Feasibility Study on the Audible Noise Measurement of Partial Discharge in Transformer Oil

Ling Lu1,2,*, Wei Hu3, Wei Cai4, Xiaofeng Peng4, Kai She4, Xuhui Zhao5, Xiaowen Wu1,2

1 State Grid Hunan Electric Power Company Limited Research Institute, Changsha, China
2 Laboratory of Electric Equipment Noise and Vibration Research, Changsha, China
3 State Grid Yueyang Power Supply Company, Yueyang, China
4 State Grid Loudi Power Supply Company, Loudi, China
5 College of Mechanical and Vehicle Engineering, Hunan University, Changsha, China

*Corresponding author e-mail: luling11@mails.ucas.ac.cn

Abstract. Partial discharge fault detection based audible noise is a kind of new method. This paper set up a needle-plate discharge system, and investigates the feasibility of measuring the audible noise of partial discharge in transformer oil. A needle-plate discharge system is built, and audio noise of partial discharge inside and outside of transformer oil is measured by a microphone and a specially designed hydrophone. According to signal processing, it's found that the characteristics of internal and external noise have good consistency on time domain wave, spectrum distribution, and time-frequency distribution, except that the former is much larger than the latter in amplitude. The experiment results show that it's feasible to measure the noise of partial discharge in the transformer oil and have significant advantage in signal to noise ratio.

1. Introduction

The transformer is one kind of important equipment in the electric power grid, which linked different voltage level electric power grid together. So, the reliability of the transformer is directly related to the power grid's safety, stability, and efficiency. However, the transformer's faults and accidents are inevitable because of long time running and huge number. Therefore, transformer monitoring and fault diagnosis technology are particularly important [1].

Partial discharge fault is one kind of common faults of the transformer. So far, the ultra-high frequency method and ultrasonic diagnosis method are the most widely used for detecting this kind of fault, because they could ignore the low-frequency noise and could location the partial discharge position [2-4]. Also, audible noise (low-frequency noise) contains lots of information [5, 6]. In the fieldwork, an experienced engineer could qualitatively estimate the transformer's internal state and fault according to the internal noise, such as over excitation, core loose, and discharge. Chinese electric power industry standard 《DL/T 573-2010 Maintenance guide for power transformers》 described different abnormal noise and the faults may reflect [7]. Wang ping introduced in detail the different noise characterizes when the outdoor distribution transformer during normal and abnormal
operation, and the corresponding disposal methods. It believed that the fault could be detected and the accident could be prevented if the inspectors make a timely and correct judgment according to the transformer noise [8]. Fu Jinsong compared the advantages and disadvantages of the acoustical detection methods such as ultrasonic detection, noise analysis method and vibration analysis method, and built a transformer discharge simulation system to study the transformer internal discharge fault diagnosis method according to audible noise [9]. Jinxiang, Shu chang etc. proposed an identification method of distribution transformer discharge fault based on audible sound signals. The sound signal of the distribution transformer is measured in the air, and an internal discharge fault simulation experiment of a distribution transformer is made to verify the accuracy of the proposed method. The analysis results show that the method identifies the internal discharge fault of the distribution transformer effectively [10-12].

Considering there is a great attenuation when the internal noise transmission to the external air, directly measuring the noise in the transformer oil could be a good choice. This paper set up a needle-plate discharge system, measured the discharge audio noise inside and outside of the transformer oil by a microphone and a specially designed hydrophone. The time domain, frequency domain and time-frequency domain characteristics are obtained, and the results show that it's feasible to measure the noise of partial discharge in the transformer oil.

2. Experimental set up

2.1. Discharge system
The experimental system consists of two subsystems, the discharge system and the acoustical measuring system. The discharge system contains a voltage regulator, a transformer, a protection resistance, a needle-plate discharging gap, oil container, and transformer oil, as shown in figure 1.

The needle and plate are copper, and the discharge gap is placed in the oil container, immersed in the transformer oil. The voltage between the needle and the plate could be adjusted from 0 to 40kV through the voltage regulator. The oil container is a cylindrical plastic barrel, with a diameter of 45cm, and the thickness of the barrel wall is about 1mm.

