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Influence of temperature on partial discharge of insulating PET backsheet in photovoltaic module

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Solar energy has been widely used as a kind of renewable power generation in recent years. In a photovoltaic (PV) system, polyethylene terephthalate (PET) is the core component of backsheet and affects the reliability of the system. In this paper, the effect of temperature on partial discharge (PD) of PET is studied. As shown by the PD measurement system, the amplitude of PD of PET films decreases significantly with temperature increasing. The mechanism of PD degradation, which is closely related to the operational temperature and the chemical change of the insulation backsheet, has been investigated.

Keywords: PET; partial discharge; temperature; phase-resolved partial discharge; micro-voids.

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1. Introduction

Solar energy, with its unique advantages, has been widely used to solve the problems caused by global resource shortage and environmental pollution.[1] In photovoltaic (PV) system, polyethylene terephthalate (PET) is widely used as the core layer of insulating backsheet.[2] It is subjected to potential-induced degradation and temperature during operation, thus the reliability of solar panels can be reduced by material degradation.

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Studies on PD characteristics of PET film have been carried out. Vladimir Nikonov *et al.* characterized the effect of dielectric charge on PD behavior and found that the electric charge exerts a significantly effect on expansion of PD channel (Vladimir Nikonov *et al.*[3]). Adhikari *et al.* measured the material deterioration by examining changes in PD on the surface of PET samples and found that internal voids affect PD and material degradation (Adhikari *et al.*[4]). Rong Tang *et al.* measured PD-induced breakdown behavior of PET and found the temperature of the crystallization of PET exerts a pronounced influence on degradation of insulation structure (Rong Tang *et al.*[5]). Wenxia Sima *et al.* adopted the pulsed electro-acoustic (PEA) method and isothermal discharge current (IDC) measurement to study the space charge accumulation on PET surface and the trap energy in the bulk before and after thermal aging (Wenxia Sima *et al.*[6]). Farhoodi *et al.* found that physical aging of PET sample has been affected by temperature as shown by differential scanning calorimetry (DSC) (M. Farhoodi *et al.*[7]). In above works, the influence of temperature on PD of PET films is seldom reported.

In this paper, the effect of temperature on PD of PET is investigated by PD measurement system. PD magnitude at different temperatures are detected in phase-resolved partial discharge (PRPD) patterns. The relation between temperature and partial discharge (PD) activities during the test is analyzed in Sec. 4.

2. Experimental Measurements

PD measurement system is employed to study the effect of temperature on PD pattern of PET. An AC power source is used to generate the required voltage waveforms applied to both sides of the samples. The voltage amplitude of the samples is detected by the high voltage differential probe and the PD activities are measured by the digital oscilloscope.[8] The schematic of PD measurement system is shown in Fig. 1.

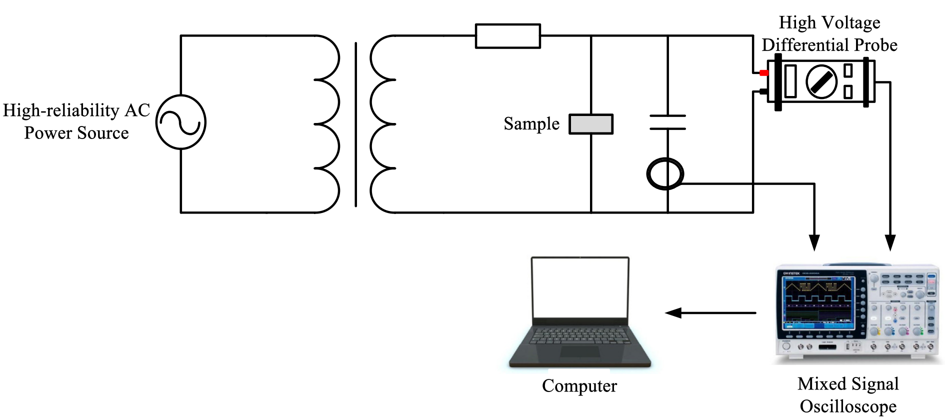

Fig. 1. (Color online) The schematic of PD measurement system.

Before PD measurements, all PET samples (20 mm × 20 mm × 0.25 mm) are pretreated to reduce uncertain factors. Therefore, anhydrous alcohol is used to clean the surface of the samples and ionizing air blower is used to dry samples and remove the residual ion on the surface. When the temperature of the samples in the temperature-controlled chamber rises to 50°C, in the PET films, a voltage of 1.5 kV for 30 and 60 min is applied to generate PD. The samples are examined at 25°C (ambient temperature) and 50°C, respectively.

