Research Journal of Applied Sciences, Engineering and Technology 5(10): 3052-3056, 2013
DOI:10.19026/rjaset.5.4622
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 27, 2012 Accepted: November 11, 2012 Published: March 25, 2013

**Research Article**

# Partial Discharge Optical Pulse Signal Characteristics for Corona Defect in Oil Immersed Transformer

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**Abstract:** Using fluorescent fiber sensor in transformer PD detection is a new method, based on the experimental platform for corona PD defect, the study has been carried out in order to show the typical corona PD defect optical pulse signal characteristics, PD single pulse waveform and pulses under industrial frequency cycle were acquired. The test results show that the optical method by using fluorescent fiber is effective in PD detection and corona PD optical pulse signals can accurately reflect the characteristics for this kind defect.

**Keywords:** Fluorescent fiber, optical pulse, partial discharge, transformer

## INTRODUCTION

Partial Discharge (PD) (Alfred *et al.*, 2003) is an important parameter and technology of reflection in insulation in power transformer insulation monitoring. When the power transformers are in a faulty state, they produce non-stationary PD pulses, accompanied by the physical phenomena of electromagnetic radiation, sound, light and so on. The primary methods for PD measurement using these physical phenomena include the pulse current, Ultra-High Frequency (UHF), ultrasonic and optical measurement methods. However, the pulse current method is vulnerable to various interferential electromagnetic signals and is thus primarily used for offline quantitative detection in smaller interferential environments. The UHF method may have a strong anti-electromagnetism interference capability (Judd *et al.*, 2005), but the PD UHF quantitative problem has not been thoroughly solved. The ultrasonic method is vulnerable to all kinds of background interferential noise and is thus primarily used for the qualitative estimation of operational equipment (Zbigniew *et al.*, 2010). Therefore, studying an effective method for PD detection and knowing the PD defect characteristics have an important, practical value.

Using optical effect in PD detection is a new method. Studies have shown that different types of insulation faults produce PD with light at different wavelengths (Anatol *et al.*, 2010). The light wavelength of a corona discharge is <400 nm and shows a purple color, most of which is ultraviolet. The light wavelength of spark discharge is between 400 and 700 nm and shows an orange color, most of which is visible light (Xu *et al.*, 2001; Tomasz *et al.*, 2004). Cui *et al.* (2008) reported on the use of solar-blinded photomultiplier tubes for corona discharge testing in experimental research. Mangeret and Farenc (1991) conducted sensitivity experiments for five different characteristics of optical fiber sensors in a needle-plate electrode defect (Mangeret *et al.*, 1991). The attenuation characteristics and absorption and emission spectra of six different doped fluorescent fibers were studied and sensitivity tests were conducted in a GIS simulation device filled with $SF_6$ (Farenc *et al.*, 1994). Austrian scholars used the optical method to study corona discharge in transformer oil (Schwarz, *et al.*, 2005). They found that fluorescent optical fiber sensors can be used for PD detection in transparent insulating medium. Therefore, PD signal detection and insulation fault judgment using optical effects is possible. At present, most fluorescent optical fiber sensors are used for detecting air-dielectric partial discharge signals, but the use of such sensors in transformer internal defects has rarely been reported, the typical PD defect optical signal characteristics have not been studied.

In the present study, based on the experimental platform using fluorescent fiber sensor for PD detection, PD light effect testing was performed on the typical corona defect model in transformer oil. The test results show that the optical method by using fluorescent fiber is effective in PD detection and corona PD optical signal can accurately reflect this kind defect, helpful for the further study in feature extraction and pattern recognition.

