Dependence of the Partial Discharge Characteristics of Ultra-high Voltage Cable Insulators on the Measuring Temperature

Jong-Yeol Shin
Department of Car Mechatronics, Sahmyook University, Gongneung 2-dong 26-21, Nowon-gu, Seoul 139-742, Korea

Hee-Doo Park
Department of Disasters Prevention Equipment, Kangwon National University, Samcheok Campus, Gyo-dong, Samcheok-si, Kangwon 245-711, Korea

Hyuk-Jin Lee, Kang-Won Lee, Won-Jong Kim, and Jin-Woong Hong[a]
Department of Electrical Engineering, Kwangwoon University, 447-1 Wolgye-dong, Nowon-gu, Seoul 139-701, Korea

[a]E-mail : ealab@kw.ac.kr

(Received September 5 2008, Accepted October 16 2008)

Cross linked polyethylene (XLPE) insulators are used as insulation in ultra-high voltage electric power cables. This study investigated the electrical properties of XLPE at different temperatures. The electrical properties of the changing tree phenomenon was examined as a function of temperature applied to the electrical conductors by measuring the partial discharge at 25 °C to 80 °C and applied voltages to the electrodes ranging from 1 kV to 40 kV. The activity of the partial discharge was examined at various temperatures using the K-means distribution. The results revealed the specimen at 80 °C to have the lowest inception voltage and breakdown voltage. In addition, the core of clusters was moved 0 ° and 180 ° at the positive region and 180 ° and 360 ° in the negative region in the K-means. The distribution of clusters was concentrated on the inception condition and spread out widely at the breakdown voltage.

Keywords : Partial discharge, Measuring temperature, Core of cluster, K-means, XLPE, Breakdown voltage

1. INTRODUCTION

Recently, the increasing electrification of most apparatuses has led to an increase in the demand for electricity. In particular, with the rapid development of electric cable or electric transfer apparatus there is a need to meet the demands of extra high voltage and large capacity equipment. In addition, the dangers of electrical accidents from the insulator are increasing due to electric stress and insulation degradation and insulation breakdown[1]. A partial discharge (PD) can occur continuously if an ultra-high voltage cable insulator has a defect, eventually causing an electrical fire. Therefore, the PD was measured in order to prevent this type of accident[2-4]. The data obtained from the PD measurement were interpreted by cluster distribution analysis. The data was clustered into certain partitions according to the distance and similarity between each other, and the relationship was analyzed based on the properties of the clusters [3,5,6]. This paper reports the results of an interpretation of the PD characteristics from an analysis of an ultra-high voltage cable insulator using a K-means clustering algorithm at various temperatures [7].

2. EXPERIMENTS

2.1 Specimens

The XLPE, an ultra-high voltage cable insulator, was examined in order to determine its PD characteristics. The specimen was divided into three layers(Fig. 1), a sheeted insulating material with 0.8 mm thickness and 70×70 mm size with an air void, 2 mm in diameter.

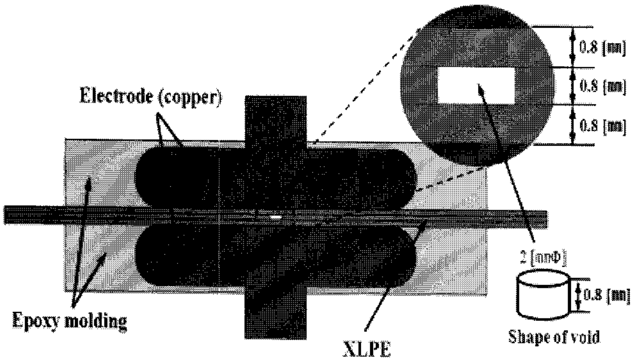


Fig. 1. Shape of an electrode.

2.2 Partial discharge

Figure 2 shows a PD detection circuit for the PD measurement. The equipment from A. company was used, and the applied voltage was increased from 1 kV until insulation breakdown occurred using the step applied voltage method.

