Partial Discharge Detection of High Voltage Electrical Equipment Based on Acoustic Imaging(AI)

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Abstract
With the development of market economy, high-voltage XLPE insulated conductor, as a key component of urban transmission line, plays an important role in maintaining the safe and stable operation of urban high-voltage line. The completion acceptance test of high-voltage conductor is a defect test before the investment and operation of high-voltage cable lines. It is an important link to prevent the investment and risk operation of high-voltage cable line. Based on the actual application of acoustic imaging technology in the partial discharge test of high-voltage distribution equipment, this paper puts forward the detection algorithm of high-voltage electrical equipment, tests the traditional AC withstand voltage method and the number of defective lines and acceptance lines when acoustic imaging is applied to the partial discharge detection method of high-voltage electrical equipment. The test results show that after the acoustic imaging proposed in this paper is applied to the partial discharge detection technology of high-voltage electrical equipment, the defect detection rate in the complete acceptance test of high-voltage cable is improved, while the number of operating lines with faults caused by small defects is reduced, which effectively reduces the number of high-voltage cables with faults caused by hidden dangers. It is verified that the application of acoustic imaging in partial discharge detection of high-voltage electrical equipment can effectively improve the fault detection rate of high-voltage cable completion acceptance and reduce the hidden dangers of high-voltage cable belts. The application of acoustic imaging in partial discharge detection of high voltage electrical equipment is the general trend in the future.

Keywords: *Acoustic Imaging, High Voltage Electrical Equipment, Discharge Detection, Application of Acoustic Imaging*

1. INTRODUCTION

At present, most electrical maintenance units only carry out on-site hand-held detection of transformers in spring and autumn. On the one hand, due to the low sensitivity of this detection method, large positioning deviation of discharge power supply and insufficient diagnostic ability of discharge type, it is unable to make predictive detection for small-scale and slight intensity partial discharge phenomenon, which is difficult to prevent the expansion of partial discharge degree, which is easy to lead to the destruction of the whole insulation system and eventually electrical equipment failure. On the other hand, this detection method is not convenient for staff to work on site in northern winter. The cold weather conditions put forward higher requirements for equipment and staff. Based on this, this paper proposes to apply AI to PDD of high voltage electrical equipment.

The application of AI in PDD of high voltage electrical equipment has been studied by many scholars at home and abroad. Lee n proposed a frequency domain active noise control algorithm for noise reduction in magnetic resonance imaging, and its feasibility was verified by experiments. In 3T magnetic resonance imaging, the noise sound pressure level is close to 130dB. The noise in 3T MRI was measured and analyzed in time and frequency domain. It has fundamental frequency and higher harmonics, and the Fourier coefficients of all peaks change slowly with time; In order to achieve this in the real-time process, a time-frequency domain transform algorithm based on discrete Fourier series is developed [8]. Darianla first reported the ability of X-ray technology to inspect the internal components of high-voltage equipment. High

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voltage minimum oil volume and SF6 circuit breaker samples were designed and tested to evaluate X-ray images and compare with known artificial defects. Evaluate the influence of X-ray spectral energy characteristics on the information obtained by X-ray imaging of objects with diffusion equivalent radiation thickness, and determine the technical requirements of this analysis [4].

This paper puts forward the detection technology of high-voltage electrical equipment, that is, during the AC withstand voltage test of high-voltage cable, measure the partial discharge at multiple positions of high-voltage cable synchronously, identify the small defects caused by the construction damage of high-voltage cable and the poor installation of accessories through the PDD at multiple positions, improve the completion acceptance test method of high-voltage cable, and reduce the hidden danger operation risk of high-voltage cable. It is verified that the application of AI in PDD of high-voltage electrical equipment can effectively improve the fault detection rate of high-voltage cable completion acceptance and reduce the hidden dangers of high-voltage cable belt [6][9].

