ON-LINE OPTICAL DETECTION OF PARTIAL DISCHARGES IN AN OIL FILLED HIGH VOLTAGE TRANSFORMER

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Abstract: Partial discharges (PDs) are a major source of insulation deterioration which caused by cumulative effect of the mechanical, chemical, thermal and electrical stresses inside the insulation in the high voltage (HV) apparatus of the power system. The deterioration of the insulation system in the HV power apparatus can lead to catastrophic failure of the entire power system without continuous monitoring of such small discharges. There are several commercially available diagnostic techniques which are used to detect and monitor for the partial discharges in the HV power equipment. The commercially available diagnostic technique not only has some advantages but also has lots of limitations. To overcome these limitations of the detection of the PDs inside the power apparatus, in this work the online detection of partial discharges are carried out by optical technique in a dielectric test cell which is considered to be a laboratory model of a transformer. In this work, a He-Ne laser, a cross polarizer, a fiber cable, a detector amplifier, a digital storage oscilloscope and a laptop computer is used for online monitoring of PDs activity and the collected data are further analyzed with the above said facilities.

1 INTRODUCTION

The recent advancement in information communication technology has opened the opportunities for the power engineers and scientists to incorporate new ideas in the field of online monitoring of partial discharges (PDs) in high voltage (HV) power equipment for its reliable operation as well as to sustain the modern civilization. The high quality insulation is required in HV power equipments for sustaining the high powers applied in the power equipment [1-15]. It is studied that the insulation used in the power equipment is not always perfect in nature. There are several impurities such as air bubble, contaminant and another unwanted impurities present in the insulation system. The presence of these impurities may cause severe failure in the entire power system while this insulation sustains a very high voltage for a long period of its service life. It is well established from the several studies that the insulation of HV equipment gradually degrades due to the cumulative effects of electrical, chemical and mechanical stresses caused by the partial discharges (PDs) [1-9]. PDs are local electrical discharges that occur within insulation of HV equipment such as switchgear, cables, transformers, motors and generators. In addition, PDs also occur at voids, contamination, poor conductor profiles and floating metal-work in the HV equipment [12-22]. As the high voltage power equipment is very costly and therefore it is very much essential to monitor continuously for early detection of PD inside the power equipment.

In this work the direct optical detection of partial discharge (DODPD) technique has been introduced for measurement and localization of PDs inside a model transformer. Two different arrangements are employed for the detection of PDs, which are described below. Firstly, the direct laser beam passes through the centre axis of the electrode arrangement as well as in different location of the model transformer and the detector detects the PD signals. Secondly, the laser beam passes through the fiber optic cable, attached with an optical sensor, placed in the centre axis of the electrode arrangement as well as in different location of the model transformer for acquiring the PD signals. Finally, the measured PD signals as collected in both the arrangements are compared and analyzed. This method is sensitive compared to other conventional methods such as, electrical detection, chemical detection and acoustic detection. The proposed method proves its superiority over the other conventional methods in view of online monitoring of PDs, immunity to Electromagnetic Interference (EMI), sensitivity and its compactness [11-18].

