論 文
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Application of the Ultrasonic Detection System for the Power Transformer

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Abstract - This paper describes the application results of an ultrasonic detection system for the power transformer. The ultrasonic detection system with 6 sensors was applied to detect partial discharge in a 154kV transformer with a dangerous levels of C_2H_2, C_2H_4 and CH_4 gases. The ultrasonic detection tests were carried out 2 times, respectively, to confirm the existence and location of the partial discharge in the transformer. As a result of internal inspection, the arc trace between the pressure ring and core due to the partial discharge was found at the estimated position based on the amplitude and arriving time of the ultrasonic signals. Therefore, it was verified that the ultrasonic detection system is effective as a preventive diagnosis method for the power transformer. Also, the reliability of the ultrasonic detection system in detecting partial discharges in the transformer was also confirmed. It is expected, therefore, that the ultrasonic detection system will have beneficial effects on applications and verifications in detecting partial discharges for the power transformer.

Key Words - Ultrasonic, Preventive Diagnosis, Partial Discharge, Power Transformer, Location

1. Introduction

Studies on the ultrasonic technique to detect partial discharges in the power transformer have been done in Korea since the early 1990s. The development of an ultrasonic detection system and experimental studies using models and 22.9kV transformers in the laboratory have suggested the possibility of detecting partial discharges in the power transformer on-site and on-line[1-2]. However, it is considered that the detection of the ultrasonic signal is interfered by various noises from the transformer such as vibration of the core, the cooling pump, the cooling fan, the on load tap changer(OLTC) operation, and the OLTC oil purifier operation as well as the attenuation of signals due to internal structures such as the core and the winding. Since the late 1980s, though various detection results of partial discharge on-site have suggested the effectiveness of the ultrasonic detection, more detection cases of partial discharge need to be proved to apply the ultrasonic detection system as a preventive diagnostic method for the power transformer.[3-5]

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In this paper, the ultrasonic detection system was applied to a 154kV power transformer for verification the detection of a partial discharge on-site. The gas analysis in oil of the transformer showed dangerous levels of C_2H_2, C_2H_4 and CH_4 gases. The ultrasonic detection tests were carried out 2 times, respectively, to confirm the existence and location of the partial discharge.

2. Ultrasonic detection system

Recently, many on-line monitoring devices such as a dissolved gas analyzer, a partial discharge detector, an ultrasonic detector, a thermometer and an OLTC monitor, etc. have been developed to detect abnormal symptoms leading to the failure of the power transformer.[6-7] Generally, the data gathered from the on-line monitoring device is transferred to a preventive diagnosis system, and then the abnormality of the transformer is determined by the standard level and the increasing trend of the data. The preventive diagnosis system can determine the types of abnormalities by analyzing the relation of the data collected with the on-line monitoring devices.

Fig. 1 shows an ultrasonic detection system applied to the 154kV power transformer. The ultrasonic detection system consists of ultrasonic sensors(including pre-amplifier), signal processing modules(analog and digital module), main control module and a display device. The ultrasonic sensors were mounted with magnetic holders on the wall of the power transformer to detect the ultrasonic signal. The ultrasonic sensor is a piezoelectric displacement transducer operating in compressional mode and has a 150kHz resonance frequency range.

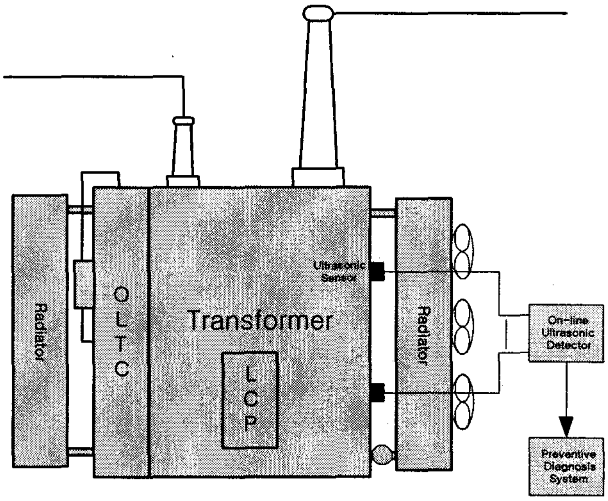


Fig. 1 Block diagram of the ultrasonic detection system applied to a 154kV power transformer

In addition, a pre-amplifier of 60dB gain is installed in the sensor to make the signal analysis easier in signal processing modules and more robust to various noises from the substation when the signal is transferred to the ultrasonic detection system.

