Hindawi
Wireless Communications and Mobile Computing
Volume 2023, Article ID 9898732, 1 page
https://doi.org/10.1155/2023/9898732

Retraction

Retracted: Intelligent Online Partial Discharge Detection and Sensor

Wireless Communications and Mobile Computing

Received 19 September 2023; Accepted 19 September 2023; Published 20 September 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] R. Zhu, Z. Chen, J. Liu, T. Zhu, and X. Du, "Intelligent Online Partial Discharge Detection and Sensor," *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 7432750, 8 pages, 2022.

Hindawi
Wireless Communications and Mobile Computing
Volume 2022, Article ID 7432750, 8 pages
https://doi.org/10.1155/2022/7432750

Research Article

Intelligent Online Partial Discharge Detection and Sensor

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Received 13 July 2022; Revised 22 August 2022; Accepted 3 September 2022; Published 14 September 2022

Academic Editor: Aruna K K

In order to realize the online monitoring of partial discharge in solid switch cabinet, obtain the real partial discharge power and evaluate the insulation status of the switch cabinet, an online detection device based on partial discharge in solid switch cabinet was proposed. The ultrasonic sensor and resonant circuit used by the device to collect the high frequency signal generated when partial discharge occurs and the high frequency signal was converted into the voltage signal. The voltage signal was sent to the STM32 main control chip after data preprocessing and analog-to-digital conversion. Through the conversion of the collected electrical data, the local discharge quantity was obtained and displayed on LCD screen in real time. If the detected discharge power was greater than a set value, an alarm would be automatically issued to remind the on-site power personnel to pay attention to it and prevent major power accidents caused by insulation damage. From the experimental results, it was found that the value of intermittent partial discharge collected by the developed device was 63pC, which was basically consistent with the DMS data. The experimental results showed that the device had the characteristics of simple operation and signal processing speed, high testing data real-time, and low cost, which was suitable for the real-time monitoring of the high voltage equipment in internal partial discharge. It was convenient for operators to maintain the equipment and ensure the normal operation of the equipment, which was of great significance to improve the reliability of power supply.

1. Introduction

Partial discharge (PD) is the phenomenon of partial discharge caused by breakdown in insulating medium. Different from breakdown or flashover, partial discharge is a small breakdown of the local area of insulation, which is the initial phenomenon of insulation deterioration. Electrical equipment insulation materials are mostly organic materials, such as transformer oil, insulating paper, and epoxy. The electric field distribution borne by the insulator of electrical equipment is usually not uniform. And the dielectric itself is usually not uniform, such as gas-solid composite insulation and liquid-solid composite insulation. Even if it is a single insulating medium, bubbles, impurities, and other substances will appear in the medium during manufacturing or operation. This results in areas of high field intensity within or on the surface of the insulating medium. Once the field intensity of these regions is high enough to cause a local breakdown in the region, a local regional discharge occurs, while the other areas will remain good insulation, which forms partial discharge [1]. It may occur in solid insulating pores, liquid insulating bubbles, or between insulating layers with different dielectric properties [2]. It can also occur in liquid or solid insulation if the electric field intensity is higher than a specific value that the medium has. Partial discharge will not cause the breakdown of insulation immediately, but its harm to insulation medium is very serious. Once partial discharge occurs in the dielectric, the whole insulation system will fail eventually through continuous erosion of the surrounding dielectric. Partial discharge is the main cause of insulation degradation, which is also the important sign and manifestation of insulation degradation. It is closely related to the deterioration of insulation materials and the breakdown process of insulation, which can effectively reflect the latent defects and faults of the internal insulation of equipment. It is much more effective especially for the early discovery of sudden faults than dielectric loss measurement, chromatography analysis, and other methods [3].

