DETECTION OF PARTIAL DISCHARGES IN A HIGH VOLTAGE EQUIPMENT

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Abstract: *Online monitoring of partial discharge (PD) in High Voltage (HV) power equipment needs to be monitored continuously for prediction of insulation life, replacement time and early indication of outages for reliable operation of the equipment. In this work, a new approach has been introduced for online monitoring of PD activity in a dielectric test cell with a needle-plate electrode configuration. The presented method has several advantages such as, it is immune to electromagnetic interference, good sensitivity, compact size and moreover it can also locate the sources of partial discharges in HV power equipment.*
Key words: *Partial discharge, High Voltage equipment, Online monitoring, Optoelectronic detection.*

1. Introduction.

Rapid growth of power sector leads to incorporate new ideas in the field of online monitoring of power equipment for reliable and its efficient operation. It has been seen from several studies that one of the main cause of failure in power equipment is the degradation of its insulation [1-6]. The degradation of High Voltage (HV) power equipment is due to accumulation of mechanical, thermal and electrical stresses for long service period. The previous studies also concluded that PD is a prime responsible phenomenon for degradation of insulation of the power equipment [3-6].

PD is a localized electrical discharge, only partially bridge the isolation between conductors which may or may not occur adjacent to a conductor. Partial discharges are in general, a consequence of local electrical stress concentration in the insulation or on the surface of the insulation. PD appears as pulses of duration of much less than one second and it produces quick transfer of charge in the localized areas. Consequently, creates a high frequency electric distortion that propagates through the medium of interest. The PD characteristics are also highly dependent on the geometry of the equipment. However, there exist several methods for detection and measurement of PDs [3-7]. Therefore, there is a need for online monitoring of PD activities of power equipment such as, transformer, rotating machines, circuit breakers, current transformers (CTs) and potential transformers (PTs).

In this paper, a direct optical detection technique has been introduced as a new approach for on line monitoring of PD activities in a dielectric test cell. The presented method is having the low signal attenuation, good sensitivity and compact in size for the PD detection. It can also locate the PD sources in the equipment and it is immune to electromagnetic interference which is a unique feature of this PD detection technique. The presented technique can be used as a cost effective tool for online monitoring of HV power equipment.

2. Overview of the existing PD detection methods

Over the past decades, the research activities has centered in the area of online monitoring of partial discharges in relation to identification, classification and location of PDs in electrical power equipment. Over the past forty years, several methods have been developed to detect PDs in HV power equipment [1-11]. The methods that have been investigated so far for measuring partial discharges are known as electric detection, chemical detection and acoustic detection methods which are described below briefly [3-11].

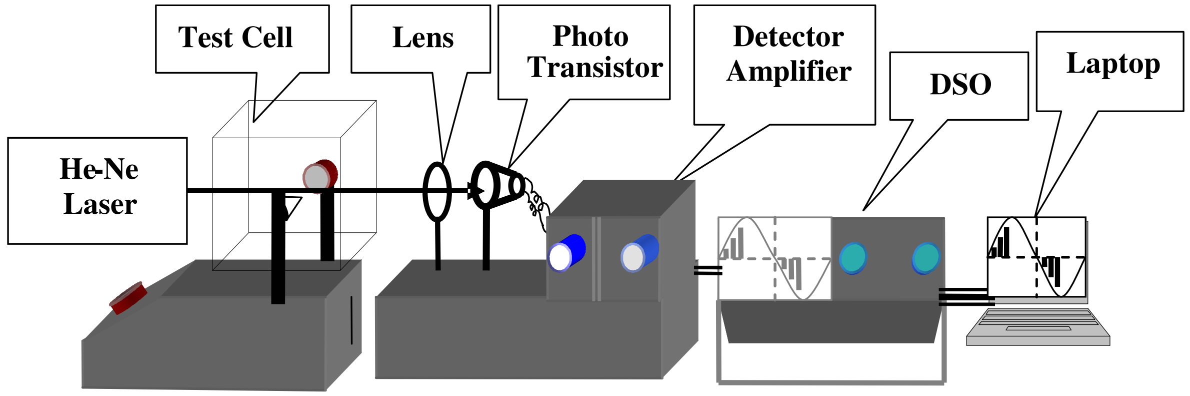

Fig. 1. The schematic of the experimental set up for on line optical detection of partial discharge in a dielectric test cell.

