Paper

Change in PD pulse shape with ageing

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The change in PD (partial discharge) pulse shape for a void bounded with LDPE was measured using a time-resolved measurement system with an ultra-wideband detector. The PD pulse shape gives us significant information about ageing and the transition of PD mechanism. In this paper, pulse shape parameters such as magnitude, width and rise time of a PD current pulse and optical PD images were analyzed to classify and recognize degradation stages. Furthermore, the frequency characteristics of PD pulses in addition to time domain analysis were also discussed. The frequency distribution of a PD pulse as well as the pulse width distribution reflected ageing stages. The frequency distribution was concluded to be applicable to an insulation diagnosis.

Keywords: PD pulse shape, Ageing, Frequency spectrum, Time-resolved measurement

1. Introduction

Partial discharge has been known to be related to the degradation of insulating materials or the lifetime of high voltage power apparatus and cables. There have been many reports on the relation between ageing and partial discharge in polymeric insulating materials. Devine(1) reported the relationship between discharge pulse shapes and various parameters such as overvoltage, void size and dielectric thickness. Morshuis(2) also showed in his doctor thesis that the pulse shape, especially the pulse width (20% level of the pulse magnitude) changes according to the transition of discharge mechanism due to ageing.

A true PD current waveform can be measured with a fast digital processing technique and an ultra-wideband system. Unlike a measurement to get apparent charges by integration circuit, the real-time measurement with a wide bandwidth has a merit, where fast and successive pulse shapes are observed in a short time.(3)(4) Many parameters of pulse shape have been proposed.(1~5) Furthermore, parameters such as magnitude, pulse width and rise time of a PD current waveform give significant information about the degradation of insulating materials.(1~3)

In this paper, the changes in PD pulse shape parameters described above with ageing were studied and the frequency spectrum of individual PD waveform by FFT processing was analyzed(6-8) in addition to the time domain analysis. Considering the changes of parameters in both the time domain and the frequency domain, we made an attempt to clarify the correlation between the change in PD shape and ageing by partial discharge.(8)

2. Experimental methods

2. 1 Samples and measurement system The experimental setup is shown in Fig. 1. The specimen is composed of a disc shaped void between two LDPE sheets. The thickness of LDPE sheets is 0.2mm and the diameter of a void 7.5, 12 or 16mm. The electrode system consists of a ground electrode and a measuring electrode filled with NaCl solution to take an optical image of discharge. The optical images taken by a camera through an intensifier enable us to verify the transition of discharge mechanism and its correlation with ageing. The diameters of the ground and the measuring electrode are

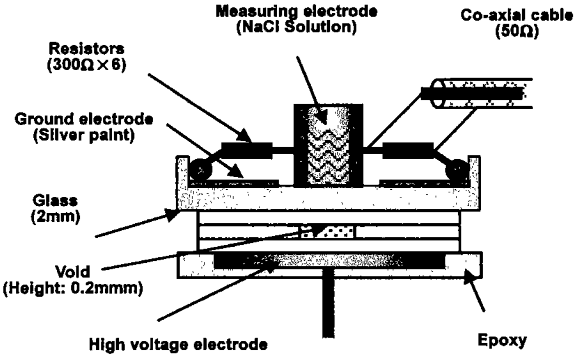

Fig. 1 Schematic of electrode system.

optimally chosen to reduce a stray capacitance.(2) The impedance of a measuring detector is 50Ω composed with six resistors of 300Ω in parallel between the measuring electrode and the ground electrode, if a stray capacitance around resistors is neglected. Therefore, the measuring detector has an excellent characteristic for frequency response up to several GHz and the detector does not affect the frequency spectrum of a PD pulse. To avoid any reflection between the measuring detector and an oscilloscope, 50Ω transmission line is used. In addition, a damping resistor 1MΩ is inserted between the power source and the specimen to keep PD current flowing away from voltage source.

The AC voltage (approximately 50% above PD inception voltage 3kVrms) was applied to the high voltage electrode. The PD currents were 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. Almost all PD discharges scattered widely can be measured by automatic scale control. The rapid measurement is performed by using the fast-frame method of a digital oscilloscope supplied by Tektronix. It takes about 15 minutes for one measurement with 4 scale levels, 2 cycles and 2 polarities.

