Research on the technology of abnormal discharge detection device for metal fittings based on optical fiber signal transmission

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Abstract. This paper aims to develop an abnormal discharge detection device based on optical fiber signal transmission, and realize the reliable detection of abnormal discharge between fittings of high voltage electrical equipment. The detector and visible light detector developed in the arc light detection part can realize the efficient detection of ultraviolet light and visible light in the arc light. By optical fiber far-range signal transmission structure, this design developed multifunctional optical signal collector, which can be converted into analog electric signal, state quantity signal, digital quantity signal and other forms while collecting arc light efficiently.

1. Introduction
There are various kinds of high voltage electrical appliances in the power grid. For the long-term operation of circuit breakers, transformers, switchgear and other primary equipment high voltage electrical equipment in the high electric field and high magnetic field environment, when there is bad weather, electromagnetic environment changes and other conditions, it is easy to occur abnormal discharge phenomenon. The energy generated by the arc is easy to damage the structure of the equipment. In severe cases, it will cause switch tripping, equipment damage, even high-voltage equipment combustion, explosion, causing a large area of power failure, and even lead to personal injury and death accidents.

There are research shows: electric arc is one of the main causes of electrical fires. When the arc current is greater than 0.5a, it may cause fire. When the arc current reach 2 ~ 10 A, it can produce high temperature above 2000℃ [1], and high temperature energy accumulates in a limited space such as switchgear, it is prone to combustion and explosion. And high temperature and high pressure, electrical
equipment produced by the toxic gas may also cause personal injury to equipment maintenance personnel. Spectral detection instruments at home and abroad are generally expensive, such as ultraviolet imager and local discharge meter, etc., which are expensive for power supply equipment discharge detection, therefore, it is difficult to popularize them. Therefore, a kind of low cost, high efficiency and easy to use discharge detection equipment is urgently needed to realize long-term detection of high voltage equipment. After studying, it is found that arc light is composed of ultraviolet light and visible light, and the intensity of ultraviolet light accounts for more than 70% of the total intensity of arc light [2]. Therefore, by detecting the energy and spectrum of ultraviolet light and visible light, this project develops a low-cost and convenient device for detecting abnormal discharge at the end of metal tools. By this way, the reliable and long-term monitoring of high voltage power equipment is realized, and the reliability of power supply is improved.

2. Key technology of arc detection

2.1. Fourier transform
An arc is usually an ionization of a gas when the voltage reaches a certain value, which i is a phenomenon of free discharge of gas. It has the characteristics of concentrated energy, high temperature, strong light and short occurrence time. The waveform of the arc has the following characteristics:

- The arc current has periodic characteristics of zero over extinguishing and zero over reigniting.
- There is a voltage drop along the arc direction.
- Arc currents generally rise faster than normal currents.
- The arc waveform contains a lot of high frequency signals.

Fourier transform and Fourier series (FS) expansion are commonly used to analyze these characteristics of arc waveform:

If the dirichlet condition is satisfied, the continuous time periodic signal whose period is T1 can be expanded into FS. In which, the Fourier series in triangular form is:

\[ x(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} \left[ a_k \cos k \omega_1 t + b_k \sin k \omega_1 t \right] = \frac{a_0}{2} + \sum_{k=1}^{\infty} \left[ a_k \cos \frac{2\pi}{T_1} kt + b_k \sin \frac{2\pi}{T_1} kt \right] \]

\[ \omega_1 = \frac{2\pi}{T_1} \]  (Fundamental frequency)

\[ a_0, a_k \text{ and } b_k \text{ are dc component, cosine amplitude and amplitude of sinusoidal component of signal } x(t) \text{ , respectively.} \]

\[ a_k = \frac{2}{T} \int_{T_0}^{t_0+T} x(t) \cos k \omega_1 t \, dt \]

\[ b_k = \frac{2}{T} \int_{T_0}^{t_0+T} x(t) \sin k \omega_1 t \, dt \]

The amplitude spectrum and phase spectrum of continuous time periodic signal x(t) are:

\[ A_k = \sqrt{a_k^2 + b_k^2} \]

\[ \varphi_k = \arctan \frac{b_k}{a_k} \]
In which, the relation between $k$ and frequency is $\omega = k\omega_1$, therefore, the above formula gives the basic law of the signal and the variation of each harmonic amplitude with frequency.

2.2. Wavelet algorithm

Fourier transform is one of the most widely used mathematical transformation methods in the field of signal detection. It is mainly aimed at the incoming line analysis of stationary signal. For arc signal, it is a fast step signal and can obtain a high time-frequency resolution when the signal is abrupt, so the Fourier transform is not very suitable.

Wavelet algorithm is a new time-frequency analysis method developed in recent years. The window shape of the wavelet transform can be adjusted. When analyzing the signal, it can double localize the signal in time-frequency domain and reflect its time-frequency domain characteristics. Wavelet analysis has strong adaptive ability. It has lower time resolution and higher frequency resolution in low frequency band, and higher time resolution and lower frequency resolution in high frequency band, so it is very suitable for detecting abnormal mutation signal [3].

