Paper

Correlation between Change in PD Current Shapes and Ageing by the Oxidation of Void Surface

Student Member Choong-Sik Kim*
Member Teruyoshi Mizutani*

A PD pulse shape gives us significant information about degradation and PD mechanism. The kurtosis(Ku) and skewness(Sk) that describe the characteristics of a pulse waveform are useful to investigate ageing stages. In this paper, a new plot that we call the Ku-Sk plot is introduced to represent PD properties changing with ageing. According to ageing, PDs tend to concentrate on the third quadrant in the Ku-Sk plot, which represents a flat and left-peaked triangular shape. Moreover, The transition to the third quadrant is accelerated by the oxidation of void surface.

Keywords : PD current shape, ageing, skewness, kurtosis, oxidation

1. Introduction

Parameters such as the amplitude and the number of PD pulses have been significant indicators to describe PD properties. Especially, the PD pattern called the ϕ-q-n pattern has been used to describe PD characteristics and it includes information about PD mechanism, the size and location of a void, ageing stage and so on (1)~(4). There have been many reports on the relation between ageing and partial discharge in a void in polymeric insulating materials (4)~(8). Suwarno reported that the PD pattern of a void shifts from "turtle-like pattern" to "rabbit-like pattern" according to ageing (5). Tanaka and Okamoto pointed out that a trajectory of skewness for the ϕ-q-n pattern moves in the third quadrant on S-plane when electrical trees are initiated from a void (3)(4). Some authors pointed out the relationship between the transition of PD mechanism and change in pulse shape parameters, especially pulse width, according to ageing (7)(8). It has been known that the oxidation of a void surface by discharge activity strongly affects a transition of PD mechanism (8).

In this paper, the changes in skewness and kurtosis indicating the asymmetry and sharpness of a single PD waveform with several usual parameters were investigated for a void bounded by LDPE. The correlation between change in PD shape and ageing by partial discharge was discussed. The oxidation effect was also discussed.

2. Experimental Method

2.1 Specimens and measurement system The schematic diagram of an experimental setup is shown in Fig. 1(6). AC high voltage is applied to the lower electrode and the upper electrode composed of a main and a guard electrode is designed to obtain a true PD current waveform with a real-time and a wide bandwidth measurement. Especially, the measuring electrode filled with *NaCl* solution enables us to take an optical image which is helpful to verify a transition of discharge mechanism and its correlation with ageing.

PD currents are measured with a fast digital oscilloscope (sampling rate: 4Gs/s, bandwidth: 1GHz). The four scale levels of 10, 1, 0.2 and 0.05V are cyclically selected in the measurement, because of pulse magnitudes in a wide range. Therefore, PD currents whose magnitudes scatter widely can be measured by an automatic scale control. The rapid measurement is performed by using the fast-frame method of a digital oscilloscope. It takes about 15 minutes for one measurement with 4 scale levels, 2 cycles and 2 polarities.

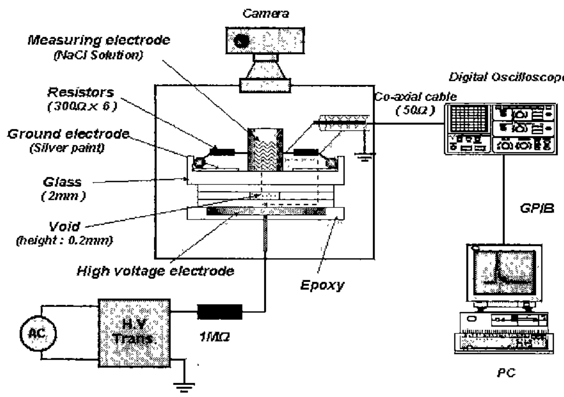


Fig. 1. Experimental setup to measure PD pulse and images without distortion

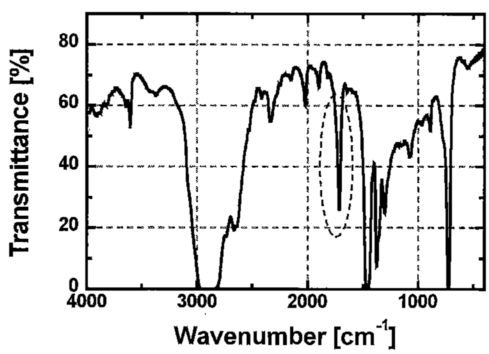


Fig. 2. FT-IR of specimen oxidized by ozone (the absorption peak at 1750cm^{-1} is due to the carbonyl group)

