International Journal of Computer Science and Information Technology
ISSN: 3005-9682 (Print), ISSN: 3005-7140 (Online) | Volume 3, Number 3, Year 2024
DOI: https://doi.org/10.62051/ijcsit.v3n3.32
Journal homepage: https://wepub.org/index.php/IJCSIT/index

Typical Partial Discharge Signal Acquisition and Feature Extraction in High Voltage Switchgear

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ABSTRACT

With the progress of power system technology, how to effectively evaluate the reliability of high-voltage switchgear equipment has become an important part of power grid power supply and industrial distribution. Switchgear is used in power system power generation, transmission, power distribution, power conversion and consumption play a role in switching, control or protection, voltage level in 3.6kV-550kV electrical products, usually contains a variety of switches, circuit breakers, contactors and other components. In the process of use, due to various reasons, partial discharge may occur. Partial discharge refers to a partial discharge phenomenon in insulating media, which is usually caused by defects in the medium or excessive local electric field intensity. In switchgear, PD may be caused by aging of equipment, deterioration of insulation materials, dust accumulation and other reasons. Pd generates discharge current and discharge heat, which may damage the insulation performance of the equipment or even cause a fire. Therefore, it is very important to detect and deal with the partial discharge phenomenon in the switchgear in time. Therefore, timely detection of partial discharge of equipment can deal with partial discharge problems by checking equipment, cleaning equipment, timely replacement of aging components, and other methods to avoid losses caused by equipment failure due to partial discharge. Due to the complex distribution site environment and the interference of wireless communication signals from other equipment, the real high-frequency signals of partial discharge will be interfered, which will affect the accuracy of insulation performance evaluation of electrical equipment in the switchgear. Therefore, how to correctly collect partial discharge signals and how to identify the characteristics of partial discharge signals will be an important part of partial discharge detection in switchgear. At present, the commonly used partial discharge signal feature recognition is mainly based on the typical signal simulated by Matlab and artificially added noise for processing. Due to the wide frequency band of local discharge and the complex field environment, the real collected waveform will be different from the typical discharge signal. The original signal is filtered and detected for processing and analysis.

KEYWORDS

Partial discharge; Signal acquisition; Envelope detection

1. INTRODUCTION

The development of smart distribution network construction puts forward higher requirements for the smooth operation of power equipment. As a key electrical equipment in the distribution network, switchgear is widely used in various substates, switching stations and other scenarios. The safe and stable operation of the equipment is of great significance to ensure the reliability of power supply in the power system. The switch cabinet is a non-closed structure and has a compact internal space. Due to its long-term operation in a complex environment, it is easy to cause partial discharge due to aging or defects of the insulation layer, which will eventually lead to insulation breakdown and flapper of

the equipment, and then cause partial or even largescale power failure. The International Electrotechnical Commission (IEC) and various countries have formulated corresponding measurement and evaluation standards for partial discharge. However, the electrical equipment in high voltage switchgear has different working environments, poor electromagnetic environment, and weak partial discharge signal. The measured partial discharge signal is often submerged, and the collection of partial discharge signal becomes extremely difficult. And the attenuation distortion of the partial discharge signal is extremely serious in the propagation process. How to judge the partial discharge signal in the collected signal has become an important part of the partial discharge signal processing.

2. PARTIAL DISCHARGE SIGNAL ACQUISITION

2.1. Overview of Local Discharge

Signal According to the research at home and abroad, electrical equipment in the occurrence of partial discharge, its internal accompanied by magnetic field, electric field changes, changes must exist a variety of energy interaction and produce electromagnetic pulse, radiation, light and other phenomena in this paper, only the high-frequency electromagnetic signal generated by partial discharge analysis and processing. The switchgear is a non-closed structure and compact internal space. Due to its long-term operation in a complex environment, the manufacturing process of the insulation device problems, resulting in partial discharge in the laminate, bending, insulation lap and other places with bubble gaps or containing impurities; The partial damage caused by mechanical damage, partial extrusion, porcelain cracking and other reasons in the assembly process of insulating devices leads to discharge; Uneven electric field distribution inside the insulating medium, if the electric field intensity in some parts is lower than the discharge field intensity, resulting in discharge; The surface of copper wire, aluminum wire and other wiring is not smooth, there are burrs or sharp angles cause discharge;