2. Literature Review

Algwari and Saleh proposed the transient voltage to earth for the first time [4]. According to Maxwell's electromagnetic field theory, the occurrence of partial discharge phenomenon generated a changing electric field, which aroused a magnetic field, and the changing magnetic field induced an electric field. In this way, the alternating electric field and magnetic field excited each other and propagated outward to form electromagnetic waves. In this way, the electromagnetic wave generated by the discharge pulse would generate an instantaneous voltage to earth on the metal box of the high voltage switchgear. Then the TEV signal would be captured by the capacitive coupling detector, so as to obtain the amplitude and frequency of partial discharge. Iwata and Kitani successfully obtained partial discharge signals by measuring 1 GHz frequency band in the experiment, which greatly promoted the mechanical research on partial discharge and the development of detection technology [5]. UHF detection was divided into UHF narrowband detection and UHF ultrawide bandwidth detection. The UHF narrowband detection bandwidth ranged from ten MHz to tens of MHz, and the center frequency was more than 500 MHz. The UHF ultrawide bandwidth detection bandwidth could reach several GHz. Li et al. proposed the sono-optical measurement method, in which the ultrasonic wave in the process of local discharge squeezed the optical fiber and forced the chemical characteristics of chemical fiber to change. By detecting the change signal of the output optical fiber, ultrasonic wave could be measured and qualitative discharge could be indirect [6]. Aydoan et al. introduced the extraction method of feature vectors for switch cabinet partial discharge pattern recognition. Feature vectors of ultrasonic and UHF partial discharge signals of switch cabinet based on information fusion technology were extracted and partial discharge types were discriminated [7]. Xh et al. used the normalized area of the two feature ultrasonic power spectrum of the switch cabinet as the input vector of the three-layer BP neural network to realize the identification of partial discharge mode of the switch cabinet [8]. Pm et al. took the partial-band energy of partial discharge of four typical defect models as feature vector and conducted cluster analysis on the feature quantity of partial discharge signal by mahalanobis distance algorithm. And the recognition rate of the discharge of the four models was as high as 99.125% [9].

At present, there are many methods to detect partial discharge, including infrared imaging method, pulse current method, and UHF method, but most of them cannot be detected under the live operation and cannot detect the whole partial discharge level in the switch cabinet in real time. So it is necessary to investigate it. In the research, STM32 was used as the main control chip and the data processing frequency was up to 72 MHz, which could collect the complete partial discharge signal. The partial discharge signal would not be missed due to the insufficient sampling speed. It was composed of signal preprocessing module, human-computer interaction module, and automatic alarm device to detect local discharge in live switch cabinet in real time, which could realize the real-time monitoring of local discharge in switch cabinet without power failure.

3. Research Methods

The partial discharge device inside the switch cabinet is composed of resonant circuit module, ultrasonic sensor module, signal preprocessing module, microprocessor, power supply, liquid crystal display unit, and alarm device unit. The overall block diagram of the detection device is shown in Figure 1 [10].

The resonant circuit receives the high frequency acoustic signal generated by partial discharge and converts it into the electrical signal. Then through filtering, amplifying, and A/D sampling, it sends the signal to the microprocessor. Through the software program design, the signal below a certain threshold is filtered. Through the analysis of the test data, the amplitude of the signal obtained after the amplification of the interference signal is mostly below 0.8 V. That is, 0.8 V is used as the threshold value of the partial discharge signal. If the value of the amplified electrical signal exceeds the preset threshold, it is judged as partial discharge. The value of this electrical signal is displayed in the current value data box. The current partial discharge in the data box is compared with the historical maximum data to judge the partial discharge level and insulation status. At the same time, the alarm rings and displays the recorded data on the LCD screen in real time. Similarly, ultrasonic sensors receive ultrasonic signals generated by partial discharge and summarize and compare the two data after amplification, mixing, detection, filtering, and A/D sampling [11]. If both high frequency signals are collected at the same time and both values exceed the preset threshold, it indicates that partial discharge does occur. Otherwise, it is automatically judged as the interference signal, which is automatically filtered. The partial discharge results are displayed on the LCD screen in real time. Power supply includes ultrasonic driving module and power supply of signal processing circuit. The microprocessor unit includes STM32 minimum system and necessary peripheral circuit. And the LCD display module adopts TFT graphic LCD touch display module [12].