* Dept. of Electrical Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603

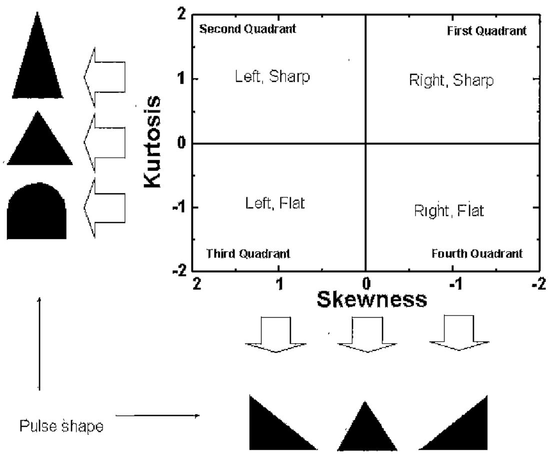


Fig. 3. Ku-Sk plot for the description of pulse shape

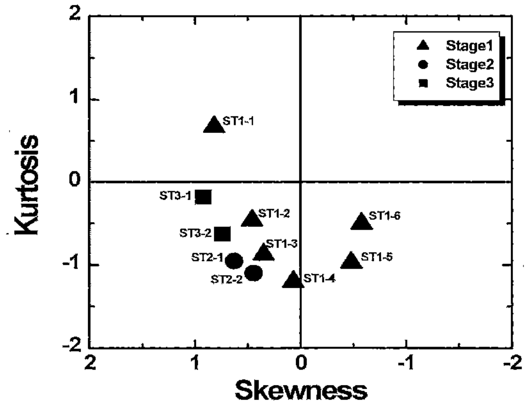
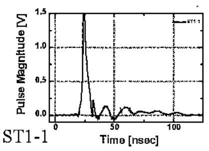
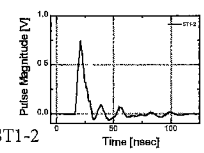
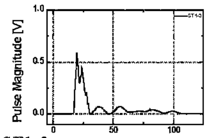
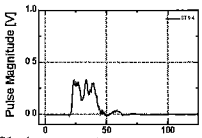
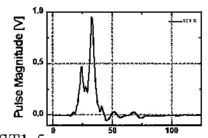
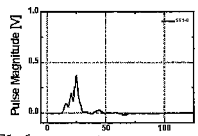
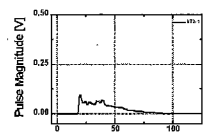
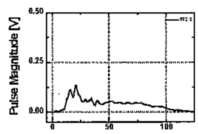
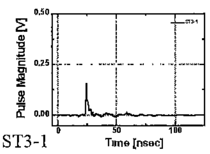
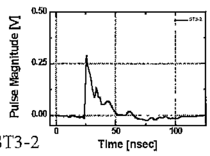


Fig. 4. Location of typical pulses on the Ku-Sk plot

Table 1. Various pulse shapes measured at 3 stages

Stages	Typical pulse shapes	
Stage1	 ST1-1	 ST1-2
	 ST1-3	 ST1-4
	 ST1-5	 ST1-6
Stage2	 ST2-1	 ST2-2
Stage3	 ST3-1	 ST3-2

Specimens consist of three LDPE films whose middle film has a hole. The surrounding of a specimen is sealed by a silicon grease to keep air flowing into void. In addition, the space between the electrode and the LDPE film is pasted by silicon grease to avoid any air gap. The thickness of a LDPE film is 0.2mm and the diameter of a hole is 12 or 16mm. Some LDPE films were oxidized by ozone in advance to simulate degradation by partial discharge. Fig. 2 shows the IR spectrum of an oxidized film. The absorption peak at 1750cm^{-1} is due to the carbonyl group and its absorption coefficient is 52cm^{-1}.

2.2 Ku-Sk plot The pulse shape of a PD current is formed by the movement of electrons and ions during a partial discharge. Therefore, the investigation of pulse shape is expected to provide a clue to understand PD mechanism. In this paper, to represent PD properties changing with ageing, the Ku-Sk plot is defined. The plot as shown in Fig. 3 is composed of kurtosis along y-axial and skewness along x-axial that indicate the sharpness and the asymmetry of a PD pulse waveform respectively. The two parameters are defined by

$$Sk = \frac{\sum_i (t_i - \mu)^3 f(t_i)}{\sigma^3 \sum_i f(t_i)} \quad \cdots\cdots (1)$$

$$Ku = \frac{\sum_i (t_i - \mu)^4 f(t_i)}{\sigma^4 \sum_i f(t_i)} - 3 \quad \cdots\cdots (2)$$

where t_i is a discrete value of time, μ is the mean value of the distribution, σ is the standard deviation.