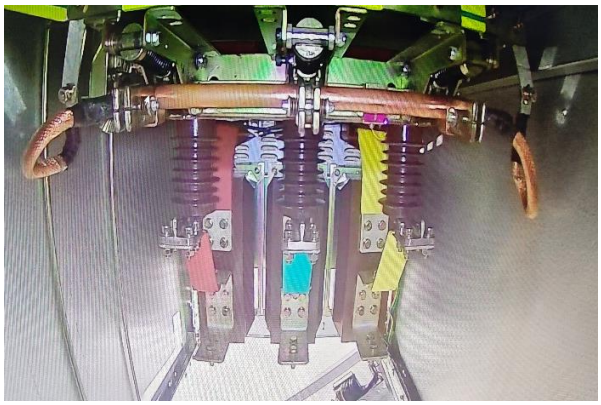

Figure 2.1. partial discharge collection site

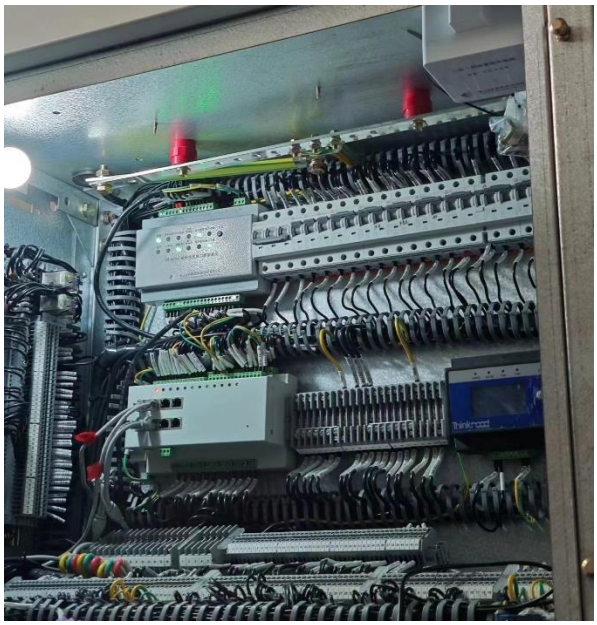

Figure 2.2. high voltage switchgear

2.2. Type of Partial Discharge

Partial discharge of electrical equipment is mainly affected by the insulation structure of electrical equipment, the insulation structure is mainly composed of insulating materials and charged metal parts, due to the composition of different insulation structures, the form of partial discharge is also different, so the common forms of partial discharge are: burr or spike, large radius of curvature, interface, bubble or air gap four kinds. At present, the mainstream research direction divides the typical signals of PD into four categories according to the location of PD: tip corona discharge, suspended potential discharge, surface discharge and internal discharge.

In this paper, different types of discharges are discussed respectively, and a high voltage of 10kv-30kv is applied to the typical discharge model to collect the actual signal of the partial discharge signal.

Figure 2.3. Shielded PD laboratory

Figure 2.4. Shielded indoor experimental environment construction

2.2.1. Tip discharge

The metal parts in the power equipment are loose or broken, so that the part is located between the high and low pressure electrodes. When the suspension potential difference is large enough, it will cause discharge, resulting in carbonization and corrosion of the surrounding medium. For example, in the long-term use of the insulating rod of the circuit breaker, the gap size is different between the opening and closing operation and the contact, and the suspension discharge will occur when the two contact is poor, so the rod carbonization fracture will occur for a long time.

Figure 2.5. Tip discharge model

2.2.2. Suspension discharge

The metal parts in the power equipment are loose or broken, so that the part is located between the high and low pressure electrodes. When the suspension potential difference is large enough, it will cause discharge, resulting in carbonization and corrosion of the surrounding medium. For example, in the long-term use of the insulating rod of the circuit breaker, the gap size is different between the opening and closing operation and the contact, and the suspension discharge will occur when the two contact is poor, so the rod carbonization fracture will occur for a long time.

Figure 2.6. Insulation terminal

Figure 2.7. Suspension discharge model

2.2.3. Surface discharge

When the surface of the solid insulating medium is rough, the surface is in contact with the moisture and dust in the air, so that a large number of free moving charges are gathered on the surface, resulting in uneven local conductance of the insulating medium, distortion of the local field strength, and surface discharge will occur when the breakdown voltage of the insulating layer is reduced When the electric field strength exceeds the breakdown strength of the insulating material, it will also lead to the excitation of electrons in the air or other media to generate discharge. Surface discharge usually occurs in a local area on the surface of the insulation.

Figure 2.8. Internal discharge model

2.3. Partial Discharge Signal Acquisition Method

More for the current study of local signals, the occurrence of partial discharge will be accompanied by corona discharge, arc discharge and other phenomena, will produce electromagnetic waves, heat energy, light energy, and produce chemical substances. These phenomena accompanied by PD can be used as a method to detect PD.