A variety of electrical techniques are in current use for detection of PD event in HV power equipment. Electrical detection focuses on capturing the electrical impulse created by the current streamer in the void and impurities. Electrical detection technique has several limitations in view of identifying the PD signals from the external noises. During the operation of HV equipment, both narrowband and broadband electrical noises are produced. Thus it becomes extremely difficult to distinguish between noise and PD, because of its short pulse width, which may leads to false detection of PDs in HV equipment. The other challenge in electrical detection is to avoid the distortion of the PD signals in different components of the equipment while it propagates from its origin to the detector terminal. This phenomenon is particularly pronounced in transformers which in turn can lead to erroneous interpretation of insulation condition [10].

Partial discharge activity changes the chemical composition of insulation which is exploited in the chemical detection method of PD in HV power equipment. In this method, the dissolve gas analysis (DGA) and high performance liquid chromatography (HPLC) are extensively used for PD measurement [10]. DGA provides the information of PD in terms of the volume of gas produced in insulation. HPLC method measures the byproducts such as glucose and degraded forms of glucose which are produced because of degradation of insulation. PD measurement by chemical detection method has some drawbacks, such as it provides little or no indication of nature, intensity and location of PD. Moreover, online monitoring of PD activity in chemical detection method requires complicated instrumentation and analyzing process.

In acoustic detection method, acoustic sensors are placed outside the HV equipment for detection of PD [6, 10]. The acoustic method endeavors to sense and record the acoustic signal created during a PD event instead of capturing an electrical signal. It is immune to electro magnetic interference (EMI) noise. It is also possible to detect the location of PD in the HV power equipment. However, acoustic detection technique has also some limitations. The primary problem with acoustic detection is the complex in nature of the acoustic wave propagation. Moreover, HV equipments are not homogeneous device; the wave does not travel in perfect spherical wave fronts.

An optical detection technique has been proposed in this paper, being an alternate scheme, for the detection and monitoring of PD activity in high voltage equipment which is described below.

3. Experimental setup for online direct optical detection technique

The experimental set up consists of a He-Ne laser,

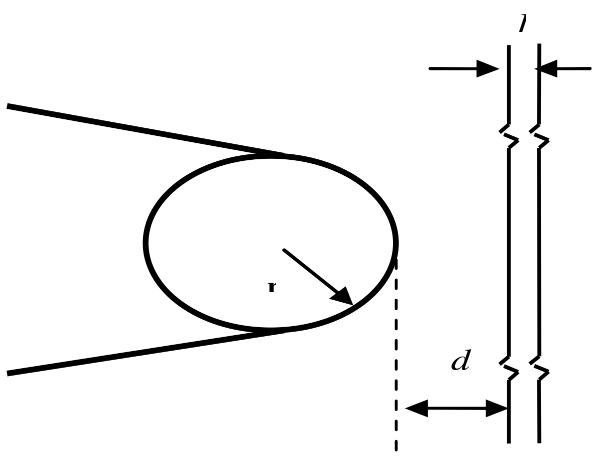

Fig. 2. Enlarged view of the needle-plate electrode configuration. Circular plate electrode has radius of 15 mm and thickness (l) = 3 mm. Tip radius of the needle electrode (r) = 125 µm. Separation of electrodes (d) = 16 mm.

dielectric test cell, photo transistor and a digital storage oscilloscope (DSO, Model No. 54641D, Agilent), and it is shown in Fig.1. He-Ne laser is used as a coherent light source at a wave length of 632.8 nm. The dielectric test cell (103mm×72mm×105 mm) is made of glass, associated with needle flat electrode arrangement, filled up with new transformer oil. A high voltage source of 0-100KV, along with other control and measuring equipment are used to study the discharge behavior in the above voltage range. To initiate and observe the PD phenomena, needle-flat electrode arrangement is used in the dielectric test cell. The radius of needle electrode tip is 125 μm and circular flat electrode having a radius of 15 mm and thickness of 3 mm. The electrodes are placed horizontally in the test cell. The electrodes are separated at a gap distance of 16 mm in order to observe the PD phenomena for a wide range of applied high voltages.