Because the equipment in the switch cabinet is complex and the space is narrow, the detection device should be easy to install. The size and shape of the device should be designed reasonably and the plastic shell with good fire resistance should be used. The inner circuit of the device is covered with metal film, which plays a good shielding role. It is beneficial to the anti-interference and maximizes the accuracy of detection data.

Because of its superior piezoelectric effect, ultrasonic sensor can directly convert the sound signal into the voltage signal. Partial discharge is accompanied by ultrasonic signal. Partial discharge signal can be detected by selecting ultrasonic sensor, which is close to the frequency band of partial

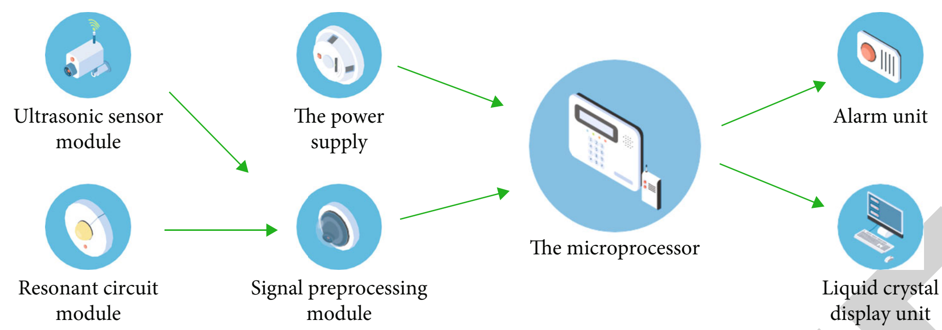


Figure 1: The overall block diagram of detection device.

discharge signal. When the insulation status of switch cabinet is tested by ultrasonic method in the field, the reliability of partial discharge test data of switch cabinet can be effectively enhanced by using sensors with different frequency bands according to different measurement objects. The relation between partial discharge signal and ultrasonic signal generated by partial discharge is difficult to be expressed by function relation. However, for partial discharge under certain environmental conditions, the characteristics of partial discharge can be described by the amplitude and frequency of ultrasonic signal [13].

Partial discharge signal and ultrasonic signal are shown in Figure 2 (a) and 2(b)

Ultrasonic sensor in the signal acquisition process will receive all frequency bandwidth signals. It is also mixed with a large number of noise signals, so it is necessary to use resonant coupling circuit to further analyze the collected signals. According to the characteristics of partial discharge signal, the frequency of partial discharge signal is 100~500 kHz. Therefore, the resonant frequency of 300 kHz is selected as the central receiving frequency in resonance. The real partial discharge signal can be obtained by comparing and analyzing the frequency collected by resonance with that collected by ultrasonic, which can effectively avoid the result error caused by inaccurate signal acquisition caused by background noise interference. The accuracy of partial discharge signal acquisition is guaranteed to the maximum extent [14].

Since the response frequency of partial discharge signal is 40~500 kHz, a bandpass filter with a bandpass of 40~500 kHz should be designed in theory to ensure that the signals not in the partial discharge signal frequency band can be filtered. In order to facilitate the design of a bandpass filter that meets the requirements, the cut-off frequency of high pass is set at about 10 kHz, and the cut-off frequency of low pass is set at 500 kHz, so as to filter the digital signals from low frequency and high frequency coupling to the maximum extent. Taking the operational amplifier INA118 used in the device as an example, the bandpass filter spectrum is shown in Figure 3 [15].

Bandpass filter is composed of a low-pass filter and a high-pass filter, and the frequency range of partial discharge signal is 10~500 kHz. Therefore, the resistance value of each circuit component can be calculated according to the calculation formula of low-pass and high-pass cut-off frequency. The calculation formula of low-pass and on-pass cut-off frequency is shown in Equation (1) and Equation (2) [16].

