Detection of Partial Discharges by a Monopole Antenna in Insulation Oil

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Abstract: - This paper dealt with the measurement and analysis of electromagnetic waves generated by partial discharge (PD) in insulation oil to develop insulation diagnostic techniques for oil-immersed transformers. Two types of narrow-band monopole antennas with resonant frequency of 500 MHz and 1 GHz were designed and fabricated. Electrode system which consists of a needle with a curvature radius of 10 μm and a plane with a diameter of 60 mm was manufactured to simulate insulation defects in insulation oil. Electromagnetic wave produced by PD was measured and analyzed. Output voltages of the fabricated antennas were compared for the same PD magnitude; 620 mV_{peak} for the 500 MHz antenna and 920 mV_{peak} for the 1 GHz antenna.

Key-Words: - Electromagnetic wave, Partial discharge (PD), Insulation oil, Insulation diagnosis, Monopole antenna, Resonant frequency

1 Introduction

Failures in power transmission, substation and distribution system can cause a large-area outage and huge economic loss. Therefore, it is essential to monitor the on-line condition of main power facilities including transformer in order to assure the reliability of power supply [1]–[4].

Insulation is an important parameter to evaluate power facilities' electrical performance and is aged by electrical, mechanical, chemical and thermal stress. Insulation deterioration leads to an electrical failure. Studies have focused on partial discharge (PD) detection as the PD is a phenomena appearing in the initial state of insulation deterioration [5]–[7]. There are two types of PD detection; off-line and on-line. The off-line detection is used in factory for quality control of power devices, and the on-line detection is applied to condition monitoring during operation of power facilities [8].

Transformers in power transmission, substation and distribution system are oil-immersed insulation type, and the development of techniques and sensors which can detect electromagnetic (EM) waves radiated from PD source are under active procedure [9]–[11].

This paper described a detection of EM waves produced by PD in insulation oil to apply to an insulation diagnosis of oil-immersed transformers. Monopole antennas each of which has the resonant frequency of 500 MHz and 1 GHz were designed and fabricated.

Characteristics such as resonant frequency and return loss of the prototype antennas were analyzed, and sensitivity of them was compared for the same PD magnitude in insulation oil.

2 Design and Fabrication

2.1 Monopole antenna

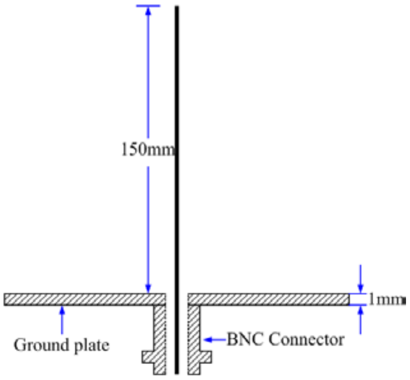
Partial discharge can be caused by the existence of defect as a void and/or a crack inside of insulation materials, due to the concentration of electric field [12]. PD pulses have a very short rise-time of a few ns and its frequency component ranges from a few hundred of kHz to a few GHz.

A monopole antenna for PD detection in insulation oil was designed and fabricated using Equation (1).

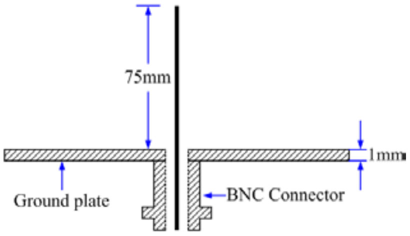
$$c = \lambda \cdot f \qquad (1)$$

The length of a monopole antennas with resonant frequency of 500 MHz and 1 GHz are 150 mm and 75 mm respectively, because one-fourth of wave length is fine for the length of antenna. Grounding electrode of the antennas was made of cooper plate which is 1 mm in thickness. The structure is shown in Fig. 1.

Return loss of the antennas was evaluated by a network analyzer (Anritsu 37369D) with frequency bandwidth of 40 MHz–40 GHz. Resonant frequency of the antennas was 500 MHz and 1 GHz, respectively, as shown in Fig. 2.