The electric field strength near the needle tip decreases with the increase of needle tip radius, which influences the PD initiation. This can further be proved using very well known Mason's equation for maximum

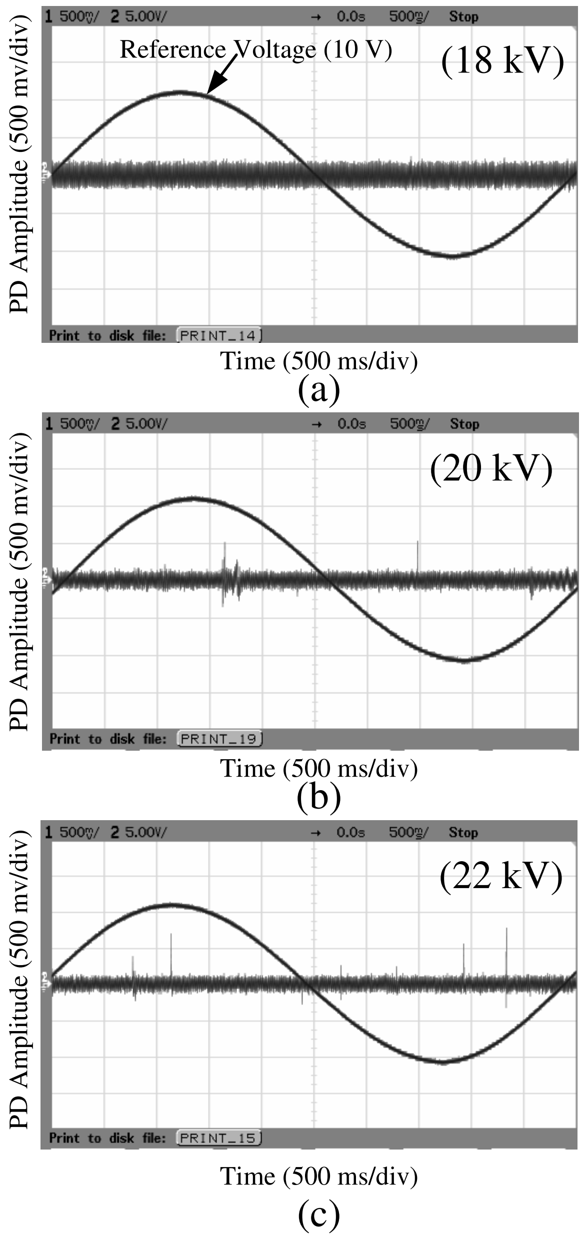

Fig. 3. Observed PDs while laser beam is passing through the centre axis of the needle-plate electrode, for applied high voltage of (a) 18 kV, (b) 20kV, and (c) 22kV.

