Analysis of Partial Discharge in Insulation Oil using Acoustic Signal Detection Method

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Abstract: This paper dealt with the frequency analysis of acoustic signal produced by partial discharge (PD) in insulation oil and the positioning of PD occurrence to apply to diagnose oil insulated transformers. We assembled three types of electrode system; the needle-plane, the plane-plane, and the void to simulate partial discharge in insulation oil. A low-noise amplifier and a decoupler were designed to detect acoustic signal with high sensitivity. The frequency ranges of acoustic signal were 70 kHz~210 kHz in the needle-plane, 65 kHz~260 kHz in the plane-plane, and 60 kHz~270 kHz in the void electrode system. Their peak frequencies were 133 kHz, 132 kHz and 128 kHz, respectively.

The position of PD occurrence was calculated by the time difference of arrival (TOA) using four acoustic emission (AE) sensors and we could find the position within the error of 3% in the experimental apparatus.

Key-Words: - Acoustic signal, Partial discharge (PD), Oil insulated transformers, Diagnosis, Electrode system, Frequency analysis, Position, Time difference of arrival (TOA)

1 Introduction

Electrical insulation is an essential element to determine the performance of power facilities, and it requires durability against mechanical, thermal, chemical, and electrical stress experienced during operation. The functionality and longevity of power facilities are closely related to the characteristics of insulation materials. The insulation performance declines when the insulation materials deteriorate. Partial discharge occurs first and breakdown follows eventually. Most large-capacity transformers adopt oil insulation and their insulation status is constantly monitored to ensure stable power supply.

Diverse technologies have been developed for last several decades to diagnose insulation performance of oil insulated transformers. Representative methods include those that measure insulation resistance and dielectric loss, analyze gas and partial discharge detection [1], [2]. Since methods that measure insulation resistance and dielectric loss should be performed off-line state, they are only available for periodic precision diagnosis but not for on-line diagnosis. On the other hand, analyze gas and partial discharge detection method is able to on-line diagnosis. Partial discharge measurement is an effective way to detect degradation of insulation status or failures as a result of electrical stress. Partial discharge measurement may divide into two method; electrical measurement and acoustic signal detection.

Electrical measurement method features merits as a high sensitivity and precision measurement but also has such demerits as vulnerability to noise. Further, in case of ultra high voltage transformers, it has another critical shortcoming that the coupling network can not be installed during operation. Acoustic signal detection method of partial discharge has lower sensitivity than electrical method but strong protection from peripheral electromagnetic noise as insulated electrically while the sensor can be easily installed during operation. In addition, we can find the location where partial discharge arises by measuring the acoustic signals' time difference of arrival (TOA) when multiple sensors over three are used [3], [4].

In this paper, we studied the frequency analysis of acoustic signal generated by partial discharge in insulation oil and the positioning of partial discharge (PD) occurrence to apply to diagnose oil insulated transformers. A decoupler and a low-noise amplifier to detect acoustic signal with high sensitivity were designed. Also, three types of electrode system; the needle-plane, the plane-plane, the void were assembled to simulate partial discharge.

2 Measurement System

In this paper, AE sensors (R15I-AST, PAC) with the operating frequency range of 50 kHz~200 kHz and resonant frequency of 150 kHz were used to detect acoustic signal generated by partial discharge.

We need a filtering decoupler to separate acoustic signal from the power source as the sensor do not provide separate cables for power and signal lines.

Also we need a wideband amplifier that includes functions to cover the frequency characteristics of the sensor to measure acoustic signal with high sensitivity though they are equipped with an embedded preamplifier. Figure 1 shows the circuit of decoupler designed to separate the acoustic signals while supplying DC voltage.

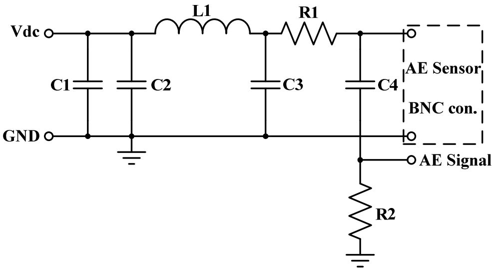


Fig.1 Circuit of the decoupler

The high frequency component of DC voltage is blocked at L1 and only DC voltage is supplied to AE sensor. The acoustic signal detected by AE sensor is passed to the amplifier via C4 and can not pass to DC source by L1 and C3. The prototype decoupler designed in this study has frequency responses shown in Figure 2.