Therefore, according to the different forms of PD phenomena, PD detection can be divided into electrical signal detection and non-electrical signal detection. At present, the main detection methods and their characteristics are summarized as follows:

(1) Non-electrical detection methods of partial discharge

Chemical reagent detection When partial discharge occurs in GIS equipment, chemical substances will decompose, and a high-activity SF4 gas will be generated. Because SF4 gas is unstable and easy to oxidize, it will react further, and its reaction products mainly exist in the form of SO2F22 and SOF.

Therefore, the partial discharge phenomenon can be judged by detecting the concentration of SO2F22 and SOF. The advantage of this method is that it can avoid the electromagnetic signal interference and noise interference in the complex distribution working environment. However, due to the poor real-time detection of chemical reagents, detection is not sensitive, and the arc generated by the circuit breaker work will also have gas generation, thus affecting the detection results, and this method can not locate the discharge position, so this method is mainly used for auxiliary analysis, and it is difficult to be used for small electrical equipment such as switchgear.

Figure 2.9. Gas detection of GIS equipment

(2) Ultrasonic detection method

When partial discharge occurs, it will be accompanied by the generation of ultrasonic signals. The ultrasonic signal generated by the partial discharge is received by the ultrasonic sensor, so as to analyze and process to determine whether there is a partial discharge. The detection frequency band of ultrasonic detection method is generally between 20kHz and 230kHz. The advantages are: ultrasonic detection is easy to realize online monitoring, and is conducive to quantitative analysis and pattern recognition of partial discharge. Ultrasonic is a sensitive sound signal when partial discharge occurs, so the ultrasonic detection method is extremely sensitive to noise. The ultrasonic signal in the complex environment of the switch cabinet, and the propagation of the insulation material has a large signal attenuation, and the detection accuracy is not high, so the method currently has large environmental limitations, and the scope of the actual use in industry is very limited.

Figure 2.10. partial discharge ultrasonic detector

(3) Optical detection method

When partial discharge occurs in electrical equipment, it will be accompanied by a series of optical reactions. In this process, charged particles generated by partial discharge collide with ions in the gas, which in turn produce photons. Therefore, photomultiplier tubes can be used to detect the photons generated in the process of partial discharge, so as to determine whether the electrical equipment has partial discharge. However, when the specific location of partial discharge is unknown, it is difficult for the optical sensor to capture the accurate discharge optical phenomenon, and the optical sensor

needs to be placed inside the switch cabinet, the internal high-voltage components are easy to destroy the effectiveness and sensitivity of the optical sensor, and the discharge type cannot be determined through the optical phenomenon, and arc light may also be generated in the process of opening and closing the circuit breaker. Therefore, the optical detection method is usually used as an auxiliary method for partial discharge detection.

Figure 2.11. Arc light sensor

(4) Temperature detection

Temperature is a very important parameter in the distribution system, which has a great impact on the overall performance and safe operation of the distribution system. For the switchgear, when there are long-term full load or overload operation caused by excessive terminal load, short circuit or open circuit and other electrical faults, improper operation of the switchgear in the process of transportation and installation causes poor copper contact, oxidation and aging of the copper surface in the long-term operation of the switchgear, reducing the specification of the copper bar in the design of the switchgear, and using inferior copper bars in production, etc. Will cause abnormal temperature in the low-voltage box. If the long-term temperature in the low-voltage cabinet is too high, it will accelerate the aging of the insulation, reduce the mechanical strength of the metal, reduce the current load of the copper row, and increase the failure of the equipment. Because partial discharge will also produce temperature transformation, temperature measurement equipment will be installed in the general switchgear to monitor the temperature. Since the specific cause of temperature anomaly cannot be determined, this method is only used to assist the judgment of partial discharge phenomenon.

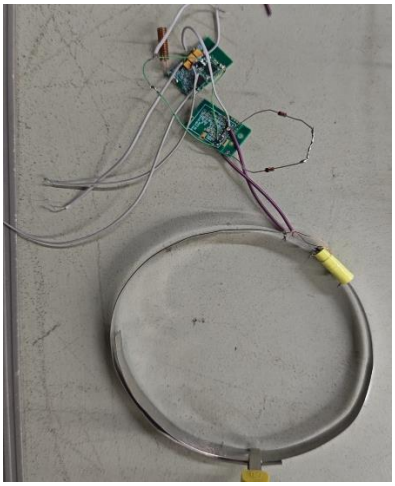

Figure 2.12. Wireless temperature measuring node

Figure 2.13. Wireless temperature measuring terminal in switchgear

3. PARTIAL DISCHARGE SIGNAL ACQUISITION

3.1. Collection of Raw PD Signal

This acquisition is for UHF signals. The UHF detection method has the advantages of high sensitivity, high detection frequency band, strong antiinterference, and basically not affected by mechanical noise. It can be directly received by antenna, and the oscilloscope uses shielded lines for acquisition. After a large number of partial discharge waveform acquisition based on four typical discharge defects and the existing mainstream research, the following waveform data obtained from the test in the shielded partial discharge laboratory are processed.