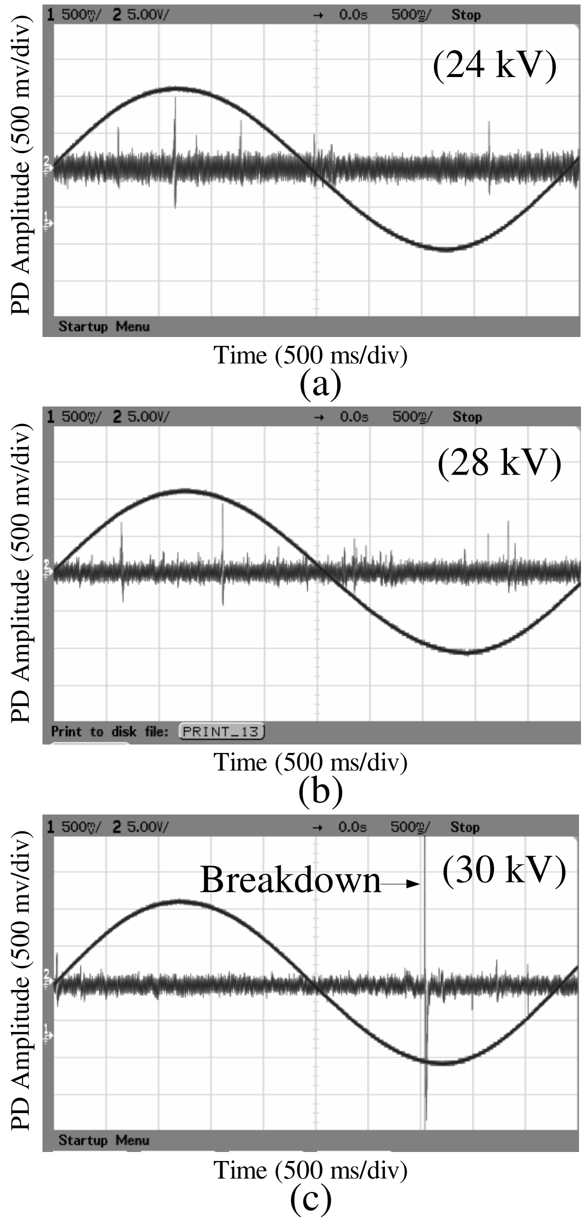

Fig. 4. Observed PDs while laser beam is passing through the centre axis of the needle-plate electrode, for applied high voltage of (a) 24 kV, (b) 28 kV, (c) 30 kV, till the breakdown occurs.

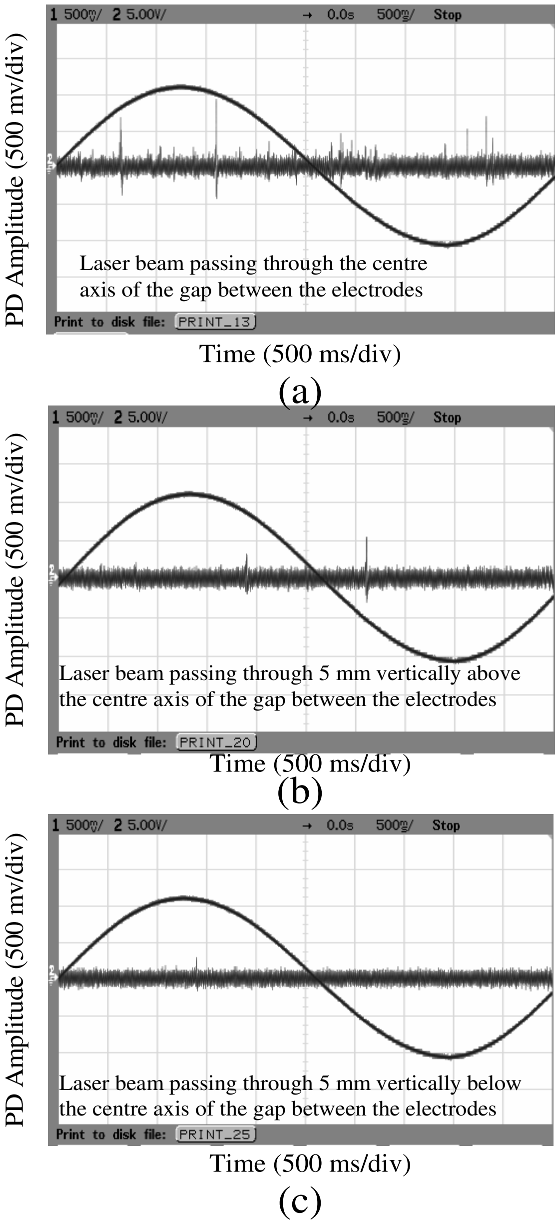

Fig. 5. Variation of PD signals with location of laser beam. Figures 5(a), 5(b), and 5(c) show the observed PD signals when the laser beam is placed, at the centre axis of the electrodes, at a distance of 5 mm above, and at a distance 5 mm below the centre axis of the electrodes, respectively.

electric strength developed at the tip of the needle is given by [8],

$$E_{\max} = \frac{2dE_{avg}}{r\ln(1+\frac{4d}{r})} \tag{1}$$

Where, E_{max} is the maximum electric field strength at the needle tip, E_{avg} is the average electric field strength applied in the gap, d is the electrode gap spacing and r is the radius of the needle tip. The details of electrode arrangement are shown in Fig. 2.

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 phototransistor has a light sensitive collector base p-n junction and it is exposed to the laser beam. The output from the phototransistor is fed to an amplifier assembly consisting of a high-pass filter circuit. The amplified output is fed to the digital storage oscilloscope for acquiring, recording and displaying the PD signal. The laptop computer is used for online monitoring of PD activities.

