A Novel Diagnosis Method through Pulse Sequence Analysis of DC Void Partial Discharge in High Temperature Superconducting Cable

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Background

- The electrical insulation layer of the HVDC HTS cable consists of PPLP impregnated with liquid nitrogen. Butt-gaps are inadvertently formed during wrapping of PPLP which may lead to formation of voids.
- When the applied voltage exceeds PDIV, partial discharge occurs due to concentration of electric field in the void resulting from difference in conductivity between the void and the PPLP. If void discharge sustains, electrical and chemical ageing commence due to collision of high energy accelerated electrons on the PPLP surface. This may lead to lowering of dielectric strength and eventual breakdown.
- DC voltage has no phase information, insulation diagnosis using the PRPD pattern analysis method applied at the AC voltage is impossible. Therefore, analysis and acquisition of patterns using PSA that analyzes the correlation between pulses of continuously occurring DC partial discharges are needed.

Objectives

- In order to suggest the insulation diagnosis method for void defects in HVDC HTS cable through the acquired patterns of DC void discharge, measurement and pattern analysis of DC void discharge were conducted according to the size of void and magnitude of applied voltage.

DC Partial Discharge Measurement System

- As shown in Fig. 1, the test jig was made from GFRP. The diameter of the high voltage electrode and ground electrode are 25 mm and 75 mm, respectively. The specimens consist of 3-layer PPLP with voids in the middle layer. Also, a circular void with a diameter of 2, 4, 6 mm was located in the center of PPLP.
- As shown in Fig. 2, DC dielectric breakdown tests were conducted using DC transformer and cryogenic test equipment. DC partial discharges were measured by adding an oscilloscope, PDMS, HFCT, and PC to DC dielectric breakdown test.
- The void discharge was measured using an HFCT sensor measuring the leakage current due to the partial discharge, and partial discharge pulses were obtained by an oscilloscope. In addition, PDMS was used to record and analyze the occurrence time, magnitude, and frequency of partial discharge.

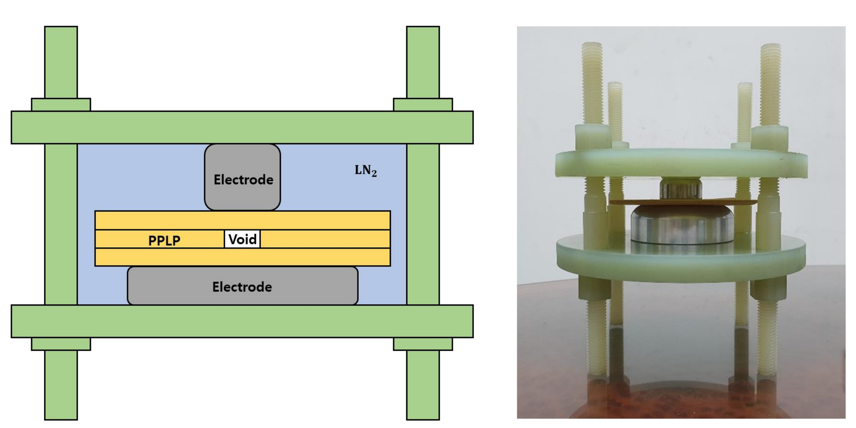


Fig. 1 Configuration of test jig and artificial defect

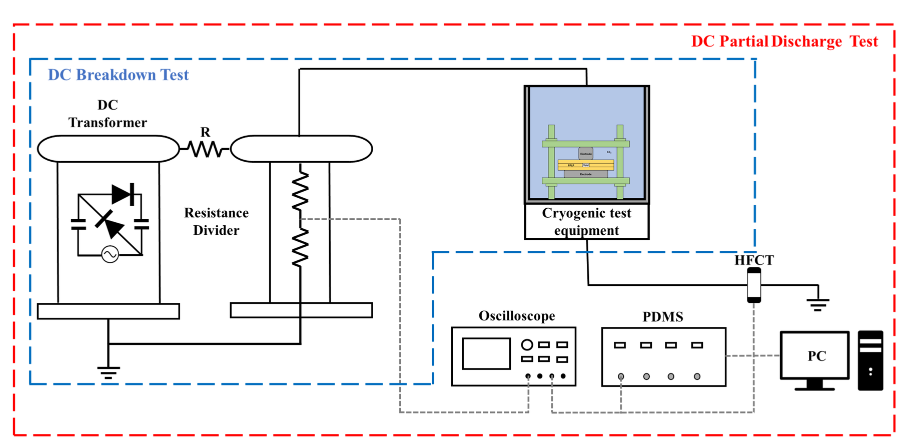


Fig. 2 Block diagram of DC dielectric breakdown test and DC partial discharge test

Conclusion

- As a result of analyzing the patterns of the DC void discharge using the PSA methods (Δq_{pre} vs Δq_{suc} and Δt_{pre} vs Δt_{suc}), TF mapping and PYTHON program, the magnitude of patterns was different as the size of void and the magnitude of applied voltage increased, but the shapes of patterns were consistent.
- Consequently, it is considered that identification of void defects and insulation diagnosis in the HVDC HTS cable can be performed based on the acquired patterns of DC void discharge.

