Measurement and Analysis of Acoustic Signal Generated by Partial Discharges in Insulation Oil

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Abstract: This paper described the measurement of acoustic signal generated by partial discharge in insulation oil and analysis of their frequency spectrum to acquire information for diagnosing oil insulated transformers. We designed a decoupler and a low-noise amplifier to detect acoustic signals with high sensitivity. Also, three types of electrode system; the needle-plane, the plane-plane, the wire-wire were assembled to simulate partial discharge in insulation oil. The frequency ranges of analyzed acoustic signal were 60 kHz~270 kHz for the needle-plane, 45 kHz~250 kHz for the plane-plane, and 50 kHz~180 kHz for the wire-wire electrode system. Their main frequencies were 145 kHz, 118 kHz and 121 kHz, respectively.

Key-Words: - Acoustic signal, Partial discharge, Oil insulated transformers, Decoupler, Needle-plane, Plane-plane, Wire-wire electrode, Frequency spectrum analysis

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 immersed 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 that analyze gas should be performed off-line state, they are only available for periodic precision diagnosis but not for on-line diagnosis. On the other hand, 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.

The 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 measurement of acoustic signal generated by partial discharge in insulation oil and analysis of their frequency spectrums 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 wire-wire were assembled to simulate partial discharge.

2 Measurement System

In this paper, AE sensors (R15I-AST, PAC) with the characteristics shown in Table 1 were used to detect acoustic signal generated by partial discharge.

Table 1 Operating Specification of AE Sensors

Dynamic	Peak sensitivity	-22 dB
	Operating Frequency range	50~200 kHz
	Resonant Frequency	150 kHz
	Directionality	+/- 1.5 dB

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.

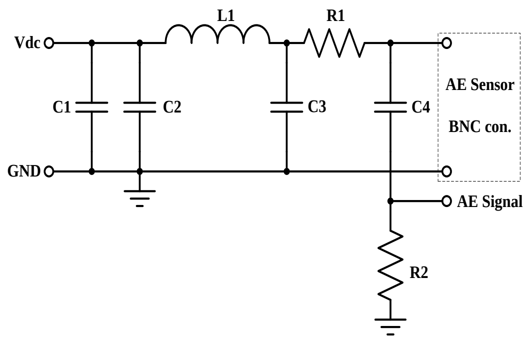


Fig.1 Circuit of the decoupler

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.

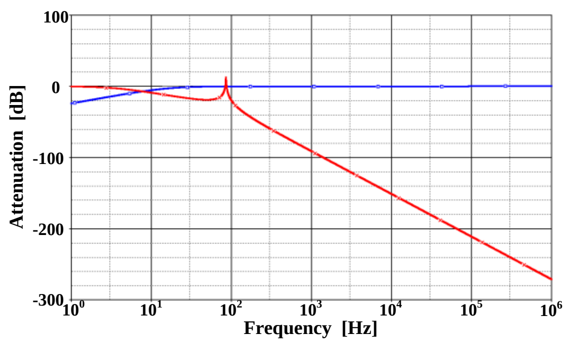


Fig.2 Frequency response of the decoupler

Any acoustic signal of 10 kHz or higher from the power source is attenuated to 150 dB but is transmitted to amplifier input, 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 operational amplifier whose gain-bandwidth is 70 MHz.

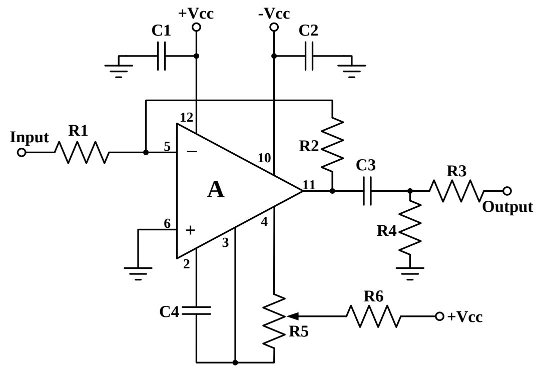


Fig.3 Circuit of the amplifier

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 1.6 MHz and a low cutoff frequency of 1.6 kHz at -3 dB as shown in Figure 4.

