Analysis of Partial Discharges as Defects of the CNCO-W Cable

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ABSTRACT : *This paper dealt with the analysis of Partial Discharges (PDs) as defects in a 22.9 kV CNCO-W cable. Two needle electrodes with radius of 10 μm and 30 μm were installed to simulate the defects in the cable. The PD signals were measured, and the magnitude and number of PD pulses were analyzed with a Data Acquisition System (DAS), with an AC voltage of 3~4 kV_{rms} applied for 100 hours. The phase (Φ), magnitude (q), and number (n) of the PD signals as defects were also presented via a Phase-Resolved Partial Discharge (PRPD) analysis to confirm the PD patterns.*

From the experimental results, it was confirmed that the magnitude and number of PD pulses decreased in accordance with the time of the applied voltage and the differences in the Φ-q-n patterns as defects.

KEY WORDS : CNCO-W cable, Partial Discharge, DAS, PRPD analysis, Φ-q-n patterns

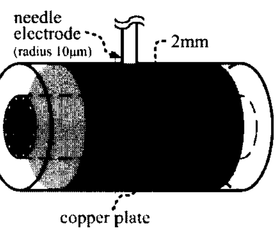
1. Introduction

An electric power cable in operation is always under stress[1]. The insulation material of the power cable can have defects when affected by humidity or foreign substances during the cable's use or fabrication. Also, if the power cable is exposed to electrical stress for a long time, the defects may cause PD and electrical trees in the insulation material. Finally, short-circuit or ground fault accidents may happen due to insulation breakdown[2-7]. To prevent such accidents, the PD measurement technique, which can be used online to diagnose cable insulation, is being widely studied in many countries[8-11].

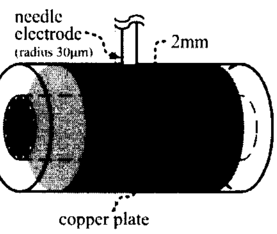
This paper described the PD characteristics as defects of the CNCO-W cable. A low-noise amplifier was fabricated to measure the PD signals, and the signals were transmitted to the Data Acquisition System (DAS) on a PC and saved there.

2. Sample and experimental procedure

Figure 1 shows the simulated electrode systems. Needle electrodes were installed in each sample to simulate the PD occurrence. Each of the electrode systems consisted of a needle electrode with 10 μm or 30 μm inserted vertically into the cable insulation. The distance between the copper wire and the needle electrode was 2 mm.



(a) A-type



(b) B-type

Fig. 1 Electrode systems

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Figure 2 shows the diagram of the experimental procedure for the measurement of the PD signals. The DAS (125 MHz, National Instruments) was used to accumulate the magnitude and number of PD pulses according to the time of the applied voltage.

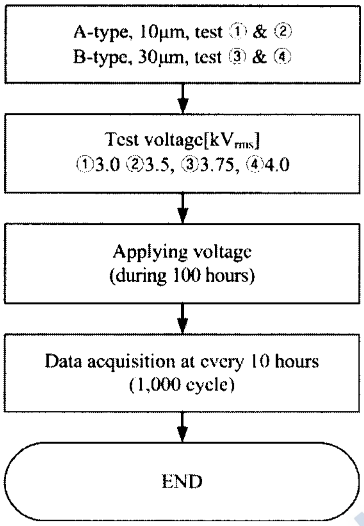


Fig. 2 Experimental procedure

The discharge inception voltage (DIV) was applied at 3.0 kV_{rms} and 3.5 kV_{rms} to the A-type electrode systems, and at 3.75 kV_{rms} and 4.0 kV_{rms} to the B-type electrode systems. The PD pulses were measured during 1,000 cycles with the DAS for 2.5 minutes every 10 hours while applying voltage to the samples for 100 hours.

3. Experimental setup

3.1 PD measurement system

Figure 3 shows the configuration of the experimental setup. The PD measurement system consisted of a PD-free transformer, a shielding enclosure, a high-voltage (HV) probe, a high-frequency current transformer (HFCT), a low-noise amplifier, and the DAS.

Test voltage with frequency of 60 Hz was applied to the samples using the PD-free transformer up to 5 kV_{rms}. The experiment was carried out in a shielding encloser to minimize the external radiative noise, and a noise cut transformer (NCT) was installed at the output of the AC power source to reduce the conductive noise. Applied voltage was measured with the HV probe at frequency range of D C~75 MHz, and the PD signals were measured via HFCT at the frequency range of 2 kHz~30 MHz. Also, it was transmitted to the DAS on a PC.