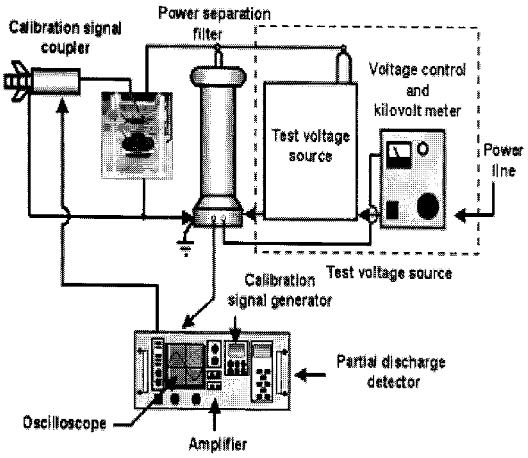


Fig. 2. PD detection circuit.

The amount of charge was detected according to the phase for 10 seconds after applying the voltage. MATLAB was used to collect the data on the amount of charge and detect the phase. In addition, the K-means algorithm was used to calibrate the amount of average discharge and standard deviation as well as the amount of charge and repetition rate of the positive and negative regions.

2.3 K-means clustering

The K-means cluster distribution method, which is a general cluster algorithm accomplishing a vector quantization, was used to analyze the data statistically.

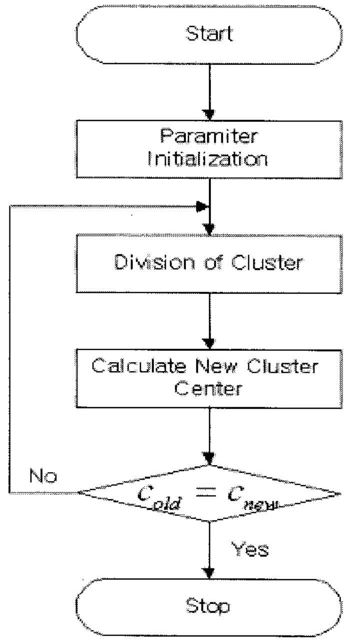


Fig. 3. Flow chart of the K-means algorithm.

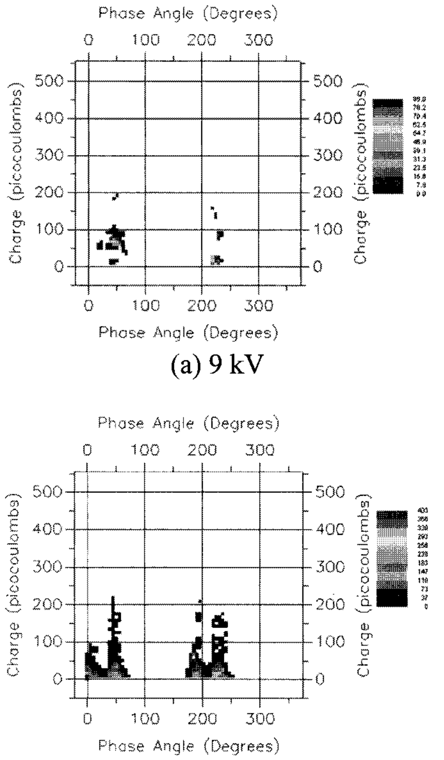
The K-means algorithm renews numerous input vectors using the k representative value determined in advance, which are the k-units of the centric value, as well as by a mapping group algorithm. The method constantly attempts to find the centers of the clusters in the data in order to minimize the total intra-cluster variance or the squared error in vector quantization, and renews the central value of the cluster repetitively. Figure 3 shows a flow chart of the K-means algorithm. There were 9 clusters in this experiment.

3. RESULTS AND DISCUSSION

3.1 Partial discharge characteristics

Figure 4 shows the PD pattern at room temperature, and Fig. 4(a) shows the PD distribution at an applied voltage of 9 kV. The PD of the positive region was concentrated approximately on the 50 $^{\circ}$ phase and the maximum repetition rate was approximately 60. The PD of the negative region was concentrated approximately on the 225 $^{\circ}$ phase, and the maximum repetition rate was 86. The total discharge of the positive and negative region was approximately 9.4×10^4 pC. The PD of the negative region was 4.0×10^3 pC higher than at the positive region. However, the repetition rate of the positive region was larger than the negative region.