$$f_0 = \frac{1}{2\pi\sqrt{C_1 C_2 R_1 R_4}}, \quad (1)$$

$$f_p = \frac{1}{2\pi\sqrt{R_5 R_6 C_4 C_5}}. \quad (2)$$

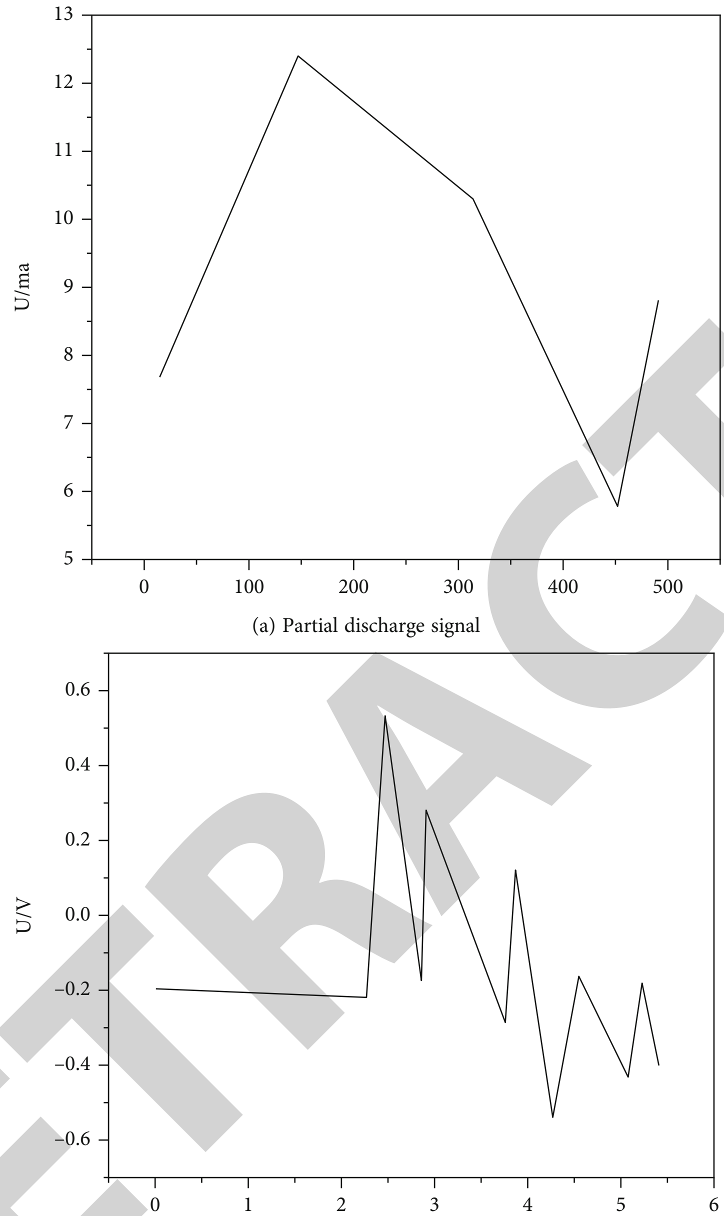
In Equation (1) and Equation (2), f_0 is the low-pass cut-off frequency. f_p is the high-pass cut-off frequency. C_1, C_2, C_4, and C_5 are capacitance values. R_1, R_2, R_4, R_5, and R_6 are resistance values.

According to the simulation spectrum, the designed bandpass filter circuit can satisfy the filtering application of partial discharge signal.

INA118 operational amplifier chip is used to amplify the original partial discharge signal after filtering. INA118 has a built-in protection circuit, and signal amplification is controlled by an external adjustable gain resistor. INA118 has the advantages of high precision and low power consumption, which is often used to amplify small signals. The whole amplifier module is composed of three operational amplifiers. By adjusting the external gain resistance, the gain of 1~1,000 dB can be adjusted freely and the application range is very wide [17]. The operational amplifier circuit is shown in Figure 4.

As can be seen from Figure 4, gain resistance R_1 is connected between pin 1 and pin 8, pin 2 and pin 3 are connected to the signal input, and pin 6 is connected to the output. According to the comparison between the original signal and the output signal, the gain multiple is determined to be 10, which meets the detection requirements. Gain resistance formula is $R = 50\,\mathrm{k}\Omega/(G-1)$. The resistance value knob is adjusted to achieve a specific multiple of weak signal amplification.