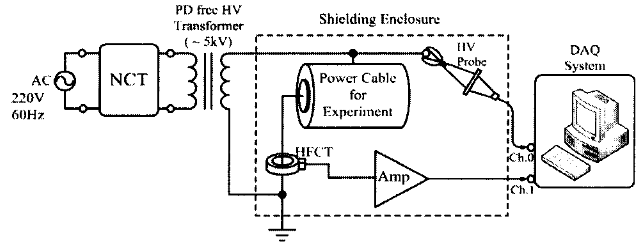
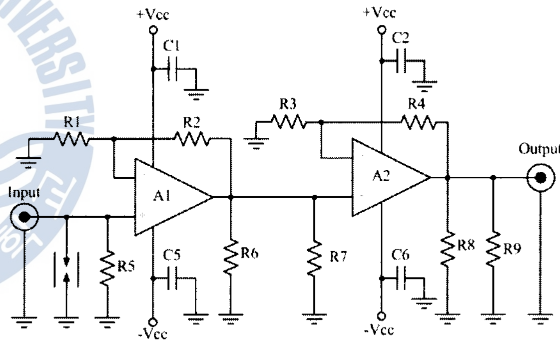


Fig. 3 Configuration of the experimental setup

3.2 Prototype amplifier

PD signals have the frequency range of a few kHz~MHz and are small magnitude of a few pC[12]. Therefore, a low-noise amplifier was designed and fabricated, as shown in Figure 4, for the measurement of the PD pulses. The amplifier consisted of double operational amplifiers (THS-3001, DC~420 MHz, CMRR : -60 dB).



(a) Circuit

(b) Photograph

Fig. 4 Prototype amplifier

Figure 5 shows the frequency response of the prototype amplifier. A signal generator with a frequency range of 100 kHz~110 MHz was used to analyze the frequency characteristics. The prototype amplifier had a frequency range of 500 kHz~30 MHz (-3 dB). Therefore, it was confirmed that the fabricated amplifier was suitable for detecting the PD signals.

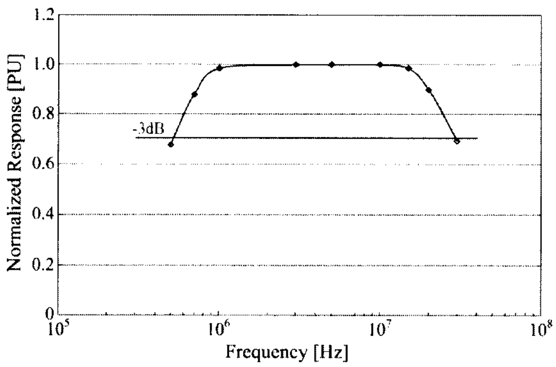


Fig. 5 Frequency characteristic of amplifier

Before the experiment, a calibration experiment was carried out by applying the pulse signal of 10~100 pC to the experimental setup presented in Figure 3. 10.28 mV/pC and 11.58 mV/pC were measured in the A- and B-type electrode systems, respectively, and the results are presented in Figure 6.

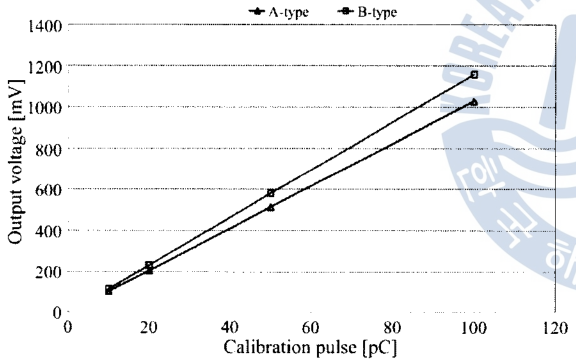


Fig. 6 Calibration charge vs. output voltage

4. Results and Discussion

4.1 PD analysis

The maximum magnitude (Q_{max}) and number of PD pulses according to the time of the applied voltage and the type of the defect are presented in Figure 7 and 8, respectively. The measured PD signals in the A- and B-type electrode systems were analyzed that the magnitude and number of PD pulses decreased as the time of the applied voltage.

These phenomena may cause carbonation and an increase in the curvature radius of the electrode due to the PD occurrence.