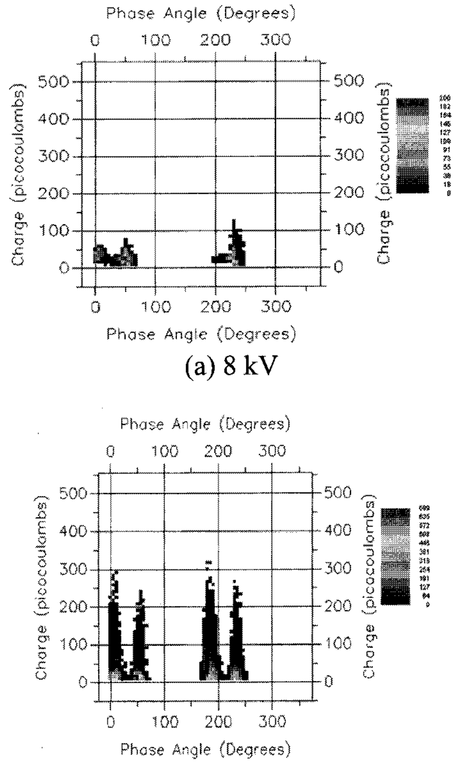
This is the region of the inception voltage because the void is located in the internal insulator. Therefore, it is believed that the discharge occurred in the void due to the low insulating strength.



(a) 9 kV

(b) 17 kV

Fig. 4. Φ- q - n distribution of the specimens(R.T).



(a) 8 kV

(b) 15 kV

Fig. 5. Φ- q - n distribution of the specimens(50 °C).

Figure 4(b) shows the PD pattern when the applied voltage was 17 kV, which is immediately before the breakdown voltage. The PD of the positive region was concentrated approximately at 10 ° and 50 °, and the maximum repetition rate was 110 at 10° and 220 at 50°. The PD of the negative region was concentrated approximately at 185 ° and 230 °. The maximum repetition rate was 200 and 403 and 185 ° at 230 °, respectively. The amount of electric charge of the negative region was 5.85 $\times$ 10^5 pC and positive region was 3.73 $\times$ 10^5 pC. The amount of electric charge in the negative region was 57 % higher than in the positive region, and the repetition rate of the negative region was 33.5 % higher than the positive region. Therefore, this study examined the inception voltage to the breakdown voltage at room temperature, the amount of discharge in the negative region was larger than that in the positive one but it was symmetrical in both cases. In particular, a concentrated discharge was observed at 185 ° and 230 ° in the negative region. It is believed that the amount of discharge increased continuously with increasing applied voltage in the void. Figure 5 shows the PD pattern at 50 °C. Figure 5(a) shows the PD distribution at an applied voltage of 8 kV. The PD of the positive region was concentrated at approximately 10 ° and 50 °, and the maximum repetition rate was 180 and 200 at 10 ° and 50 °, respectively. The PD of the negative region was concentrated at approximately 190 ° and 230 °, and the maximum repetition rate was 30 and 182 at 190 ° and 230 °, respectively.

The amount of average discharge from the positive region was 75 pC and the amount of average discharge from the negative region was 90 pC. The amount of electric charge at the negative region was 20 % larger than at the positive region. As the maximum repetition rate of the positive the negative region was 460 and 540, respectively, the repetition rate of the negative region was 17.4 % higher than the positive region. The repetition rate and amount of discharge was almost proportional at low voltages and the pattern of discharge was symmetrical. Figure 5(b) shows the PD pattern when the applied voltage was 15 kV, which is immediately before the breakdown voltage. The PD of the positive region was concentrated at approximately 10 ° and 50 °, and the maximum repetition rate was 550 and 699 at 10 ° and 50 °, respectively. The PD of the negative region was concentrated at 190 ° and 230 °, and the maximum repetition rate was 500 and 550 at 190 ° and 230 °, respectively. The amount of average discharge and maximum repetition rate were similar.