Wavelet transform is used for multi-scale analysis of signal and function incoming line by operation of expansion and translation, finally, it achieves frequency subdivision at low frequency and time subdivision at high frequency, so as to meet the requirements of time-frequency signal analysis. Wavelet transform makes up the defect of Fourier transform.

The meaning of wavelet transform is that after the displacement of a certain function called basic generating wavelet $\Psi(t)$, the inner product of it with the signal $x(t)$ to be analyzed at different scales $a$ is:

$$WT_x(a, \tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t) \Psi \left( \frac{t - \tau}{a} \right) dt$$

where $a > 0$ is a scale factor, $\tau$ is used to reflect the displacement, it can be positive or negative.

For continuous wavelet transform, scale and translation parameters must be discretized. The filtering coefficient $h_0(n)$, $h_1(n)$ are the main parameters in the discrete wavelet transform, we can use the known $h_0$, $h_1$ to obtain $\Phi(n)$, $\Psi(n)$.

3. Design of arc detection device

High voltage electrical equipment has the characteristics of high voltage and high electromagnetic radiation. The abnormal discharge detection device at the end of the fixture based on optical fiber signal transmission is designed to adopt innovative design schemes, such as multi-light source acquisition, telescopic link transmission and split structure. From arc light capture, acquisition, transmission and analysis, the all-fiber channel of arc light can be realized. At the same time, it can satisfy the electromagnetic environment of the test site, improve the safety and realize the safe and reliable monitoring.

Based on optical fiber signal transmission, the general connection mode of material among each part of the abnormal discharge detection device at the end of the hardware makes the detection device easy to operate. Innovative design refers to the design of innovative, creative and practical equipment by making full use of the relevant technology and knowledge of modern society [4]. The simpler the
operation, the stronger the generalization. The scheme combines innovative design with modern design to break the conventional design concept and create a new structure.

3.1 Integral structure plan

Based on optical fiber signal transmission, the whole structure of abnormal discharge detection device at the end of hardware is divided into three parts: arc light detection part, optical signal transmission part and arc light analysis and display part. As shown in figure 1, the main function of arc light detection part is to realize efficient detection of arc light and acquisition of arc light signal. In the optical signal transmission part, arc optical signal is transmitted far without attenuation to ensure reliable transmission of arc optical signal. The arc light analysis display part realizes the conversion from optical signal to electric signal, which can realize the analysis and digitization of arc information, as well as the visualization of arc information.

![Diagram](image)

**Figure 1.** Integral structure diagram of abnormal discharge detection device at the end of hardware based on optical fiber signal transmission

The detection part of arc light should be able to detect not only the ultraviolet light signal of arc light, but also the visible light signal of arc light, which greatly increases the detection reliability when the discharge phenomenon occurs.

The reliability of arc signal transmission and the applicability of working site are considered in optical signal transmission. Therefore, the transmission of arc light signal can be divided into two modes. One is the local detection mode, the other is the portable detection mode. The local detection mode is that the arc light detection part resides on the primary power supply equipment for a long time, so that the substation equipment can carry out the detection work at any time. Portable detection mode is specially designed for devices that can detect discharge phenomenon in a close range, which can realize the monitoring of substation equipment at any time.

Arc light analysis shows that when discharge occurs, it can send out alarm signals such as sound and light at a distance or detect discharge intensity, which can intuitively show the occurrence of discharge phenomenon, or display discharge intensity through special instruments and meters, providing guarantee for equipment maintenance and safe operation.

3.2. Arc light detection scheme

The essence of arc light is the photoelectric effect accompanied by gas discharge, which radiates ultraviolet radiation. Its wavelength is mostly in the range of 280-400 nm, and a small part is 230-280 nm [5]. The part of arc light detection is to study the targeted ultraviolet and visible detectors, fully capture the characteristics of ultraviolet and visible light, improve the accuracy and reliability of detection.

When the intensity of arc light is not very large, the high-precision ultraviolet detector only detects
the ultraviolet part. While the intensity of visible light transmission above 450nm is very small. Even if the arc light intensity is very large, only a small part of visible light can pass through the probe, fully ensuring the reliable detection of ultraviolet light. The response of the ultraviolet probe is basically the same at every angle from the normal incident to the side incident of the light source. In which, the response of lateral incidence is 70% ~ 130% of that of normal incidence. When light is incident direction of 90° ~ 135°, the responsiveness can still reach more than 50% of the normal incidence, which reflects the wide angle and wide range sensitivity consistency. See figures 2 and 3.

![Figure 2. Wavelength response curve of the ultraviolet probe](image1)

![Figure 3. Angular response characteristics of the ultraviolet probe](image2)

Visible light detector is a visible light sensitive sensor specially used for detecting fault arcs of power system, transformers and high-voltage line arcs, etc. It receives arc light over a very wide spectrum, which improves the spectrum detection range of the system. And it can receive optical signal in the half space of 180°×360°, and the output deviation <30% under the same light intensity on the sensor.