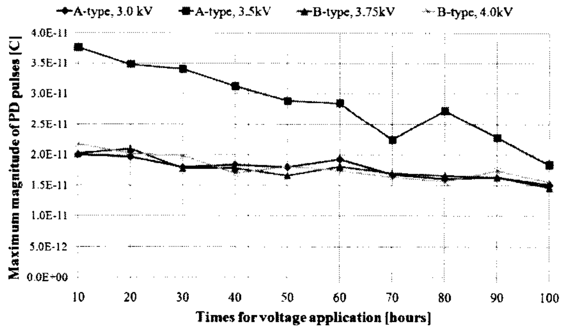


Fig. 7 Changes in the Q_{max} as a function of time

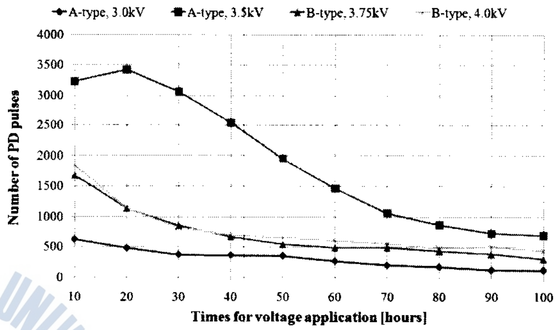
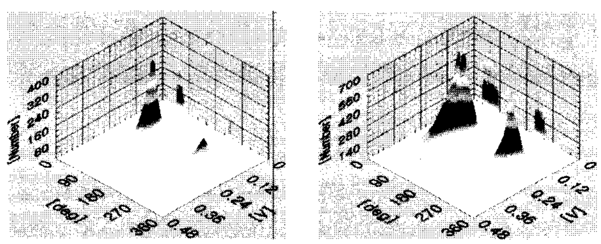


Fig. 8 Changes in the PD pulse as a function of time

4.2 Φ-q-n analysis

While the voltage was applied through the experiment, the PD pulses were measured every 10 hours and accumulated by cycle. Figures 9 and 10 show the Φ-q-n patterns as defects by PRPD analysis. In the A-type electrode system, most of the PD pulses occurred at the 45~90° and 215~250° phases, with the applied voltage of 3.0 kV$_{rms}$, and 2,657 times at the positive (+) phase and 420 times at the negative (-) phase. Q_{max} was measured at 20.03 pC. With the applied voltage of 3.5 kV$_{rms}$, the PD pulses mainly occurred at the 1 5~95° and 200~275° phases, and the number of PD pulses appeared 15,690 times at the positive (+) phase and 3,349 times at the negative (-) phase. Q_{max} was measured at 37.65 pC.



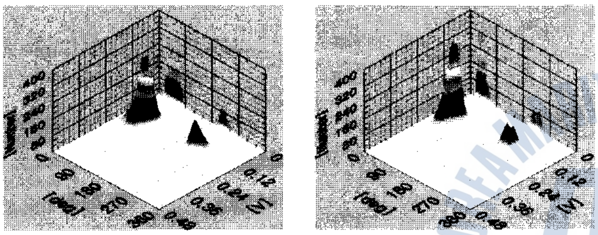
(a) 3.0 kV$_{rms}$ (b) 3.5 kV$_{rms}$

Fig. 9 Φ-q-n patterns at the A-type of the electrode system

The results showed that the phase ranges, number of PD pulses, and Q_{max} increased as the applied voltage increased.

In the needle electrode system B, most of the PD pulses occurred at the 5~90° and 190~270° phases, with the applied voltage of 3.75 kV_{rms}, and 5,850 times at the positive (+) phase and 1,117 times at the negative (-) phase. Q_{max} was measured as 20.21 pC. With the applied voltage of 4.0 kV_{rms}, the PD pulses mainly occurred at the 5~85° and 190~240° phases, and the number of PD pulses appeared 6,307 times at the positive (+) phase and 1,413 times at the negative (-) phase. Q_{max} was measured at 21.68 pC.

In other words, unlike the A-type electrode system, the B type showed that while the number of generated PD pulses and Q_{max} rose with the increase in the applied voltage, the bandwidth of the phase for PD pulses became less wide.



(a) 3.75 kV_{rms} (b) 4.0 kV_{rms}

Fig. 10 Φ-q-n patterns at the B-type of the electrode system

5. Conclusion

In this paper, we measured partial discharges and analyzed phase distribution as defects in a 22.9 kV CNCO-W cable. Two needle electrodes with radius of 10 μm and 30 μm were used to simulate the defects in the cable. A low-noise amplifier with a frequency range of 500 kHz to 30 MHz (-3 dB) was designed to measure the PD pulse. The sensitivity of the PD measurement system in each electrode was 10.28 mV/pC for the A-type and 11.58 mV/pC for the B-type.

The PD pulses were measured, and the magnitude and number of PD pulses were analyzed with a DAS, with an AC voltage of 3~4 kV applied for 100 hours. The phase (Φ), magnitude (q), and number (n) of the PD pulses as defects were presented from the PRPD analysis.

From the experimental results, it was confirmed that the magnitude and number of PD pulses decreased according to the time of the applied voltage, and the Φ-q-n patterns differed as defects.

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