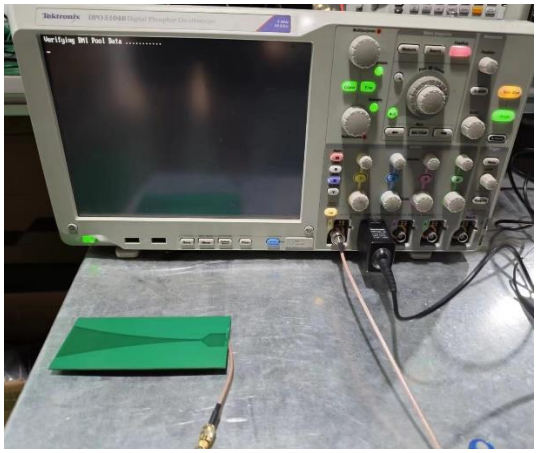

Figure 3.1. Construction of partial discharge waveform acquisition environment

The study shows that the waveform of partial discharge signal has a steep rising edge, which is generally exponential oscillation attenuation, and the higher the oscillation frequency, the faster the attenuation. In order to accurately detect the partial discharge signal, the signal time domain model can be summarized into four types: single exponential decay type, double exponential decay type, single exponential shock decay type and double exponential shock decay type.

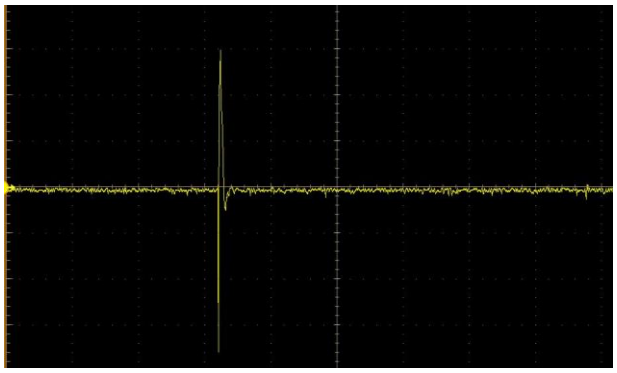

Figure 3.2. Waveform of single exponential decay type

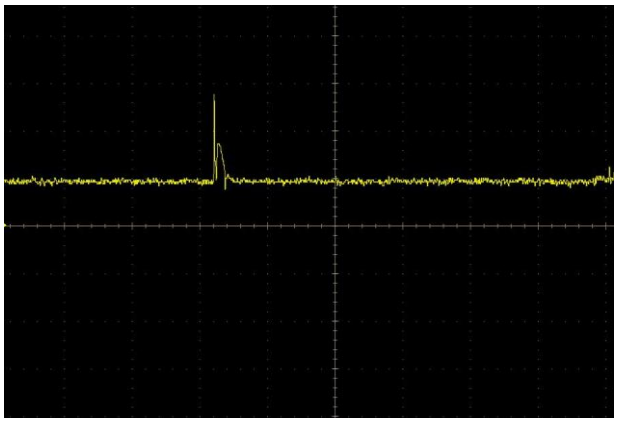

Figure 3.3. A double exponentially decaying waveform

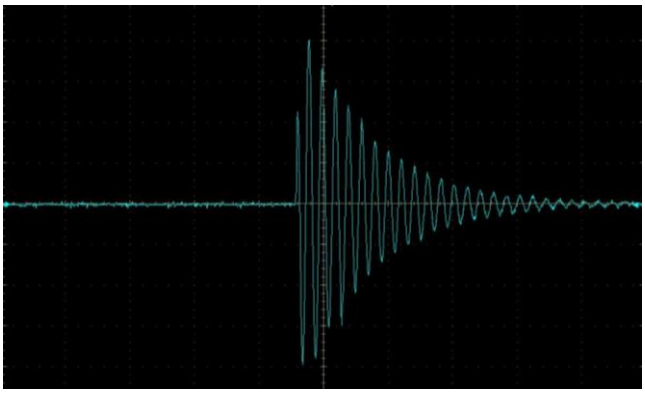

Figure 3.4. Double exponential oscillating waveform

They can be represented by the following four mathematical expressions:

(1) Single exponential decay

$$x(t) = Ae^{-(t-t_0)/\tau} \tag{0.1}$$

(2) Single exponential decay

$$x(t) = A\left(e^{-1.3t/\tau} - e^{-2.2t/\tau}\right) \tag{0.2}$$

(3) Single exponential oscillation attenuation type

$$x(t) = Ae^{-t/\tau} \sin 2\pi f_c t \tag{0.3}$$

(4) Double exponential oscillation attenuation type

$$x(t) = A\left(e^{-1.3t/\tau} - e^{-2.2t/\tau}\right)\sin 2\pi f_c t \tag{0.4}$$

In the above formula, A represents the amplitude of the partial discharge signal, t0 represents the start time of the signal, τ represents the attenuation coefficient of the partial discharge signal, which determines the decay time of the discharge pulse, and fc represents the oscillation frequency of the signal. The signals of the four PD models simulated by MATLAB R2018aFIG.

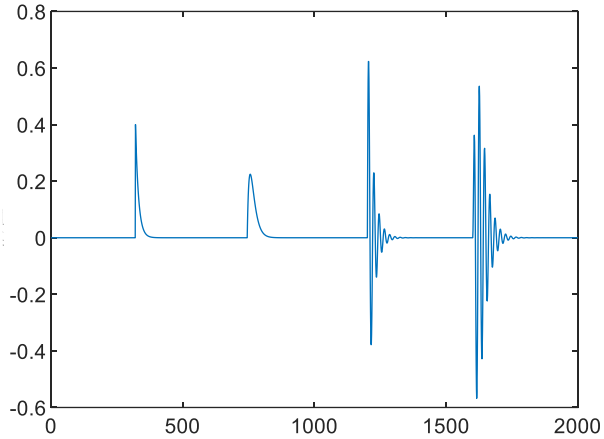

Figure 3.5. Four types of simulated PD signals

According to a large number of experimental data based on four discharge defect models in switchgear, this paper mainly analyzes the double exponential oscillation waveform.

3.2. Partial Discharge Signal

In industrial practical applications, it is difficult to use complex algorithms for noise reduction identification. Also considering the cost factor, the current mainstream noise reduction algorithm research on matlab is also extremely limited in the actual equipment. This study uses signal amplification, bandpass filtering, envelope detection, low-pass filtering, signal amplification for processing. To make the single-chip microcomputer and other equipment better for identification, the overall design process is shown in Figure 3.6.

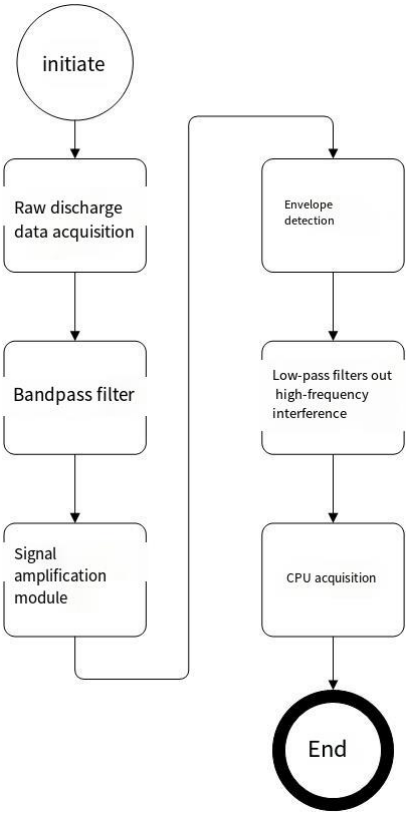

Figure 3.6. Signal processing system flow chart

Through this series of processes, the partial discharge signal with interference is converted into a characteristic level signal that can be read by the cpu, so that the partial discharge detection equipment can be more stable and effective to monitor the generation of partial discharge, and it is more difficult to be triggered by the interference signal, which leads to the misjudgment of the operator.

3.2.1. Hardware circuit design

Ideas of circuit modularization in terms of hardware circuit design, the circuit is divided into partial discharge signal amplification module, envelope detection module, and envelope detection signal amplification and filtering module according to the flowchart idea. The signal is processed into the CPU through the three modules, as shown in Figure 3-2.

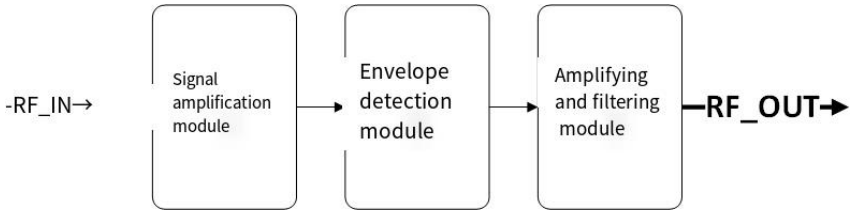

Figure 3.7. Circuit modules

Through the modular design of the circuit, it is easy to debug the signal at different levels and observe whether the signal meets the form that should theoretically appear. In this way, the development and design cycle are accelerated and the changes of PCB in the later stage are reduced.

