Partial Discharge Properties of PET Film with Carbon Black

Young-Hwan Lee*, Jong-Chan Lee, Yong-Sung Choi*** and Dae-Hee Park******

Abstract - This paper presents an investigation of the phase-resolved partial discharge (PD) pattern of PET (Poly Ethylene Telephthalate) films with carbon black particles. The phase-resolved PD pattern and statistical parameter from PET samples according to the number of included semiconductor particles were measured. The measurement system consisted of a conventional PD detector using a digital signal processing technique. The partial discharge patterns of the PET films that include the semiconductor particles were investigated to simulate an actual situation that may exist in the cable. In addition, difference of PD patterns between semiconducting particles in PET films and artificial voids was studied. The relationship between the numbers of semiconductor particles in PET films was discussed through the difference of ψ- q-n distribution and statistical analysis.

Keywords: Partial discharge, PET film, Carbon black

1. Introduction

Polymers used in electric power cable applications must have superior electrical and mechanical properties. Particularly, the macromolecule of polyethylene type is widely used in power cables [1]. Most high-voltage power cables also use a semiconducting layer between the conductor and the layer of insulation. Due to the semiconducting layer, semiconducting particles can be created over time.

Among the various degradation mechanisms that affect the reliability of HV apparatus, those regarding insulation systems are often PD phenomena; that is, partial breakdown of gas or liquid inclusions in the solid insulation. PD phenomena accelerate the local degradation and can generate electrical trees that are the final stage leading to breakdown. Since PDs are essentially electron avalanches, they give rise to an impulse of electric charge, which produces a burst of current and voltage signals outside of the insulation system. The separation and identification of PD features is, thus, a fundamental requirement to obtain effective insulation diagnosis and avoid misleading evaluation of the defects generating the PD [2].

In this paper, partial discharge patterns of the PET films, which include semiconductor particles, were investigated to simulate the actual situation that may exist in power cables. Additionally, disparity of PD patterns between semiconducting particles in PET films [3] and artificial voids were studied. Partial discharge measured by the phase-resolved partial discharge [4, 5] was analyzed using statistical operator [6, 7] to evaluate the change in partial discharge pattern. These results may provide essential information about various partial discharge sources.

2. Experimental

The samples used in this experiment were PET films, including semiconducting particles with a size of $1\,mm^2$ between two $100\mu m$ thick PET films as shown in Fig. 1. Insulation oil was filled to the rim of the upper electrode to minimize surface discharge. The inception voltage applied to the samples was 0.7kV.

Partial discharge was measured by the analogue PD Hipotronix detector CDO-77A (Fig. 2). The measured signal was digitalized through a digital oscilloscope (HP 54522A, 2Gsa/s) and data was transferred to a PC through GPIB interface.

The data acquired were processed repeatedly during a particular cycle, and were saved by the maximum discharge amount (Hqmax (ψ)), average discharge amount (Hqn (ψ)), number of discharge (Hn (ψ)), etc. It is important to keep external noise to a minimum level because the partial discharge signal is measured in a PC. To accomplish this, the filtered signal in the PD detector was basically software filtered through FIR (Finite Impulse Response) and any voltage smaller than partial discharge was removed before signal processing.

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Received: June 5, 2003 ; Accepted: January 19, 2004

PD patterns of the samples, which include semiconducting particles (1~5), were analyzed by adding the number of semiconducting particles and the discharge time. The discharge amount measured in each sample were shown and analyzed by the ψ-q-n distribution. Furthermore, the PD pattern of the PET film with 15mm ψ void was tested to gain an understanding of the difference of PD patterns shown in the artificial void.