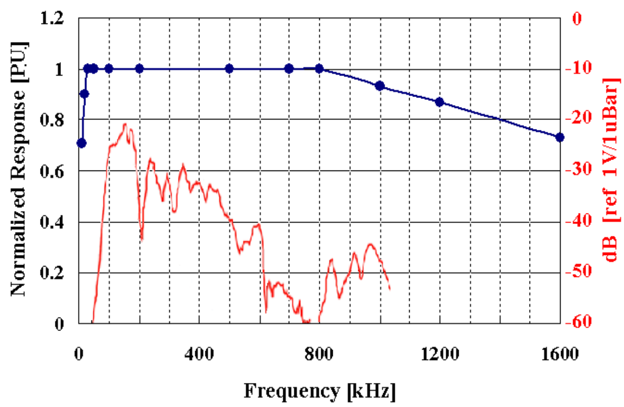


Fig.4 Frequency response of the amplifier

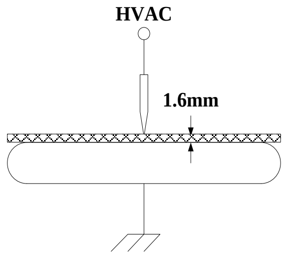
3 Experiment and Analysis

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

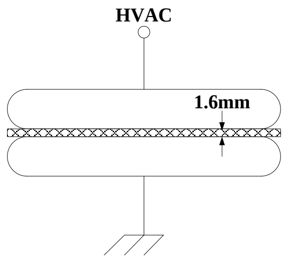
The deterioration of insulation materials also may cause defects during operation. Partial discharge is generated by electric field concentration on spots where the insulation material has defects [5], [6].

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

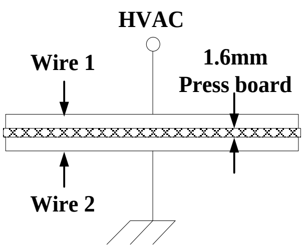
As shown in Figure 5, we assembled electrode system of the needle-plane, the plane-plane and the wire-wire in equivalent models to simulate partial discharge generated in oil insulated transformers.



(a) needle-plane



(b) plane-plane



(c) wire-wire

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 (750 mm×750 mm×1000 mm). We could generate partial discharge by increasing the AC voltage from 0 to 50 kV while placing the electrode system in oil.

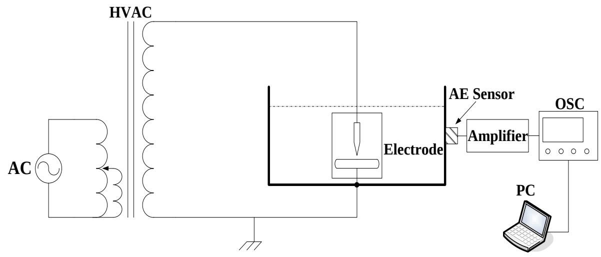
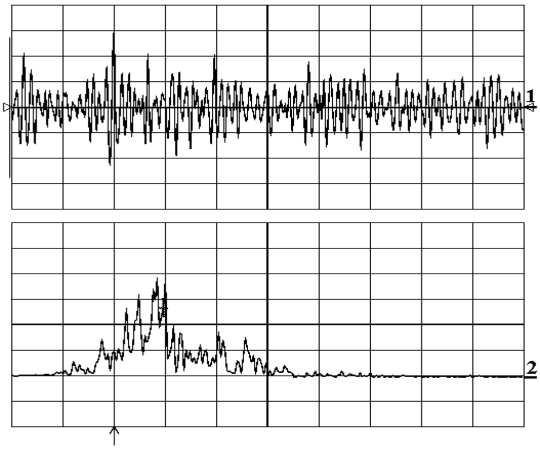