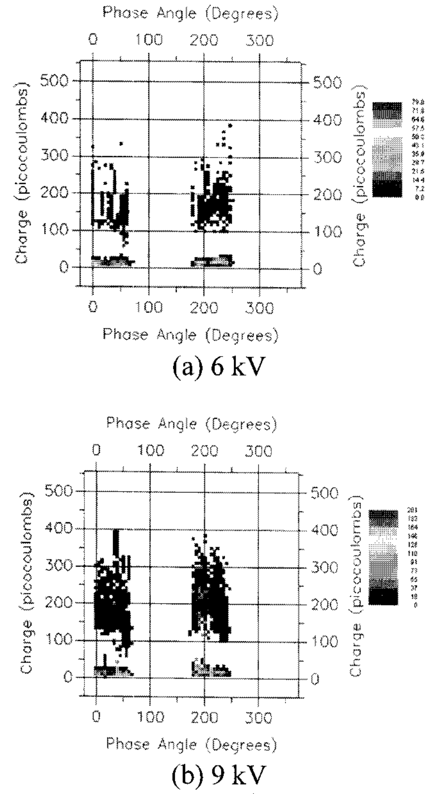


Fig. 6. Φ- q - n distribution of the specimens (80 °C).

Figure 6 shows the PD pattern at 80 °C. Figure 6(a) shows the PD distribution at an applied voltage of 6 kV. The PD of the positive region was concentrated at 10 ° and 50 °. The maximum repetition rate of the positive region was 50 and 79 at 10 ° and 50 °, respectively, and the maximum repetition rate of the negative region was 50 and 50 at 190 ° and 230 °, respectively. It is believed that the maximum repetition rate was lower than other cases because the applied voltage was lower. In addition, there were few PD but the total repetition rate depended on temperature.

It is believed that the un-crystallized specimen and the small crystallites had melted at the testing temperature (80 °C), and the repetition rate was different in the PD as a result of the repulsion action of the injected charge.

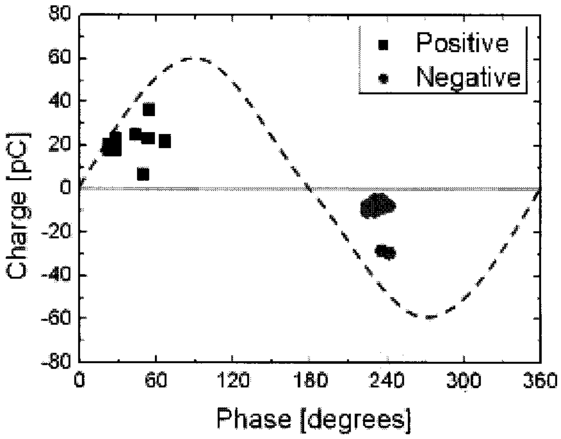
Figure 6(b) shows the PD pattern under an applied voltage of 9 kV at 80 °C. The PD of the negative region was concentrated at approximately 190 ° and 230 °, and the maximum repetition rate was 201 and 110 at 10 ° and 230 °, respectively. The amount of discharge of the negative region was 62 % higher than that of the positive region. Compared with the applied voltage of 8 kV, the amount of total discharges increased to 46 % at 9 kV. The maximum repetition rate of discharge was 10,007 at the negative region and 6,404 at the positive region. Hence, the maximum repetition rate was 56.3 % higher at the negative region than at the positive region. It is believed that the discharge was activated quite well due to the contribution of the applied voltage and heat energy together. The Φ-q-n distribution between the positive and negative regions was approximately symmetrical for the discharge occurring in the void in the internal insulator.

3.2 K-means clustering

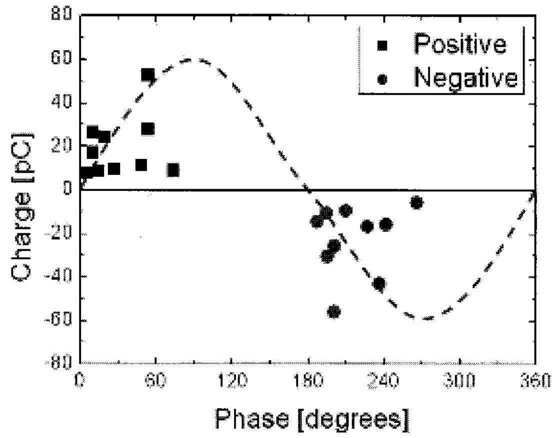
Figure 7 shows the distribution of clusters of the specimen at room temperature. Figure 7(a) shows a distribution of clusters at the inception voltage of 9 kV. The amount of average discharge of the positive region was 21.4 pC and the standard deviation was 7.3. The amount of average discharge of the negative region was 12.1 pC and the standard deviation was 9.1. This shows that the concentration of the positive region is excellent. The discharge phenomenon of internal insulator was confirmed because the centroid of the positive region was located in the 51.6 ° phase with a charge of 23.1 pC, and the centroid of the negative region was located in the 234.6 ° phase with a charge of 15.5 pC, and the phases of the positive and negative regions were symmetrical.