Data A/D conversion module is ADC0801. It has a sampling frequency of 20 MHz, 12 bit data processing capability, accuracy of 1/4,096, and features of high signal-to-noise ratio and low power consumption. A conversion module is used to process the received analog signal. The STM32 main chip is responsible for driving the high-precision sampling



(a) Partial discharge signal

(b) Ultrasonic signal

Figure 2: Partial discharge signal and ultrasonic signal.

circuit, and the ADC0801 conversion chip consumes only about 300 mW during normal operation. ADC0801 has low requirement on analog input signal voltage, so it is very suitable for original partial discharge signal analog-to-digital conversion.

ADC0801 has two working modes, namely, unipolar and bipolar. Since no additional reference voltage is required in the research, the unipolar operating mode can meet the requirements. The chip requires an external of +3.3 V reference source, which is as a reference voltage value and to supply power to the chip. Since ADC0801 does not require high voltage value of input signal, its range FSR is determined by the partial resistances R_1 and R_2 between the reference voltage value of UREF and SEL pins. The relationship is

$$\mathrm{FSR} = 2 \times U_{\mathrm{REF}} = 2U\left(1 + \frac{R_1}{R_2}\right). \tag{3}$$

In Equation (3), R_1 is 5 kΩ, and R_2 is 10 kΩ.

The maximum input analog voltage does not exceed the power supply voltage of +3.3 V, and the voltage value converted from ADC digital output is

$$U = \left(D - 2^{N-1}\right) \times \frac{\mathrm{FSR}}{2^N} \tag{4}$$

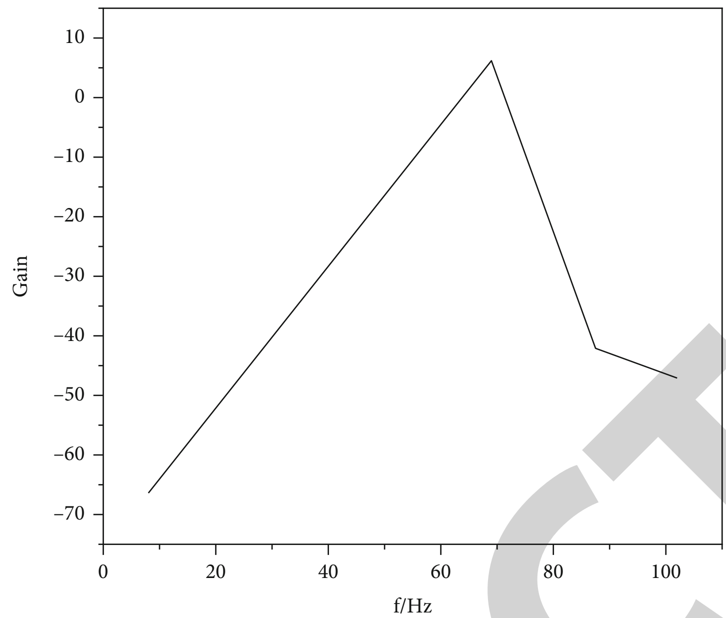


FIGURE 3: Bandpass filter spectrum.

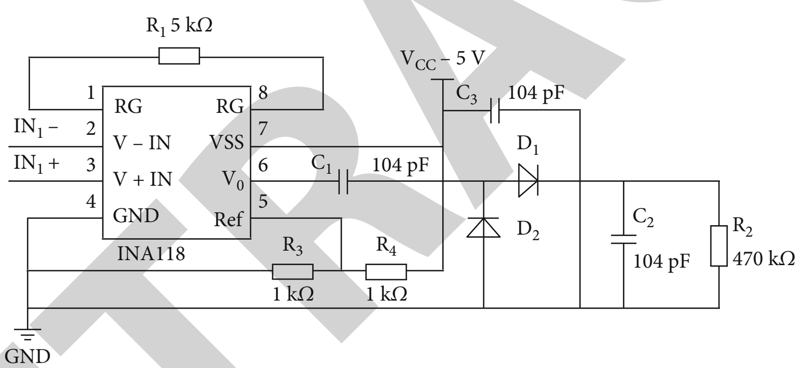


FIGURE 4: Operational amplifier circuit diagram.

