10]. This affects the injection and migration of charge, leading to a gradient of conductivity and then a gradient of electric field[11-13]. The localized field enhancement in a polymeric cable due to space charge accumulation is unpredictable, posing a vital threat to the cable insulation in service, especially under applied dc voltage reversal or outage. In recent years, a few studies on the space charge dynamics in a cross-linked polyethylene (XLPE) cable under temperature gradient and dc voltage have been published [14-23].

In this paper, a modified PEA measurement system suitable for coaxial cables under a temperature gradient was realized by pulse injection from the PEA measuring electrode. Aside from the equipotential oscilloscope, the measuring electrode was insulated from the ground by an epoxy column and powered by a battery. The isolation between the oscilloscope and the computer was realized through a digital optical fiber, which could avoid the limit of the frequency band of the A/D fiber optic linker. The computer was used to remotely control the oscilloscope and to realize waveform acquisition and data processing. Moreover, an induced current heating device that was an AC current induction transformer was used to form the temperature gradient along the radial insulation. Lastly, the space charge waveform of DC coaxial cable under 10kV/mm stresses and different temperature gradient (10℃, 20℃) were measured.

EXPERIMENTAL

Induction of the modified PEA system

Figure 1 shows the schematic of the modified PEA system used for coaxial cables under temperature gradient. In this new system, the nanosecond pulse was injected into a shielded measuring electrode which was insulated from ground by four epoxy columns. Similar with the measuring electrode, the oscilloscope was also located at floating high potential and powered by batteries. The operator could operate the computer safely and remotely to control the oscilloscope just through a digital optical fiber connecting with the oscilloscope.

HVDC voltage was applied to the cable conductor through a current-limited resistor and the plate measuring electrode was tightly attached to the middle part of the

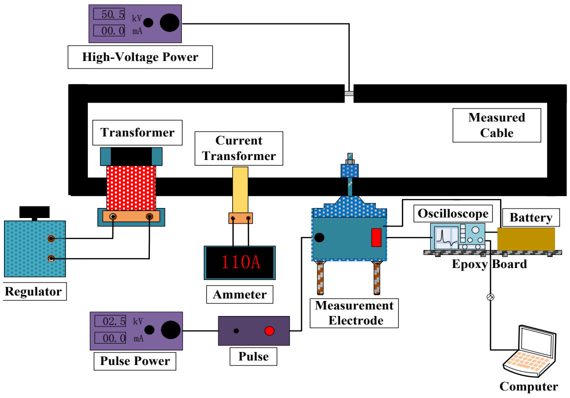


Fig. 1: Schematic diagram of PEA system for a coaxial cable under a temperature gradient.

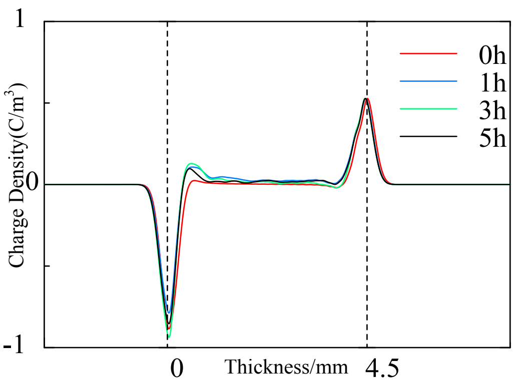
cable's outer semiconductive layer. Both end of the cable was assembled with rubber terminals and connected together. By means of an induced current heating device which consisted of a transformer, a current transformer, a voltage regulator and an ammeter, the induced current was generated inside the cable conductor and flowed in a closed loop, the cable was passed through a transformer and functioned as the secondary winding of the transformer. In this way, the test cable was heated up as resistive loss, so the temperature at the inner conductor would be higher than that at the outer semiconductive layer. Therefore, a temperature gradient was formed along the radial insulation from the inner conductor to the outer semiconductive layer. A voltage regulator was used to apply a voltage to the primary winding of the transformer. A current transformer and an ammeter were used to induce and detect the current of the test cable. A thermocouple sensor was used to detect the temperature of the outer semi conductive layer

Space charge measurement

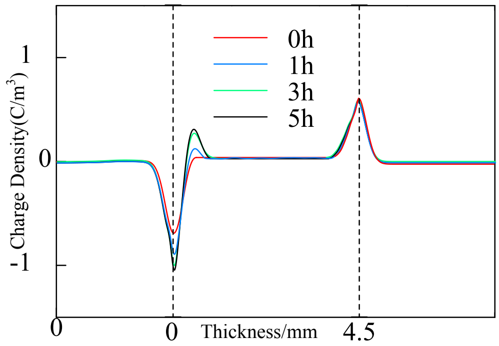
The purpose of this experiment was to investigate the space charge behaviors in the full-size HVDC XLPE cable.

In our experiments, the inducted current of cable were set to 100A and 150A respectively, therefore, the temperature difference of cable conductor and semi-conductor could be 10℃ and 20℃. The applied stress were 45kV and -45kV.