2. 2 Parameters of PD pulse shape

The pulse shape of PD current reflects the movements of electrons and ions in a PD activity. Thus, the investigation of the pulse shape is expected to provide a clue to understand PD mechanisms. In this paper, shape parameters such as magnitude, width (20% level of the pulse magnitude) and rise time (between 10% and 90% levels of the pulse magnitude) of a PD current waveform were calculated by the software developed for this experiment.

In addition to shape parameters of time domain signals, the frequency spectra of PD pulses were analyzed by FFT processing.(6~8) A new parameter, the 30dB attenuation frequency that corresponds to the highest value among points at which the 30dB attenuation level and the frequency spectrum crosses was selected as an indicator. It means that a PD signal is well preserved through a filter whose cutoff frequency is the 30dB attenuation frequency. It reflects the type of the PD pulses and explains the characteristics by means of frequency. The analysis of the spectrum permits to design the proper frequency range of a filter in the measurement system including the detecting impedance. Moreover, it is useful to identify the ageing stages.

We measured all PD pulses with 0.25nsec sampling interval and 125nsec duration per single waveform. Therefore, the minimum interval frequency in the spectrum is 8GHz and the maximum frequency range that can be recognized is 2GHz from Nyquist theorem.

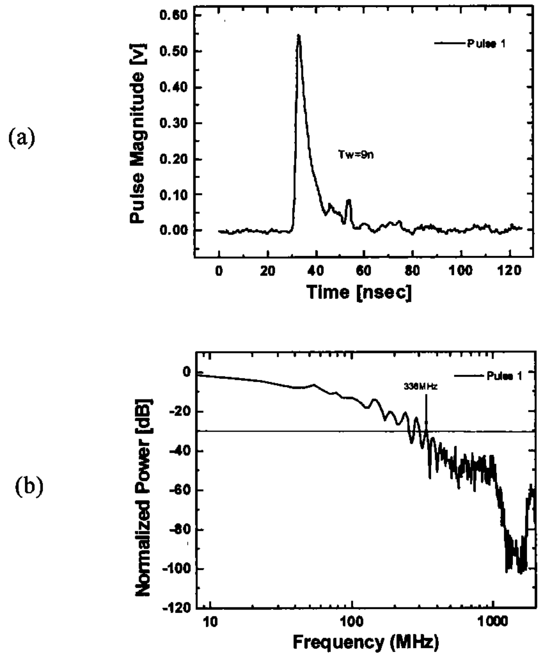

Fig. 2 Typical waveform of streamer-like discharge whose frequency at the 30dB attenuation of power spectrum is 336MHz.

(a) Fast discharge pulse (pulse 1) and (b) Frequency spectrum of pulse 1.

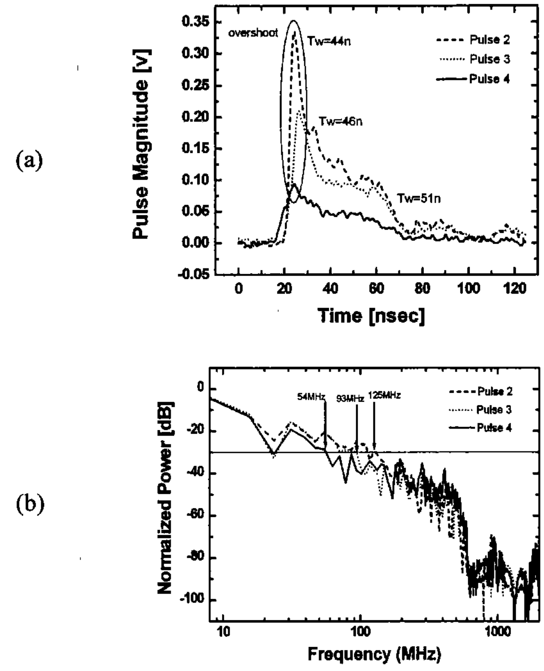

Fig. 3 Three types of Townsend-like pulse whose frequencies at the 30dB attenuation of power spectra are 125MHz, 93MHz and 54MHz, respectively.

(a) Slow discharge pulses (pulse 2, 3 and 4) and (b) Their frequency spectra.