For the normal distribution, kurtosis = 0. If kurtosis > 0, then the shape is shaper than the normal distribution shape, and if kurtosis < 0, it is flatter. If the shape is symmetric, skewness = 0. Skewness > 0 means asymmetric to the left and skewness < 0 means asymmetric to the right. If the kurtosis and skewness of PD pulse current are plotted in the first quadrant of the Ku-Sk plot, the PD pulse current is a sharp and right-peaked triangular shape. The second quadrant means a sharp and left-peaked triangular shape. The third and fourth quadrants correspond to flat and left- and right-peaked triangular shape, respectively.

Table 1 shows typical pulse shapes measured at three stages. To reduce error by noise on the ground line, the data of 10% pulse height are chosen and calculated. The pulses such as ST1-3, 4, 5 and 6 which are superposed by consecutive discharges have very different values of kurtosis and skewness. For example, the skewness of ST1-3 that is composed of two pulses, a large pulse and a successive small one, is 0.35. On the contrary, ST1-5 with a small pulse and a successive large one is −0.48. In cases of ST2-1 and ST2-2, they have a broad pulse shape with long duration behind a peak pulse. The long pulse width is due to the motion of positive ions. As shown in Fig. 4, their kurtosis becomes smaller with increasing pulse width. The shapes of ST3-1 and ST3-2 are similar to those of ST1-1 and ST1-2. However, they relatively have a small rise time and a long falling time. Therefore, they are located in the left and lower side in comparison with ST1-1 and ST1-2.

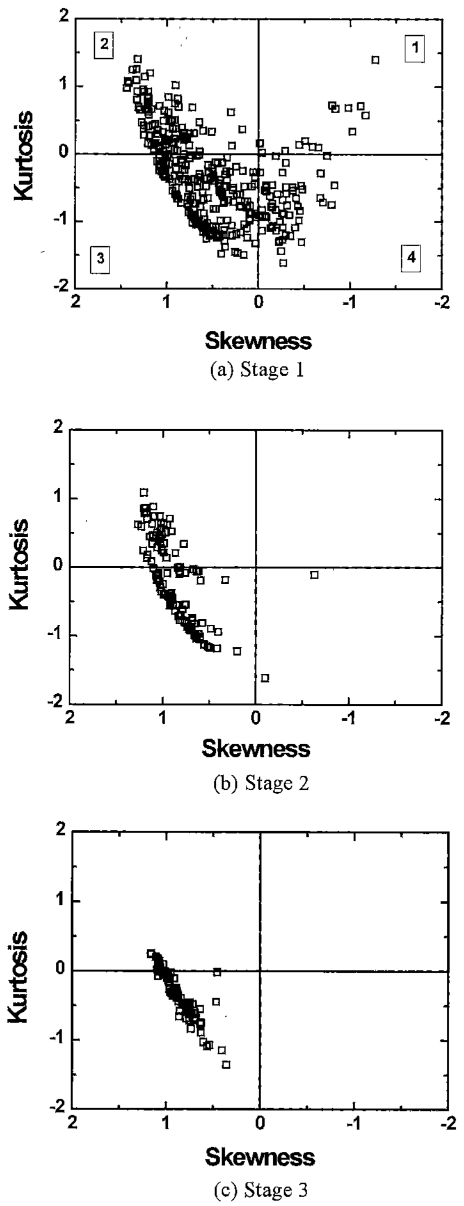


Fig. 5. Changes in the Ku-Sk plot of a non-oxidized specimen with ageing

3. Results and Discussion

3.1 Ageing stages The ageing process due to PD in a void is divided into three stages according to pulse width distribution, which reflects the change in PD mechanism [7][8].

Stage 1 is the initial stage, where most PD current pulses have narrow pulse width below about 10nsec and large peak height. The large pulse magnitude shown in Stage 1 of Table 1 is caused by a large overvoltge across the void due to a large time-lag which is related to oxygen in a void.

After several minutes or hours, most PD pulses become wider in pulse width (about 50n~70nsec) and smaller in pulse height. However, their magnitude ranges are scattered by various overshoots in front of a broad pulse [8]. This stage is defined as Stage 2. Roughly speaking, it takes about 2 hours to be Stage 2 for a non-oxidized specimen and about 30 minutes for an oxidized specimen. It suggests that the oxidation of the void surface accelerates the transition of PD mechanism.