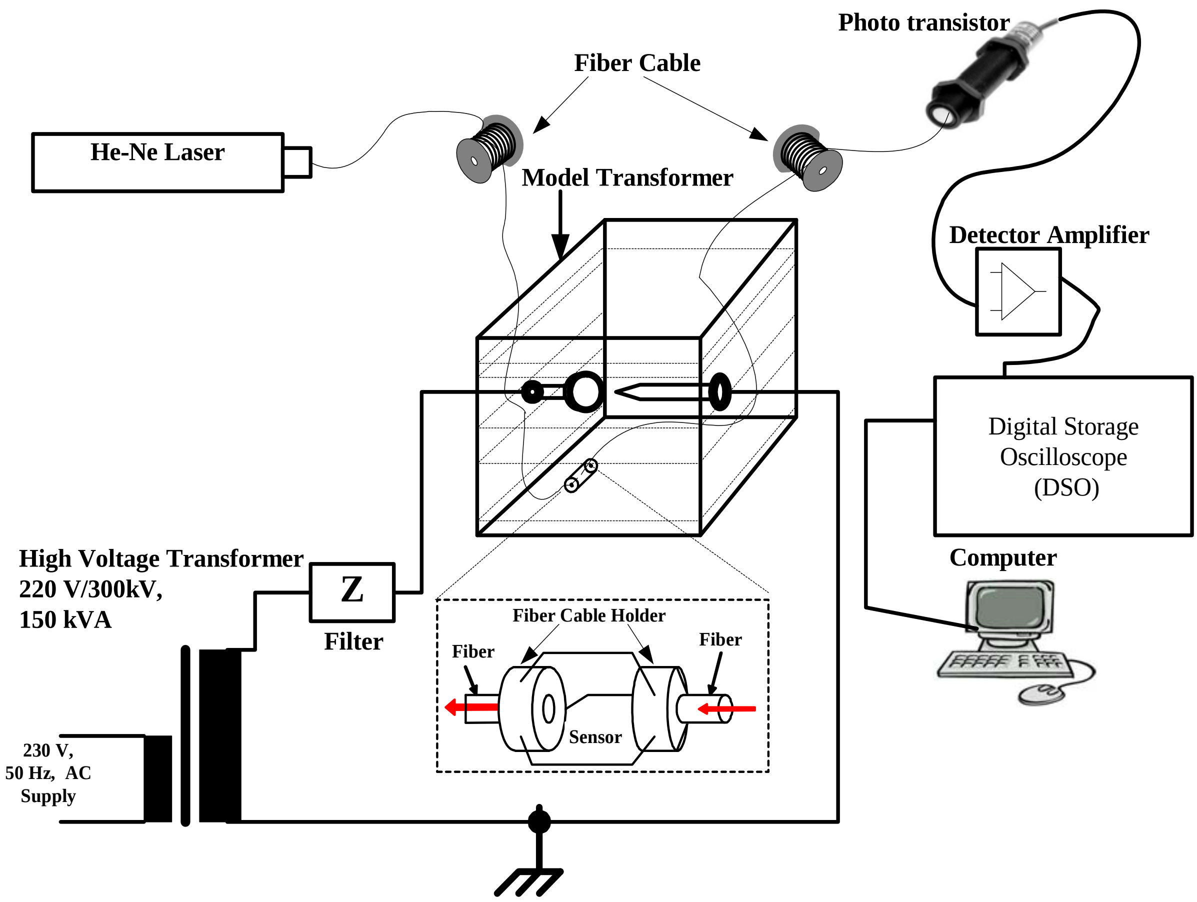

Fig.1. The schematic diagram of the experimental setup with sensor arrangement.

2 EXPERIMENTAL SETUP AND PROCEDURE

The experimental arrangement of the proposed technique, namely direct optical detection of partial discharge (DODPD) is shown in Fig. 1, which consists of a He-Ne laser, transformer oil test cell for simulation of PDs in a model transformer, photo detector and a digital storage oscilloscope (DSO). Here, He-Ne laser is used as a coherent light source which emits light having wavelength of 632.8nm. The model transformer (600mm×600mm×600 mm) is made of glass,

Fig. 2. Direct optical detection of PDs measurement setup.

associated with needle flat electrode arrangement, filled with new transformer oil. The needle-flat electrode arrangement is fixed at one end of the test cell. The diameter of needle electrode tip and the circular flat electrode is 125 μm and 50 mm, respectively. The thickness of the circular flat electrode is 3mm. The electrodes are horizontally placed at a distance of 40 mm in order to observe the PDs phenomena for a wide range of applied high voltages across the electrodes. A high voltage source of 0-300 kV, along with other control and measuring equipments are used to simulate the PDs of a model transformer in the above voltage range. A lens of a focal length of 10 cm is used to focus the laser light in such a way that maximum laser output can feed to the photo transistor. A photo transistor along with an amplifier unit is used as a detector in this experiment. The optical sensor is inserted in a holder along with fiber optic cable. The optical sensor is designed indigenously in the Laser Laboratory of the Institute, which is shown in the inset of Fig. 1. The photograph of the direct optical detection of PD measurement setup is shown in Fig. 2.

The phototransistor is exposed to the laser beam to detect the PDs. The output from the phototransistor is fed to an amplifier assembly consisting of a high-pass filter circuit. The amplifier output from the amplifier is fed to the digital storage oscilloscope (DSO, Model No. 54641D, Agilent) for data storage. The band width and sampling rate of the DSO are 100 MHz and 200 MSa/s, respectively. DSO is used for acquiring, recording and displaying the PDs within a bandwidth of 40 kHz - 400 kHz as the PDs presence is dominant in this frequency range [1-22]. The acquired data are analyzed by using a desktop computer with LABVIEW software.