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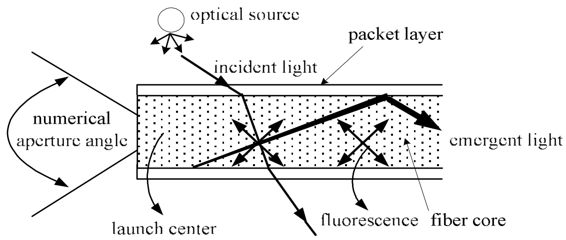



Fig. 1: Optical signals received by fluorescent fiber

## PD OPTICAL MEASUREMENT SYSTEM

**Fluorescent fiber sensing principle:** Fluorescent fibers have a structure similar to that of ordinary fiber, both are made of a fiber core with covering. However, the fiber core of fluorescent fiber is mixed with a trace of fluorescent material that is selectively absorbent of certain wavelengths for optical signals. When the incident light of certain wavelengths (such as PD-produced light) illuminates the fluorescent fibers, the light will be absorbed by the fluorescent molecules in the fiber core. The electrons of the fluorescent molecules will leap from the ground state to the excited state and the excited-state electrons create instability. When excited-state electrons return to the ground state, they often release energy (light electroluminescence) in the form of rays of light (fluorescence). The fluorescent signal spreads in the fiber and is consequently detected (Watterson, 2001). The diagram of a fluorescent fiber detecting a weak fluorescent signal is shown in Fig. 1. Compared with ordinary fiber, fluorescent fiber can receive PD light signals from the whole side face without being limited by the numerical aperture angle at the end face, thus implying that fluorescent fiber has high sensitivity for light signal measurement.

The stimulated fluorescent molecules in the fluorescent fiber will subsequently serve as the fluorescence unch center. When the fluorescence launch direction meets the total reflection conditions of the fiber core-packet layer interface (Beaoul and Buret, 1991), the fluorescence transmits forward along the fiber axial and finally shoots from the end face for detection. The inducted fluorescent light signal strength comes from the sum of each axial launch center, which accounts for the higher sensitivity of fluorescent fiber in testing weak light signals. In addition, higher PD pulse steepness produces a greater number of high-frequency components, indicating that greater electromagnetic energy generates stronger light. Thus, the measured fluorescent light signal is also stronger.

**PD optical signal test platform:** Figure 2 shows a fluorescent fiber sensing system, the system comprises the following parts: a fluorescent fiber sensor for sensing micro optics PD signals, common fiber used for fluorescent signal transmission, a photoelectric detector for fluorescent signal conversion and digital oscilloscopes for signal acquisition and display.

Based on the fluorescent fiber sensing system, a research platform for PD simulation in transformer oil is built. Figure 3 shows the schematic of the experimental circuit for PD detection. T1 is a 0 V to 380 V induction voltage regulator and T2 is a 100 kV/0.5A testing transformer without corona. C1 and C2 constitute the capacitive voltage divider and R is a 10 kΩ protective resistor. The corona defect model was a needle-plate discharge model, designed to simulate typical metal protrusions in the transformer. A shiny copper needle (with curvature radius of the sharp electrode tip less than 0.1 mm) and copper circular plate (electrode diameter of 150 mm and thickness of 8 mm, with a polished smooth edge) were used to simulate this type of defect. A circular epoxy resin board with thickness of 0.5 mm was placed in the gap between the needle and plate electrodes. An epoxy board was placed on the grounded electrode and the distance between the electrode tip and epoxy plate was 5 mm. Transformer oil is complicated