Generally, the ultrasonic signal due to partial discharge in the transformer exponentially decreases, and its duration is several tens of milliseconds. However, the duration of the electrical noise due to corona from the overhead transmission lines is less than a few microseconds, and the duration of the noise caused by the OLTC operation is over a few hundred milliseconds.[8]

Fig. 2 shows the ultrasonic sensor and the ultrasonic detection system for this measurement.

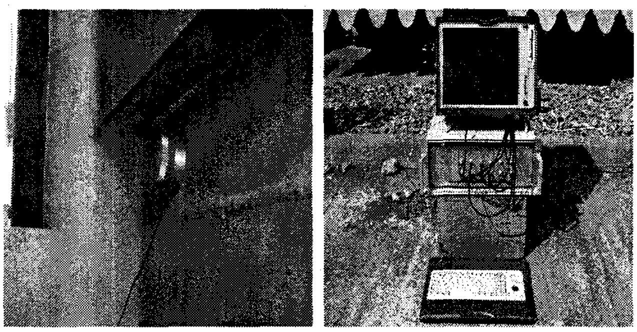


Fig. 2 Ultrasonic sensor and the ultrasonic detection system

3. Detection of ultrasonic signal at transformer

In this chapter, the cases which preventing the fault of a 154kV power transformer by ultrasonic signal detection are presented. To detect the ultrasonic signal due to partial discharge, 6 ultrasonic sensors were attached to the 154kV transformer. This transformer, 154kV/23kV 30/40MVA, had been in operation since 1978.

Table 1 The results of dissolved gas analysis in oil of the transformer

Dissolved Gas	H_2	CO_2	C_2H_2	C_2H_4	C_2H_6	CH_4	CO	TCG
2002.03.07	0	580	0	0	0	0	10	47
2003.03.05	0	427	0	0	0	2	66	68
2004.02.06	393	1,732	124	4,659	545	1,739	94	8,629
Attention Level	400	5,000	25	300	250	250	400	1,000
Abnormal Level	800	7,000	80	750	750	750	700	2,500
Danger Level	1,200	-	150	1,000	1,000	1,000	1,000	4,000

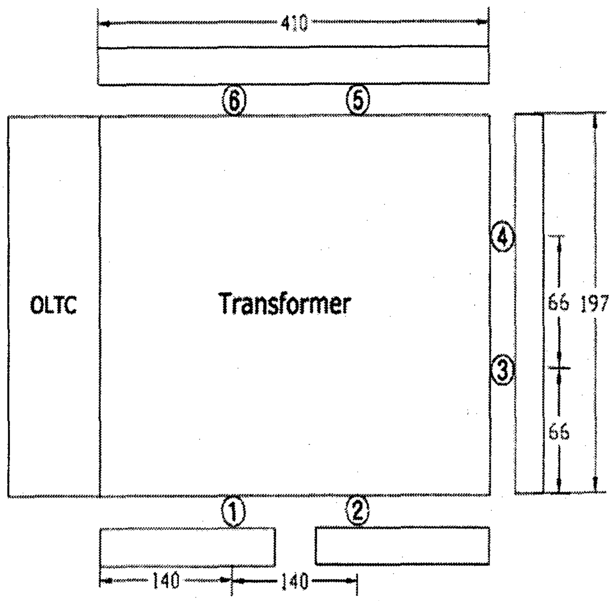


Fig. 3 The position of ultrasonic sensors attached on the wall for the first test