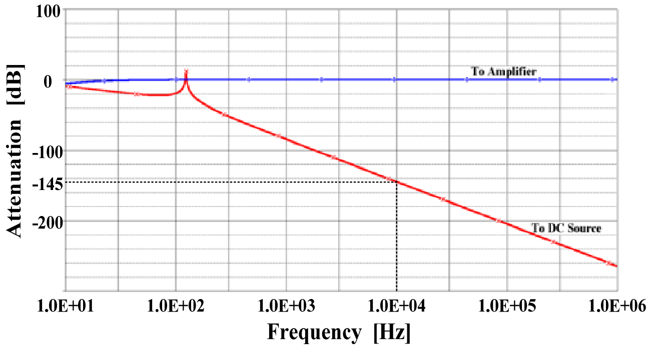


Fig.2 Frequency response of the decoupler

Any acoustic signal of 10 kHz or higher from the power source is attenuated to 145 dB but is transmitted to amplifier input terminal, R2 without attenuation.

As shown in Figure 3, the low-noise amplifier was designed and fabricated to have wideband characteristics to acquire 40 dB gains using the low-noise, wide-band operational amplifier whose gain-bandwidth is 70 MHz.

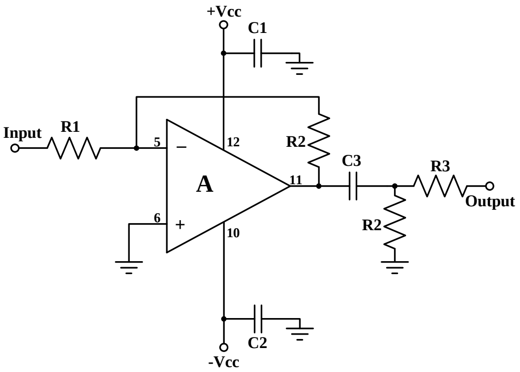


Fig.3 Circuit of the amplifier

The frequency response of the amplifier is analyzed by the ratio of output voltage to sine-wave input voltage from 1 kHz to 2 MHz using a signal generator as shown in Figure 4. The amplifier has a high cutoff frequency of 1.8 MHz and a low cutoff frequency of 1.6 kHz at -3 dB as shown in Figure 4.

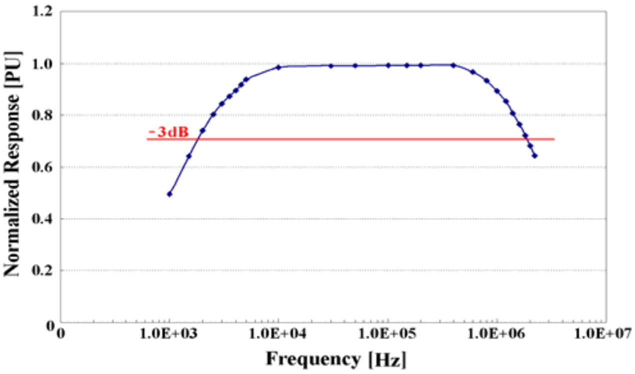


Fig.4 Frequency response of the amplifier

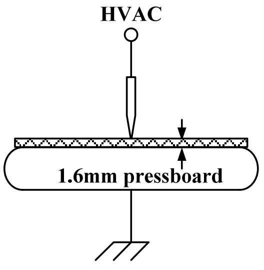
3 Experiment and Analysis

Insulation materials used on power facilities may have such production defects as spires, foreign substances, voids or cracks.

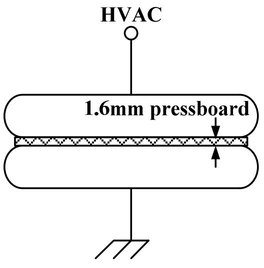
The deterioration of insulation materials also causes defects during operation. Partial discharge is generated by electric field concentration on spots where the insulation material has defects [5], [6].