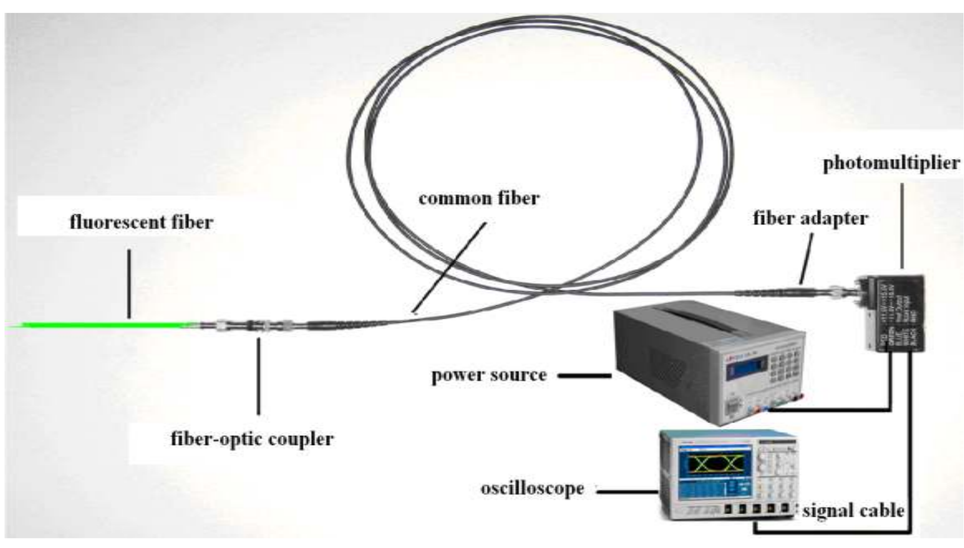



Fig. 2: Image of the fluorescent fiber sensing system

due to its various components, thus resulting in diverse light radiation absorption, refraction and reflection results. PD signal in transformer oil shows significant irregularity, as well. In the experiment, the oil cup was filled with 25# transformer oil. The applied 50 Hz AC voltage was manually increased from 0 kV to 50 kV peak. PD was generated by simultaneously applying high AC voltage above the discharge inception level of the transformer oil. The industrial frequency signal was simultaneously collected as the PD phase reference. Signal acquisition and processing is accomplished using a Tektronix DPO7104 oscilloscope, which has a 1 GHz bandwidth, 20 GS sampling rate and storage length of 40 MB to satisfy the requirements of PD signal acquisition.

## TEST RESULTS

**Waveform of single PD optical pulse:** For the corona defect model in Fig. 3, at the test voltage of 15.0 kV, the PD optical pulse of the positive and negative polarities collected by oscilloscope are shown in Fig. 4 and 5, respectively.

Contrasting Fig. 4 and 5, the PD optical pulse of positive and negative polarity corona discharges in transformer oil are observed to be different. The waveform shape of the positive polarity corona discharge PD optical pulse was both a single-peak (Fig. 4a) and multi-peak (Fig. 4b) waveform. However, the negative corona discharge optical pulse showed only a single-peak waveform. Positive polarity corona discharge in transformer oil is then assumed to be very irregular.

**PD optical pulses under industrial frequency cycle:** Under industrial frequency cycle, to study the relationship between corona PD optical pulse and applied voltage, the authors used step up voltage method. The PD incipient discharge voltage is 14.0kV and the breakdown voltage is 16.0kV. In the experiment, the applied voltage was increased step by 0.5kV till breakdown. Figure 6 shows the PD optical signals in an industrial frequency cycle under test voltage of 15.0kV.

In transformer oil, whether it is positive polarity corona discharge or a negative corona discharge, PD optical pulses, respectively, first appeared in the peak voltage nearby. At the same test voltage, the positive polarity PD optical pulse amplitude is greater than the negative polarity ones, the pulse number of positive polarity PD is less than the negative polarity part.

To further study the PD optical pulse characteristics, the statistics of PD optical pulse maximum amplitude and average amplitude for the positive and negative half cycle were got, shown in Fig. 7.

Figure 7 show that, with the rise of test voltage, the maximum amplitude of PD optical pulse for positive great. Comparing the amplitude values in Fig. 7a and b, the maximum amplitude and average amplitude of positive half cycle are much large than the negative part.

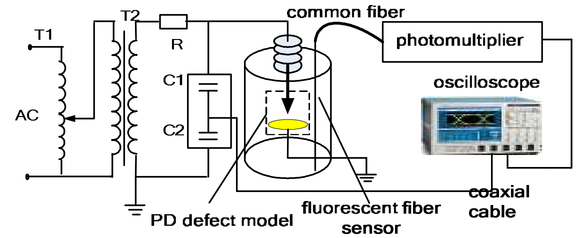
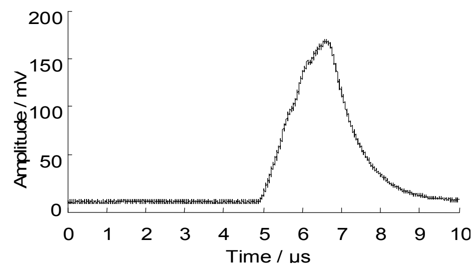
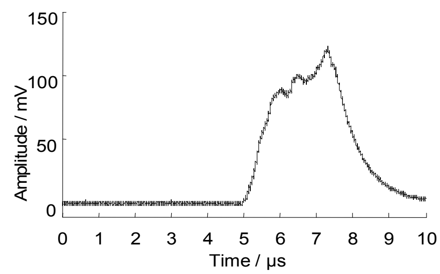



