Comparative Study on Characteristics of Partial Discharge Optical Pulse and UHF Pulse in Switch Equipment

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Abstract. The article explores the performance of the new silicon photoelectric sensor in partial discharge detection, and compares the measured optical pulse with the traditional UHF pulse. Through optical and electrical synchronous partial discharge experiments, the article analyzes and discusses the detection performance, working characteristics and statistical characteristics of various sensors, and explores the advantages and feasibility of silicon photoelectric partial discharge sensors in actual discharge monitoring; In addition, the statistical performance of the two physical phenomena of partial light radiation and electromagnetic radiation was obtained through the analysis of optical and electrical synchronous monitoring data. Compared with UHF sensor, silicon photoelectric sensor under the optimal working voltage has a higher signal-to-noise ratio (SNR); Under the electromagnetic interference of the high-frequency motor, silicon photoelectric sensor exhibits better anti-electromagnetic interference ability; Discharge phase interval and characteristics reflected by the PRPD obtained by two detection methods maintain good consistency; Pulse repetition rate has the same trend with applied voltage, but statistical frequency of optical pulses obtained is higher than that of electromagnetic pulses because silicon photoelectric sensor has a higher SNR and single-photon sensitivity.

1. Introduction

Partial discharge is usually used to detect the internal fault of the switchgear. Common methods of partial discharge usually include ultra-high frequency (UHF) method[1], ultrasonic method[2], optical method[3] and so on. The UHF method is now widely used in the field because of its wide detection frequency, high sensitivity, and online monitoring. Optical method has inherent advantages such as strong anti-interference ability and rich information contained in the discharge spectrum, which is closest to the intrinsic characteristics of partial discharge. However, limited to the development of optical detection devices, it cannot be effectively applied in the field environment.

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With the development of silicon optoelectronic semiconductor technology, Silicon photomultiplier (SiPM) with single photon efficiency, high gain, and long life are becoming mature and are increasingly used in laser radar (LiDar)[4] and Positron Emission Computed Tomography (PET)[5], low-light imaging[6] and other fields. Due to its small size, anti-interference, low cost and many other advantages, it can replace traditional external field effect optoelectronic devices, such as photomultiplier tubes (PMT), and are used in many industrial fields. For example, in the literature, a photoelectric sensor based on an avalanche diode array is introduced and used for the light pulse detection of partial discharge. Due to the differences in different types of partial discharges’ activity level, these differences are not only manifested in the discharge value, but in both electromagnetic and optical radiation. There have been a lot of research and experience on the electromagnetic wave intensity and frequency band range of PD, but there is still no clear understanding of the intensity and characteristics of partial discharge light radiation. In order to explore the advantages and feasibility of silicon photoelectric PD sensors in actual discharge monitoring, and to gain a basic understanding of the characteristics of PD electromagnetic wave and optical radiation at the same time, a photoelectric joint tracking test platform was established. In addition, the synchronous tracking test of UHF and optical methods was carried out for three common defects in switch equipment. The similarities and differences of the phase-based statistical maps and statistical characteristic parameters of UHF and optical method under different defects and different discharge intensities are analyzed and compared, which establishes the basis for the practical application of silicon photoelectric partial discharge sensors

2. Test platform

2.1. Partial discharge measurement system

In this paper, partial discharge simulation experiments are used to obtain the synchronous signal characteristics of partial discharge light radiation and electromagnetic radiation, and the basic characteristics of partial discharge light pulses and UHF pulses of switching equipment are compared and analyzed. This paper builds a set of partial discharge optical and electrical combined Synchronous tracking measurement system. The system mainly includes: transformer and PD test circuit, test cavity, simulated PD defect, PMT sensor, self-made silicon photoelectric PD sensor, self-made UHF partial discharge sensor and signal measurement system, as shown in Fig.1. The main performance parameters of various partial discharge sensors are shown in Table 1. Among them, in order to better compare the detection results of optical radiation and electromagnetic wave radiation, the bandwidth, directivity, standing wave ratio, sensitivity and other parameters of the UHF sensor used in this article are consistent with the parameters of most commercial sensors and have a good representative. There are many types of insulation defects inside switchgear, and they are distributed widely. In order to accurately study the general law of partial discharge light radiation of various types of insulation defects, this paper designs three partial discharge defect models, namely creeping discharge, tip corona discharge and floating discharge.
Figure 1. Partial discharge optical-electrical combined testing platform