Fig.6 Configuration of the experimental apparatus

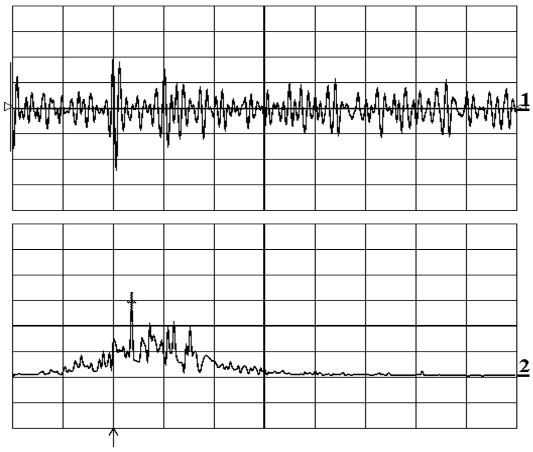
The partial discharge in oil was detected by the AE sensor installed on the outer surface of the tank and transmitted to an oscilloscope (LeCroy 9314C, 400 MHz) through the amplifier.

We acquired acoustic signal produced by partial discharge at the three types of electrode system and their results are shown in Figure 7.



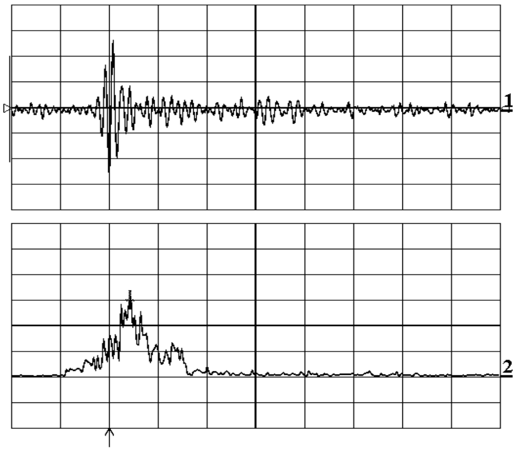
Ch.1: Acoustic signal [500 mV/div, 50 us/div]
Ch.2: FFT result [38 mV/div, 50 kHz/div]

(a) needle-plane



Ch.1: Acoustic signal [200 mV/div, 50 us/div]
Ch.2: FFT result [16.4 mV/div, 50 kHz/div]

(b) plane-plane



Ch.1: Acoustic signal [500 mV/div, 50 us/div]
Ch.2: FFT result [24.5 mV/div, 50 kHz/div]

(c) wire-wire

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 60 kHz~270 kHz and the main frequency was 145 kHz. The frequency range of the plane-plane was 45 kHz~250 kHz and the main frequency was 118 kHz, which is lower than that generated at the needle-plane electrode system. The frequency range in the wire-wire electrode system was 50 kHz~180 kHz and the main frequency was 121 kHz, which is similar to that in the plane-plane electrode system. As discussed above, we can acquire the acoustic signal of partial discharge generated in oil insulating 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 Conclusion

This paper described the experimental results on detection techniques of acoustic signal produced by partial discharge and frequency characteristics of acoustic signal depending on different electrode system in insulation oil.

1. We could separate the DC voltage and acoustic signal using a decoupler to detect the acoustic signal.
2. A low-noise wideband amplifier with a gain of 40 dB and a frequency range of 1.6 kHz~1.6 MHz at -3 dB was designed to measure acoustic signal with high sensitivity.
3. Three types of electrode system; the needle-plane, the plane-plane and the wire-wire were set up to simulate partial discharge in oil insulated transformers. The frequency ranges of acoustic signal were 60 kHz~270 kHz for the needle-plane, 45 kHz~250 kHz for the plane-plane, and 50 kHz~180 kHz for the wire-wire electrode system. Further, their main frequencies were 145 kHz, 118 kHz and 121 kHz, respectively.

ACKNOWLEDGEMENT

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