3.2.2. Signal amplification module

The function of the signal amplification module is to amplify the collected PD signal to a size that is convenient for envelope detection. If all signals enter the amplification circuit, the interference signal will be amplified at the same time, the signal needs to be classified and processed here. A bandpass filter is a circuit that only allows a specific frequency to pass while effectively suppressing the signal

of the remaining frequencies. Because it is selective to the signal, it is widely used in electronic design. A bandpass filter is shown in Figure 3.8.

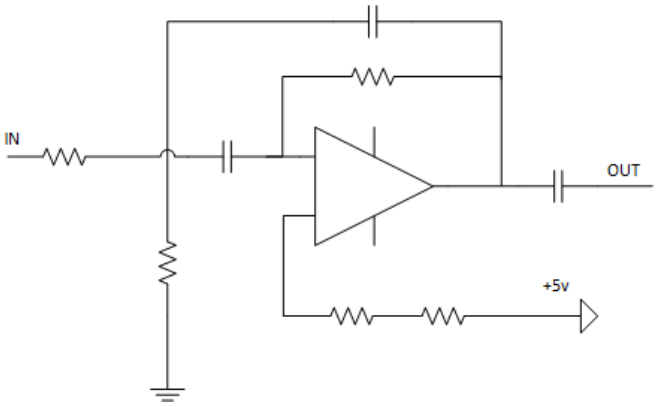

Figure 3.8. The bandpass filter

The frequency of the passing signal is set from 10Mhz to 500Mhz through the bandpass filter. Any signal below 10Mhz or above 500Mhz is considered as an interference signal. In the amplification circuit, the chip SBB-5089 is selected to amplify the partial discharge signal. The official peripheral-use circuit provided by SBB-5089 is shown in Figure 3-4.

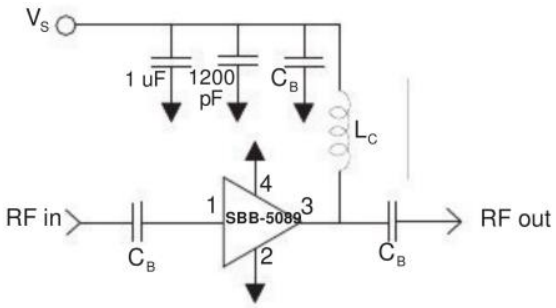

Figure 3.9. Official SBB-5089

Peripheral reference circuit the signal amplification module is formed by combining a bandpass filter with a signal amplifier as shown in Figure 3-5.

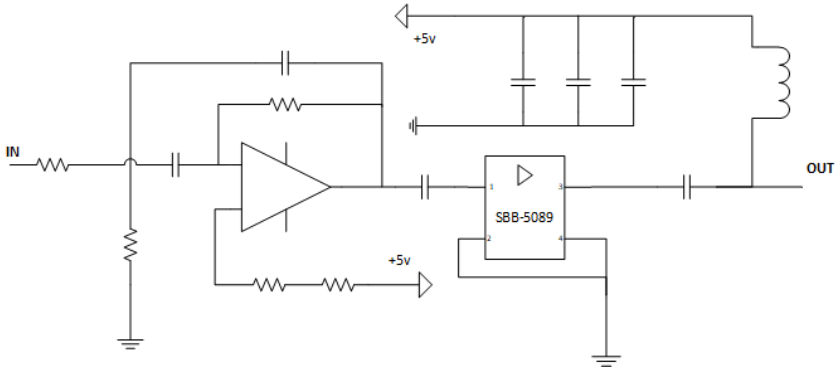

Figure 3.10. Signal amplifier module

Envelope detection is a vibration signal processing method based on filter detection, which has strong recognition ability for incipient faults and fault signals with low signal-to-noise ratio. Connect the peak point of the high-frequency signal for a period of time, you can get a line above (positive) and a line below (negative), these two lines are called envelope. The envelope is the curve that reflects the amplitude change of the high-frequency signal. For high frequency signals of constant amplitude, these two envelopes are parallel lines. When a low-frequency signal is amplitude modulated (i.e., amplitude modulated) to a high-frequency signal, the low-frequency signal becomes the envelope of the high-frequency signal. The PD envelope uses power detection, that is, the output voltage of the

detector corresponds to the input signal power. In this way, the envelope of the PD waveform can be obtained. We regard the envelope as carrier information, so as to judge whether a partial discharge signal occurs inside the device. The partial discharge waveform of the input envelope module is shown in Figure 3.11.