Table 1. Specifications of pd sensors used in test

| Sensor                  | Performance Parameter index |
|-------------------------|------------------------------|
| Silicon photoelectric sensor (homemade) | Gain $\geq 10^6$ |
|                         | Operating voltage 27V |
|                         | PDE 38% |
|                         | Dark count rate 50kHz/mm$^2$ |
|                         | Crosstalk 8% |
|                         | Residual pulse 0.75% |
|                         | Model R3896 |
|                         | Detection area $8 \times 24$ mm$^2$ |
| PMT sensor              | Gain $2 \times 106$ |
|                         | Operating voltage -500V |
|                         | Bandwidth 300MHz-1.5GHz |
|                         | Sensitivity -75dBm$^-35$dBm |
| UHF sensor (Homemade)   | Work efficiency 60% |
|                         | Signal gain 40dB |
|                         | Insertion loss $<1$dB |
|                         | Signal fluctuation $<1$dB |

3. Analysis of test results

3.1. Signal-to-noise ratio

The signal-to-noise ratio (SNR) is one of the key operating characteristics of the sensor[7]. This section compares and analyzes the SNR of silicon photoelectric and UHF sensors. Unlike UHF
sensors, the SNR of silicon photoelectric sensors is less affected by external electromagnetic interference, and mainly depends on the thermal noise of the device itself. The level of thermal noise is related to the drive voltage and dark current. Therefore, this paper studies the SNR changes of silicon photoelectric sensors by changing the applied driving voltage to obtain the optimal SNR under working conditions. In order to compare SNR effects of silicon photoelectric sensors and UHF sensors for different detection objects, this paper uses three different defect models to test, and compares these two sensors under the same electromagnetic noise environment through a step-by-step boost method. The curve of SNR versus test voltage level is shown in Figure 2a-2c. In the test, the environmental background noise level is about 5pC.

![SNR vs. Applied Voltage](image)

**Figure 2.** Response characteristics of two detection methods under different discharge defects

It can be seen from Fig.2a-Fig.2c that in tip corona discharge and creeping discharge defects, the SNR of sensor measured by the light measurement method and UHF method increases with the increase of the voltage amplitude. But under the same voltage amplitude, the SNR of the silicon photoelectric partial discharge sensor will be significantly greater than the SNR of UHF sensor. This shows that under the same background noise level, the silicon photoelectric partial discharge sensor has a relatively good effect in detecting partial discharge on site. For floating discharge, because its generation is mainly determined by the critical breakdown voltage of the levitation potential gap, its discharge energy and light radiation are relatively stable, and change little with the increase of applied voltage. During this process, the SNR of the photometric method remains high level.

The noise of silicon photoelectric partial discharge sensor mainly comes from device noise, and the influence of external electromagnetic interference is small. Therefore, under the same gain condition, its SNR will be significantly greater than that of UHF sensor. Therefore, in actual partial discharge detection, it can shows higher detection sensitivity.

3.2. **Comparison of phase-based statistical maps of optical and electrical pulses**

Phase-Resolved Partial Discharge (PRPD) is currently a common tool for partial discharge type discrimination and signal-to-noise recognition. Its principle is to map the partial discharge pulse sequences that occur in many different cycles with phase overlap to fully reflect the characteristics of randomness and periodic repetition of discharge, are the partial discharge data representation methods that are often used to implement defect pattern recognition algorithms.

Since the discharge optical radiation pulse and the electromagnetic radiation pulse have high synchronization, the PRPD spectrum can also be used to analyze the statistical characteristics of the partial discharge optical pulse. Therefore, this section uses the boost method to study the PRPD patterns obtained by the simultaneous measurement of UHF sensors and silicon
photoelectric PD sensors under different severity of partial discharges, and compare and analyze them. Fig.3 to Fig.5 are the PRPD patterns of light pulses and UHF pulses obtained under 1.4 times the partial discharge initial voltage (PDIV) for needle plate discharge, creeping discharge, and floating discharge.

