Particle Size Identification in GIS by Ultra High Speed Measurement of Partial Discharge

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***Abstract*--Gas insulated switchgear (GIS) is reliable equipment. However, when a metallic particle is in it, the insulation reliability of GIS sometimes reduces. Partial discharge (PD) measurement is usually performed to detect a metallic particle in GIS. After the PD detection, the criticality of PD must be estimated. For this purpose, identification of a particle size is very important. In this paper, every PD pulse of various particle sizes was measured sequentially with an ultra-high speed measuring system. And physical PD parameters were systematically analyzed. As a result, it was clarified that identification of the particle size was possible by considering the PD pulse number and current at positive and negative polarities. Finally, correspondence between electromagnetic wave emitted from PD and PD current was discussed.**

***Index Terms*--Partial discharges, Gas insulated switchgear, SF_6, UHF measurements**

I. Introduction

GIS is widely used in electric power systems as highly-reliable equipment. However, if defects like particles and protrusions exist inside GIS, the electric field concentrates at their tips, and the insulation reliability of GIS will be greatly influenced. As these defects usually generate partial discharge (PD), GIS is diagnosed by the PD measurement [1, 2, 3, 4]. The criticality of defects greatly depends on their length and diameter. Several studies such as jumping height analyses of particles have been tried [2, 3]. However, the correct size identification is very difficult, if physical PD properties are not clarified.

Authors introduced the ultra high-speed PD measuring system called PD-CPWA [4, 5, 6] and the UHF method [1]. Under the operating electric field strength of GIS, all PD current pulses of different sizes of particles were measured and recorded sequentially with PD-CPWA. And physical PD quantities were systematically analyzed. It was clarified that the size identification was possible by considering the PD pulse number and the PD current at positive and negative half cycles. Moreover, PD characteristics were compared between PD-CPWA and the UHF method.

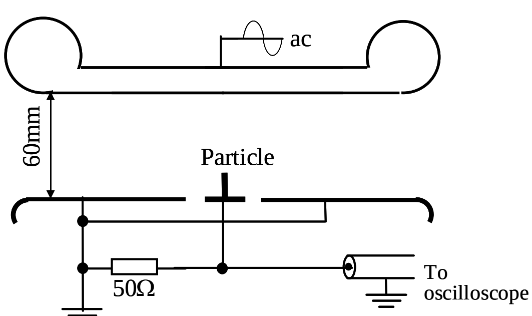

Fig. 1 Electrode setup

II. Experimental Method

Figure 1 shows the parallel-plane electrode of a 60 mm gap used in the experiments. A metallic particle was fixed on the grounded electrode. Material of a metallic particle was aluminum (D = 0.25 mm) and copper (D = 0.45 mm). The electrodes were placed in the GIS tank (Figure 2). Seven sizes of particles in Table 1 were examined. The particle tip has rectangular or hemispherical shape (Figure 3). PD pulses were measured through the detecting resistance of 50 Ω with PD-CPWA (20 GS/s, 4 GHz and 32 MWord), and all PD current pulses were recorded sequentially. The electromagnetic waves

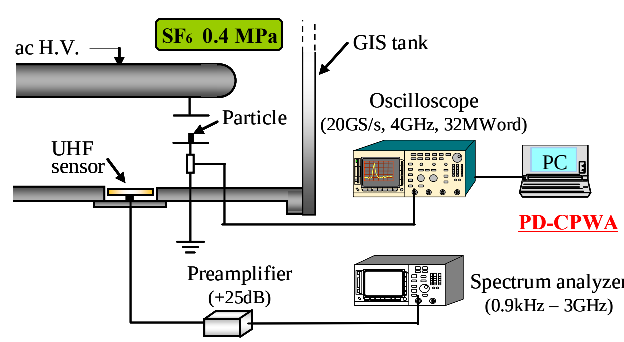

Fig. 2 Experimental setup

Table 1 Particle size and PDIV

Tip shape	Particle size: Diameter D [mm]	Particle size: Length L [mm]	PDIV [kV_{rms}]	$120kV_{rms}$/PDIV
Rectangular	0.25	10	31	3.87
		5	58	2.07
		3	75	1.60
	0.45	10	60	2.00
		5	81	1.48
		3	120	1.00
Hemisphere	0.45	10	70	1.71