In particular, it is necessary to steadily monitor partial discharge as which partial discharge in insulation oil gradually decline the performance of insulation system.

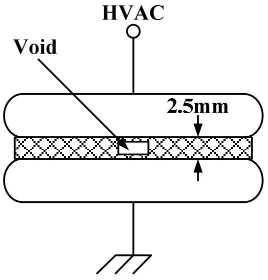
As shown in Figure 5, we assembled electrode system of the needle-plane, the plane-plane and the void in equivalent models to simulate partial discharge generated in oil insulated transformers.



(a) needle-plane



(b) plane-plane



(c) void

Fig.5 Configuration of the electrode system

The plane electrode was made of a tungsten-copper alloy disc of 1.5 mm thick and 60 mm in diameter to avoid electric field concentration. A 1.6 mm thick pressed board was inserted between the electrodes to provide a condition that is similar to that of oil insulated transformers.

As shown in Figure 6, the experimental apparatus for the simulation of oil insulated transformers was built using a metallic enclosure (740 mm×740 mm×1000 mm). We could generate partial discharge by increasing the AC voltage from 0 to 50 kV while placing the electrode system in insulation oil.

The partial discharge in oil was detected by the AE sensor installed on the outer surface of the tank and transmitted to an oscilloscope (LeCroy 9314C, 400 MHz) through the amplifier.

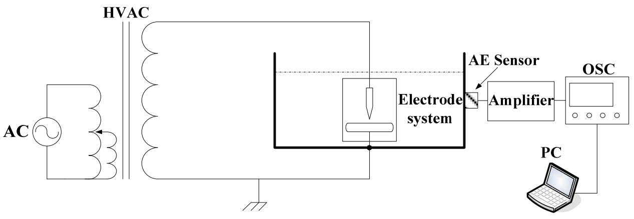
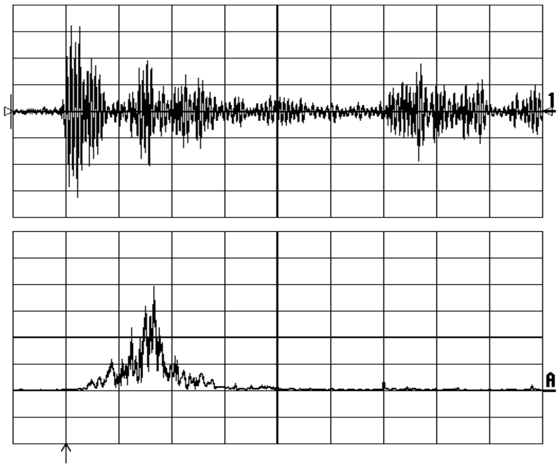


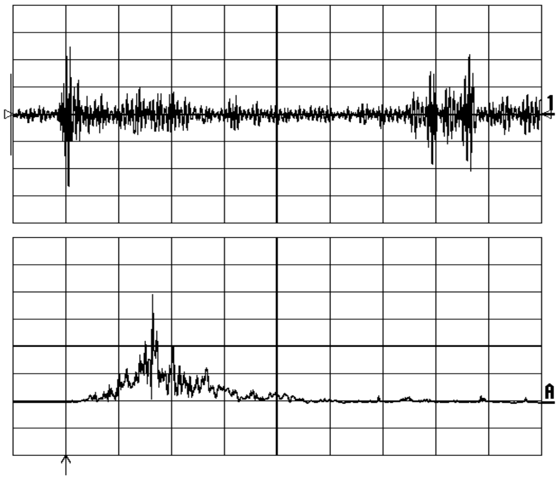
Fig.6 Configuration of the experimental apparatus

We acquired acoustic signal generated by partial discharge at the three types of electrode system to simulate defects in oil immersed transformers and their results are shown in Figure 7.