Measurement and Pattern Analysis Method of DC Partial Discharge

- The PSA analyzes the correlation between the time and magnitude of continuously occurring DC partial discharges, as shown in Fig. 3. Therefore, to acquire DC void discharge pattern in HTS cable, Δq_{pre} vs Δq_{suc} and Δt_{pre} vs Δt_{suc} method were used.
- In order to measure the void discharge according to the magnitude of the applied voltage, the applied voltages were set as 35kV, 40kV and 45kV which are between the lowest value of BDV and the highest value of PDIV as shown in Fig. 4.
- TF mapping analyzes the standard deviation of the measured pulse waveform in the time and frequency domain. Also, TF mapping varies according to the shape of the pulse, so it is easy to detect noise and identify defects. Therefore, in order to acquire a pattern of DC void discharge, it is required to remove noise.
- The results of TF mapping according to the size of void and magnitude of applied voltage is shown in Fig. 5(a). On average, DC void discharges appear as cluster with a frequency standard deviation of 180 kHz to 3.0 MHz and a time standard deviation of 470 ns to 580 ns. Also, the pulse of DC void discharge included in the cluster shows the damped sine wave as shown in Fig 5(b).

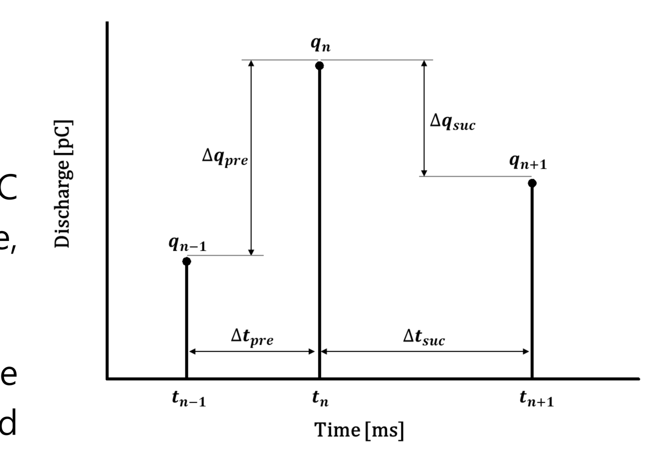


Fig. 3 Basic parameter of PSA

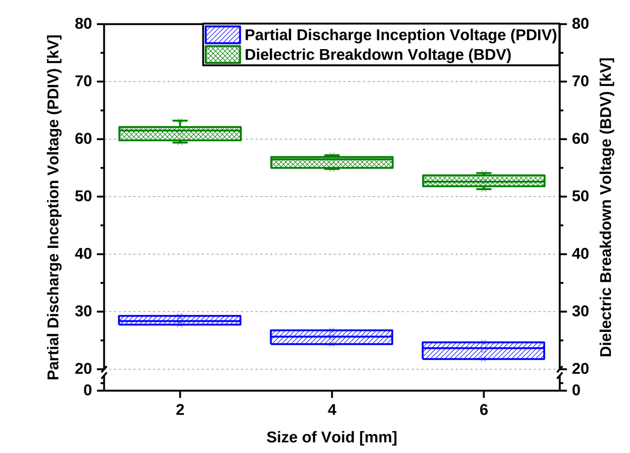
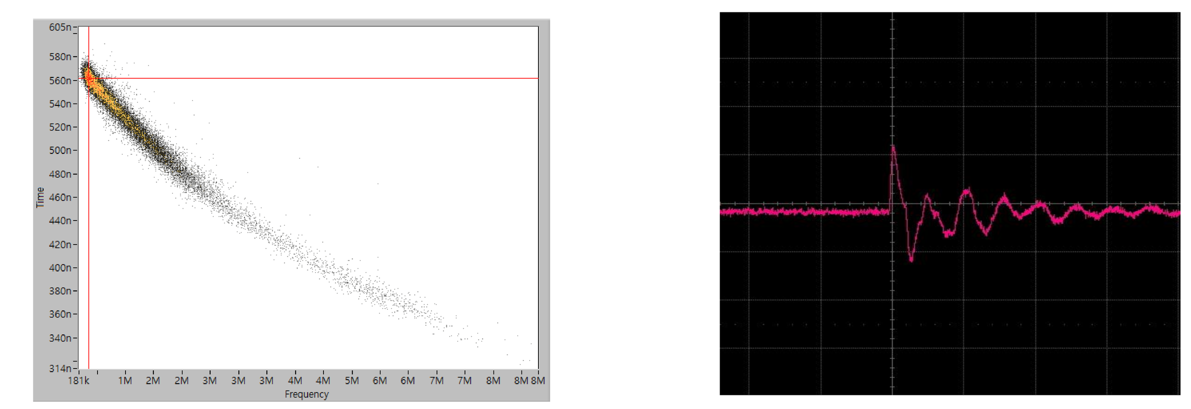