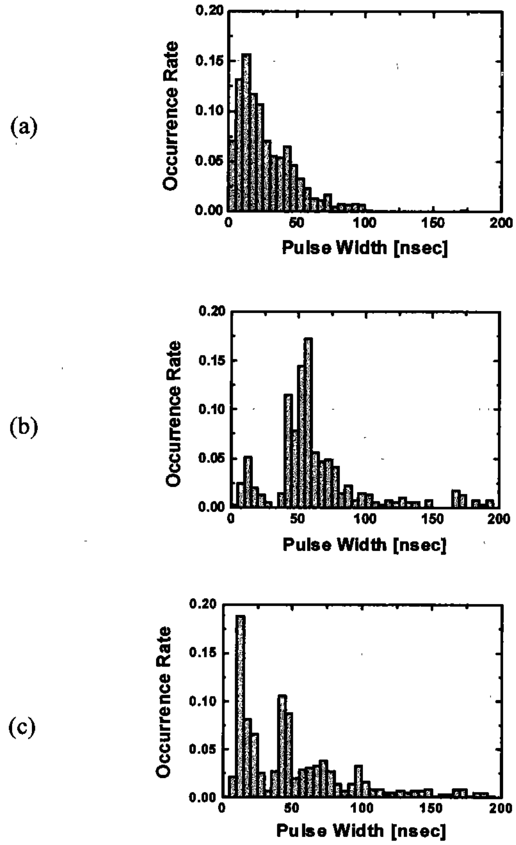

Fig. 4 Pulse width histograms of stages 1~3 for a disc shaped void bounded with LDPE.
(a) Stage 1 (initial), (b) Stage 2 (3~5 hour) and (c) Stage 3 (40 hour).

3. Experimental Results

3. 1 Typical pulse shapes during ageing process

The two typical types of PD waveforms as shown in Figs. 2(a) and 3(a) have been observed during ageing in the void. The slow type pulses of Fig. 3(a) show the characteristics of Townsend-like discharge.(1) They have usually an asymmetrical shape with longer pulse width and lower magnitude than the fast type discharge shown in Fig. 2(a). Additionally, different overshoots in front of the flat pulses were observed in pulse 2, 3 and 4. They are related to the effect of overvoltages on the PD pulses.(1)(2) In addition to the time domain analysis, the frequency spectra of individual PD pulses were analyzed as shown in Figs. 2(b) and 3(b). The frequency spectra of the slow type pulses as shown in Fig. 3(b) become lower in the high frequency region than that of the fast type pulse. The frequency of the 30dB attenuation in the spectrum was in the 50~250MHz range for the slow discharge pulse and in the 300~550MHz range for the fast discharge pulse.

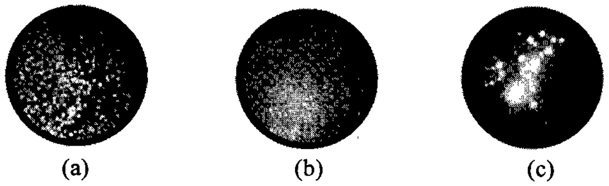
(a) (b) (c)

Fig. 5 Partial discharge images of various ageing stages. (a void of 16mm diameter and 0.2mm height).
(a) Stage 1, (b) Stage 2 and (c) Stage 3.

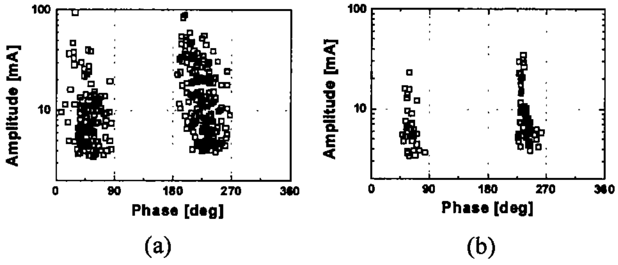

Fig. 6 ϕ-q-n patterns (phase-resolved patterns).
(a) Stage 1 and (b) Stage 2.

In this paper, the fast type pulse means that its pulse width is below about 10nsec and the slow type pulse has a pulse width above 40nsec. However, it is difficult to define clearly because the pulse shape depends on applied voltage, internal pressure, void height and so on.

3. 2 Change in pulse width with ageing stages

The ageing stages are classified to three stages according to the change in pulse width. Each stage is defined as follows.

-Stage 1(initial): Pulses have a short pulse width about 10nsec and a high magnitude. As shown in Fig. 5(a), the PD image is featured by many bright and circular spots in some parts of the void.

-Stage 2: long pulse width and low magnitude. PD image shows dim and small spots. However, discharges occur in a whole of the void.

-Stage 3: Pulses are characterized by a short pulse width and a low magnitude. The PD image is highly lightened and remarkable localized in the limited area.