4. Results and discussion

In view of detection, measurement of PDs, the measuring equipment as well as the HV source are standardised as per the standards IS 2071. To measure the PDs and applied input voltage simultaneously, the output from the amplifier and an input reference voltage are fed to two different channels of the oscilloscope. In order to detect and measure the PD signals in dielectric test cell, high voltages are applied in the range of 18 to 30 kV between the electrodes. To acquire the maximum intensity of PDs, produced during the application of high voltages, the laser beam is placed at the centre axis of the electrodes. For observing the phase angle of PD appearance with reference to the input of high voltage source, a reference voltage of 10V is applied, which is fed to the channel 2 of the DSO. No PDs are observed for an applied high voltage of 18 kV, which is shown in Fig. 3(a). When the voltage of 20 and 22 kV are applied, PDs are appeared mostly at both the positive and negative peak of the applied voltage which is shown in Figs. 3(b) and 3(c) respectively. For higher voltage of 24 and 28kV, PDs are appeared at the peak as well as in the transition region which are shown in Figs. 4(a) and 4(b) respectively. Moreover, it is observed that for variation of applied voltage from 20 to 28 kV, the PD signal varies from 250 mV to 1000 mV. It is also observed from Fig. 4(b) that PDs are found under the prebreakdown condition continuously. When the applied voltage is further increased to 30 kV, breakdown occurs and PD signal disappears instantly which is shown in Fig. 4(c). Therefore, it is understood from Figs. 3 and 4 that the intensity of PD signals is increased with the increasing value of the applied voltage until breakdown occurs.

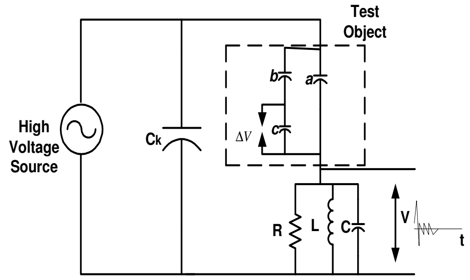

Fig. 6 Electrical equivalent circuit of PD measurement.

To identify the location of PD event, the laser beam is directed in different position from the centre axis of the electrode with a constant applied voltage of 28 kV. The variations of PDs with the location, at the centre axis of the electrodes, at a distance of 5 mm above and 5 mm below the centre axis of the electrodes are shown in Figs. 5(a), 5(b) and 5(c), respectively. Figure 5(a) shows that the maximum amplitude of PD is of 1000 mV with the application of 28 kV, when laser beam is passing through the centre axis of the electrodes. However, the maximum amplitude of the PD signal measured at a distance of 5 mm vertically above the centre axis is reduced to 550 mV with the same value of the applied voltage of 28 kV, which is shown in Fig. 5(b). Figure 5(c) shows that maximum amplitude of the PD signal reduced to 250 mV with the same value of the applied voltage of 28 kV, at a distance of 5 mm vertically below the centre axis. Therefore, it is understood from the above results that the intensity of PDs varies not only with the value of the applied high voltage but also with the location of the laser beam inside the dielectric test cell.

5. Simulation of PD pulses

To simulate the PD activities in the dielectric test cell an insulation model is presented by an equivalent circuit, which is shown in Fig. 6 [5]. The insulating material is inhomogeneous and imperfect in nature. In Fig. 6, *c, b* and *a* represent the capacitance of a void present inside the insulation, the remaining series insulation with void and the capacitance of the remaining discharge-free insulation, respectively. Generally, $c<<b<<a$. When the voltage is raised in the insulation model, a critical value is reached across the capacitor c and a discharge occurs through the capacitor, i.e. it becomes short circuited. A charge q which was present in the capacitor c flows through b and a, giving rise to a voltage pulse across the capacitor a. The voltage pulse measured across the capacitor gives the amount of discharge which is difficult for measurement in practice. So, an apparent charge measurement is made through a parallel RLC circuit as shown in Fig. 6.