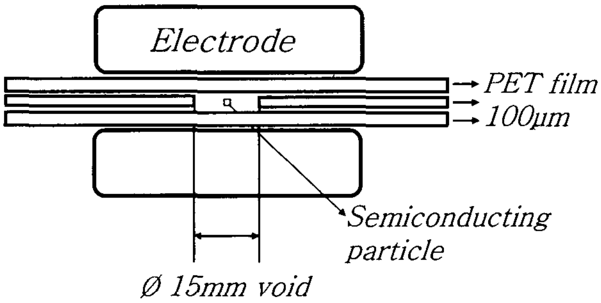


Fig. 1 Electrode and sample structure

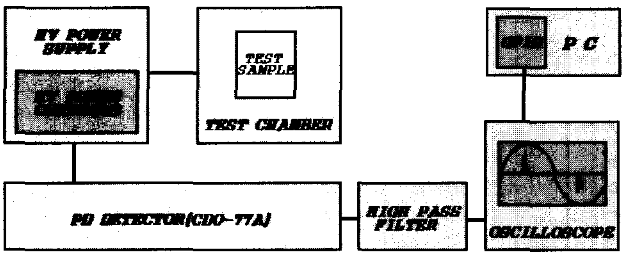


Fig. 2 PD detection system

3. Results and Discussion

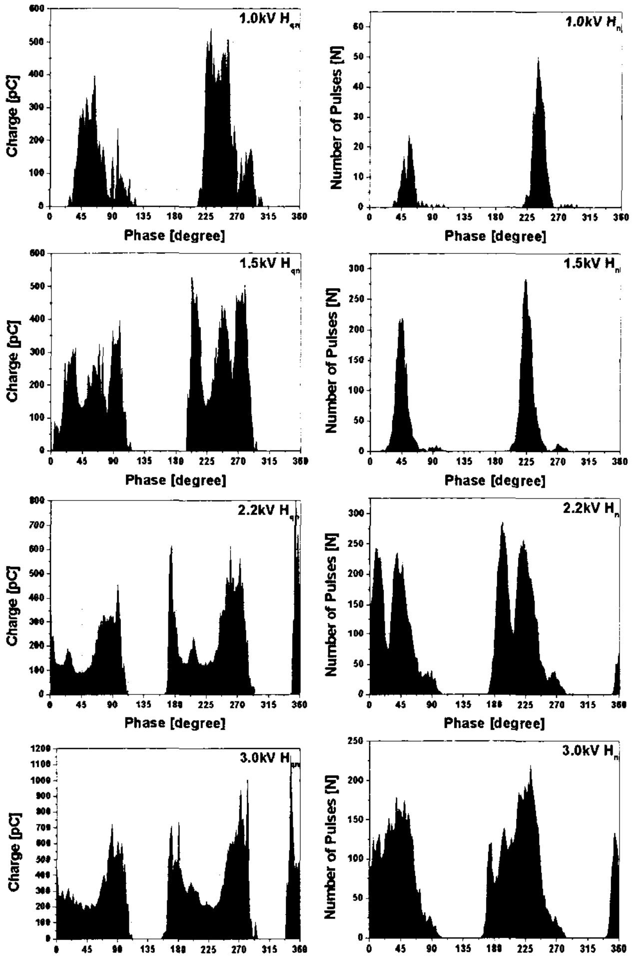
3.1 PD patterns in 15mm ψ void to approve 1~3kV

Fig. 3 shows ψ-q and ψ-n distribution results of 100㎛ thick PET film for different applied voltages that are gradually increased from 1 to 3kV, which are higher than the starting voltage of partial discharge. With the increment of the applied voltage, the amplitude of discharge pulse and the number of discharge pulses were increased, while the distribution of pulses was relaxed. Also, we discovered that the pulse number generated in the negative half-period is greater than the pulse number generated in the positive half-period.

The pulse amplitudes of the partial discharge were abnormal at relatively low applied voltage, but were relaxed and became normal with increments of applied voltage. It is suspected that the discharge in relatively low voltage occurs at the partial area of void interior and the number of discharge channels at the full area of the void becomes greater as the applied voltage is increased.

Moreover, the effect of space charge by partial discharge pulse that took place previously cannot be neglected.