2. APPLICATION OF AI IN PDD OF HIGH VOLTAGE ELECTRICAL EQUIPMENT

2.1. Application of AI in PDD

X-ray perspective imaging detection technology: through the application of X-ray perspective imaging technology, realize the visualization of the internal state of GIS, circuit breaker, cable and other equipment, and carry out internal structure inspection, defect diagnosis and positioning. Photoacoustic spectrum detection technology: the composition and content of dissolved gas in oil in transformer and other equipment can diagnose the severity and type of defects. Through the quantitative relationship between gas concentration and acoustic intensity, the concentration of each gas can be accurately detected. At present, the on-line monitoring of oil chromatography can not meet the requirement of once every 4 hours required by the State Grid Company. Photoacoustic spectroscopy technology can effectively solve this problem. Controlled array ultrasonic imaging nondestructive testing technology: conduct nondestructive testing on GIS equipment shell through phased array ultrasonic imager [5]. The so-called phased array ultrasound is composed of multiple piezoelectric wafers. These piezoelectric wafers are arranged in order according to the specified order, and then the piezoelectric wafers are started in order according to a certain time interval, so that the ultrasonic waves generated by all piezoelectric wafers are combined into an integral wave array.

2.2. Characteristics of Partial Discharge Under Ultrasonic Testing

When partial discharge is detected by ultrasonic method, the amplitude spectrum, phase spectrum, pulse spectrum and waveform spectrum of discharge signal will be obtained. Whether the phase of the measured signal can be determined by displaying the phase spectrum of the measured signal; The pulse spectrum records the time and pulse amplitude of particles colliding with the shell each time; The waveform map shows the time amplitude information of the measured signal. When using ultrasonic method to detect partial discharge, because corona defect and free metal particle defect are very different from the characteristics of general partial discharge signal, the atlas of corona discharge and metal particle discharge are analyzed separately. When using ultrasonic method to detect partial discharge, it is necessary to determine the background signal [7][9].

The basis of partial discharge detection of high-voltage electrical equipment is transformer state signal acquisition, and the key components of signal acquisition are various sensors. Sensors refer to the components that can convert the received physical and chemical measurement into available signals according to certain laws. The performance of sensors directly determines the accuracy and reliability of information acquisition. With the rapid development of power electronic technology and the emergence of new physical and chemical materials, sensor technology also develops. The production cost of sensors is gradually reduced, the accuracy is greatly improved, and the sensor technology is becoming more and more mature. The traditional sensors are gradually replaced by new sensors, and the new sensors are more digital, miniaturized, systematic, intelligent and multifunctional.

2.3. Transformer PDD Method

PDD methods basically use these changes to judge whether the partial discharge occurs, how the intensity is, and locate the partial discharge. At present, the commonly used PDD technology is mainly divided into non electrical detection and electrical detection. Among them, non electrical detection technology can only carry out qualitative detection to judge whether partial discharge occurs, but can not quantitatively detect the intensity of partial discharge. In practical application, the electrical detection method is more widely used. When detecting the partial discharge of bubbles in insulation, the partial discharge intensity can also be measured.

2.3.1. Ultrasonic testing method

The basic principle of ultrasonic detection method is: when partial discharge occurs in the air gap inside the insulation, the gas molecules will hit the insulation medium and cause ultrasonic wave. The ultrasonic wave propagates through the insulation medium, transformer winding and other parts and is received by the ultrasonic sensor or ultrasonic detector installed on the transformer tank wall. Because there is a lot of noise in the working environment of the transformer, the internal structure of the transformer is complex and the sound wave attenuation is serious, when using the ultrasonic detection method for detection, the frequency range with large component in the spectrum will be selected as the measurement frequency through the filter, which can improve the detection accuracy to a certain extent. If more than one ultrasonic sensor or ultrasonic detector is installed, partial discharge location can be carried out [2][11].