At Stage 3, several tens hours after Stage 2, PD current pulses have small magnitude and narrow pulse width. However, PD in the oxidized specimen was extinguished after Stage 2. The self-extinction may be attributed to excessive increase in conductivity of void surface by PD activity.

3.2 Non-oxidized specimen PDs at Stage 1 are scattered more widely in the Ku-Sk plot [Fig. 5(a)] than those at other stages [Fig. 5(b) and (c)]due to pulse groups with successive PD such as ST1-3, 4, 5 and 6. It suggests that the superposition pulses are caused by large number of almost simultaneously occurring PD. However, according to ageing, PDs concentrate on the second and the third quadrant. The range of plotted area is reduced as shown in Fig. 5(b). It means that the PD pulses become similar shape as like left-peaked triangle. After Stage 2, most of PD pulses converge on the third quadrant as shown in Fig. 5(c). Fig. 6 shows the distribution of Ku-Sk plots for a non-oxidized specimen with ageing. It shows that the distributions in the first and the fourth quadrants are promptly reduced after Stage 1. The third quadrant extends up to the amount of 85% by ageing. As the ageing proceeds, Ku-Sk plots concentrate more on the third quadrant. Therefore, it suggests that PD pulse shapes tend to change to normal sharpness and left-peaked triangle according to ageing.

3.3 Oxidized specimen Fig. 7 shows the change in the distribution of Ku-Sk plots with ageing for two kinds of specimens. At Stage 1, PDs of a non-oxidized specimen are scattered in all quadrants as shown in Fig. 7(a). However, PDs of an oxidized specimen are almost limited in the second and the third quadrants. At Stage 2, the proportion of the third quadrant increases as shown in Fig. 7(b). Especially, more than 95% of PDs are concentrated there for an oxidized specimen. The proportion of the third quadrant is larger for an oxidized specimen than for a non-oxidized one at every stage.

It has been known that one of factors that affect a transition of PD mechanism is the oxidation of the void surface by partial discharge [4][8]. As shown in Figs. 6 and 7, PDs tend to concentrate on the third quadrant in the Ku-Sk plot according to ageing. Moreover, an oxidized specimen has more PDs in the third quadrant than a non-oxidized one at Stage 1. The distribution ratio of quadrants for an oxidized specimen at Stage 1 is similar to that of a non-oxidized specimen at Stage 2 as shown in Fig. 7(b). In other words, the proportion of the third quadrant strongly depends on the degree of oxidation of the void surface, i.e. ageing.

The transition of PD mechanism due to the oxidation of void surface can be explained as follows. Oxidation due to PD makes void surface more conductive and, as a result, free electrons are supplied more easily. Therefore, the overvoltage across the void is reduced and a Townsend-like discharge having a small and broad current pulse occurs.

These results mentioned above show that the Ku-Sk plot gives useful information on pulse shape and ageing stage. Although the pulse width histogram shows the change in pulse width that is also useful to clarify the PD mechanism, it cannot distinguish the existence of superposed pulses that may make an error for pulse width calculation, for example. On the other hand, the Ku-Sk plot indicates more information about pulse shape as well as ageing stage. The ageing stage can be distinguished by the change in distribution of Ku-Sk plots.

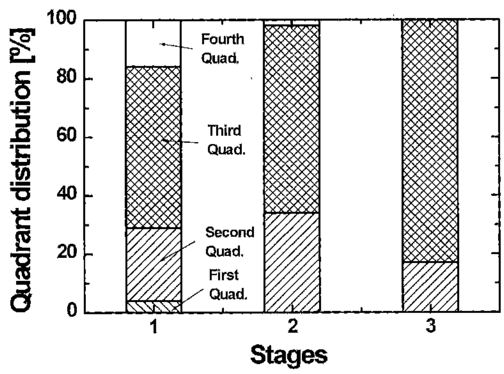
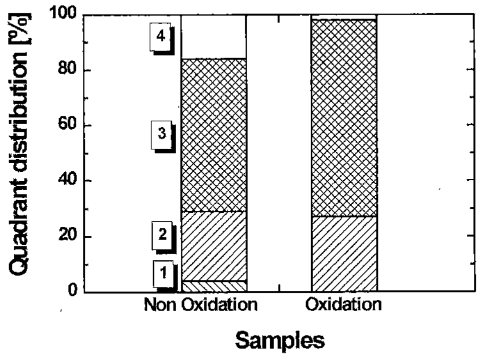
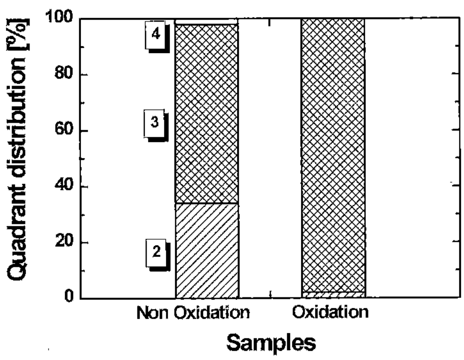