For measurement of PDs in the model transformer, the HV unit (0-300kV) is standardized as per IS 2071. The amplifier output and an input reference voltage of 10 V from a standard voltage source are fed to two different channels of the oscilloscope for measurement of PDs and applied input voltage, simultaneously. The PDs are measured following two different methods which are described as method-I and method-II.

Method –I In this arrangement, the laser beam directly passes through the centre axis of the electrode arrangement of the model transformer.

Method –II In this arrangement, the laser beam passes through optical fiber cable and an optical sensor placed in the centre axis of the electrode arrangement of the model transformer.

3. RESULTS AND DISCUSSIONS

In both methods, to simulate the PDs in the model transformer, an increasing high voltage from 22 kV to 28 kV is applied between the electrodes. It is found that the PD magnitudes increase with increase of the high voltages applied in between the needle-flat electrode until breakdown takes place. It is observed in both methods that PDs are appeared mostly at both the positive and negative peaks of the applied voltage which are shown in Fig. 3. From Fig. 3 (a) it is clear that the when the laser beam passes directly through the centre axis of the need-flat electrode the magnitude of the PDs are lying between 200 mV to 900 mV, on the other hand when the optical sensor is placed at the centre axis of the needle-flat electrode the magnitude of the PDs are lying within 100 mV to 1000 mV which is shown in Fig. 3 (b). Several observations are also made to record the PD signal level by varying the applied voltages from 22 kV to 28 kV. For an each applied voltage the PD data are been collected 10 times and it is found that the PD signal level varies with certain range of magnitude. The observed variations of magnitudes

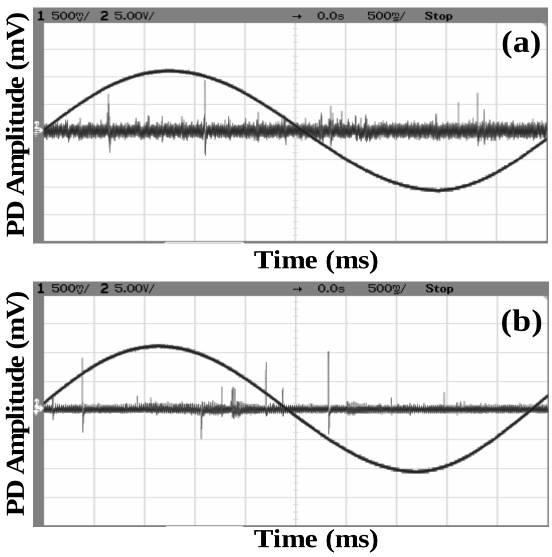

Fig. 3. PDs are observed at 28 kV applied voltage (a) Laser beam is passing through the centre axis of the needle-flat electrode. (b) Sensor is placed at the centre axis of the needle-flat electrode.

TABLE-I
VARIATION OF PDs AMPLITUDE WITH THE APPLIED VOLTAGE

Applied voltage (kV)	Range of PDs Amplitude (mV)	
	Method-I	Method-II
22	540-770	40-275
24	540-950	450-650
26	470-950	470-950
28	650-1200	250-1000

of PDs with the application of different applied voltages between the needle-flat electrodes in both methods are summarized in Table 1. From the Table-1 it is clear that the PD amplitude is smaller in *Method-II* than those measured by using *Method-I*. And it is seen that for a variation of applied voltages between 22 kV to 28 kV, the amplitude of PDs varies from 550 mV to 1200 mV and 50 mV to 1000 mV in *Method-I* and *Method-II*, respectively. The three meters of fiber optic cable has been used to detect the PDs inside the model transformer in *Method-II* that may be reason of the low value of the amplitude of the PDs. It is found that PDs amplitude is varying significantly with the variation of the applied voltage between the needle-flat electrodes as shown in Fig. 4 where experimental points have been joined by lines to show the trends of the variation of the experimental data.