The main structure of the arc light detection part includes an arc light detector and a concentrator. Detector adopts universal thread interface, which is convenient for docking with all kinds of rear equipment, as shown in figure 4.
When the arc light probe is directly installed on the primary equipment such as switch cabinet and circuit breaker, it can be fixed directly on the primary equipment shell through the fixed bracket instead of the condenser, as shown in figure 5.

![Figure 5. Local detection mode](image)

**3.3. Optical signal transmission part of the scheme**

Optical signals can be transmitted over long distances through optical fibers without electromagnetic interference and converted to voltage signals by receivers [6]. Therefore, optical signal is an ideal transmission medium for safe and reliable detection of arc optical signal in high voltage power equipment. The photoelectric transmission part of this project can be divided into local detection mode and portable detection mode. The two modes adopt hard link and soft link respectively. Hard link is a telescopic link as the main body, which is embedded efficient transmission cable. The soft connection part uses the high quality optical cable production, the attenuation is small, the flexibility is good.

Soft connection mode is the connection scheme of local detection mode. As shown in figure 6, the cable connector can be plugged on the fiber interface of the locally installed arc light probe directly. The other end of the cable is connected to the detection and analysis part of arc light. This method has a long transmission distance, which can carry out continuous detection of arc light far away from the primary power supply equipment to ensure the safety and reliability of detection.

![Figure 6. Cable connector](image)
A multistage telescopic rod structure is adopted for hard connection, and a special optical cable is embedded in the multistage telescopic rod. As shown in figure 7, one end of the multi-stage telescopic pole is equipped with arc light detection equipment, and the other end is connected with optical cable. The optical signal is transmitted to the detection and analysis equipment of arc light through optical cable. The multistage telescopic rod has a handle and can be held by hand to detect arc light at a safe distance. As the high-voltage power supply equipment is in actual operation, it is forbidden to open the door of the equipment, therefore, the detection range of this method is limited to a certain extent.

3.4. Arc analysis display section

The display part of the arc light can display the arc light visually through sound, light and other alarm signals. Through the intelligent equipment information processing, the detected discharge intensity provides the foundation for the high voltage equipment discharge signal advanced application, as well as RS485 and analog interface.

The arc light tester is extremely sensitive to weak light sources, and it can detect light sources with light intensity less than 100nW/cm2. The photoelectric analysis module, which is composed of digital circuit and analog circuit, is embedded inside to realize RS485 communication interface based on MOD bus and TTL level simulation interface. The arc light tester is equipped with a buzzer, which will sound alarm when the device arc discharge is detected. Therefore, the arc light tester is easy to use and expandable, as shown in figure 8.
4. Technical features of arc detection device

On the basis of fully understanding the research results of arc light in China, designers have done a lot of work in order to solve the problem of safe and reliable detection of arc faults in electrical equipment and reduce the cost of detection. In this project, a large number of advanced design ideas and new technologies have been adopted, and many innovations have been realized. Realize the design goal of easy to use, good safety and high reliability.

(1) Using split design, each part of the detection device can achieve independent functions, so that each part of the detection device can be applied to different occasions, to achieve a multi-purpose machine, greatly reducing the cost of the late detection work.

(2) Develop multi-purpose detector to improve detection reliability.

Study the characteristics of arc light source, study targeted ultraviolet light detector and visible light detector, fully capture the characteristic quantity of ultraviolet light and visible light, and improve the acquisition accuracy and reliability of detection.

(3) Research and development of multi-purpose sensors to support visible and ultraviolet detection, support a variety of data output methods, increase the versatility of sensors, reduce detection costs.

(4) The reliability of arc detection can be improved greatly by innovating the way of light source acquisition and increasing the concentrator facilities.

In the acquisition of weak light source signal, the biggest problem is signal capture. It is the top priority in detection to reliably capture signals, therefore, small improvements in signal capture are innovations. This project makes use of the reflection principle of light to produce the reflector of weak light source, gathering the signal of light source to the detector as much as possible to improve the reliability of detection.

(4) Multi-stage telescopic rod structure is adopted to improve test safety.

The multistage telescopic rod structure is an important innovative part of portable testing, which solves the interface problem of optical fiber transmission well in portable test. It also solves the problem of safe distance for testers and makes it possible for portable detection of discharge in high voltage equipment.

5. Conclusion

In this paper, the detection device of abnormal discharge at the end of fittings based on optical fiber signal transmission is introduced in detail. By adopting split structure, developing multi-purpose
detectors and multi-purpose sensors, innovating detector structure and light source acquisition mode, the arc detection of high and low voltage electrical equipment is realized safely and reliably, the cost of detection is greatly reduced, the detection process becomes simple, safe and reliable, the popularization of primary equipment discharge detection is greatly promoted, and the reliability of substation power supply is improved. Sex and staff security can play a very good role. At the same time, it can also play a great role in improving the quality of power supply and promoting the development of national economy.

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