The results of dissolved gas analysis in oil from 1987 to 2003 showed normal status. But as shown in Table 1, the result of dissolved gas analysis in oil in Feb. of 2004 showed that the C_2H_2, C_2H_4 and CH_4 gases reached dangerous levels and the C_2H_6 gas reached attention level as well. Generally, the C_2H_2 and C_2H_4 gases are produced by partial discharge or an arc inside the transformer referring to the results of worldwide dissolved gas analysis methods such as the IEC Method, the Donenberg Method and the Rogers Method, etc.[9]

The ultrasonic detection tests were carried out 2 times, respectively, to confirm the existence and location of the partial discharge. First, it was examined whether the ultrasonic signal due to partial discharge existed in the transformer. After detecting the ultrasonic signals, the sensors were replaced for the second test, where the estimated position of partial discharge occurred to detect ultrasonic signals more accurately.

For the first ultrasonic test, the 6 sensors were attached at the same height on the wall of the transformer except for the OLTC side. The existence as well as location of partial discharge inside the transformer are assumed with this first test. Fig. 3 shows the position of 6 sensors on the wall of the transformer for the first test.

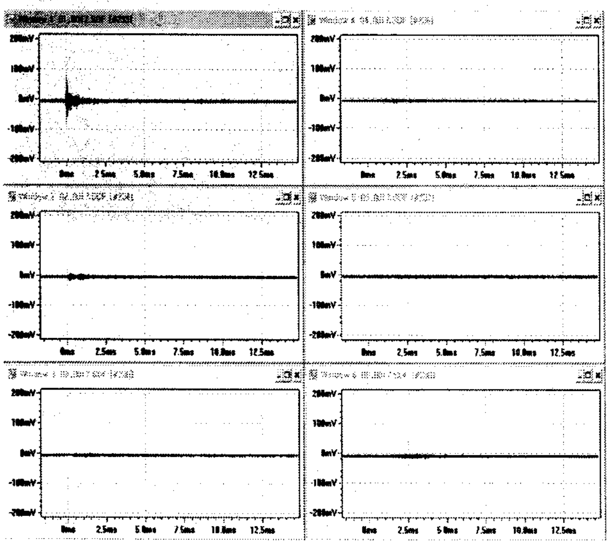


Fig. 4 Ultrasonic signals of the first test

Fig. 4 showed the ultrasonic signals of 6 sensors measured by the first test. In the results of the first test, the order of the ultrasonic signal amplitude appeared as ①>②>⑥>③≥④>⑤ and the largest ultrasonic signal was detected by sensor ①. This result illustrates that the partial discharge was the closest to the sensor ①. From the result of analyzing the amplitude and arriving time of the ultrasonic signals, it was estimated that the partial discharge occurred at the upper part of A phase near the OLTC side. Therefore, a second test was done replacing 3 sensors around sensor ① to estimate the position of partial discharge in detail.

Fig. 5 shows the position of each sensors for the second test. Sensors ②, ③ and ⑥ in Fig. 3 were moved around sensor ① to detect ultrasonic signals more precisely. Sensor ② was attached at the lower position of the transformer, and sensor ③ was attached at the upper position. Sensor ⑥ was attached at the opposite side of sensor ①.

Fig. 6 shows the ultrasonic signal and its FFT signal of the second test with sensor ①. As shown in Fig. 6, the signal shows a typical ultrasonic signal due to partial discharge and the bandwidth of the frequency spectrum was 80~160kHz. This also coincides with the ultrasonic signal by partial discharge in transformers in general.