![Figure 1. The circuit diagram of discharge system.](image)

2.2. Acoustical measuring system
The acoustical measuring system contains a hydrophone, a microphone, a signal acquisition module, and a computer which used for signal post-processing. The signal acquisition module and signal post-processing module based on B&K LAN-XI data acquisition hardware (type 3160) and PULSE platform.

The hydrophone is specially designed for noise monitoring in transformer oil, as shown in figure 2. Its sensing element is made of piezoelectric ceramics, and the polyurethane is selected as the sensor's encapsulation material based on compatibility tests [13]. Long time high temperature oil immersion test confirmed that the sensor has a good performance on transformer oil resistance and heat resistance.
Its sensitivity is about -202dB (reference: 1V/Pa). The microphone is a B&K type 4189-A-21 pre-polarization capacitance transducer, which is a kind of high sensitivity universal microphone and has been sold worldwide for decades due to excellent performance.

![Figure 2. The picture of hydrophone](image)

In the experiment, the voltage between the needle and plate is adjusted manually after the wires are correctly connected. The voltage is regulated higher and higher from 0kV, until spark discharge occurs, and then gradually reduce to 0kV. The hydrophone is placed in the oil, as far as possible from the discharge gap. The microphone is placed in the air, close to the barrel wall and hydrophone.

3. Experimental results
In the experiment, the signal sampling rate of signal acquisition device (B&K 3160) is 65536Hz. The time domain data obtained directly, and then the frequency domain results and time-frequency domain results are obtained through digital signal processing technology.

![Figure 3. The time domain results](image)
The time domain results obtained by the hydrophone and microphone are shown in figure 3(a) and figure 3(b), respectively. It could be found a huge impulse noise occurred at about 12.9s, which is a spark discharge occurs. The hydrophone and microphone obtained the impulse signal simultaneously. Significant difference between the two waves is the amplitude. The peak amplitude of the noise measured by the hydrophone is about 4500 Pa, while that of the microphone is about 6 Pa. The former is about 750 times larger than the latter. It is consistent with the theory of acoustics. As is well known that, great attenuation exists in the processing of sound transmits through liquid-structure-air path. It means measuring the partial discharge noise in the oil is possible, and could even obtain higher signal-to-noise of noise. The experimental results verified the theory.

With the digital signal processing technique (auto-power spectrum analysis method and peak hold method), the frequency domain results are obtained, as shown in figure 4. The blue solid curve and red dashed curve stand for the results of hydrophone and microphone, respectively. It could be found that the noises are broadband (up to 20kHz), the curves are highly similar to each other except amplitude. There are many resonance peaks in two curves and good corresponding relationship in the whole band between them. The peak amplitude of the noise measured by the hydrophone and microphone distributed between about 80~150dB and 24~95dB (the reference pressure is 1uPa), respectively. And the former is much bigger larger than the latter over the whole frequency band.

The characteristics of noise spectrum changing with time are analyzed with Short Time Fourier Transform (STFT). The STFT is used to analyze how the frequency content of a nonstationary signal changes over time [14]. The time-frequency domain results are shown in figure 5.

According to the results of time domain, spectrum, and time-frequency distribution, it could be found that the hydrophone works as well as the microphone. As is well known that the type 4189-A-21 pre-polarization capacitance transducer is mature and reliable, which implies that the hydrophone is reliable too. Besides, the hydrophone could obtain higher signal to noise ratio signal and much more details.
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Figure 5. The time-frequency domain results

4. Conclusion
This paper studied the feasibility of measuring the audible noise measurement of partial discharge in transformer oil. A specially designed hydrophone and a microphone are used for measuring the audio noise of partial discharge inside and outside of the transformer oil. It's found that the characteristics of internal and external noise have good consistency on time domain wave, spectrum distribution, and time-frequency distribution, except that the former is much larger than the latter in amplitude. It means measuring the audible noise of partial discharge in the transformer oil with specially designed hydrophone is feasible, and could have higher signal-to-noise ratio.

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