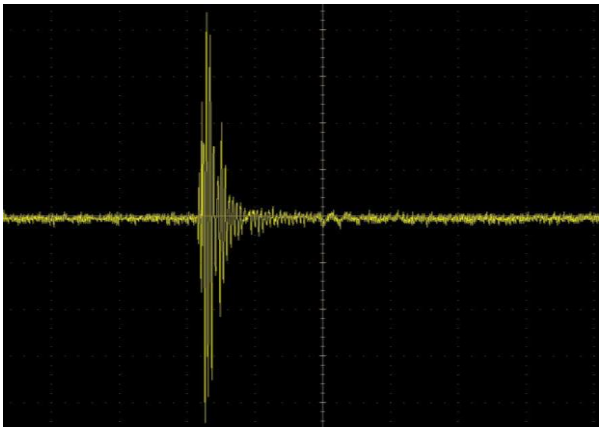

Figure 3.11. Partial discharge waveform of input envelope module

The core of the envelope module is the power detector. Here, we use ADL5501 chip as the power detector. The official reference circuit of ADL5501 chip is shown in Figure 3-12.

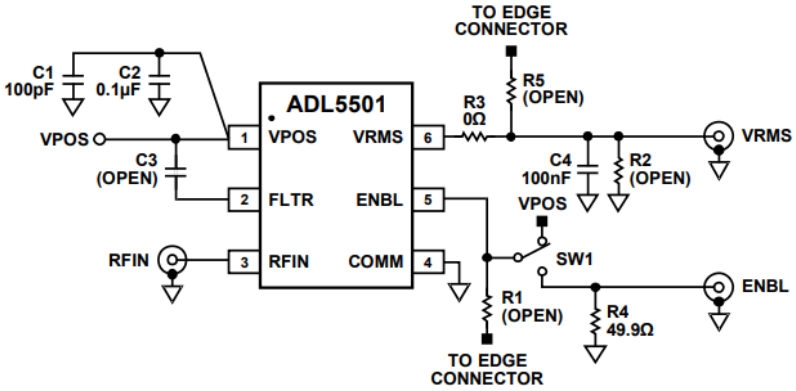

Figure 3.12. Official reference circuit of ADL5501 chip

In this design, we refer to the example circuit given by the official to modify. The schematic diagram of ADL5501 detector module after modification is shown in Figure 3-8.

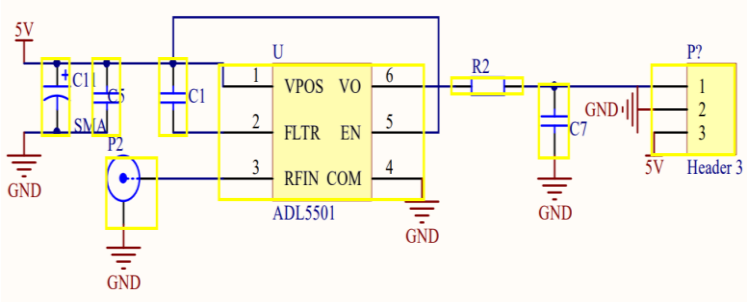

Figure 3.13. Schematic diagram of ADL5501 detector module

After the envelope detection module, the envelope characteristics of the partial discharge signal can be obviously observed. The envelope waveform of the partial discharge signal after the module is shown in Figure 3-14.

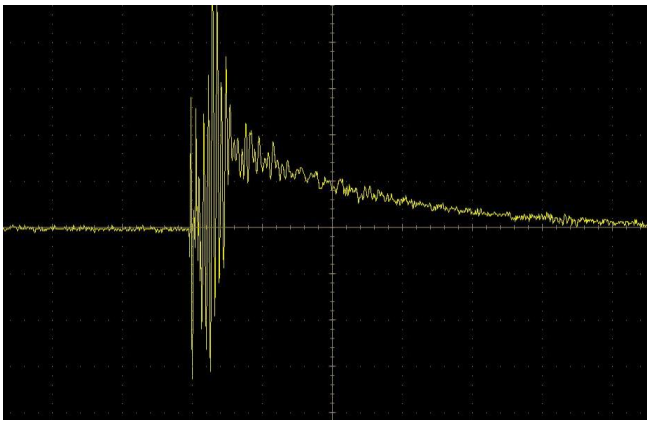

Figure 3.14. Waveform acquisition behind the envelope module

From the analysis of Figure 3-9, it can be clearly seen that there is still a great deal of high-frequency clutter interference after the envelope. These interference may be the high-frequency electromagnetic noise of communication equipment and the spatial coupling of high-frequency electrical signals when the discharge phenomenon is generated, so it is necessary to process the signal. For the envelope signal obtained through a large number of experimental data, the effective signal frequency was set at about 1Mhz, and the signal was processed for the third time through the last stage of amplification filtering. The chip used here is TQP3M9008, and the official reference circuit of the chip is shown in Figure 3-10.