Figure 7(b) shows the distribution of the clusters when the voltage was 17 kV. The centroid of the positive region was located in the 42.7 ° phase and the amount of charge was 22.7 pC. The centroid of the negative region was located in the 221.1 ° phase and the amount of charge was 23.6 pC. The amount of average discharge of the positive region was 19.4 pC and the standard deviation was 14.1. On the other hand, the amount of average discharge of the negative region was 22.94 pC and standard deviation was 16.1. Therefore, the crowding of the centroid of the positive region was excellent.

Figure 8 shows the distribution of clusters of the specimen at 50 °C. Figure 8(a) shows the distribution of clusters at an inception voltage of 8 kV. The centroid of the positive region was located in the 40.5 ° phase and the amount of charge was 12.2 pC. The centroid of the negative region was located in the 236.3 ° phase and the amount of charge was 17.3 pC. It was found that the phase between the positive and negative region was approximately symmetrical. The maximum amount of discharge was 19.8 pC in the 50 ° phase and the minimum amount of discharge was 8.5 pC in the 41.8 ° phase. The maximum amount of discharge was 31.8 pC in the 237.9 ° phase and the minimum amount of discharge was 9.95 pC in the 248.1 ° phase. The amount of average discharge of the positive region was 12.2 pC and the standard deviation was 4.1, which shows a high

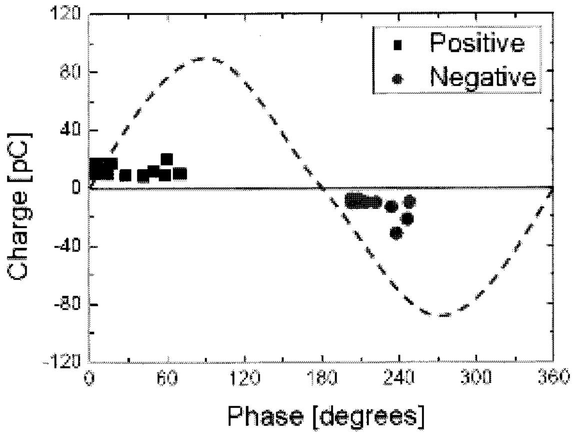


(a) 9 kV

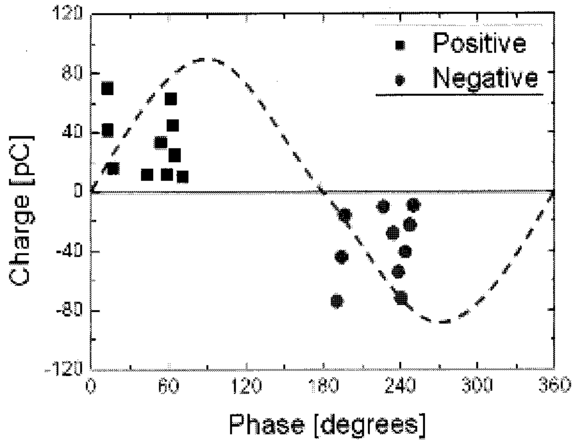


(b) 17 kV

Fig. 7. Centroid distribution of the Φ- q cluster (R.T).



(a) 8 kV



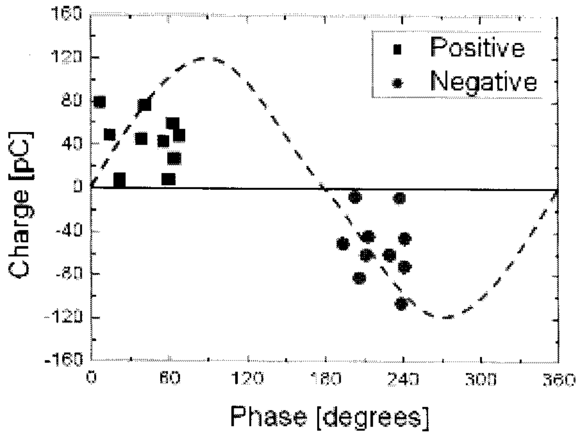
(b) 15 kV

Fig. 8. Centroid distribution of the Φ- q cluster (50 °C).