The basic principle of partial discharge location using ultrasonic detection method is: according to the time of ultrasonic signals received by ultrasonic sensors installed in different positions from the same discharge power supply, the time difference between each ultrasonic sensor will be obtained, which is due to the time delay caused by the different distance between each sensor and the discharge power supply. According to the principle of spatial positioning, at least three ultrasonic sensors need to be installed, and then the position coordinates of discharge power can be obtained by solving the equations.

2.3.2. Light detection method

When partial discharge occurs, the generated photons will radiate outward. When the medium is transparent, the light of light radiation can be captured by photomultiplier technology to realize PDD, that is, the optical pulse signal received by the photoelectric detector is transformed into electrical signal and amplified. Different discharge types produce light waves with different wavelengths due to different photon motion. Corona discharge belongs to the preliminary stage of partial discharge. The wavelength of small corona light wave is less than or equal to 400nm, which belongs to the ultraviolet frequency band, so it presents purple; The light wave of strong spark discharge is from 400nm to 700nm, which belongs to the visible wave band. In order to avoid the interference of sunlight, the optical sensor needs to be equipped with filter equipment [3]. The ultraviolet detection method avoids the spectral range of visible light, so it can not be interfered by sunlight and electromagnetic, and has high detection sensitivity. Because the spectrum of corona discharge is within the ultraviolet frequency band, it can detect the discharge signal before the occurrence of partial discharge, so it has a certain warning effect. Local discharge photometry has the advantages of good insulation performance, strong anti electromagnetic interference ability, high detection sensitivity, accurate detection results, easy operation and use, etc.

2.3.3. Temperature detection method

A commonly used temperature detection method is the infrared detection method. When the medium has partial discharge, there will be heat generation, and the heat accumulation will lead to the rise of the surrounding temperature. The infrared detection method can use the thermal imager to carry out thermal imaging of the object, and the place with the highest temperature is often the place with problems. Infrared thermal imager can be used to qualitatively measure whether there are partial discharge defects, but it can not be measured quantitatively, and some detection can not be monitored online in real time. As the transformer itself is a complex heating body and the heat transfer process inside the transformer is also very complex, the effect of using infrared thermal imager to detect the internal fault of the transformer is not good. Moreover, when there is no obvious overheating in partial discharge, the abnormal temperature cannot be distinguished. Taking corona discharge as an example, when the infrared image shows abnormal temperature, it often indicates that the electrical equipment has serious heat release, Therefore, infrared detection method is often used to detect external faults of transformer, and it is also used to evaluate the state of transformer by directly detecting the temperature change of transformer [12].

2.3.4. UHF detection method

The detection effect of PDD using UHF method is also limited by some factors: UHF detection needs to receive partial discharge signal through antenna. Different installation positions of antenna make the propagation path of electromagnetic wave from partial discharge source to antenna different. The frequency spectrum of UHF signal will be affected by various mediums and conductors encountered in the propagation path of electromagnetic wave, This will lead to different spectrum of partial discharge signals of the same power supply detected by the same type of antenna at different installation positions, which makes it difficult to locate and distinguish the type of partial discharge [1].

3. DETECTION ALGORITHM OF HIGH VOLTAGE ELECTRICAL EQUIPMENT

Assuming that the medium is lossless, the sound wave has no attenuation in the core, winding or transformer oil. In the setting of boundary conditions, the first is the external boundary. The shell of the transformer is assumed to be "absolute soft boundary", that is, the sound pressure H value is zero. The numerical calculation of sound pressure h in the model is shown in formula (1)

$$\nabla^2 h = \frac{1\delta^2 h}{s^2 \delta t^2} \quad (1)$$

Where, s refers to the propagation velocity of sound wave in the medium, and H refers to the effective value of sound pressure. The sound pressure level G [DB] is used to replace the sound pressure h for graphic display. The calculation of sound pressure level G is shown in formula (2)

$$G = 20\log(h / h_0) \quad (2)$$

Where, H represents the effective value of sound pressure, in Pascal, H0 represents the reference sound pressure, and the default value is 20Pa.