$120kV_{rms}$: Applied voltage

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Fig. 3 Shape of the particle tip

emitted from PD were detected with a UHF sensor placed near the particle, and were analyzed with a 25 dBm preamplifier and a 3 GHz spectrum analyzer (sweep time : 1 ms - 4000s). The UHF system was calibrated based on the CIGRE method [7].

As GIS is usually operated under the electric field strength from 2 to 2.5 kV_{rms}/mm on a high voltage conductor, the applied ac voltage was selected to be 120 kV_{rms} (2 kV_{rms}/mm) and 150 kV_{rms} (2.5 kV_{rms}/mm). SF_6 gas pressure was 0.4 MPa.

III. Experimental Results

A. PD inception voltages

PD inception voltages (PDIV) decreased when particles became long and thin (Table 1). The over-voltage ratio (= 120 kV_{rms}/PDIV) was in the range from 1.0 to 3.87. PDIV increased when the particle tip was changed from a rectangular shape to a hemispherical one.

B. Influence of particle size on PD characteristics at 120kV$_{rms}$

Figure 4 shows voltage phase - PD current (ϕ-I) characteristics of rectangular particles (D = 0.25 mm) at a certain one cycle. The voltage polarity was expressed as that of particles. PD pulses appeared around the voltage peak at both polarities. When a particle was long, the voltage phase of PD appearance became wide. The PD pulse number increased with the particle length. However, the magnitudes of PD current were almost constant among different particles.

Figure 5 shows the influence of the particle diameter on ϕ - I characteristics. Large PD pulses appeared around the voltage peak at the positive polarity when a particle became long. The region of the voltage phase where PD appeared was narrower at D = 0.45 mm than at D = 0.25 mm.

PD pulses were measured continuously for 10 minutes. Figure 6 shows the time trend of the PD pulse number. PD pulses were counted for 3 cycles at each time and expressed as the unit of pulse per second (pps). And Figure 7 shows the time trend of the PD current. The magnitude of PD current is expressed as the average magnitude for 3 cycles. Following characteristics were obtained.

(i) The PD pulse number and the PD current were almost independent of time. These tendencies were observed at different particle sizes.

(ii) At a 10 mm long particle of 0.45 mm diameter, though the

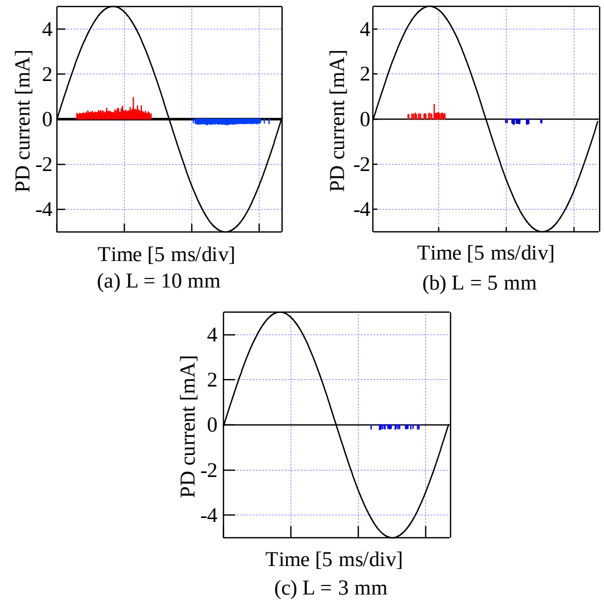


Fig. 4 ϕ-I characteristics at 120 kV_{rms} (D = 0.25 mm, rectangular)