In Equation (4), D is the digital quantity output by ADC after analog-to-digital conversion. FSR is the maximum range of analog input. N is the bit number of the ADC conversion chip.

As the core processor in the whole device, STM32 is mainly responsible for controlling A/D acquisition of ultrasonic sensor and resonant circuit signals, storing them in SRAM, and extracting stored data. The data is converted into partial discharge signal through internal functions. The display screen is connected with the main control chip through SPI data interface, which greatly strengthens the ability of data processing and speeds up data processing. A/D module uses a 12-bit conversion chip to convert analog signal data into digital signal through IIC protocol, with digital accuracy up to 1/4,096, which avoids the loss and omission of sampling data due to the short time of partial discharge. Using IIC data bus for data transmission is helpful to improve the response speed of the system.

The partial discharge detection device uses STM32 chip as the processor in the ARM system framework to process the data in real time. The software program is written in KEIL5. Finally, the compiled program is downloaded to the partial discharge detection device through the serial port. The software program can be updated and replaced according to the actual needs, which is conducive to the subsequent supplement of device functions [18]. The processing flow of the software system is shown in Figure 5.

First of all, starting from the starting power, the system supplied power to the device, then the master control chip and other sensors. The data is collected. High frequency signal of the partial discharge collected by the resonant circuit and ultrasonic sensors is sent into the signal processing link, including filtering and signal amplification. And then the partial discharge signals in analog-to-digital conversion are performed. Each collected analog signal is converted into a group of digital quantities, which are used as a group of partial discharge values to enter the next stage of data conversion [19]. If the data processing is not complete, it needs to reenter the signal processing process until the data processing is complete. The relation between electrical signal

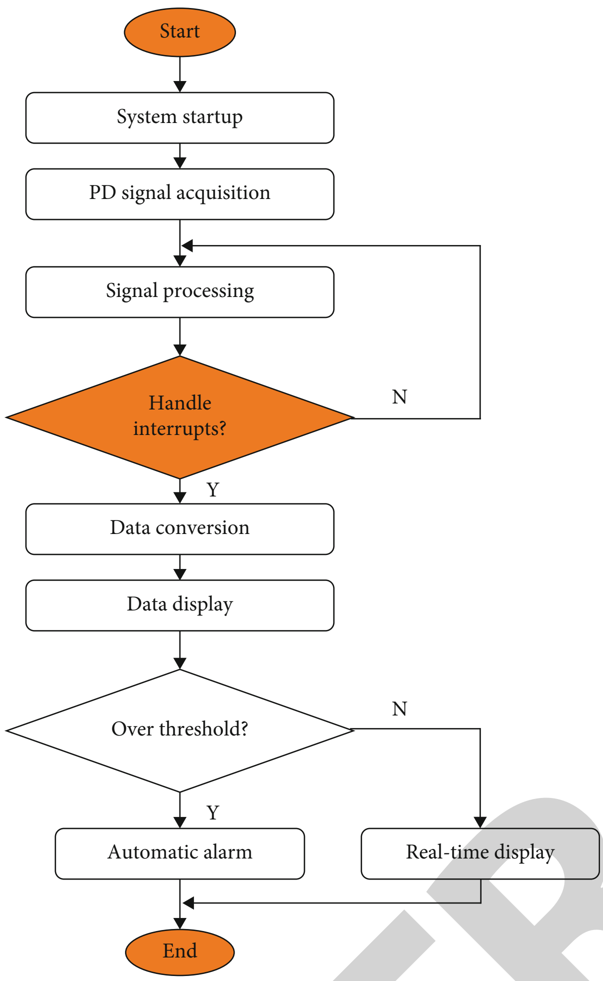


Figure 5: The processing flow chart of software system.

and local discharge quantity is obtained by function fitting. Finally, the converted local discharge quantity is displayed and whether the local discharge quantity exceeds the preset threshold is judged at the same time. If not, it will not trigger the alarm device. If the value exceeds the preset value, the alarm device will be triggered automatically to remind related maintenance personnel to carry out on-site maintenance.