4. EXPERIMENTAL ANALYSIS OF DISCHARGE DETECTION OF HIGH VOLTAGE APPARATUS

In this paper, the application of AI in the PDD of high-voltage electrical equipment is tested. In the process of AC voltage withstand test, the partial discharge of each detection intermediate joint in is detected through the detection algorithm of high-voltage electrical equipment, that is, the withstand voltage of 1.7 times the rated operating voltage of the detection line. The test results are shown in Table 1 and figure 1

Table 1. Withstand voltage of 1.7 times rated operating voltage

	A	A	B	C
Test voltage	220KV	220KV	220KV	220KV
Test current	130.8A	130.8A	130.7A	130.6A
frequency	33.07	33.05	33.04	33.06
Q value	152.9	148.5	150	151.4

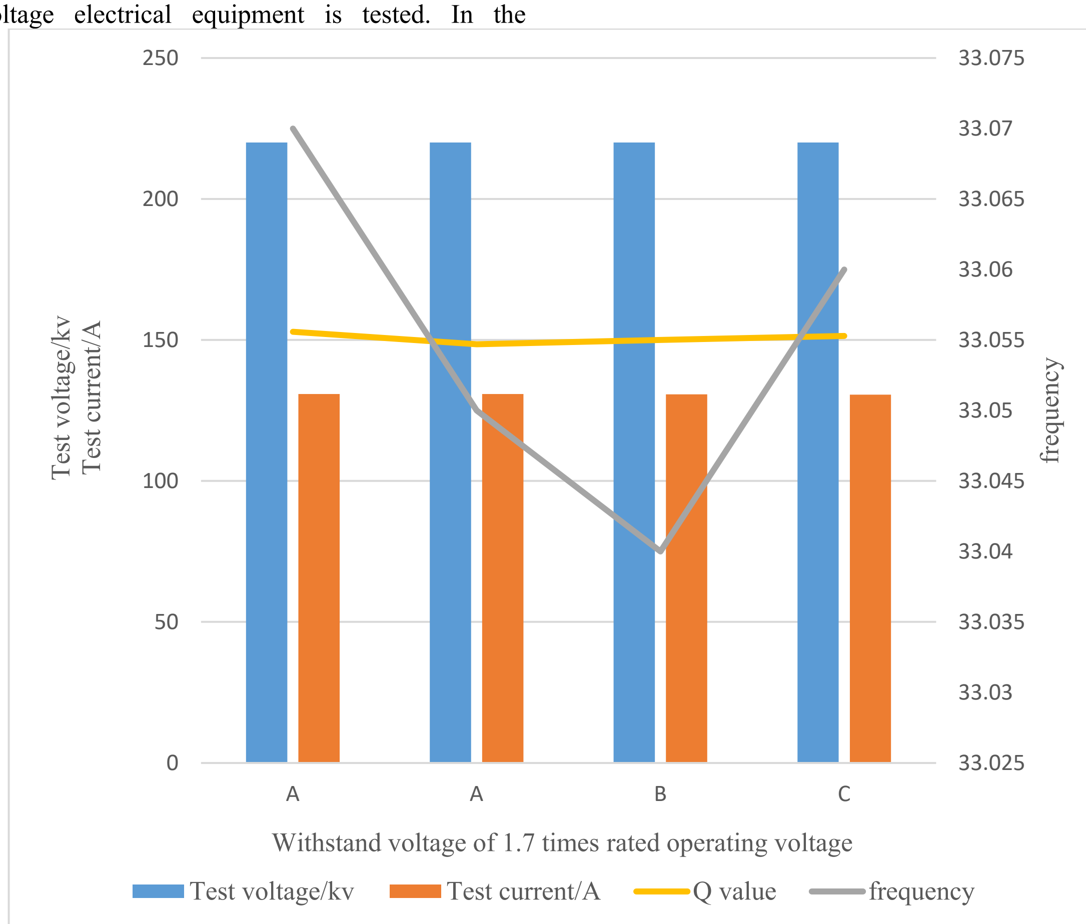

Figure 1. Withstand voltage of 1.7 times rated operating voltage

According to the analysis of the above test results, the withstand voltage test results show that each phase of lines a, B and C withstand voltage for 1 hour under 220kV (1.7 times the rated operating voltage), and there is no breakdown; Withstand voltage for 1 hour at 220kV (1.7 times of rated operating voltage) without breakdown. No partial discharge was found. The line has successfully passed the AC withstand voltage test of 1.7 times the rated operating voltage and has been in normal operation so far.

Next, the fault condition of high-voltage cable line put into operation in an area is tested. In the first two years, the traditional AC withstand voltage method is adopted. In the third year, the AI proposed in this paper is applied to the PDD technology of high-voltage electrical equipment. By testing and comparing the number of defective lines and the number of acceptance lines under different methods, the test results are shown in Figure 2

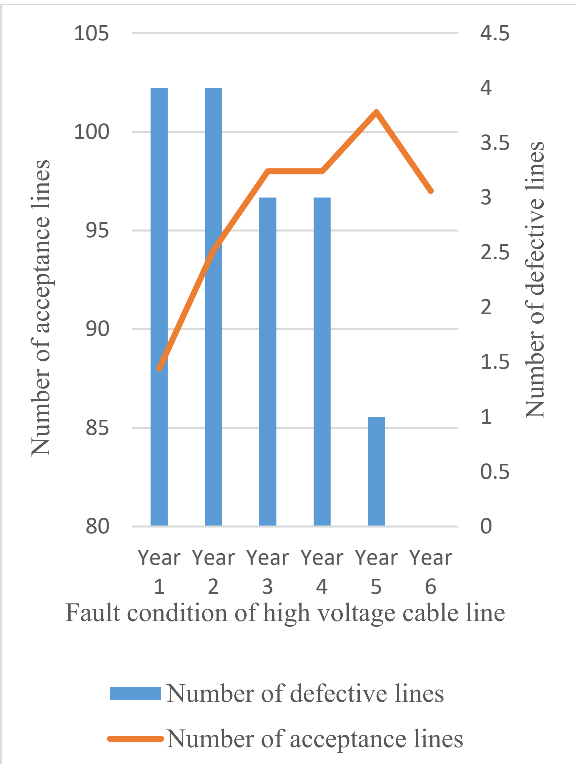

Figure 2. Fault condition of high voltage cable line

