Rapid and Non-destructive Detection of Partial Discharge Based on Holography

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Abstract. To detect the partial discharge sensitively and non-destructively, a holographic detection is proposed firstly in this paper. By capturing the light signal emitted during the process of discharge, the discharge can be detected. The interferograms with the light signal emitted by discharge can be collected online. As a result, the partial discharge can be detected non-destructively in real time. The experiments based on an artificially localized discharge source verify that the visible light at any band emitted by partial discharge can be captured. With sensitivity, universality, non-destructiveness and rapid speed, the proposed method has reduced the implantation difficulty and has potential to field application and assist other methods conveniently.

Introduction

Partial discharges (PD) are often caused by the local enhancements of the electric field in non-homogenous areas of gaseous, liquid or solid medium [1]. When PD occurs, electrical pulses, electromagnetic waves, ultrasonic waves, light, local overheating, and some new chemical products are generated [2]. The optical PD detection is based on the light produced as a result of various ionization, excitation and recombination process during the discharge [3]. As a non-destructive method to test and monitor the insulation condition of high voltage equipment sensitively, the optical detection has been a potential monitor method with growing concern today [4,5].

In the PD detection by using optical signals, it is usually necessary to provide night vision environment or amplify the optical signals, and the problem of sensor implantation has been a bottleneck restricting its development [6]. For example, S. Karmakar et al. proposed a optical network consisting of a detector amplifier to amplify the optical signal for PD detection [7]. The recent researches has been devoted to solving the above problems. S. P. Nepobedimyĭ et al. described an optical method using the monophoton sensor to detect and analyze the UV-C-radiation from the corona discharge with high time resolution [8]; D. Siebler et al. combined fluorescent polymer optical fibers sensors with two single-photon detectors and coincidence filtering technique realizing low picocoulomb-level optical-only PD detection [9]; Shang Yana et al. applied the double-layer SU-8 diaphragm to improve the fabrication of optical sensor [10]. Some researches have combined multiple sensors. S. Biswas et al. tested the collaborative reception of optical signals using multiple optical sensors under laboratory conditions [11]; J. Lee combined Sagnac interferometer and fiber optic sensor array [12]; Gao Chaofei proposed a 2×2 Fabry-Pérot optical fiber sensor array detection system [13]; Ren Ming et al. combined several different sensors realizing the multi-spectral random PD diagnosis [14]; In addition, some researches have combined the optical detection and other methods. Tang Ju et al. combined UHF and optical signal detection for transformer PD measurement [15]; Yin Zelin et al. proposed an all-fiber system combing the acoustic and optical signal detection [16]; Biswas, Subrata combined acoustic PD detection and fluorescent fiber to detect PD [17]; Han Xutao et al. described a novel PD detection based on a combination of UHF and several optical sensors [18]; Dong Ming et al. combined optics and acoustics and the realized joint visual diagnosis of outdoor insulation state [19]; Li Junhao et al. combined the UHF and optical detection and solved the problem
of sensor implantation by placing optical fibers on the surface of UHF sensors to form integrated sensors [20]. In a word, to detect optical signals in multiple bands, the number and type of sensors applied to PD detection has increased, increasing the implantation difficulty and the combination of optical methods and other methods also faced with the same problem.

As a sensitive and cost effective tool, the interferometer has been frequently used in PD detection. Posada-Roman J et al., Si Wenrong et al. and Wang Gao used different interferometric sensors for PD detection [21,22,23]. In order to detect the PD sensitively and non-destructively, reduce the implantation difficulty and assist other methods conveniently, we proposed a holographic method to monitor the PD online by capturing the PD optical signals. Its feasibility has verified by the experiments based on an artificially localized discharge source proving its potential to field application and assist other methods.