Fig. 3: Experimental platform for PD optical detection in transformer oil




(a)




(b)

Fig. 4: Positive PD optical pulses in transformer oil. (a) Single-peak PD optical pulse, (b) Multi-peak PD optical pulse

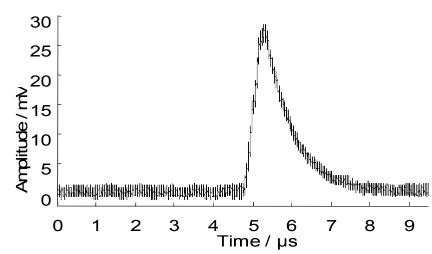



Fig. 5: Negative PD optical pulse in transformer oil

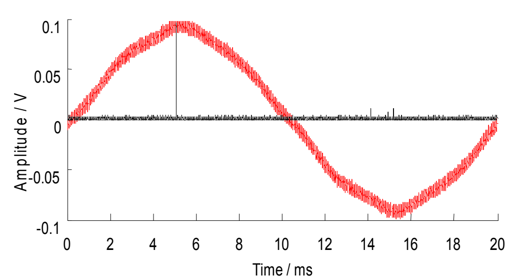
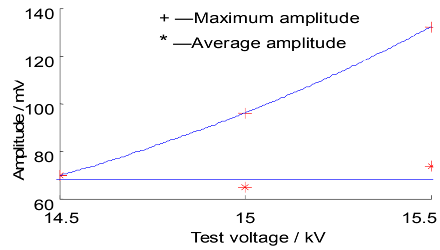
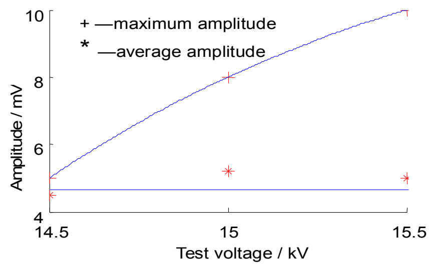



Fig. 6: PD optical pulses in one cycle

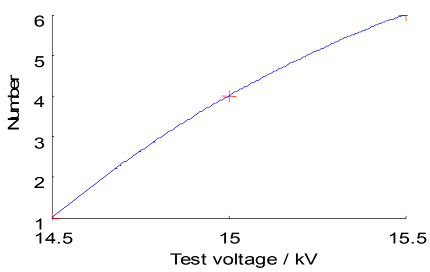



(a)

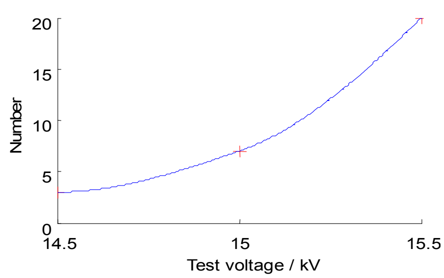



(b)

Fig. 7: The relationship between PD optical amplitude and test voltage. (a) Positive PD optical pulse, (b) Negative PD optical pulse



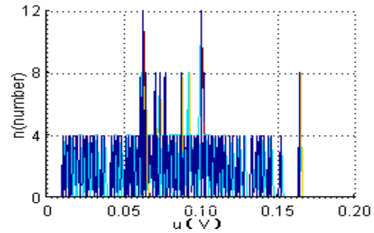

(a)



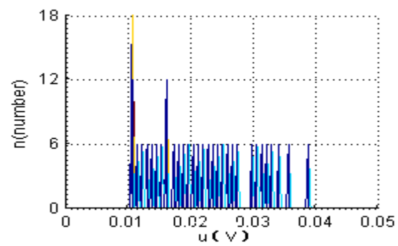

(b)