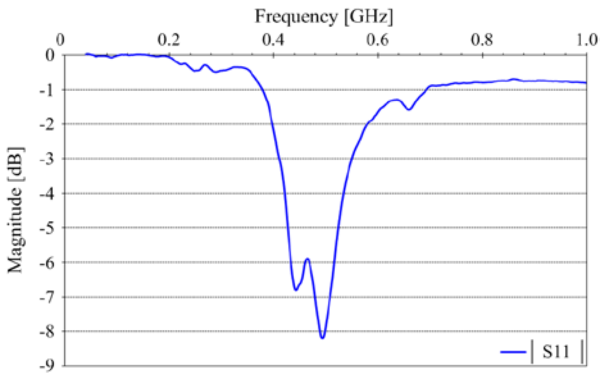


(a) 500 MHz antenna

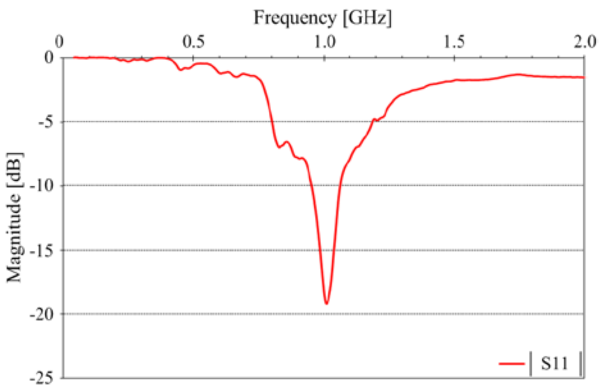


(b) 1 GHz antenna

Fig. 1 Structure of the monopole antennas



(a) 150 mm



(b) 75 mm

Fig. 2 Return loss as a function of frequency

2.2 Electrode system

A needle-plane electrode system was fabricated to simulate the defects that may exist in oil-immersed transformers. As shown in Fig. 3, the plane electrode was made of a tungsten-copper alloy disc of 15 mm in thickness and 60 mm in diameters to avoid electric field concentration, and the radius of curvature of the needle was 10 μm. Also, a press-board with thickness of 1.6 mm was inserted between the needle and plane electrode.

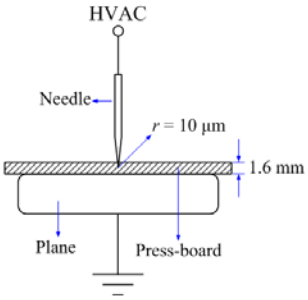
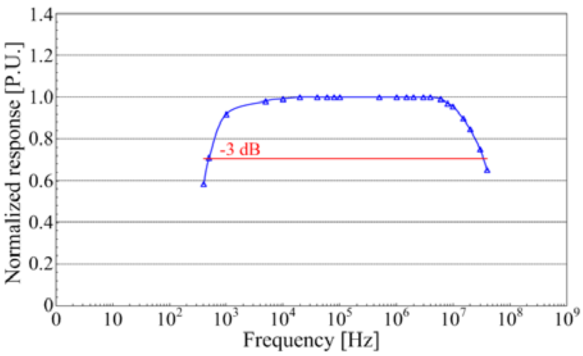


Fig. 3 Structure of the electrode system

2.3 PD measurement system

PD pulse is a high frequency current with rise-time of a few ns. To detect these PD pulses, a PD free coupling capacitor or high frequency current transformer (HFCT) is necessary [13]. In this paper, a HFCT with frequency bandwidth of 100 kHz–20 MHz was used to detect the PD pulse flowing through a ground line. A low-noise amplifier shown in Fig. 4(a) was fabricated to detect small PD pulses.

(a) Photograph



(b) Frequency response

Fig. 4 The prototype low-noise amplifier

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We evaluated the frequency response of the low-noise amplifier by the ratio of output signals to sine wave input, using signal generator. Frequency bandwidth of the prototype amplifier was in ranges of 500 Hz–45 MHz (-3 dB) at a gain of 40 dB.

3 Experiment and Analysis

An experiment system was set up as shown in Fig. 5 to calculate the sensitivity of the PD measurement system with a HFCT.

The sensitivity is calculated by the ratio of the input pulse to the output voltage of the PD measurement system, and the input pulse was applied by a standard pulse generator (CAL 1A, 10 pC–100 pC).

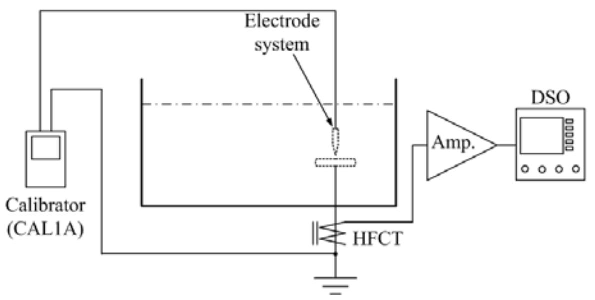


Fig. 5 Configuration of the calibration experiment system

Output voltage of the PD measurement device to input pulse is shown in Table 1. The calculated sensitivity is about 22 mV/pC, and Fig. 6 shows linearity in ranges of 10 pC–100 pC.