Fig. 4 DC PDIV and BDV depending on size of void



(a) TF mapping of void discharge

(b) Pulse of void discharge

Fig. 5 Result of TF mapping and DC void discharge

Measurement and Pattern Analysis Method of DC Partial Discharge

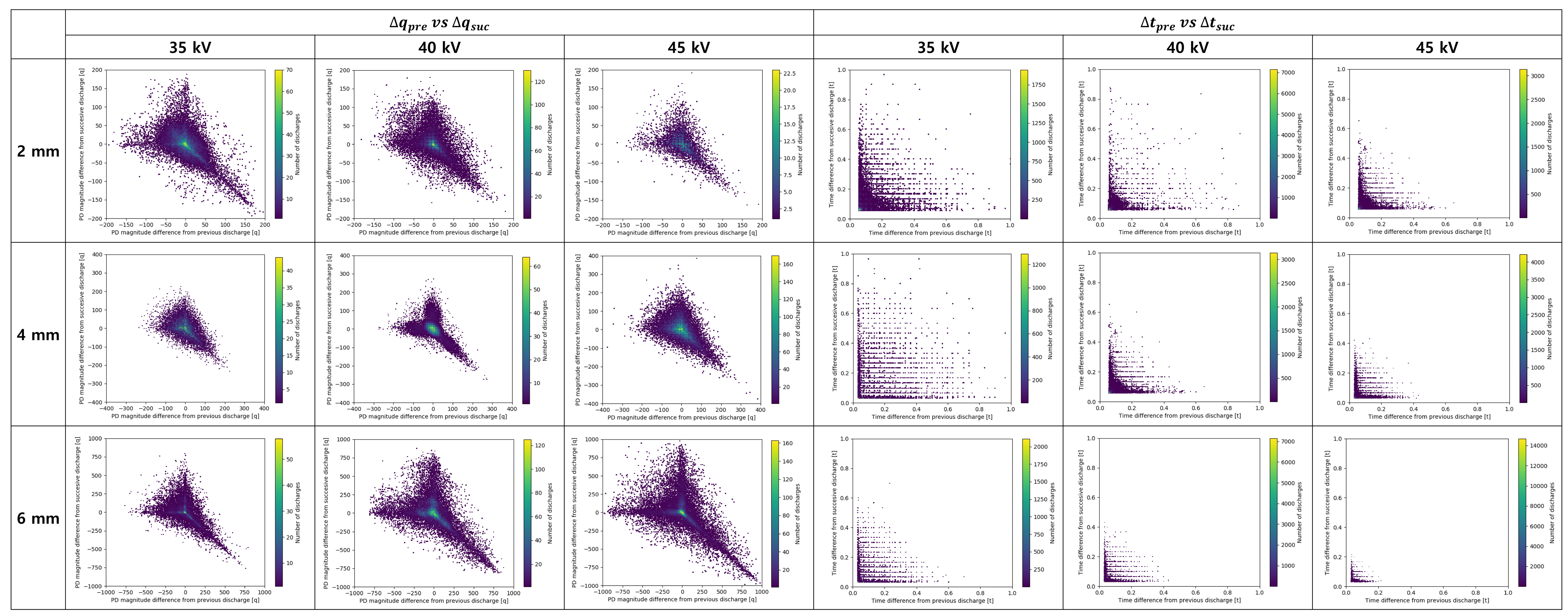


Fig. 6 Patterns of DC void discharge according to the size of void and magnitude of applied voltage

- The method of pattern acquisition could be summarized as following sequence. Firstly, the DC void discharge data are accumulated in real time according to the size of void and the magnitude of applied voltage. Secondly, in order to remove the noises included in DC void discharge data, TF mapping in DC void discharge is performed. Third, based on the results of TF mapping, the pattern of DC void discharge is analyzed using the PSA method. Finally, the patterns acquired through the PSA method are plotted using the PYTHON program.
- As shown in Fig. 6, from the results of pattern analysis using Δq_{pre} vs Δq_{suc} method, a triangular star patterns in which discharges were concentrated at the origin were obtained. Also, from the results of pattern analysis using Δt_{pre} vs Δt_{suc} method, a decreasing exponential function patterns in which discharges were distributed horizontally in the x-axis direction were obtained.