The test results show that after the AI proposed in this paper was applied to the PDD technology of high-voltage electrical equipment at the end of the third year, the defect detection rate in the completion acceptance test of high-voltage cables in this area increased, while the number of operating lines with faults caused by small defects decreased, which effectively reduced the number of high-voltage cables with faults caused by hidden dangers.

5. CONCLUSIONS

By studying the relevant inspection algorithms and various technologies of background management end and mobile end, this paper realizes the application of AI in PDD of high-voltage electrical equipment, and solves the intellectualization and remoteness of partial discharge monitoring of high-voltage electrical equipment to a certain extent. At the same time, due to the limited time and energy and the lack of understanding of the actual operation of electrical equipment, the following improvements need to be made: because the relevant discharge phenomena are simulated with Tesla coil, there is still a certain gap with the real discharge phenomenon. In the real monitoring environment, the discharge type will be more changeable, and the interference factors of the background environment will be more complex. Therefore, in the future related research, we should try to use the actual data of the field for experiments, so as to be more effectively applied to the actual situation. In this paper, the research on detection algorithm is carried out on notebook computer. Because the current intelligent video surveillance system is generally applied on embedded platform, its performance must have more limitations compared with PC, so in the follow-up research, it is also necessary to transplant the detection system to embedded platform to detect its real-time performance. In the later research, the intelligent analysis function can be added to make statistics on the discharge parts of electrical equipment, and focus on the image acquisition of the frequently discharged parts.

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