As shown in Fig.3-Fig.5, the creeping discharge has no obvious polarity effect and the number of discharge pulses in the positive and negative cycles is close, showing an obvious hump distribution.
The phase of the discharge is mainly concentrated in $0^\circ -103^\circ$, $172^\circ -291^\circ$. Between the two intervals; the PRPD pattern of the tip conora discharge reflects the obvious polarity effect. There is basically no discharge phenomenon in the range of $0-180^\circ$, and the discharge is mainly concentrated in the negative half cycle; the floating discharge basically has no polarity effect. Partial discharge is mainly concentrated in the range of $9-92^\circ$ and $186-264^\circ$.

It can be found that under the same voltage level, the PRPD pattern measured by the UHF sensor has a relatively good consistency, which can reflect the phase interval and the frequency of the partial discharge occurring in several cycles.

3.3. Comparison of anti-interference ability of optical sensors

In order to investigate the anti-electromagnetic interference of the silicon photoelectric sensor, a strong electromagnetic interference source (high-frequency motor) was added near the sample in the experiment, and the silicon photoelectric sensor was used for synchronous measurement with PMT. The partial discharge model is a cutting-edge corona discharge model. The test result is shown in Fig.6.

![Figure 6](image)

Figure 6. The detection results of the two sensor light pulses of tip corona discharge under time sequence (applied voltage is 1.8 PDIV)

It can be seen from Fig.6 that the test results of the silicon photoelectric sensor are almost unaffected by electromagnetic interference, while the PMT sensor is greatly affected by the electromagnetic interference. The partial discharge signal with a small amplitude is almost submerged by the electromagnetic pulse signal, which will be greatly reduced. The confidence level of the small PMT sensor in partial discharge detection. It can be seen that, due to the immunity characteristics of the base material of the silicon photoelectric sensor to electromagnetic fields, its extremely strong anti-electromagnetic interference ability is guaranteed, and it can be applied to the complex electromagnetic interference environment on site. At the same time, the experimental results also reflect that the traditional PMT sensor, which is also an optical detection method, is slightly less resistant to electromagnetic interference than silicon photoelectric sensors. The partial discharge signals with small amplitudes are easily submerged by noise, although most can be removed by narrowband filtering. Electromagnetic interference, but it needs to reduce the sensitivity in the bandwidth as the cost, and the effect of electromagnetic interference in the wide frequency domain is not so good.

4. Conclusion

This paper builds an optical-electric synchronous partial discharge test platform, and simulates the creeping discharge, tip corona discharge and floating discharge in high-voltage switchgear.
Comparing the results measured by two detection methods, the following conclusions are obtained:

a) The signal-to-noise ratio of sensor measured by the two detection methods is consistent with the change trend of the voltage amplitude, but the signal-to-noise ratio of the silicon photoelectric partial discharge sensor is higher than that of the UHF sensor; in the high-frequency motor, the strong electromagnetic interference. Under the action of the source, compared with the traditional PMT sensor, the silicon photoelectric sensor is less affected by the background electromagnetic noise and has better anti-electromagnetic interference ability. Therefore, the sensor has a higher confidence in the on-site partial discharge detection.

b) Judging from the PRPD spectrum, the spectrum measured by the two detection methods has good consistency, and the surface discharge has obvious hump distribution, and the phase of the discharge is mainly concentrated in 0° -103°, 172° -291°. Between the two intervals; the needle plate discharge reflects the obvious polarity effect, there is basically no discharge in the positive half cycle, and the discharge is mainly concentrated in the negative half cycle; the suspension discharge basically has no polarity effect, and the partial discharge is mainly concentrated in 9° -92°, within the range of 186° -264°.

Acknowledgments
This work was supported by the Science and Technology Program of the State Grid Corporation of China (J2020041).

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