Fig. 8: The relationship between PD optical numbers and test voltage. (a) Positive PD optical pulse, (b) Negative PD optical pulse

polarity corona discharge and negative corona discharge have a gradually increasing trend, but the average amplitude shows a certain stability, the change is not

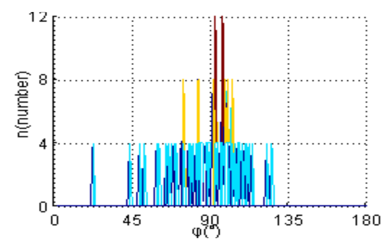



(a)

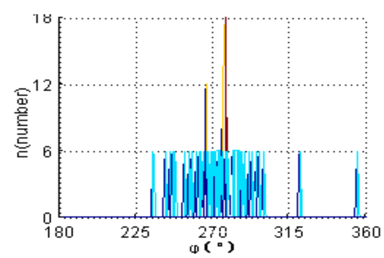



(b)

Fig. 9: PD *n-u* distribution. (a) PD optical pulses under positive half cycle, (b) PD optical pulses under negative half cycle




(a)




(b)

Fig. 10: PD *n-φ* distribution. (a) PD optical pulses under positive half cycle, (b) PD optical pulses under negative half cycle

The relationship between the number of PD optical pulses and the test voltage in the positive and negative half cycle is shown in Fig. 8. It can be seen that, with the increasing of test voltage, PD optical pulse numbers all present the increasing trend and the number in the positive half cycle is less than the negative part.

**PD n-u and n-φ distribution (Fig. 9):** To conduct a more comprehensive analysis of corona discharge characteristics, with the applied voltage of 15.0 kV, 200 groups of continuous, complete PD optical pulse sequences were collected and the industrial frequency cycle 360°phase was divided into 360 subspaces. PD n-u distribution and n-φ distribution were got, where n stands for the number of pulses emitted, u is the PD pulse amplitude and φ is the PD pulse phase.

The n-u distribution is shown in Fig. 10; the PD optical pulse amplitude in the positive half cycle is from 0.02V to 0.17V, while the amplitude in the negative half cycle is from 0.01V to 0.04V. PD pulse in the positive half cycle showed a random distribution trend, whereas the PD pulse in the negative half cycle presented a decreasing trend.

The n-φ distribution is shown in Fig. 10; PD pulse phase distribution in the positive half cycle was within 45° to 130° subspaces and presented a single–peak symmetric distribution. Most PD signals of the positive cycle were concentrated within the nearby 90° phase. While in the negative half part, the PD pulse phase distribution was within 230° to 300° subspaces and also presented a single-peak symmetric distribution. Most PD signals of the negative cycle were concentrated within the nearby 270° phase.

## CONCLUSION

Based on a fluorescent fiber sensing system for PD measurement, corona PD optical signals are acquired using a high-speed sampling system and PD n-u distribution and n-φ distribution are constructed in the experiments. The positive polarity corona discharge PD optical pulse waveform shape exhibited single-peak and multi-peak pulses, whereas its negative counterpart showed only a single-peak waveform.

With the rise of test voltage, the maximum amplitude of PD optical pulse for positive polarity corona discharge and negative corona discharge have a gradually increasing trend, but the average amplitude shows a certain stability; PD optical pulse numbers all present the increasing trend and the number in the positive half cycle is less than the negative part.

PD n-u distribution and n-φ distribution were obtained to analyze corona PD optical signal characteristics, the PD optical pulse amplitude in the positive half cycle is significantly greater than the negative half cycle, most of the PD signals were concentrated in the nearby industrial frequency voltage peak value. The test results showed that corona PD optical signal can accurately reflect this kind defect and has its own characteristics, helpful for the further feature extraction and pattern recognition research.


## ACKNOWLEDGMENT

The authors would like to thank the National Basic Research Program of China (Project No. 2009CB724506) for the financial support.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