Fig. 6. The distribution of Ku-Sk for a non-oxidized specimen by ageing



(a) Stage 1



(b) Stage 2

Fig. 7. Comparison of Ku-Sk distributions for non-oxidized and oxidized specimens

4. Conclusion

The correlation between change in PD current shape and ageing and its oxidation effect were analyzed by stochastic parameters such as kurtosis and skewness. The following conclusions were obtained.

(1) PDs in a non-oxidized specimen at Stage 1 were scattered widely in all quadrants of the Ku-Sk plot. According to ageing, however, they gradually concentrated on the third quadrant.

(2) PDs in an oxidized specimen at Stage 1 concentrated on the second and the third quadrants of the Ku-Sk plot, unlike those in a non-oxidized one.

(3) The Ku-Sk plot shows that the transition of PD mechanism was accelerated by the pre-oxidation of void surface.

(4) The Ku-Sk plot for PD current pulses reflects ageing stage and the distribution of Ku-Sk plot is applicable to insulation diagnosis.

(Manuscript received Jan.15, 2002, reviced July 1, 2002)

References

(1) R J Van Brunt : "Stochastic Properties of Partial Discharge Phenomena", *IEEE Trans. DEI*, **EI-19**, No.5, pp.475-495 (1984-10)

(2) E.Gulski : "Discharge Pattern Recognition in High Voltage Equipment", *IEE Proc.-Sci. Meas.Technol.*, **142**, No.1, pp.51-61 (1995)

(3) Okamoto : "Novel Partial Discharge Measurement Computer-Aided Measurement Systems", *IEEE Trans. DEI*, **21**, No.6, pp.1015-1019 (1986)

(4) T.Tanaka : "Internal Partial Discharge and Material Degradation", *IEEE Trans. DEI*, **21**, No.6, pp.899-905 (1986)

(5) Suwarno, Y.Suzuoki, T.Mizutani, and K.Uchida . "Partial Discharge Pattern Changes due to Electrical Tree Growth in Polyethylen", *T. IEE Japan*, **115-A**, No 11, pp.1121-1129 (1995-11) (in japanese)

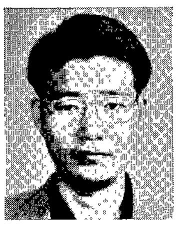
(6) C.S.Kim, Y.Tani, and T.Mizutani : "Correlation between Change in PD Current Shape and Aging by Oxidation in Void Bounded with LDPE", *ICSD*, pp.420-422 (2001)

(7) J.C.Devins : "The Physics of Partial Discharges in Solid Dielectrics", *IEEE Trans. DEI*, **19**, No.5, pp.475-495 (1984)

(8) P H F.Morshuis : "Assessment of Dielectric Degradation by Ultrawide-band PD Detection", *IEEE Trans. DEI*, **2**, No.5, pp.744-756 (1995)

(9) M.Hikita, K.Yamada, A.Nakamura, and T.Mizutani, A Oohasi : "Measurements of Partial Discharges by Computer and Analysis of Partial Discharges Distribution by the Monte Carlo Method", *IEEE Trans. DEI*, **25**, No.3, pp.453-468 (1990)

Choong-Sik Kim (Student Member) graduated from Hanyang University, Seoul, Korea. In 1988 he joined LG Cable, R&D Laboratory, Korea. His research interests include the diagnosis of electrical insulation. He is presently a doctor course student in Nagoya University, Japan. He is a student member of the IEE of Japan.



Teruyoshi Mizutani (Member) received the B.S., M.S. and Ph. D. degree from Nagoya University. He is now Professor at Dept. of Electrical Eng., Nagoya Univ. He was Visiting Researcher at Laval University, Canada (1973/4) and Visiting Professor at TU Braunschweig, Germany (1994). His research interests include electrical insulation, thin film devices and organic EL devices. He is IEEE Fellow and Member of Jpn. Soc. Appl. Phys., Soc. Polymer Science, Jpn. and IE Elect. Discharge, Jpn