Field Application Research of Ultrasonic Partial Discharge Detection Technology in 500kV Reactor

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Abstract. The article introduces the working principle of ultrasonic based on the live detection technology of the reactor, and combines the actual application case of the ultrasonic test system to verify the feasibility of ultrasonic application in the field of live detection, and provide a basis for further research.

1. Ultrasonic testing technology
Ultrasonic live detection technology is a detection technology that detects and analyzes ultrasonic signals in electrical equipment. In the internal structure of the power transformer, the local weak point of insulation generates high-frequency pulse discharge under the action of electric field, and the discharge arc generates a burst-like ultrasonic signal by transient impact on the oil medium \cite{2, 3}. Partial discharge causes a strong impact between molecules. This kind of impact creates a kind of pressure on the macroscopic. Since the discharge is a series of pulse formation, the resulting pressure wave is also pulsed. It contains various frequency components and is also a frequency band. Very wide sound wave \cite{4}. The ultrasonic signal propagates to the periphery in the form of a spherical wave, and is transmitted to the acoustic emission sensor closely attached to the outer wall of the transformer through the oil medium at different times. The ultrasonic signal is converted into an electric pulse signal by ultrasonic sensor pick-up, and the high-speed analog-to-digital converter converts the partial discharge acoustic emission analog signal into a digital signal, and transmits it to a computer and analyzes and processes the digital signal by using relevant software to determine the fault. Location and type. At the same time, using the delay of the sensor signals of each channel, the localization of the partial discharge is realized by the calculation of the positioning algorithm.

2. Ultrasonic signal recognition
The primary problem with ultrasonic testing of transformer partial discharge is how to identify useful signals and eliminate interference signals in capturing many signals. The detection system can remove \textit{some} interference signals by hardware and software filtering. For example, the threshold value of the signal and the signal frequency range can be set to remove the interference, but at the same time, the valuable information is filtered out, so more needs to be needed. Manual analysis and judgment. \cite{1}
2.1. Judging from the waveform characteristics and delay of the signal.
The amplitude of the waveform of the partial discharge ultrasonic signal of the reactor is much larger than the general background noise, and it is a pulsed diamond wave that gradually attenuates the oscillation. The duration of the waveform has a certain relationship with the detection system, signal amplitude and discharge type. According to the simulation experiment and testing experience, the duration of the ultrasonic PD signal is generally 60-200 microseconds. If the waveform duration of the signal is very short [6], and the frequency of the signal is very high, it is usually an electromagnetic interference signal; if the signal waveform if the duration is too long, the signal may be caused by mechanical vibration.In addition, the propagation speed of sound waves in dielectric oil, steel plate and other media is much lower than that of electromagnetic signals, and the equivalent velocity of sound waves is affected by factors such as propagation path and angle of incidence. Acoustic signals received by sensors at different positions there should be a certain delay relationship [5], if all signals arrive at the same time, then this group of signals is likely to be some kind of interference.

2.2. From the stability of the signal amplitude and the periodic judgment of signal generation
According to the classical discharge theory, when the voltage of the discharge gap increases with the applied voltage to the discharge voltage of the air gap, the gap discharges. Under the periodic applied voltage, as long as the voltage difference between the gaps reaches the discharge voltage, the discharge gap will generate a discharge in each cycle, and each discharge energy of the same discharge gap should be substantially stable [4], thereby the gap The amplitude of the sound pressure signal generated by the discharge should also be stable. The signal shown in Figure 2 below is a typical partial discharge map, while Figure 1 is the interference signal. Although the ultrasonic signal has different loss laws under different media and different propagation conditions, the ultrasonic signal received by the same channel should be stable and continuous for the same discharge source. Therefore, the amplitude stability and persistence of each sensor signal can be used as a basis for whether the signal is generated by the same PD signal source.

2.3. Judging from the correlation and periodic characteristics of signal and frequency
The partial discharge of the dielectric medium is excited by the applied voltage, and its discharge law must have a certain correlation with the applied voltage. The partial discharge of the transformer in
operation is caused by the power frequency voltage, so the partial discharge ultrasonic signal should be correlated with the frequency of the power frequency voltage. As shown in Figures 3 and 4, the horizontal axis of the graph is time, 10 ms per grid, and the vertical axis is the number of signals. The interval of all acoustic signals in Figure 3 is 20ms, that is, the frequency of occurrence of partial discharge is 1 time of the first power frequency cycle, with a typical 50Hz frequency correlation, while Figure 4 is disordered or irregular, and has no correlation with 50Hz. It can be considered as an interference signal.

![Figure 3. Signal with 50Hz correlation](image1)

![Figure 4. Signal does not have 50Hz correlation](image2)

3. On-site inspection examples

3.1. Fault condition
On July 3, 2014, the B phase of Qunxing Qunxing No. 1 reactor of Qunlin 500kV substation showed that the chromatographic data of Qunxing No.1 B phase reactor was abnormal, and the acetylene content reached 19.72μL/L. The hydrogen content reached 205.16μL/L, and the hydrogen and acetylene contents exceeded the attention values specified in the regulations. The specific gas component content is shown in the following table.