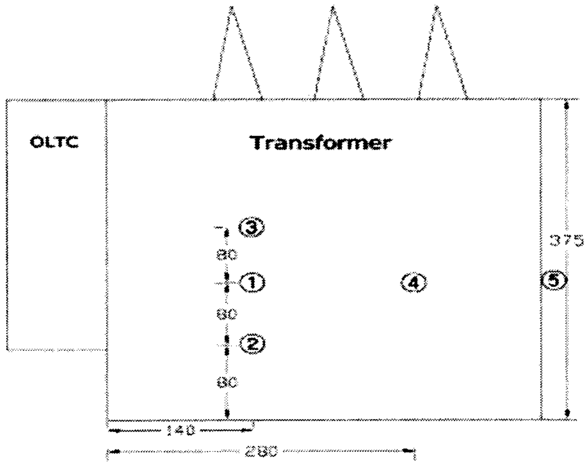
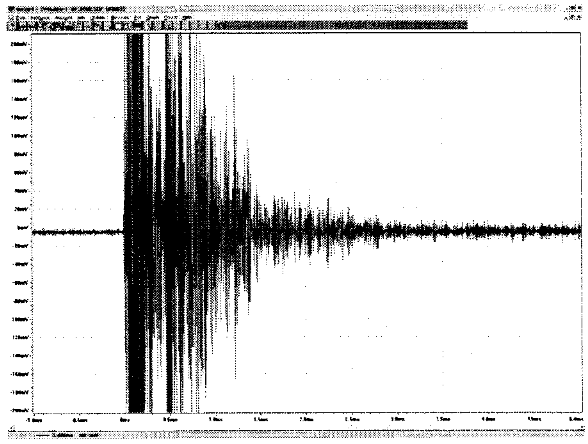
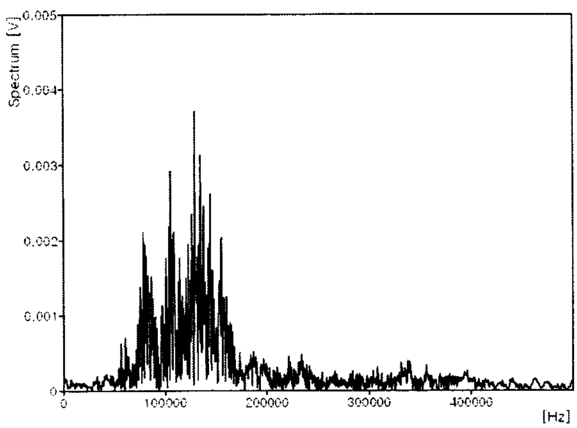