3. Results and Discussions

The influence of temperature on space charge is shown in Figs. 2 and 3.

In Fig. 2, the amplitude of PD decreases significantly as the temperature increases and the number of PD points also increases as temperature increases. It can be seen that 7564 PD points are found in Fig. 3(a) and 8200 PD events are shown in Fig. 3(b). This phenomenon is similar as the measurement carried out for 30 min.

The voltage amplitude of PD at 50°C is lower than that at 25°C (room temperature), indicating that temperature has the effect on PD activities. With increasing temperature, the voltage amplitude of PD decreases. This phenomenon is caused by the change of chemical bond structure affected by the reaction between polymer surface and air.[9] PET is an amorphous or crystalline polymer, which is generated by condensation polymerization of terephthalic acid (PTA) and ethylene glycol (EG). The chemical structure and bond energy of PET are shown in Fig. 4.

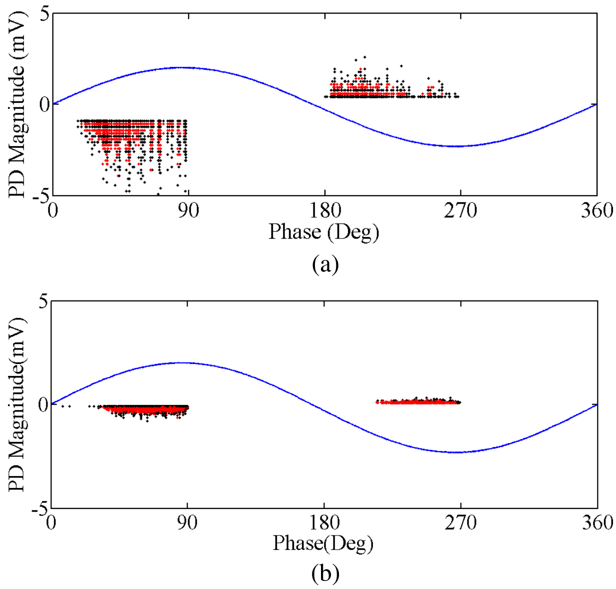

Fig. 2. (Color online) Patterns of PRPD for 30 min: (a) 25°C and (b) 50°C.

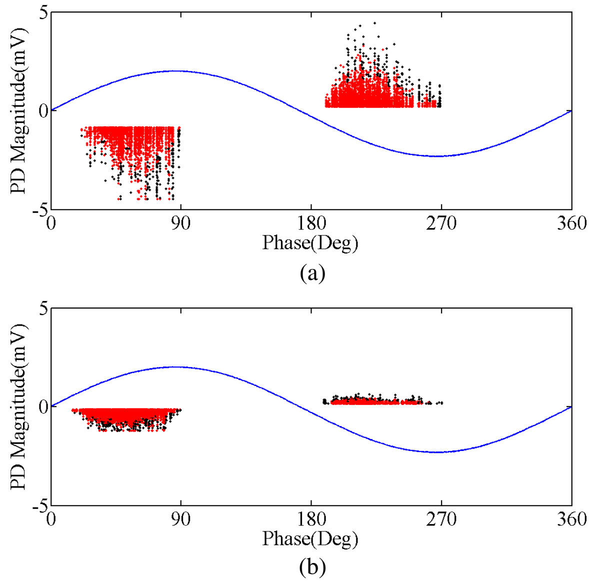

Fig. 3. (Color online) Patterns of PRPD for 60 min: (a) 25°C and (b) 50°C.

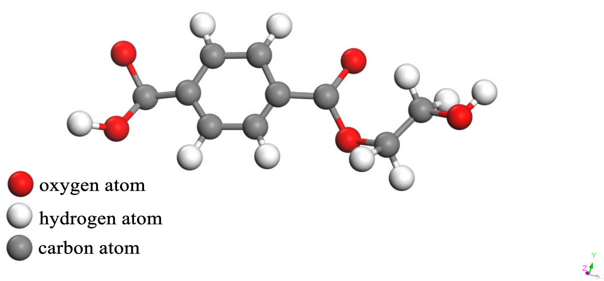

Fig. 4. (Color online) The chemical structure of PET.