The properties by phase change are as follows. The amplitude of discharge pulse near the starting voltage of 1kV partial discharge showed a decreasing pattern with the central 45° after beginning positive and negative periods. But, the amplitude of discharge pulse was increased in both directions with center of 45°degree 1.5kV, and had pattern to have phase difference more than 2.2kV. The number of discharge pulses showed a similar pattern to the amplitude of discharge pulse around the starting voltage of 1kV partial discharge and also showed the phase difference similarly with the amplitude of discharge pulse more than 2.2kV.

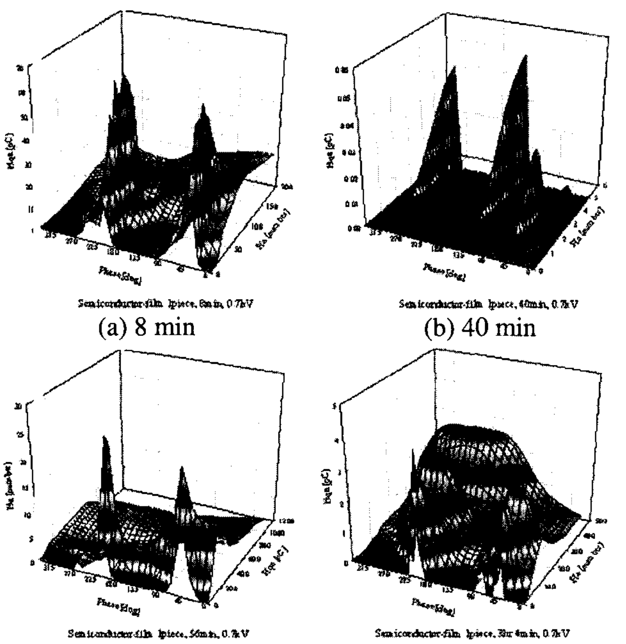


(a) pulse amplitude of distribution (b) pulse number of distribution

Fig. 3 ψ-q and ψ-n distribution according to the applied voltage

3.2 PD patterns with one piece of added semi-conducting particle

With the addition of the semiconducting particle, PD occurs in the surrounding microscopic void of semiconducting particles. Therefore, the number of conductive paths multiplies as the number of added semiconducting particle increases. PD patterns with one piece of added semiconducting particle as discharge progresses are shown in Fig. 4. The discharge amount appeared in a particular period because the discharge was developed after a typical PD pattern, such as the streamer-process pattern. After all, discharge amount q and discharge number n are found to be decreased over time. PD was increased or decreased within a particular period, or PD hardly occurred at all. As compared with PD patterns in the artificial void, the distribution differences were shown because the time difference of applied voltage an the patterns itself were similar.



(a) 8 min (b) 40 min
(c) 56 min (d) 184 min

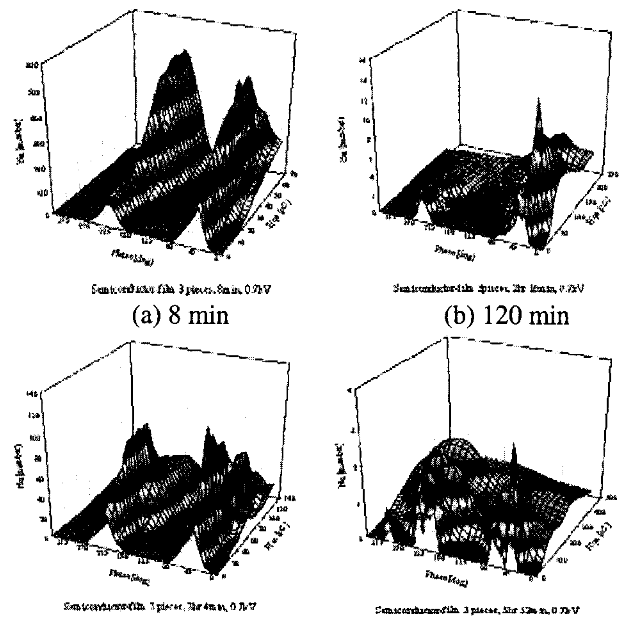
Fig. 4 PD patterns to add one piece of semi-conducting particle at an applied voltage of 0.7 kV

