Application of acoustic imaging technology in power transformer condition evaluation

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Abstract. Power transformer is the core equipment of the power system. Its operation status directly affects the security and reliability of the whole system. Therefore, it is of great significance to evaluate its status timely and accurately. Acoustic imaging technology is first used in medical, communication and other fields, which can effectively sense abnormal sound and locate it accurately, which greatly improves the work efficiency. This paper introduces the application of acoustic imaging technology in live detection of power transformer. The result shows that the combination of acoustic imaging technology and traditional live detection technology can improve the working efficiency of live detection and the accuracy of transformer condition evaluation, which is conducive to maintaining the safe and reliable operation of power grid.

1. Introduction
With the development of national economy and the improvement of people's living standard, the requirements of power supply reliability and security of power system are also improved. As one of the most important equipment in the power system, the safe and stable operation of power transformer is also under more severe condition. In order to cope with the increasing demand and quality of power consumption, reduce the waste of resources caused by planned maintenance, and improve the reliability and safety of power supply, it is an inevitable trend in the future to adopt advanced condition monitoring means to carry out timely and accurate transformer condition assessment[1] and guide the maintenance.

Since the sound generated by power equipment contains the status information of mechanical vibration and partial discharge, especially the open equipment, such as dry-type power transformer, circuit breaker, independent transformer, etc. Therefore, when the operating parameters of some parts or equipment are abnormal, the sound generated by power equipment often changes to a certain extent. By analyzing the difference of loudness and timbre, the location of abnormal sound can be effectively identified, and the type and severity of abnormal noise can be identified according to these sound characteristics. Professionals can judge the state of the equipment and make the maintenance strategy accordingly[2,3].

2. Acoustic imaging technology
Acoustic imaging technology is based on various reconstruction algorithms, which reconstructs the three-dimensional sound field surrounding the sound source surface by measuring the sound pressure on the two-dimensional plane, including sound pressure field, sound intensity field and particle velocity field. And finally the sound field is displayed in the form of graphics or animation. Compared
with other noise source identification methods, acoustic imaging technology not only uses the intensity information of sound, but also uses the phase information of sound. That makes the results are particularly intuitive, which can easily locate and quantify the noise source, and even display the propagation path of noise. At the mean time, combined with spectrum analysis, the results are further processed to provide reliable basis for noise control and acoustic fault diagnosis.

The specific principles are as follows:

The main principle of sound source location is beam forming technology. Beam forming technology is first used in radar, sonar, wireless communication and other fields. It is based on acoustic array measurement method which is used for sound source positioning in medium or long-distance. It is especially suitable for long-distance measurement of steady-state sound source, with fast test speed and good resolution for sound source identification.

The basic principle of identifying noise source is that a group of microphones are arranged in different positions of space in a certain way to form a microphone array to receive sound signals. After proper filtering and delay summation processing, interference signals and uninterested signals are filtered out, and the main sound source location, signal frequency and sound source strength are extracted.

(1) When the distance between the sound source and the acoustic array is far, the amplitude difference between the received signals of each array element is very small. At this time, the wave surface of the acoustic wave can be regarded as the plane wave parallel to each other and in the same direction, as shown in Fig. 1.

![Fig. 1 Receiving model 1](image)

The sound source spreads to the microphone in the form of plane wave. When the wave front of microphone 1 is taken as the reference, the time delay of receiving the wave by other microphones in the array is delayed relative to microphone 1. For microphone m in the array plane, the delay can be expressed as follows:

\[ \Delta t_m = (m-1) \frac{d_m \cos \theta}{c} \]  

Where \( d_m \) is the distance between microphone 1 and microphone m; \( \theta \) is the angle between microphone m and the direction of incoming wave. Since plane waves are parallel to each other, the angle between array plane and incoming wave direction is also \( \theta \); c is the value of speed of light.

So the signal received by microphone m can be expressed as follows:

\[ s_m(t) = p(t + \Delta t_m) \]  

When the reference microphone is selected, the signals received by other microphones in the array can be determined by the above formula.

(2) When the source is not far from the the acoustic array, the signals picked up by different microphones are different in both direction and amplitude. The plane wave hypothesis will cause
serious distortion of the signal. So we need to take amplitude attenuation and phase shift into consideration and use spherical wave model, which is shown in Fig. 2.

![Fig. 2 Receiving model 2](image)

Taking one single sound source as an example and microphone 1 is still selected as the reference. At this time, the direction of the sound source is no longer parallel, and the angle between the sound source and different microphone is no longer the same. The distance between the source and each microphone is represented by \( r_1, r_2, r_3, ..., r_m \), then the delay between the source and microphone \( m \) can be expressed as follows:

\[
\Delta t_m = \frac{(r_i - r_m)}{c} \tag{3}
\]

When the array is fixed, the distance between microphones is determined. The \( r_m \) can be obtained by formula as follows:

\[
r_m = \sqrt{r_1^2 + d_m^2 - 2 \cdot r_1 \cdot d_m \cdot \sin \theta} \tag{4}
\]

Taking formula (4) into formula (2) and formula (3), the time delay values between different microphones and the signal values received by other microphones can be obtained.

3. Case study

During the online detection of AC UHV substation, technicians found that the high frequency partial discharge signal at the core grounding of No. 2 main transformer was abnormal[4]. So technicians enlarged the detecting range and found more irregular high frequency partial discharge signals around the transformer. They were very similar both in PRPD pattern and PRPS pattern, and the maximum amplitude of high frequency partial discharge signals was found at the 1000kV lead frame of No. 2 main transformer, as shown in Fig. 3, where (a) was high frequency partial discharge signal of grounding spot of 1000kV lead frame of No. 2 main transformer and (b) was high frequency partial discharge signal of grounding spot of core of No. 2 main transformer.

![Fig. 3 High frequency signals of different positions](image)
The acoustic imaging technology was used to scan the three-phase lead for a long time and analyzed the sound spectrum. It was found that there was a discharge signal on the basis of corona noise, which had higher frequency and insignificant amplitude. The discharge source was finally located at the connection part of 1000kV capacitor voltage transformer lead and bushing lead of 1000kV GIS, and existing in all three phases which were color spots in Figure 4.

![Acoustic imaging of the discharge source](image)

Fig. 4 Acoustic imaging of the discharge source

So it was judged that the signal comes from the metal discharge at the lead connection position, which has little impact on the equipment operation. Technicians decided to check the problem when the equipment were in outage period.

4. Conclusion

Acoustic imaging technology is based on the measurement of acoustic microphone array, and the distribution of sound source in space is displayed with visible light signal. It can excavate the distribution pattern of sound under different abnormal or fault conditions, and directly locate the position. It is applied in the noise identification in substation, mechanical fault location and so on, which can effectively improve the inspection and detection effect of the whole substation. Combined with the case above, it can be seen that when there is a discharge signal with low energy in the surrounding live equipment and lead wire, and it is far away from the detection position, the ultraviolet detection effect is not good[5], and it is likely that the discharge point can not be located. But the acoustic imaging technology can effectively detect the abnormal sound source signal within the audible range of the human ear, which has a certain detection effect on the low energy and stable corona discharge. When combined with high frequency detection technology and ultra-high frequency detection technology, it is helpful to identify interference signal on partial discharge instrument and improve the accuracy of transformer partial discharge judgment.

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