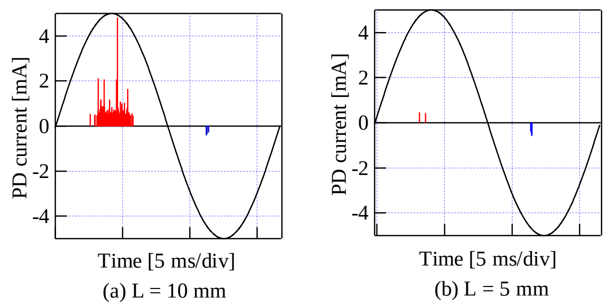


Fig. 5 ϕ-I characteristics at 120 kV_{rms} (D = 0.45 mm, rectangular)

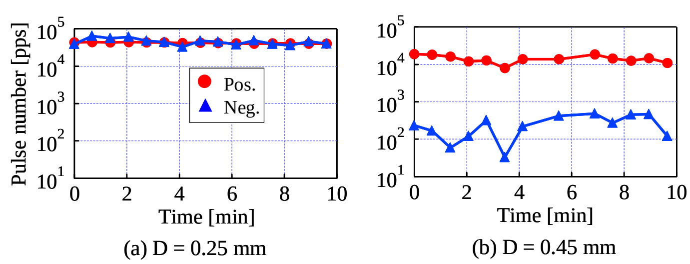


Fig. 6 Trend of PD pulse number at 120 kV_{rms} (L = 10 mm, rectangular)

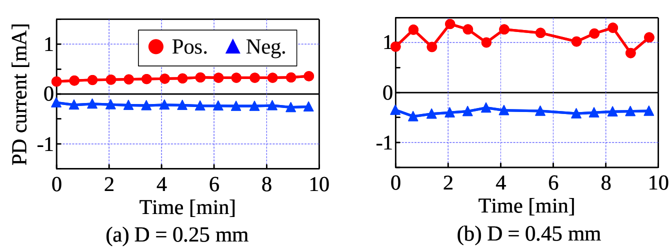


Fig. 7 Trend of PD current at 120 kV_{rms} (L = 10 mm, rectangular)

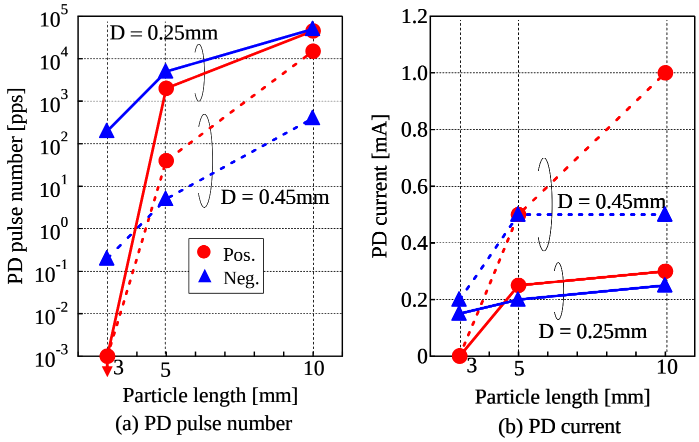


Fig. 8 Dependence of PD characteristics on particle sizes at 120 kV_{rms} (rectangular)

0.25 mm diameter, the PD pulse number at the positive polarity was almost equivalent to that of a thin particle. However, the PD pulse number of the negative polarity decreased extraordinarily

(iii) At a 10 mm long particle of 0.25 mm diameter, the difference in PD current between both polarities was very small. However, when the particle diameter became large, PD currents increased, especially in the positive polarity.