The discharge magnitude $q = b \times \Delta V$ is related to the discharge area A and discharge voltage ΔV which is shown in Fig. 7. As the thickness of the discharge gap is small as compared to the insulation thickness d, the electric field is taken to be homogeneous and so the capacitance, $b \cong \varepsilon_0 \varepsilon \times (A/d)$. Here d is the thickness of the dielectric, ε_0 and ε are the dielectric constant of air and relative dielectric constant of the insulating oil, respectively. Thus, $q \cong \varepsilon_0 \varepsilon \times A \times \Delta V \times (1/d)$ and the discharge voltage (V) across the resistor R is given by the following equation.

$$V = \frac{q}{\left(1+\frac{C}{C_k}\right).a+C}.\exp(-t/2Rm).Cos(wt) \quad , \qquad (2)$$

where, $w = \sqrt{\left(\frac{1}{Lm} - \frac{1}{4R^2m^2}\right)}$, $m = \frac{a.C_k}{a+C_k} + C$ and C_k is the coupling capacitor. It has been observed that the PDs are similar in nature for the applied high voltage varying between 20 to 30 kV. By using Eqn. (2), the discharge voltage (V) has been simulated through a MATLAB code developed in-house. The simulated and measured PDs are shown in Fig. 8 for an applied high voltage of 24 kV for an example. During simulation, the typical values of R, L, and C are taken as 100 kΩ, 0.007mH, and 2.077μF, respectively. The values of *a, b, c* and C_k are taken as 0.265pF, 1nF, 2μF and 100pF, respectively. To analyse the PD pulse shape , a single peak from the measured train of PD pulses has been chosen as shown in Fig. 8 (a). The

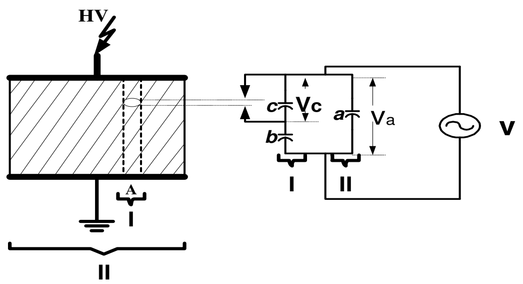

Fig. 7 Representation of void in dielectrics.

enlarged view of the measured PD pulse as well as the simulated PD pulse obtained using Eqn. (2) are shown in Fig. 8(b). It is observed from Fig. 8(b) that measured PD through direct optical detection method and the

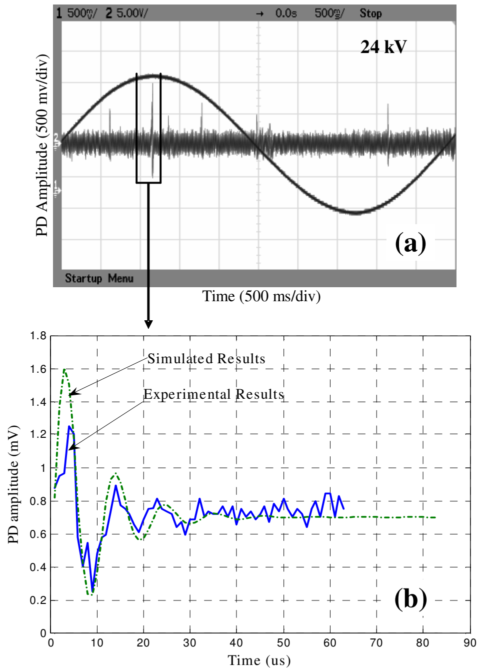

Fig. 8. Experimental and simulated PD pulse with applied voltage at 24 kV; (a) measured PD pulse through direct optical detection, (b) simulated PD pulses with the enlarged view of a experimental PD

simulated PD in dielectric test cell is similar in nature.

6. Conclusions

Online monitoring of partial discharge in HV power equipment is increasingly getting its importance in the field of maintenance as well as prediction of its health for the reliable operation of power system. Although several research activities have been carried out for detection and monitoring of PD event in HV power equipment, direct optical detection method of PDs remain unexplored. Having several limitations of this technology such as including the low or nonexistent level of sensitivity imposed by transformer geometry and materials which are usually optically non transparent [10]. In this paper, a new approach is presented for online monitoring of PDs within a dielectric test cell to replicate the PD activities in HV power equipment. The presented technique has several advantages: it is sensitive and effective for online monitoring of PD activities, it is compact in size and it is free from Electro Magnetic Interference (EMI). In addition to the detection of a PD event, it is also possible to identify the location of the PDs, produced in the HV equipment such as transformers, circuit breakers, current transformers and potential transformers. Using the above method, an advance indication of insulation failure of HV equipment is also possible which helps to assess the life of the equipment. In view of the extreme sensitivity of optical detectors, presented direct optical detection technique will open a new era in the field of on line monitoring of PDs in HV power equipment.

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