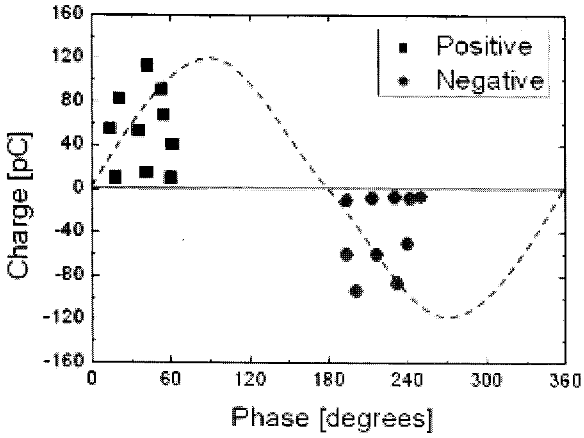
concentration. The amount of average discharge of the negative region was 13.4 pC and the standard deviation was 7.6, which shows some dispersion.

Figure 8(b) shows the distribution of clusters when the voltage was 15 kV. The centroid of the positive region was located in the 36.3 ° phase and the amount of charge was 34.9 pC. The centroid of the negative region was located at 216.5 ° and the amount of charge was 37.2 pC. They showed an approximately symmetrical distribution. The maximum amount of charge of the positive region was 70.1 pC in the 12.6 ° phase and the minimum amount of charge was 74.5 pC in the 190.5 ° phase. The amount of discharge was similar to the minimum amount of charge, 9.8 pC in the 7.09 ° phase. The amount of average discharge in the positive region was 32.5 pC and the standard deviation was 21.9. The amount of average discharge in the negative region was 37.4 pC and the standard deviation was 24.0. Therefore, the crowding of the centroid in the positive region was better than at the negative region.

Figure 9 shows the distribution of clusters of the specimen at 80 °C. Figure 9(a) shows the distribution of clusters at the inception voltage of 6 kV. The centroid of the positive region was located in the 40.8 ° phase and its amount of charge was 42.8 pC. The centroid of the negative region was located in the 220.7 ° phase and its amount of charge was 49.6 pC. Therefore, the distribution of positive and negative regions was symmetrical due to the void in the internal specimen. The maximum amount of charge of the positive region was 79.6 pC in the 7.0 ° phase and the minimum amount of charge was 7.5 pC in the 21.9 ° phase. The maximum amount of charge of the negative region was 105.9 pC in the 238.6 ° phase and the minimum amount of charge was 7.6 pC in the 203.4 ° phase. The amount of average discharge of the negative region was 20 % higher than at the positive region. The standard deviation of the negative region was also 22 % higher than the positive region. Hence, the crowding of the centroid of the negative region was better than the positive region.



(a) 6 kV



(b) 9 kV

Fig. 9. Centroid distribution of the Φ- q cluster (80 °C).

Figure 9(b) shows the distribution of clusters at the same condition shown in Fig. 9(a), when the applied voltage was 9 kV. Immediately before breakdown, the distribution of the cluster of discharge in the centroid of the positive region was located in the 38.6 ° phase and the amount of charge was 58.9 pC. The centroid of the negative region was located in the 216.7 ° phase and the amount of average discharge was 61.4 pC. The distribution was symmetrical but the amount of average discharge of the negative region had a few more charge than the positive region.

Figure 10 shows the centroid distribution of the Φ – q cluster at 9 kV. The crowding distribution of the Φ – q characteristics in the phase range of the positive and negative regions were set to 10 when the applied voltages were changed to 25 °, 50 ° and 80 ° using the k-means distribution graph.