Fig. 5 The position of the sensors of the second test



(a) Ultrasonic signal due to partial discharge



(b) FFT signal of the ultrasonic signal

Fig. 6 The detected ultrasonic signal and its FFT signal of the second test

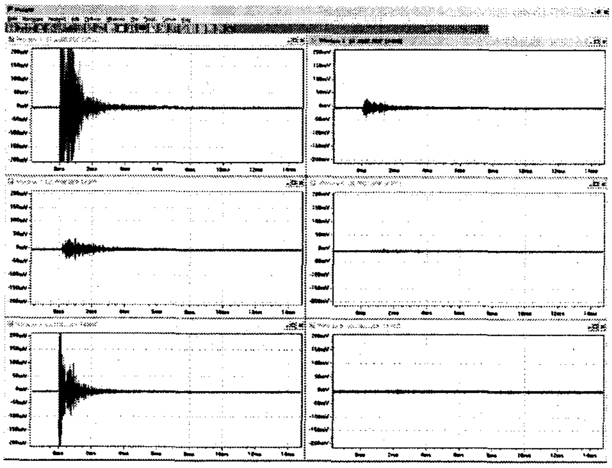


Fig. 7 Ultrasonic signals of the second test

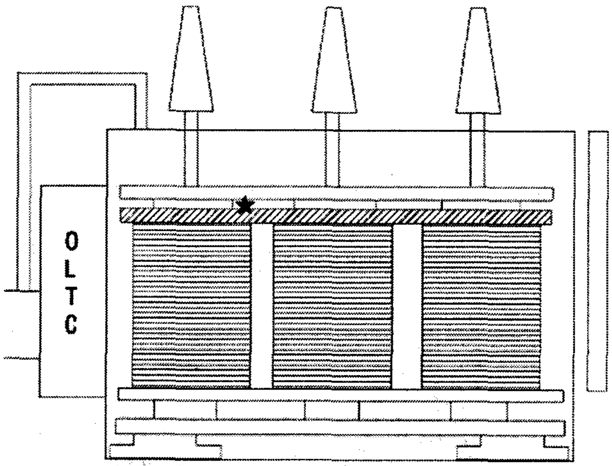


Fig. 8 Estimated location of partial discharge

Fig. 7 shows the ultrasonic signals of the second test. From the results of the second test, the order of ultrasonic signal amplitude appeared as ①≥③>②>④>⑥≥⑤, and the arrival time of each signal was ①>③>④>②>⑤>⑥ in order. The difference in the arrival time between sensor ① and sensor ③ was about 15.6μs. Therefore, it is estimated that the position of the partial discharge is located closer to sensor ① than sensor ③. Also the arrival time of sensor ④(54μs) is 72μs faster than sensor ②(126μs). Therefore it is assumed that the partial discharge occurred at the middle-upper position of the transformer near the OLTC side. Based on the ultrasonic signal of sensor ② and ④, arrive signals can be estimated through internal structures such as the core and the winding in the transformer. From the amplitude and arrival time of the signals, it was inferred that the partial discharge occur around sensor ① and ③, that is, the middle-upper position of phase A in the transformer.

Based on the results of the first and second ultrasonic tests, it was estimated that a partial discharge exists at the middle-upper position of phase A near the OLTC side. Fig. 8 shows the estimated location of the partial discharge based on the amplitude and arriving time of the ultrasonic signals.

An internal inspection was carried out to discover the source of partial discharge based on the results of ultrasonic tests. According to a visual inspection of the transformer, an arc trace was discovered at the estimated position between the upper position of A phase core near OLTC side and pressure ring based on the results of ultrasonic tests.

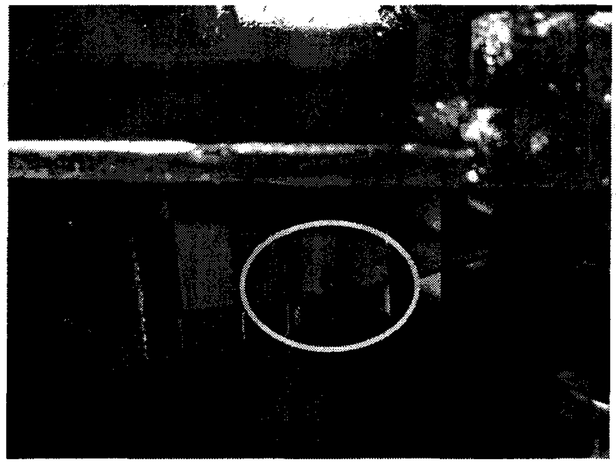


Fig. 9 The arc trace by partial discharge

Fig. 9 shows the arc trace due to the partial discharge found in the transformer. It was considered that the partial discharge occurred because of the deterioration of insulation paper between the pressure ring and the core as well as deterioration of oil through ageing.

The transformer was repaired by cleaning the arc trace mark and filtering the oil. The reliability of the ultrasonic detection system could be confirmed by measuring the ultrasonic signal due to partial discharge in the power transformer. Therefore, it is expected that the ultrasonic detection system will have beneficial effects on the application and verification when detecting partial discharges for power transformers.

4. Conclusions

This paper showed the results of the detection of ultrasonic signals due to partial discharges in a 154kV transformer through an ultrasonic detection system. The ultrasonic signal was detected in the 154kV transformer with dangerous level of gas in oil analysis using the ultrasonic detection system. As a result of internal inspections, the arc trace between pressure ring and core was found at the estimated position based on the amplitude and arriving time of the ultrasonic signals. Therefore, it was verified that the ultrasonic detection system is effective as a preventive diagnosis device for the transformer. And the reliability of the ultrasonic detection system to detect partial discharges in the transformer was confirmed. It is expected, therefore, that the ultrasonic detection system will have beneficial effects on the application and verification when detecting partial discharges for power transformers.

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