It can be seen that PD changes under the mutual influence of electric field and temperature. Due to the low bond energy of the ester group in PET molecular chain, C–O bond is more likely to break at high temperature.[10] With the increase of temperature, the angle of molecular polymerization narrows.[11] Due to the effect of the electric field on the molecules, the endurance capacity of PET molecules to the electric field drops rapidly. When intermolecular forces of the material are weakened by the electric field, the activity and mechanical strength of molecular chain decrease. The methylene of PET chains becomes active and is more likely to fall off from the main chain, resulting in PET decompositions into PTA and C_2H_4. Figure 5 shows the decompositions of PET into PTA and C_2H_4.[12]

As the structure of PET cracks, the internal surface of the material rapidly adheres to C_2H_4, and micro-voids are formed inside the material.[13] As shown in

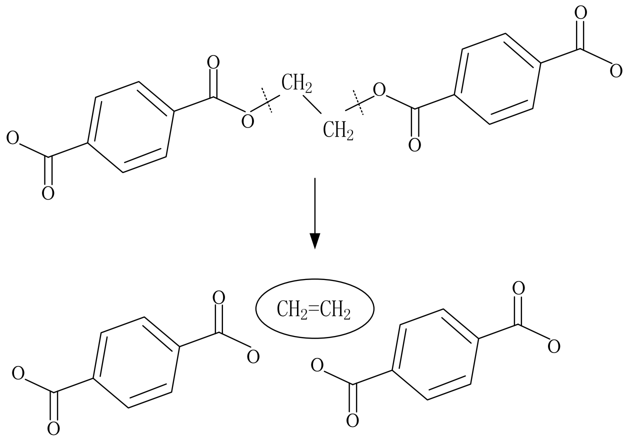

Fig. 5. The process of decomposing PET into PTA and C_2H_4.

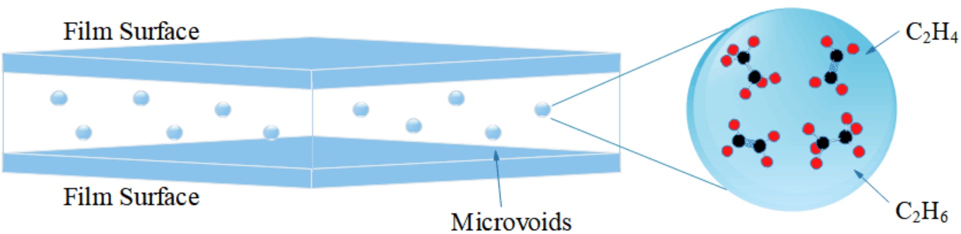

Fig. 6. (Color online) The composition of gases within the micro-voids.

Fig. 6, the composition of gases within the micro-voids is different from that of air. CH_2 and C_2H_6 gases are generated by a chemical reaction when PD occurs within the micro-voids.[14] In addition, the PET structure changes due to the formation of –OH bonds and unsaturated rings within the material. The discharge process within the micro-voids is affected by its internal chemical composition, and the potential for electron injection and space charge accumulation within the micro-voids change accordingly.

The initial electron is the prerequisite for PD. It affects PD on inception delay, frequency of occurrence and voltage phase. The critical field to generate PD within a void is calculated according to Eq. (1)[15]:

$$E_c = K * P^{0.7} * d^{-0.3} \text{ (kV/mm)}, \tag{1}$$

where E_c is the critical field, K is a constant (8×10^{-3}), P is pressure within the micro-voids (mmHg), and d is void radius (mm). Therefore, the size of the micro-voids and the air pressure within the micro-voids affects the critical electric field. With PET degradation and decomposition, the micro-voids are enlarged by temperature, and the changing chemical composition within the micro-voids leads to a change in pressure within the micro-voids. This suggests the change of critical field is arising from the contribution of pressure, which is influenced by temperature and thus greatly contributes to the character of PD.

4. Conclusion

In order to study the relationship between temperature and PD, PET is discharged for 30 and 60 min under different temperatures. It can be observed from the PRPD patterns that the amplitude of PD decreases significantly as temperature increases.

The results show that the chemical and physical properties of PET are influenced by temperature and voltage. Micropores in the material affects the amplitude of PD. When PET operates at high temperature, the voids in the material lead to a reduction in the amplitude of PD, which is hard to detect. At the same time, the aging speed of the material will be accelerated and eventually lead to the reduction of material life and equipment damage due to the simultaneous action of electric field and heat.

Acknowledgments

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