As shown in Fig. 4 (a), many pulses were concentrated on the short pulse width around 10nsec, at Stage 1. In case of Stage 2, the distribution of pulse width shifted to 50n~70nsec. This change in the pulse width suggests the transition from streamer-like discharge to Townsend-like discharge characterized by the long pulse width which is caused by the movement of positive ions.

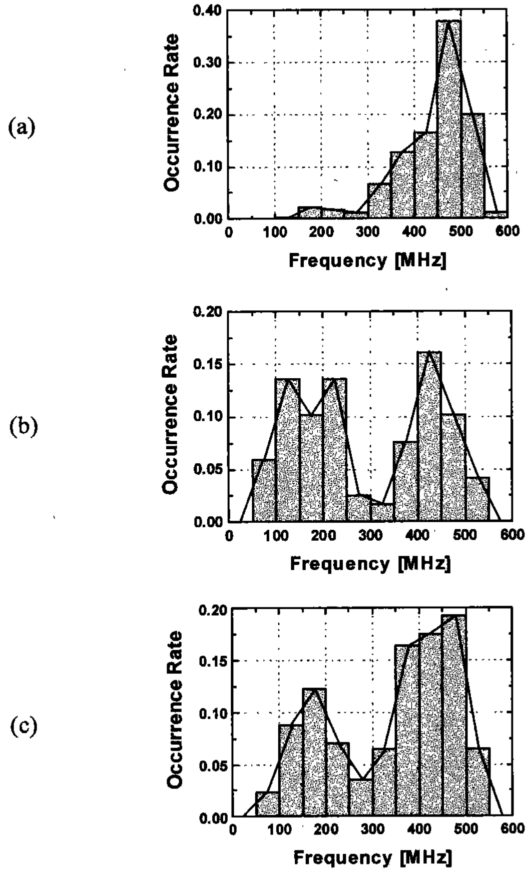

Fig. 7 The histograms of frequencies at the 30dB attenuation of frequeny spectrum.
(a) Stage 1, (b) Stage 2 and (c) Stage 3.

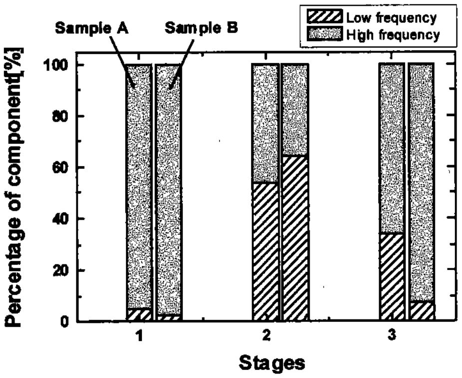

Fig. 8 Change in frequency components with ageing for sample A and B (sample A: ϕ12mm, sample B: ϕ7.5mm).

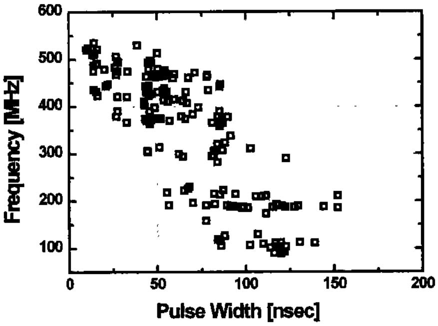

Fig. 9 The relationship between the 30dB attenuation frequency and the pulse width (Stage 2~Stage 3).

The transition from Stage 1 to Stage 2 can be also observed in the *ϕ-q-n* patterns as shown in Fig. 6. The pattern shown in Fig. 6(a) shows that the phase angle of PD inception is around 0° and 180°. However, in Stage 2 shown in Fig. 6(b), PD inception shifts to the right side of phase angle and PD occurrence range becomes narrow. It suggests that the influence of space charge is decreased by the increase of surface conductivity of a void due to PD degradation.(9)

The PD pulse at Stage 3 has a small magnitude and a short pulse width. The occurrence rate of a short pulse width around 10nsec increased more in Stage 3 than in Stage 1. Moreover, the distribution of the pulse width as shown in Fig. 4(c) was scattered in comparison with Stage 1.