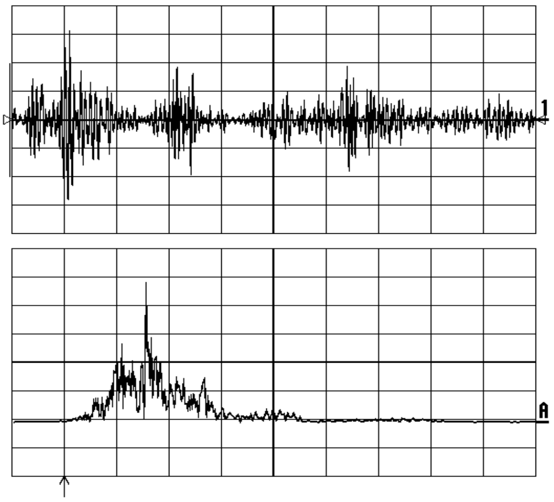
Ch.1: Acoustic signal [2 V/div, 100 μs/div]
Ch.2: FFT result [146 mV/div, 50 kHz/div]

(a) needle-plane electrode



Ch.1: Acoustic signal [2 V/div, 100 μs/div]
Ch.2: FFT result [100 mV/div, 50 kHz/div]

(b) plane-plane electrode



Ch.1: Acoustic signal [2 V/div, 100 μs/div]
Ch.2: FFT result [100 mV/div, 50 kHz/div]

(c) void electrode

Fig. 7 Acoustic signals and their FFT results

The frequency range of acoustic signal generated by the needle-plane and the plane-plane electrode system was 70 kHz~210 kHz and the peak frequency was 133 kHz. The frequency range of the plane-plane was 65 kHz~260 kHz and the peak frequency was 132 kHz, which is similar to that in the needle-plane electrode system. The frequency range in the void electrode system was 60 kHz~270 kHz and the peak frequency was 128 kHz, which is lower than that generated at the plane-plane electrode system. As discussed above, we can acquire the acoustic signal of partial discharge generated in oil insulated transformers and confirmed that the frequency ranges of the acoustic signal differ depending on defect types.

From the results, we will be able to improve the reliability on diagnosis of power facilities by accumulating and analyzing data acquired in the fields.

4 PD positioning

The diagnostic technique for transformers using acoustic signal can estimate the insulation status and find the defection spot where PD occurs.

The spot of defection can be found by two ways; electric-acoustic and acoustic-acoustic method.

The electric-acoustic method measures PD signal using a HFCT (High Frequency Current Transformer) and an AE sensor, and calculates the spot from the arrival time difference between electric and acoustic signal.

However, it is difficult to detect PD signal with HFCT because the PD signal is much too small and many different high frequency noises exist on the ground wire.

On the contrary, the acoustic-acoustic method has advantages of the possibility of insulation from electrical circuit and no influence from electrical noise.

In this paper, we used the acoustic-acoustic method to find the spot on the two plane dimension by the arrival time difference of acoustic signals.

Let us assume the propagation velocity of the acoustic signal is v , then the distance l_1, l_2 and l_3 from the sensors AE1, AE2, and AE3 in Fig. 8 can be calculated as following equations ;

$$l_1 = v \cdot t \qquad (1)$$

$$l_2 = v \cdot (t + \Delta t_1) \qquad (2)$$

$$l_3 = v \cdot (t + \Delta t_2) \qquad (3)$$

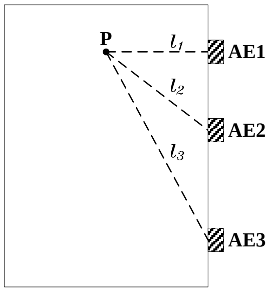


Fig. 8 PD positioning method using AE sensors

The experimental apparatus consists of metallic enclosure, discharge electrode and four AE sensors.

We marked plane-coordinates on the enclosure to calculate the spot, and installed AE sensors as shown in Fig. 9.