Table 1 Sensitivity of the PD measurement system

Applied charge [pC]	Output voltage [mV]	Sensitivity [mV/pC]
10	220	22.0
20	438	21.9
50	1090	21.8
100	2180	2.18

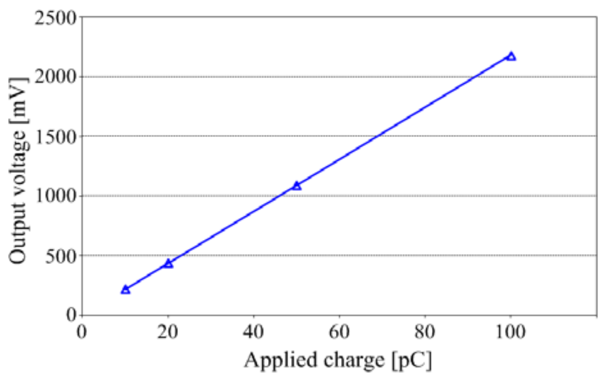


Fig. 6 Linearity of the PD measurement system

After the calibration, a PD measurement system was set up as shown in Fig. 7 to evaluate the performance of the antennas by detecting EM waves radiated from a PD origin in insulation oil. The needle-plane electrode system and the monopole antenna were set in insulation oil, and PD pulse was generated by applying high voltage up to 15 kV.

Fig. 8 shows typical EM waveforms detected by the fabricated antenna.

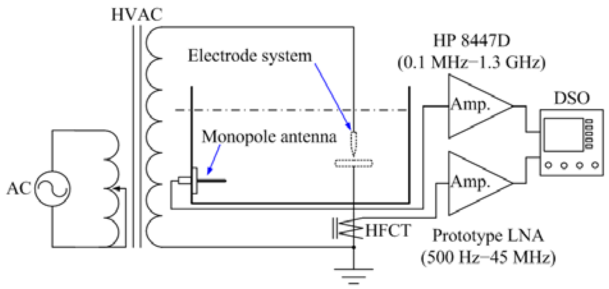
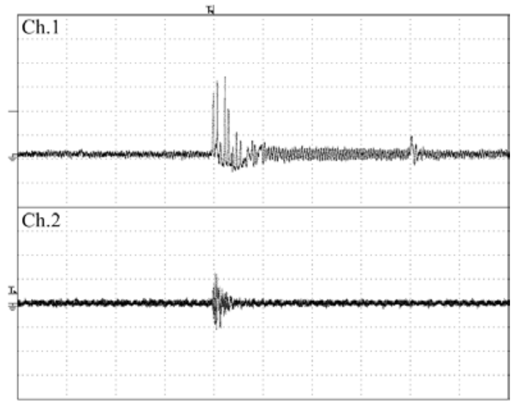
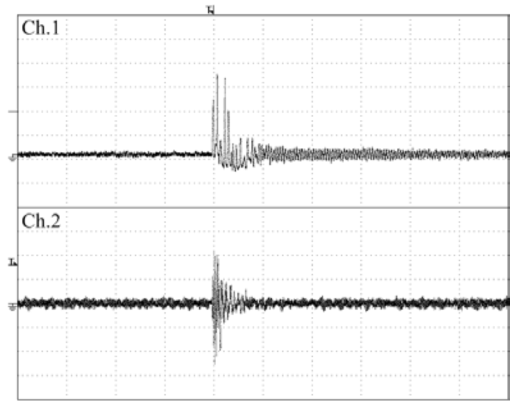


Fig. 7 Configuration of the PD measurement system



Ch.1: HFCT [500 mV/div, 500 ns/div]
Ch.2: Antenna [500 mV/div, 500 ns/div]
(a) 500 MHz antenna



Ch.1: HFCT [500 mV/div, 500 ns/div]
Ch.2: Antenna [500 mV/div, 500 ns/div]
(b) 1 GHz antenna

Fig. 8 Typical EM waveforms detected by the monopole antenna

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Output voltages of the PD measurement system were 620 mV_{peak} in the 500 MHz antenna and 920 mV_{peak} in the 1 GHz antenna for the same PD magnitude of 73.6 pC.

4 Conclusion

In this paper, the measurement and analysis of electromagnetic waves generated by partial discharge (PD) in insulation oil was described to develop insulation diagnostic techniques for oil-immerged transformers. Narrow-band monopole antennas with resonant frequency of 500 MHz and 1 GHz were designed and fabricated. The output voltages of the antennas were compared at the same PD magnitude, and the results showed 620 mV_{peak} for the 500 MHz antenna and 920 mV_{peak} for the 1 GHz antenna.

Consequently, it was confirmed that EM waves generated by partial discharges in insulation oil can be effectively detected using a monopole antenna with resonant frequency of 500 MHz–1 GHz.

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