Both the PD pulse number and the PD current magnitude depended on the particle length and diameter (Figure 8). The PD pulse number markedly increased when particles became long. The tendency of its increase was extremely different between two particle diameters. Moreover, the large polarity effect was observed. At 3 mm long particles, as the positive PD did not appear, the PD pulse number increased rapidly between the particle length 3 - 5 mm. The positive PD current increase with the particle length was more rapid at 0.45 mm diameter than at 0.25 mm diameter. On the other hand, the negative PD current gradually increased between the particle length 5 - 10 mm.

The rise time of the positive PD current pulse was about 0.6 ns, and tended to increase when particles became thick. But it was almost independent of particle length. On the other hand, the rise time of the negative PD current pulse was about 0.45 ns, and was almost independent of both the particle length and diameter.

C. Influence of electric field strength on PD characteristics

Figure 9 (a) shows ϕ-I characteristics of a 5 mm long particle of 0.25 mm diameter at 150 kV_{rms}. The tip shape was rectangular. By comparing with Figure 9 (b) at 120 kV_{rms}, it was shown that PD appeared in the wider voltage phase and the PD pulse number was larger when applied voltages became higher. These phenomena were observed in different particle sizes.

Figure 10 shows the dependence of the PD pulse number and current on the applied electric field strength. The particle tip was rectangular. At 10 mm long particles, the PD pulse number at 2.5 kV_{rms}/mm was almost equal to that at 2.0 kV_{rms}/mm. But at short particles, the PD pulse number increased extremely with the electric field strength, especially at the positive polarity. The magnitude of positive PD current increased with the electric field strength. On the other hand, the magnitude of negative ones was almost constant.

From the sections B and C, the increase of PD pulse number and PD current magnitude was related closely not only to the over-voltage ratio but also to the possible ionizing volume and the corona stabilization effect.

D. Influence of the shape of the particle tip on PD characteristics at 120 kV_{rms}

PD characteristics are markedly influenced by the shape of the particle tip. Figure 11 (a) shows ϕ - I characteristics of a 10 mm long particle with a hemispherical tip. By comparing with characteristics of Figure 11 (b), obvious difference can be recognized. Though positive PD current pulses appeared about the same voltage phase in two tip shapes, negative ones appeared in the wider voltage phase at the hemispherical tip than at the rectangular tip. Moreover, the magnitude of negative PD current was extremely larger at the hemispherical tip than at the rectangular one.

The PD pulse number and current are compared in Figure 12. The number of the positive PD pulse was almost equal between two tip shapes. However, the number of the negative one was remarkably smaller at the rectangular tip than at the hemispherical one. The average value of positive PD current was remarkably larger at the rectangular tip than at the hemispherical one.

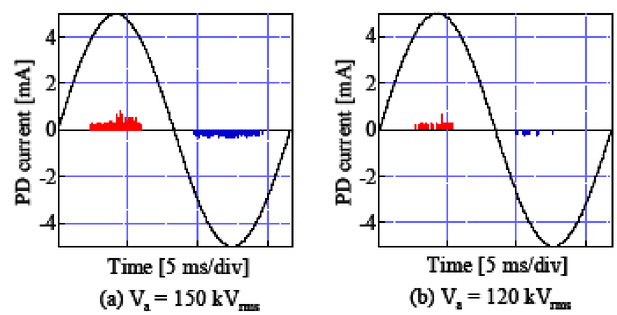


Fig. 9 ϕ-I characteristics at two different voltages (D = 0.25 mm, L = 5 mm, rectangular)