The PD images of Fig. 5 clearly show the change of PD mechanism with ageing stages. Especially, the PD image with high lightened and remarkably localized spots as shown in Fig. 5(c) suggests the formation of weak points in a part of the void surface.(2)(9)

3. 3 30dB attenuation frequency As mentioned in section 3.1, the spectrum of a PD pulse depends on the type and the mechanism of a PD pulse. Fig. 7 shows the histograms of the 30dB attenuation frequency in the spectrum for the various ageing stages. Most PD pulses showed 300MHz~550MHz for the 30dB attenuation frequency at Stage 1. The PD pulses were similar to the fast type pulse shown in Fig. 2(a). At Stage 2, the histogram has two peaks as shown in Fig. 7(b). Especially, the low frequency peak around 50MHz~250MHz increased. It suggests that the slow type pulses shown in Fig. 3(a) occurred so often in this stage. Stage 3 has the frequency histogram similar to Stage 2, but the high frequency peak is higher than the low frequency one as shown in Fig. 7(c).

From the above results, it is clear that there are two kinds of frequency components, the high frequency (300MHz~550MHz) and the low frequency (50MHz~250MHz) components, and they change with ageing. As shown in Fig. 8, the high frequency component is dominant at Stage 1 and 3, however at Stage 2, the low frequency component is dominant.

A close correlation is founded between the 30dB attenuation frequency and the pulse width. In general, a frequency spectrum is affected by rise time and falling time of a pulse waveform.

Therefore, a low 30dB attenuation frequency suggests the long pulse width of a PD pulse which has long rise time and falling time as shown in Fig. 3(a). The 30dB attenuation frequency is inversely proportional to the pulse width as shown in Fig. 9.

4. Discussion

PD mechanisms are strongly affected by gas and surface condition in a void. At Stage 1, initial electrons to ignite a PD depend on the above conditions and a long time lag due to the presence of oxygen that catches free electrons causes a large overvoltage to the void. The large overvoltage triggers the fast type discharge (streamer-like discharge) characterized by the high magnitude and the short pulse width with the highlightened image. Figs. 4(a) and 7(a) show that the fast type discharges are prevalent at Stage 1. Pulses concentrate on around 10nsec for the pulse width and around 450MHz for the 30dB attenuation frequency, which represent the properties of the fast type discharge shown in Fig. 2(a).

The PD activity during Stage 1 modifies the property of the void surface through chemical reaction. The surface conductivity, for example, may be increased by the by-products of oxidation. With ageing, the overvoltage becomes small due to the easy liberation of electrons trapped in the surface at Stage 2. Moreover, the consumption of oxygen results in ease occurrence of PD. The small overvoltage corresponds to the slow type discharge with a long pulse width and a slow rise time as shown in Fig. 3(a). The long wave tail may be caused by positive ions which move slowly to anode.(1) Therefore, pulses with the low frequency component in the 50MHz~250MHz range as shown in Fig. 3(b) were mostly observed at Stage 2.

After a long PD activity, the degradation by-products such as crystals of oxalic acid appear on a part of the void surface. They lead to the local field enhancement and to the concentration of PD that causes severe erosion and thus results in initiating a tree. The discharge image in Fig. 5(c) manifests that discharges stably occur in some limited points. Pulses are characterized by a short pulse width, which is similar to that of Stage 1, but a low magnitude. The characteristic of frequency shows that the high frequency components in the 300MHz~550MHz were dominant at Stage 3.

5. Conclusion

The change in PD pulse shape due to degradation was analyzed by the frequency spectrum in addition to usual parameters such as magnitude, pulse width and rise time of a PD pulse. The following conclusions were obtained in our experimental condition.

1. The 30dB attenuation frequency consists of the two components, the high frequency component in the range of 300MHz~550MHz and the low frequency one in the range of 50MHz~250MHz.
2. At the initial stage of ageing (Stage 1), PD pulses with a short pulse width about 10nsec and the high frequency component in range of 300MHz~550MHz occurred mostly.
3. At the second stage (Stage 2), the slow pulse types with a long width and a low frequency component in range of 50MHz~250MHz occurred due to the consumption of oxygen and the slight degradation of the void surface.
4. The pulse width became short again at Stage3 and the high frequency component increased.
5. The 30dB attenuation frequency was inversely proportional to the pulse width.
6. The discrimination of degradation stages by means of elaborated filters with different frequency bandwidth is expected to be powerful method for insulation diagnosis.

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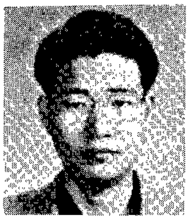

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