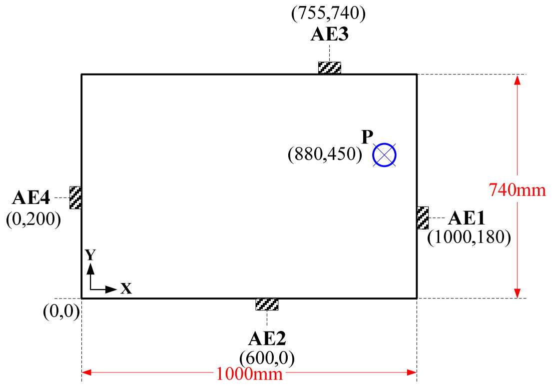
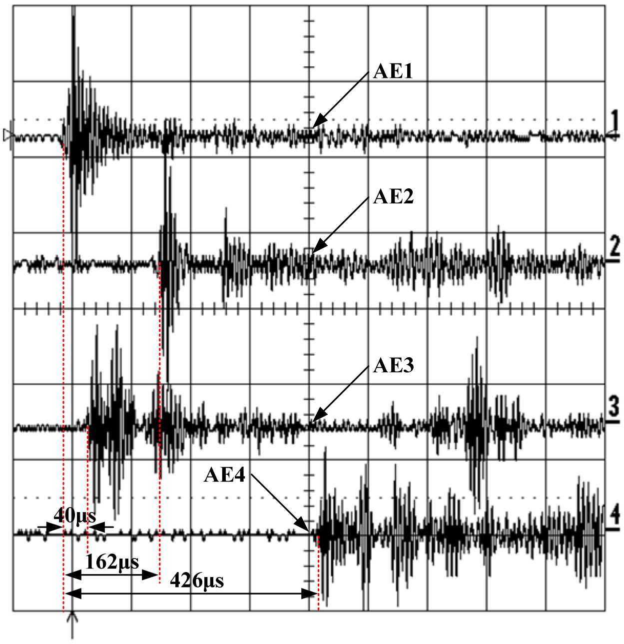


Fig. 9 Configuration of the experimental apparatus

Figure 10 shows acoustic signal detected by the three AE sensors and the arrival time differences were 162 μs between AE1 and AE2, 40 μs between AE1 and AE3, 426 μs between AE1 and AE4, respectively.



[2 V/div, 100 μs/div]

Fig. 10 Result of acoustic signal measurement

From the Equation (1) ~ (3) and the plane-coordinates of the enclosure, we can derive following equations.

$$t_{2-1} = \frac{1}{v} \cdot \left(\sqrt{(x-600)^2 + y^2} - \sqrt{(x-1000)^2 + (y-180)^2}\right) \quad (4)$$

$$t_{3-1} = \frac{1}{v} \cdot \left(\sqrt{(x-755)^2 + (y-740)^2} - \sqrt{(x-1000)^2 + (y-180)^2}\right) \quad (5)$$

$$t_{4-1} = \frac{1}{v} \cdot \left(\sqrt{x^2 + (y-200)^2} - \sqrt{(x-1000)^2 + (y-180)^2}\right) \quad (6)$$

Here, t_{2-1} is the arrival time difference between AE1 and AE2, t_{3-1} is between AE1 and AE3 and t_{4-1} is between AE1 and AE4.

The coordinates calculated by the Equation (4) ~ (6) were x=885.09 mm, y=443.55 mm and x=877.71 mm, y=427.75 mm.

The position of the electrode in this experiment was x=880 mm and y=450 mm, and the error was within 3 %.

5 Conclusion

In this paper, we carried out analysis of acoustic signal produced by PD in insulation oil and studied to find where PD occurs.

To acquire acoustic signal only, we fabricated a decoupler with the attenuation ratio of 145 dB at 10 kHz, and a low-noise amplifier with a frequency bandwidth of 1.6 kHz~1.8 MHz at -3 dB. Three types of electrode system; the needle-plane, the plane-plane and the void electrode, were assembled to generate partial discharge in insulation oil.

The frequency ranges of acoustic signal were 70 kHz~210 kHz for the needle-plane, 65 kHz~260 kHz for the plane-plane, and 60 kHz~270 kHz for the void electrode system. Further, their peak frequencies were 133 kHz, 132 kHz and 128 kHz, respectively.

Also, we could calculate the spot where PD occurs within 3% error by four AE sensors.

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