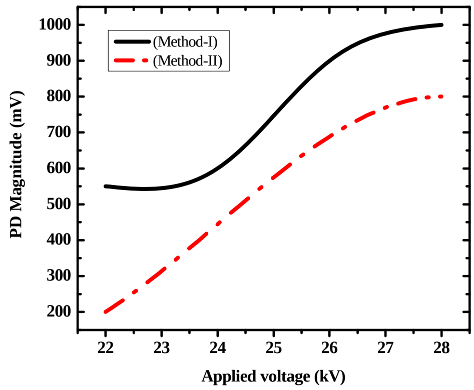

Fig. 4. Variations of the PDs signal amplitude with different values of the applied voltages in both the methods. Continuous lines have been drawn to show the trends of variations of the data.

It is studied from several literatures that the occurrence of PD is the random phenomenon and the number of the PD pulse appears in the different applied voltage for one cycle is not fixed [1-10]. Therefore, an investigation has been made in this work to calculate the number of the PD pulse appears for a different applied voltage. The above calculation has been made for the applied voltage range of 22-28kV and measured, viz. by *Method-I* and it is shown in Fig. 5.

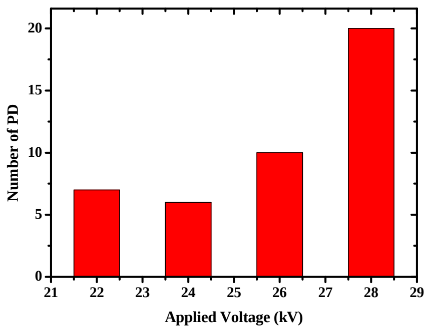

Fig. 5. Number of PD appears at different applied voltages in both the Method-I and Method-II.

To measure the variation of PDs with location, the laser beam in *Method-I* and the optical sensor in *Method –II* is placed at three different locations; at the centre axis of the electrodes, 5 mm above and 5 mm below it, for a constant applied voltage of 28 kV for both the cases. It is observed from

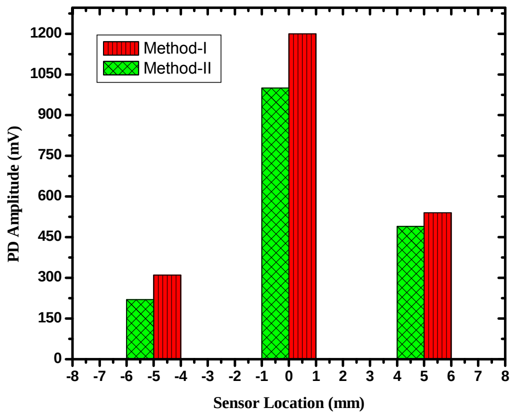

Fig. 6. Variations of PDs with the location of laser beam (*method-I*) and the optical sensor (*method-II*) at an applied voltage of 28 kV. In the *Method-II,* sensor location at 0 mm, +5 mm, and -5 mm mean that it is placed at the centre axis of the electrodes, at a distance of 5 mm above the centre axis of the electrodes, and at a distance 5 mm below the centre axis of the electrodes, respectively. Similarly for *Method-I,* location at 0 mm, +5 mm, and -5 mm mean that laser beam is passing through the centre axis of the electrodes, at a distance of 5 mm above the centre axis of the electrodes, and at a distance 5 mm below the centre axis of the electrodes, respectively.

both the cases that the intensity of the PDs varies not only with the applied high voltages but also with the location of the laser beam and optical sensor inside the model transformer which is shown in Fig. 6. Therefore, it is a useful tool for on line monitoring of the HV power apparatus for detection and the location of PDs remotely.

4 CONCLUSION

Continuous online monitoring of PDs in a high voltage apparatus is essential as PDs are a major source of insulation failure in a power system. There are several methods that have been used so far for measurement of PDs including the acoustic method for PD detection, the most popular one. However, in acoustic method, the sensors are placed outside the transformer which results a low energy signal with background noise contamination and a significant difficulty in determining the location of the PDs because of multiple sound paths. In this work, optical method for detection of PDs is presented as an alternate method for detection and online monitoring of PDs within a model transformer to replicate the PDs in power transformer. The use of laser light facilitates online and electromagnetic interference free detection and monitoring of PDs within the used high voltage transformer test cell. In addition to the detection of PD, there is possibility to pin point the location of the PDs. As the optical sensor is placed inside the transformer oil, it can detect very small discharges, their location, and provide diagnostics and prediction of power system. The presented method is to be extended for further study of PDs in other high voltage power apparatus, such as transformers, circuit breakers, current transformers and potential transformers.

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