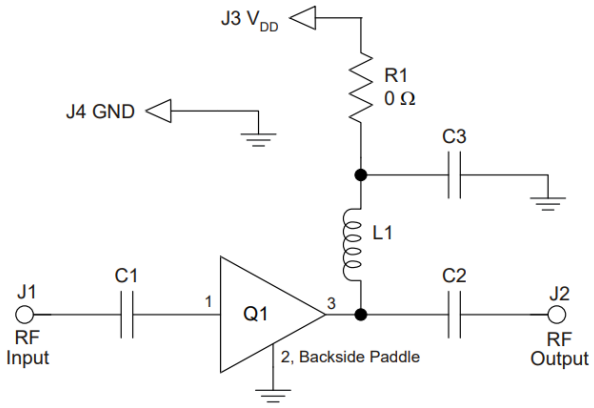

Figure 3.15. Official reference circuit of TQP3M9008

The module is designed according to the official reference circuit, and the schematic diagram is shown in Figure 3-11.

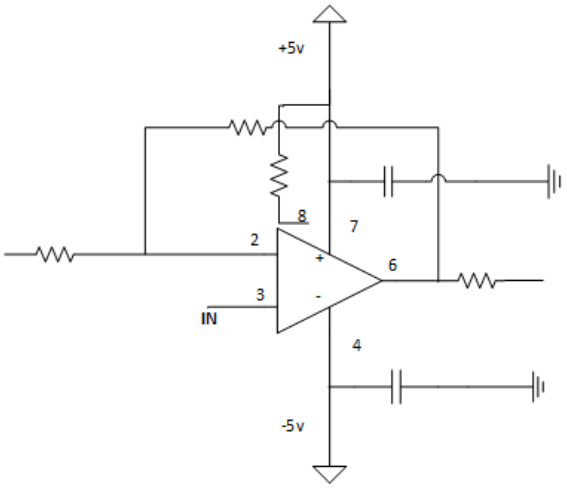

Figure 3.16. Schematic diagram of the final amplification end

Add the RC low-on circuit at the exit of the final amplifying terminal, and the resulting waveform is shown in Figure 3-12.

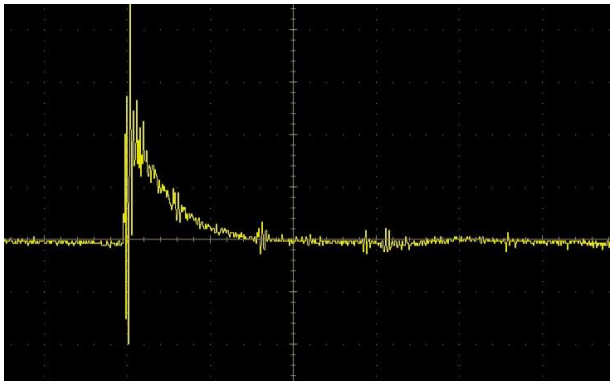

Figure 3.17. Final envelope waveform image

At present, there are still shortcomings in this scheme. When the envelope waveform is tested by the oscilloscope, it is inevitable that the probe receives the interference of spatial coupling high-frequency signals. For the interference of clutter signals, this scheme cannot completely filter out, but the current envelope image can make the CPU stably identify and drive the subsequent partial discharge monitoring equipment.

4. SUMMARY

Partial discharge often occurs in switchgear and other electrical equipment, partial discharge phenomenon will produce discharge current and discharge heat, may damage the insulation performance of the equipment, and even cause fire. Therefore, it is very important to find and deal with the partial discharge phenomenon in the switchgear in time. Therefore, timely detection of partial discharge of equipment can deal with partial discharge problems by checking equipment, cleaning equipment, timely replacement of aging components, and other methods to avoid losses caused by equipment failure due to partial discharge. The design scheme for the current commonly used partial discharge signal feature recognition is mainly based on the Matlab simulation of typical signals and artificial addition of noise for processing. Due to the wide frequency band of local discharge and complex field environment, the real collected waveform will be different from the typical discharge signal. In this paper, the collection of a large number of real data in the industrial distribution environment in Dalian is compared with the theoretical simulation, and the original signal is filtered and the power detection method is used to process the partial discharge signal to facilitate the formation of CPU identifiable pulse signal.

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