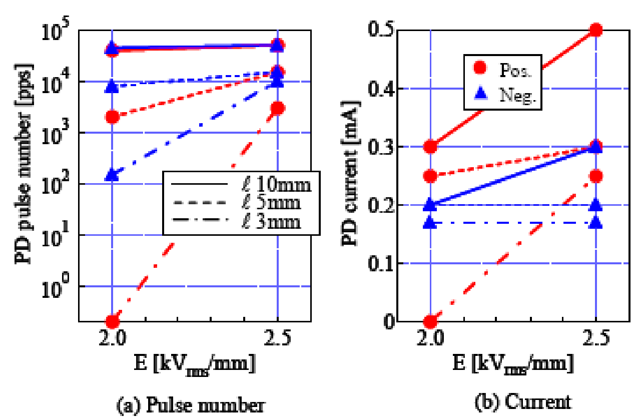
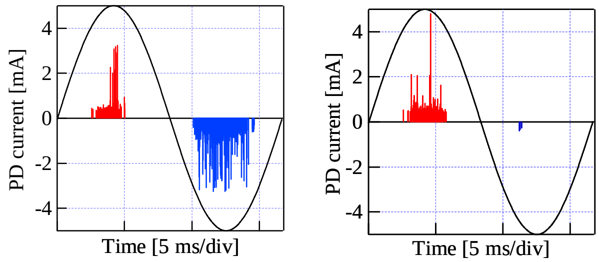
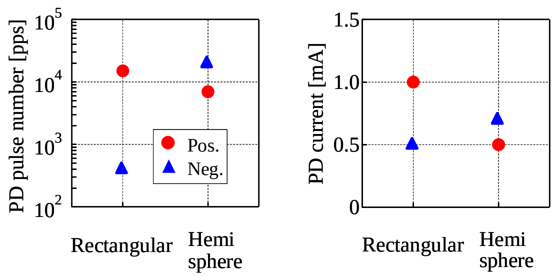


Fig. 10 Dependence of PD characteristics on applied electric field strength (D = 0.25 mm, L = 10 mm, rectangular



(a) Hemisphere (b) Rectangular

Fig. 11 ϕ-I characteristics at 120 kV_{rms}
(D = 0.45 mm, L = 10 mm,)



(a) PD pulse number (b) PD current

Fig. 12 PD characteristics at 120 kV_{rms}
(D = 0.45 mm, L = 10 mm)

These phenomena would be attributed to the differences both in the microscopic electric field distribution around the particle tip and in the volume of the ionization space, besides the over-voltage ratio between two tip shapes.

E. UHF Electromagnetic waves emitted from partial discharges

It is well known that electromagnetic (EM) waves in the ultra-high frequency (UHF) region are emitted from PD in SF_6 gas. Emitted UHF EM waves are usually analyzed with the spectrum analyzer. The examined spectrum analyzer was operated on the manner that the sweep time was 50 ms in full scale and the number of trace point was 5000. PD pulses could be measured every 10 µs. However, the time interval of PD pulses was sometimes shorter than 10 µs, when many PD pulses appeared in one cycle. So, the PD detectability of the spectrum analyzer (UHF method) is studied in this section. Figure 13 shows the frequency spectrum of UHF EM waves measured with the spectrum analyzer (Maxhold : 1.5 min). Back ground noises (BGN) stood around 850 MHz and at frequencies lower than 100 MHz. Many spectra by PD appeared from 0 to 1.3 GHz. UHF EM waves became strongest at 408 MHz (-29.5 dBm) at 120 kV_{rms}. Then, the spectrum power P was measured at 408 MHz with the zero span mode of the spectrum analyzer (UHF method). The PD pulse number was in the order of 10^4 pps. The ϕ-P characteristics were displayed in Figure 14 (a). The ϕ-I characteristics were measured synchronously with PD-CPWA, and were displayed in Figure 14 (b). The characteristics were nearly equal between the two methods. It seems that the spectrum analyzer (UHF method) is satisfactory for the measuring of the voltage phase characteristics of PD.