At 25 °C, because the insulating characteristics of specimen was excellent and the testing temperature is low, the amount of charge of the specimen was relatively

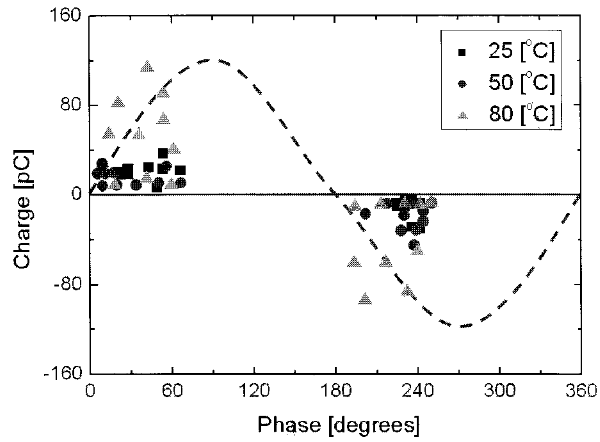


Fig. 10. Centroid distribution of Φ- q cluster at 9 kV.

low, 9.5×10^4 pC. However, when the temperature was increased to 50 °C, there was a significant change in the physical properties of specimen in several tests, but the amount of charge was increased by only 15.4 % to 10.96×10^4 pC due to the easier charge injection. When the temperature was increased to 80 °C, the amount of charge was increased to 7.32×10^5 pC (approximately 5.7 times higher than at 50 °C) due to the joint contribution of the electrical field and temperature. It was confirmed that the amount of charge and the distribution of clusters increased with increasing temperature, moving the centroid phase from 51.5 ° to 38.6 ° in the positive polarity and from 234.6 ° to 216.7 ° in the negative one.

4. CONCLUSION

This study examined the PD characteristics of the ultra-high voltage cable insulators according to various temperatures. The average discharge of the negative region was larger than at the positive region but they were symmetrical. The phase was moved to 90 ° and 270 ° in the positive and negative regions, respectively. When the temperature was increased to 80 °C, the amorphous and small crystal partitions of the specimen melted as the PD in the internal insulator was activated. This shows that charge moves due to repulsion between the injected charge and the polarity, eventually leading to rapid breakdown. The PD in the internal void of the insulator in the charging phase was symmetrical. In addition, the PD characteristics of the specimen due determined by clustering analysis showed that the internal discharge and concentration rate of the centroid were excellent in both the positive and negative regions. Finally, the amount of charge of the positive region was higher at low temperatures and voltages. However, the amount of charge of the negative region increased with increasing temperature because the discharge is activated by temperature and applied voltage.

REFERENCES

[1] S. Matsumoto, "Recent technology of sensing, monitoring, diagnosis and maintenance for aged electric power and energy system", Trans. on IEEJ, Vol. 126-B, No. 6, p. 574, 2006.

[2] T. Okamoto and T. Tanaka, "Auto-correlation function of PD pulses under electrical treeing degradation", IEEE Trans. on Dielectrics EI, Vol. 2, No. 5, p. 857, 1995.

[3] IEC Publication 270, "Partial Discharge Measurement", 2nd Edition, 1981.

[4] T.-Y. Kim, B.-C. Ahn, H.-J. Lee, D.-G. Byun, and J.-W. Hong, "The analyswas of partial discharge using k-means on ignition coil", CMD 2006, p. 160, 2006.

[5] A. Contin, M. Cacciari, and G. C. Montanari, "Estimation of Weibull Distribution Parameters for Partial Discharge Inference", 1994 Annual Report IEEE CEIDP, p. 71, 1994.

[6] E. Gulski, "Digital analysis of partial discharges", IEEE Trans. on Dielectrics EI, Vol. 2, No. 4, p. 822, 1995.

[7] R. A. Johnson and D. W. Wichern, "Applied multivariate statistical analysis", Prentice Hall, p. 573, 1992.

[8] R. O. Duda, P. E. Hart, and D. G. Stork, "Pattern Classification", John Wiley & Sons Ltd., p. 517, 2001.

[9] T. Tanaka, "Internal partial discharge and material degradation", IEEE Trans. DEI, Vol. 21, No. 6, p. 899, 1986.

[10] T. Shimakage, K. Wu, T. Okamoto, and Y. Suzuoki, "Life-cycle-cost evaluation on degradation diagnosis for cables", Trans. on IEEJ, Vol. 124-A, No. 3, p. 277, 2004.

[11] K. S. Cho, K. W. Lee, W. J. Kim, J. Y. Shin, and J. W. Hong, "Partial discharge diagnosis of interface defect by the distribution statistical analysis", J. of the KIEEME(in Korean), Vol. 21, No. 4, p. 348, 2008.