3.3 PD patterns with three pieces of added semiconducting particles

PD patterns with three pieces of added semiconducting particles are shown in Fig. 5. The period of PD patterns was prolonged with increments of the particle number and PD was picked up a long time later. It is suspected that void size was finally increased and that microscopic void was increased together around the semiconducting particle as the particle number increases, as described above. Entire PD patterns were not clearly different and were a bit spread out compared with the phase when one piece of particle was added. Also, the phase movement of mainly generated PD was investigated over time.

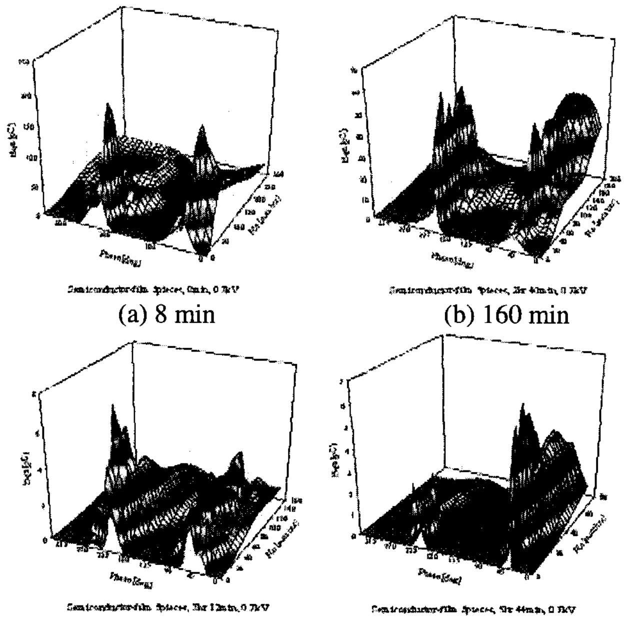
3.4 PD patterns with five pieces of added semiconducting particles

PD patterns with five pieces of added semiconducting particles were shown in Fig. 6. It was shown nearly in a pattern that was more typical than before. This is due to the increment of the conductive path number according to the increment of particle number. The changed period of patterns became longer than in the case of three pieces of added particles, but the entire discharge amount decreased a bit earlier. However, it shows a particular discharge amount and discharge number for a longer time.



(a) 8 min (b) 120 min
(c) 184 min (d) 352 min

Fig. 5 PD patterns to add three pieces of semiconducting particles at an applied voltage of 0.7kV



(a) 8 min (b) 160 min
(c) 192 min (d) 344 min

Fig. 6 PD patterns to add five pieces of semiconducting particles at an applied voltage of 0.7kV

4. Conclusion

In this paper, the difference of PD patterns between semiconducting particles in PET films and artificial voids was discovered. The partial discharge pulse was measured with increments of the number of semiconducting particles and changes of discharge and PD pattern through distribution were analyzed. The semiconducting particles were influenced on partial discharge in insulators, but were not observed as the distinguishing singular phenomenon with artificial void. With addition of the semiconducting particle, PD occurred in the surrounding microscopic void of semiconducting particles. Therefore, the number of conductive paths increases as the number of semiconducting particle increases. This can be thought that void size was finally increased and the microscopic void was increased together around semiconducting particles according to increments of particle number as referred before.

Acknowledgement

This work has been supported by EESRI (R-2003-B-274), which is funded by MOCIE (Ministry of Commerce, Industry and Energy).

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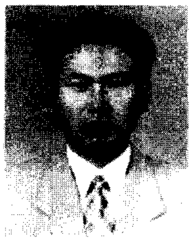

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