Next, the sequential behavior of PD pulses was compared

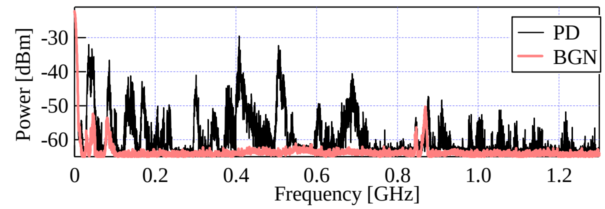
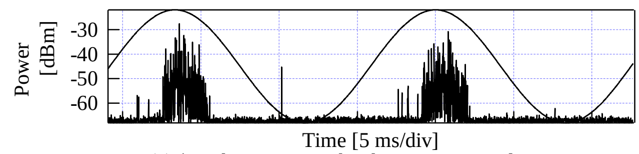
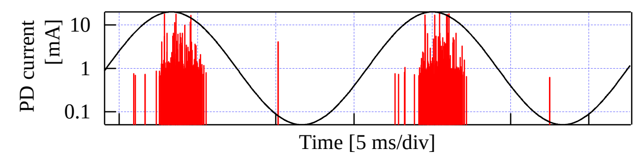


Fig. 13 EM wave spectra at 120 kV_{rms}
(D = 0.45 mm, L = 10 mm, rectangular,)

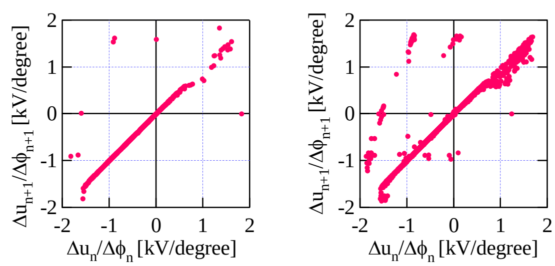


(a) ϕ-P characteristics by the spectrum analyzer



(b) ϕ-I characteristics by PD-CPWA

Fig. 14 Voltage phase characteristics of PD current and EM wave at 120 kV_{rms}
(D = 0.45 mm, L = 10 mm, rectangular)



(a) Spectrum analyzer (UHF method) (b) PD-CPWA

Fig. 15 Sequential behavior of PD pulses at 120 kV_{rms}
(D = 0.45 mm, L = 10 mm, rectangular)

between the two methods in Figure 15. The Δu/Δϕ pattern [8] was often applied for the analysis of the PD behavior. In the case of the UHF method (Figure 15 (a)), most PD pulses were on the straight line in the first and the third quadrants, and the number of plotted PD pulses was smaller than the case of PD-CPWA (Figure 15 (b)). But the shape of Δu/Δϕ pattern was equivalent to that of PD-CPWA. The above-mentioned results mean that the UHF method is applicable for both the voltage phase analysis and the sequential analysis of PD. However, on the viewpoint of the PD magnitude, the spectrum power did not always agree with the magnitude of PD current pulses, especially when many PD pulses appeared in one cycle. Further investigations are needed for its clarification.

From the sections B~E, it became obvious that particles of different sizes had their inherent PD characteristics. Based on ϕ-I characteristics, PD pulse number of both polarities and the ratio of positive PD current to negative one, correct identification of the particle size would be possible. The UHF method was effective to analyze the ϕ-P (i.e.ϕ-I) characteristics and the polarity effect of PD.

IV. CONCLUSION

PD characteristics were measured at different sizes of metallic particles under the operating electric field strength of GIS. PD measurements were performed with the ultra-high speed PD-CPWA and the UHF method. And PD characteristics were analyzed in detail. As a result, following results were obtained.

(1) The PD pulse number and the average value of PD current increased when particles became long. And the difference of those PD quantities between positive and negative polarities was very small at 0.25 mm diameter. However, at 0.45 mm diameter, the ratio of positive PD quantities to negative ones was large.

(2) The shorter the particle length, the greater the increase of PD pulse number and magnitude of PD current, especially for positive PD current.

(3) The UHF method using a spectrum analyzer was compared with the ultra-high speed PD measurement system (PD-CPWA) under the large number of PD pulses (~ 10^4 pps). Both methods were almost equivalent in the voltage phase characteristics and the sequential PD characteristics.

(4) The ϕ-I characteristics, the PD pulse number, and PD current depended markedly on the size and the tip shape of particles. By using their relationships, the correct size identification of particles would be possible.

V. References:

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