![Table 1. Dissolved Gas Analysis Report Form](image3)

| Dissolved gas in oil. | Uni: μL/L |
|----------------------|-----------|
| H2                   | 205.16    |
| CO                   | 86.77     |
| CO2                  | 1384.34   |
| CH4                  | 44.07     |
| C2H4                 | 14.16     |
| C2H6                 | 3.39      |
| C2H2                 | 19.72     |
| Total hydrocarbon    | 81.34     |
In order to find out the cause of the abnormality, the detection personnel were immediately organized to carry out the ultrasonic partial discharge detection and diagnosis of the phase reactor. The following is a detailed analysis of the detection data: first, analyze the signal waveform. From Figure 5, it can be seen that the signal on the time domain spectrum has obvious periodicity. There are two discharges in each power frequency cycle. The signal shape is spindle shaped. The positive and negative half waves have highly similar partial discharge signals, and the signal amplitude is stable.

![Figure 5. Long waveform map of 7 and 8 channels partial discharge signal](image)

In order to further confirm whether the signal is the partial discharge signal inside the reactor, the amplitude, phase, polar coordinates and characteristic index are intercepted. During the detection, the background of PD test is 26dB, and the normal amplitude of each channel is 28dB, while the amplitude is significantly increased, with the maximum value reaching 55dB. There is also a very obvious 90 degree and 270 degree phase correlation in the phase and polar coordinate, most of the discharge occurs near the 90 degree and 270 degree phases of each power frequency cycle. It can be seen from the analysis of the characteristic index map that the number of impacts collected during the discharge is very large, which indicates that the degree of partial discharge is relatively severe, and the most frequent impact points are located at the integer 2 and integer 4 positions of the characteristic index. Therefore, the partial discharge occurs once per cycle, which belongs to the typical type of suspended discharge. Therefore, it is preliminarily determined that the defect is located near the lower part of the iron core and the small sleeve of the clamp.

3.2. On-site disintegration inspection and treatment.

In view of the results of dissolved gas analysis and partial discharge measurement in oil, the reactor was scheduled to be overhauled from September 17 to September 25, 2015. After the oil discharge inspection, it was found that the lead wire of the yoke of the iron core had obvious discharge marks, and the positioning device of the core cake, the four nails and the spare cap showed obvious looseness, as shown in Figs. 6 and 7 below. The treatment method adopted in the field is: re-wrapping the grounding lead with insulating paper to retighten the loosened nail. Fig. 8 is a yoke screen lead line in the iron core after the treatment.

![Figure 6. Trace diagram of the discharge line of the yoke screen in the iron core](image)

![Figure 7. The nail and cap are loose](image)
3.3. Failure Cause Analysis

3.3.1. Loose nails cause the magnetic shield of the coil to be loose and move.

3.3.2. The inner screen of the coil leads to the grounding lead (ie, the screen line of the core column) is in contact with the magnetic shield, and vibration occurs during the operation of the product, causing the magnetic shield to break the outer insulation of the lead and generate partial discharge.

4. Conclusion

The fault of 500kV reactor in Heilongjiang Province is very typical. It is recommended to strengthen the ultrasonic and ultra-high frequency partial discharge detection of transformers and reactors in the future. If there is any abnormality, the detection period should be shortened. Diagnostic tests should be carried out under conditions and equipment defects should be discovered in time. When a chromatographic test abnormality is found, transformers, reactors, etc. must be combined with other electrification detection methods to make a comprehensive judgment, so as to avoid the uncertainty of the defect by a single detection means.

References

[1] YAN Zhang, ZHU Deheng. High voltage insulation technology [M]. Beijing, China: China Electric Power Press, 2002: 205-206.
[2] WANG Guoli, YUAN Peng, SHAN Ping, et al. Study on theul-tra-high-frequency discharge signals of typical PD models in transformers [J]. High Voltage Engineering, 2002, 28 (11): 28-31.
[3] WANG Guoli, HAO Yanpeng, JIA Zhidong, et al. Study on pulse cur-rent of typical PD models in power transformer [J]. High Voltage Engineering, 2001, 27 (2): 5-8.
[4] Dong Qigu. Power transformer fault and diagnosis [M]. Beijing: China Electric Power Press, 2000.
[5] Wang Guoli, Hao Yanbang, Li Yanming. Research on Mixing Technology in Ultra-high Frequency Detection of Transformer Partial Discharge[J]. Chinese Journal of Electrical Engineering, 2004, 24 (10): 115-119.
[6] Tang Ju, Wang Jing, Li Jian, etc. Statistical parameters for partial discharge pattern recognition [J], High Voltage Technology, 2002, 28 (8): 4-6.
[7] Zhang Yupeng, Yang Yongming, Wang Bo et al. Ultrasonic testing method for partial discharge of electrical equipment [J], Piezoelectric and Acousto-optic, 2010, 32 (3): 414-41.