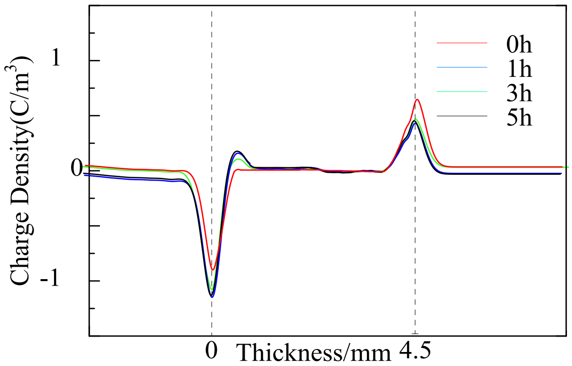
RESULTS AND DISCUSSION



(a) TG=0℃



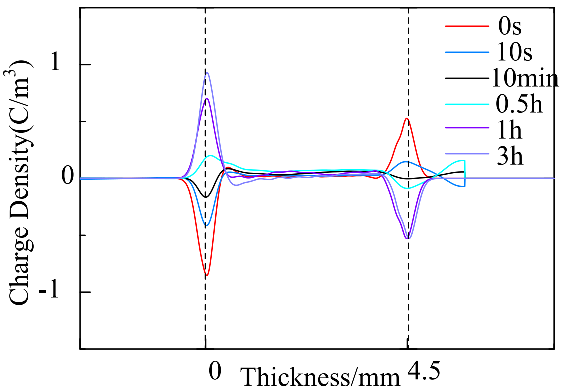
(b) TG=10℃



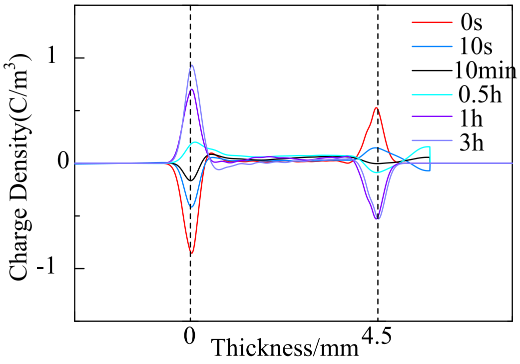
（c） TG=20℃

Fig. 2: the charge waveforms in the 10 kV/mm cable under the temperature gradient of 0℃, 10℃ and 20℃ with the stresses of 10kV/mm.

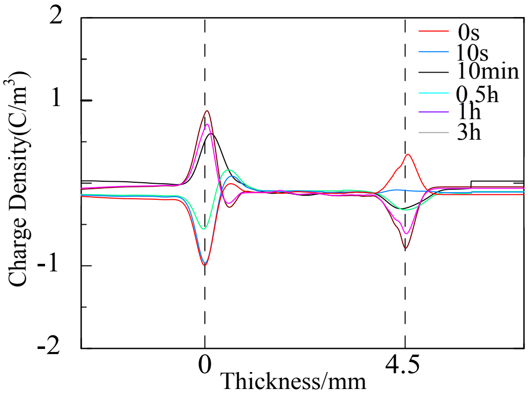
Figure 2 shows the charge waveforms in the coaxial XLPE cable under different temperature gradients and 10kV/mm stress. As Figure 2 shows, the accumulation of hetero-charge appears near the outer semi-conductive layer, and the amount of the hetero-charge increases with the application time. Simultaneously, the induced charge peak at cable conductor decreases gradually. It indicates that the hetero-charge near the outer semi-conductive layer comes from the charge injecting at the electrode of the inner and then migrates to the opposite electrode.



（a）TG=0℃



(b) TG=10℃



(c) TG=20℃

Fig. 3: the charge waveforms in the 10 kV/mm cable during voltage reversal under the temperature gradient of 0℃, 10℃ and 20℃..

Figure 3 shows the charge waveforms in the 10 kV/mm cable during voltage reversal under the temperature gradient of 0℃, 10℃ and 20℃. As the figure showed, with the increase of application time, hetero-charge accumulation appears near the outer semi-conductive layer, and the amount of the hetero-charge increases. Simultaneously, the charge peak at cable conductor decreases gradually. during voltage reversal, the charge peak at cable conductor reverses with voltage reversal quickly, however, the charge peak at the outer semi-conductive layer doesn't reverse quickly but decreases to some extent. Maybe it means that there are some remnant positive charges injecting from the outer semi-conductor electrode.

CONCLUSIONS

1) With cable's outer semi-conductive layer pulse injection, oscilloscope's being isolated from ground, the using of digital optical isolation technology, induced current heating device, the space charge of full-size coaxial cable under temperature gradient would be obtained.

2) There is a little hetero-charge accumulation near semi-conductor under room temperauture, and the charge amount increases with the application time.

3) During voltage reversal, the charge peak at cable conductor reverses with voltage reversal quickly, however, the charge peak at the outer semi-conductive layer doesn't reverse quickly but decreases to some extent.

4) Under temperature gradient, hetero-charges appear near the outer semi-conductive layer at the low temperature electrode and the amount of the hetero-charge increases with the increase of temperature difference.

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