Theory

To detect the PD sensitively and capture the optical signal emitted by PD, this paper proposed a holography detection. Without any additional conditions, the interference fringes formed in the interferometer are light-dark, parallel and equidistant (Fig. 1 (a)). If apply the PD source into the sample optical path of the interferometer, then a transient electric field will be generated when the PD occurs. The refractive index $n$ is defined as the ratio of the propagation velocity $c$ of light in the vacuum to the propagation velocity $v$ in the medium. And $n = \frac{c}{v} = \sqrt{\varepsilon_r \mu_r}$, where $\varepsilon_r$ and $\mu_r$ are relative permittivity and relative permeability respectively. The refractive index of the medium of the sample optical path will change following the change of the transient electric field. When two coherent beams interfere, the combined light intensity distribution at any point in the interference field is:

$$I = I_R + I_S + 2\sqrt{I_R I_S} \cos \frac{2\pi}{\lambda} \Delta$$

Among them, $I_R$ and $I_S$ are light intensity of reference light and sample light respectively, $\Delta$ is the optical path difference between two beams reaching the same point, and $\lambda$ is the wavelength. Keep the parameters of the reference optical path in the interferometer unchanged, and introduce the additional electric field into the sample path, then the refractive index of the medium in the sample path will be changed, equivalent to introducing additional phase difference. As a result, the interference fringes formed by the superposition of the reference light and sample light will be offset and deflected (Fig.1 (b)). With the increase of electric field intensity in the medium, part of the air will be ionized and part of the discharge energy will be released in the form of light. The interferogram can capture the PD optical signal with random spectrum (Fig.1 (b)).

![Figure 1. (a) The interferogram formed without any additional conditions; (b) the interferogram effected by the PD.](image)

In conclusion, by capturing the change of transient electric field and the light signal generated during the process of discharge, the discharge can be detected. The offset and deflected interferograms with the light signal emitted by discharge can be collected online. As a result, the partial discharge can be detected non-destructively in real time.
Experiment

To detect the PD sensitively and non-destructively, we proposed to receive the PD optical signal by using the interferograms formed by the interferometer. An experiment platform was built with a lightning surge generator (SUG61005TB, China) as the artificially localized discharge source to verify the feasibility of the proposed method. The setup included: the interferometer, CCD camera and lightning surge generator (Fig. 2).

![Figure 2. Experimental setup.](image)

The wavelength of He-Ne laser is 632.8nm; the laser beam was separated into two beams with equal intensity via beam splitter (BS), the sample optical path and reference optical path; the interference fringes formed by the interferometer were projected onto the CCD camera (Sun Time 200A, China. Its pixel size is 3.2μm and pixel number is 640 × 480).

The PD source was generated by two electrodes, connected to high voltage end and grounding end of the lightning surge generator respectively, whose length were both 1.5 cm and the distance between them was 0.5 cm. The output pulse waveform of the lightning surge generator (Fig. 3 (a)) was 1.2/50μs (Fig. 3 (b)).

![Figure 3. (a) the lightning surge generator; (b) the output pulse waveform of the lightning surge generator.](image)

In experiment, the peak value of the voltage was 5kV, 5.5kV and 6kV respectively. The PD source was placed above and below the sample optical path 1, 2 cm respectively to simulate discharge process.

The proposed method can detect the PD occurring above and below the sample optical path 1, 2 cm respectively, contributing to convenient detection in field. With high sensitivity, the tested PD with discharge inception voltage of 5kV, 5.5kV and 6kV were applied to test at each position, and the interferograms with the optical signal emitted by PD collected online are as follows:
As can be seen from the offset and deflection interferograms with the optical signal emitted by PD above, the PD can be monitored online. What’s more, the detection range of the holographic detection covers 2 cm above and below the sample optical path.

**Conclusion**

To detect the partial discharge sensitively and non-destructively, a holographic detection is proposed firstly in this paper. By capturing the light signal with random spectrum emitted by PD, the discharge can be detected online. With sensitivity, universality, non-destructiveness and rapid speed, its feasibility has verified by the experiments based on the artificially localized discharge source. Reducing the implantation difficulty, the proposed method has great potential to field application and assist other PD detection conveniently.

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