In order to display the detection results in real time better, the design of TFT LCD screen and automatic alarm circuit is adopted [20]. The interface has two data boxes. One is the historical maximum data box and the other is the real-time display data box. The severity of partial discharge in switch cabinet can be judged by comparing the historical maximum value, the partial discharge value, and the real-time detected partial discharge value. If the historical value is constantly replaced by the real value, it indicates that the partial discharge degree is more and more serious. If the real-time partial discharge value is lower than the historical maximum value, it indicates that the partial discharge level remains the current status, and there is no need for power outage maintenance. And corresponding programs are written according to the software. When the detected partial discharge value is greater than the preset threshold, the buzzer alarm circuit is automatically triggered to remind the staff to pay attention to it and grasp the partial discharge level inside the switch cabinet in time.

4. Result Analysis

As the partial discharge detection device directly obtains the voltage and cannot directly display the local discharge quantity, it is necessary to verify the voltage value and the local discharge quantity mutually. And the steps are as follows: firstly, the sensor of partial discharge device and the probe of the standard PD meter are placed in the same position to ensure the accuracy of the original partial discharge signal. Secondly, the real-time voltage measured by the partial discharge detection device and the real-time local discharge measured by the standard local discharge meter are recorded. And the one-to-one correspondence between different voltage values and local discharge is obtained through multiple groups of tests. Thirdly, the relation between voltage and local discharge quantity is obtained by using polynomial fitting function. Fourthly, the original data and partial discharge data are fitted by function, so as to adjust the original parameters of partial discharge device and complete the verification process of partial discharge device.

Partial discharge detection device is used to measure partial discharge in switch cabinet and the local discharge quantity detected can be displayed in real time. The model of local discharge meter used in the verification process is WDJFY-2009, which can display the local discharge quantity in real time. Partial discharge detection device is used to detect partial discharge. In order to verify the accuracy of partial discharge device measurement results, electric spark is used as partial discharge signal to verify them [21].

The partial discharge device can accurately measure the size of partial discharge. As partial discharge is a random phenomenon, the detected data varies greatly. But as a device that can detect the local discharge level in real time, it has been able to meet the needs of the site. It is also easy to understand the degree of partial discharge in the solid switch cabinet by comparing the maximum value of historical data with the real-time value. The automatic alarm function can be realized according to different thresholds, which greatly reduces the workload of on-site maintenance personnel. Maintenance personnel only need to record the partial discharge value at intervals to evaluate the partial discharge status inside the switch cabinet. The detection of partial discharge can be completed in the case of continuous power supply, which is conducive to improving the reliability of power supply [22].

Partial discharge detection device with the DMS online is adopted as the standard data source compare to the data collected by the developed detection device. The DMS partial discharge detector data shows that intermittent PD does exist. The same position is measured by the developed device and individual data can also be collected. The displayed value is 63pC, which is consistent with the DMS data. [23].

5. Conclusions

In the research, the device completed partial discharge detection in switch cabinet by using ultrasonic and resonant circuit. The two methods not only ensured the reliability of the test data but also could complete partial discharge detection under the condition of continuous electricity. Repeated testing results showed that the device had good practicability and stability, which could quickly and effectively complete partial discharge detection. Compared with the existing partial discharge detection methods, the device could monitor the local discharge level online without power outage. Although there was room for improvement in the measurement accuracy, it could meet the actual needs of the site. By comparing the current data with the historical maximum data, the discharge intensity could be reflected and the trend of partial discharge severity could be judged. At the same time, the device also had the advantages of fast action time, strong anti-interference ability, low cost, no need to consume more manpower and material resources, easy installation, etc. It could find the potential insulation safety hazards in the switch cabinet timely, ensure the continuous, safe, and effective operation of the switch cabinet and improve the reliability of power supply.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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