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Online Partial Discharge Monitoring of Medium Voltage Cable Termination by Fluorescent Optical Fiber

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Abstract

MV Power Cable System is the backbone of a power distribution network of modern city/smart city infrastructure and industrial power distribution network in process industries, petrochemical plants and heavy industries. Failure of critical feeders can lead to forced outages, economic losses to distribution companies and huge production losses to industries. Therefore, online monitoring of critical feeders is gaining importance. Sensored terminations and joints are becoming popular. In this paper partial discharge detection capability of fluorescent optical fiber in cable termination is discussed. From the experimental investigations, it is concluded that fluorescent optical fibre along with a suitable optical transducer is capable of detecting partial discharges in cable termination. It is a promising tool for online partial discharge monitoring of cable terminations and it will be another feather on the cap of sensored cable terminations.

Keywords: Fluorescent Optical Fiber, Partial Discharges

1. Introduction

Field diagnostic testing of power cable systems is performed to assess the state and condition of the cable insulation system and its accessories. Field testing of cable systems, data analysis and initiating appropriate actions presents many challenges. Various field testing methods currently available or under development are listed and described in IEEE 400 point documents[1-4]. IEEE Std. 400.2 elaborately discusses Very Low Frequency testing for laminated and extruded cables rated 5 kV through 69 kV. IEEE 400.3 covers diagnostic testing of new or service-aged installed power cable systems using Partial discharge detection, detection, measurement and location. IEEE 400.4 describes the application of Damped AC (DAC) for field testing of power cable systems. Partial Discharge (PD) measurement is a common diagnostic tool to test High Voltage (HV) cable accessories under real-life conditions for defects that would otherwise limit the estimated lifetime of the devices. Onsite field diagnostic data analysis requires highly efficient noise elimination and signal processing algorithm leading high-cost software. In some cases, a useful signal gate is filtered and the algorithm gives false negatives. The optical PD measurement method has unique advantages over other methods for monitoring cable terminations. As conventional electric and electromagnetic methods suffer from Electromagnetic Interference (EMI), EMI-resistant-PD measurement methods would be beneficial, especially for on-site and online testing. In this context, fibre optic[5] and fibre acoustic[6] PD detection have been discussed recently, but until now only electrical PD measurement systems for HV applications and acoustic systems for medium voltage applications are accepted. We have shown elsewhere[7] that fibre-optic PD detection can suppress external electromagnetic noise of the conventional electric PD measurement in an electrically polluted environment. In that context, fibre-optic PD detection is an add-on to conventional techniques to gain EMI resistance. Hence, it is necessary to elucidate if the fibre-optic method can act as a reliable stand-alone method for PD detection in translucent MV cable termination.

2. Principle of Fluorescent Optical Fiber Sensor

The working principle of fluorescent optical fibre sensor is based on the phenomenon of fluorescence.

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Fluorescence is defined as the emission of light when a material is bombarded by high-energy particles or photons. Specially treated plastic material fabricated into optical fibres as shown in Figure 1 are used for this application.

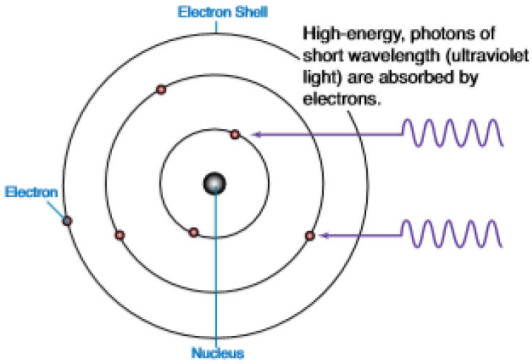


Figure 1. Plastic fluorescent fibers.

Atoms, are the basic building blocks of matter, consisting of a small and dense centre (nucleus) surrounded by electrons- the same particles that produce electric currents. Electrons circle the nucleus in different orbits or distances from the nucleus. The farther they are from the nucleus, the more energy they possess.

When electrons pick up sufficient additional energy from an outside source, they must jump to the next outer orbit or energy level (think of the car travelling in a larger circle). Conversely, when an electron moves from an outer orbit to an inner one, it must give up energy. This energy is released as a particle of light called a photon. Most atoms contain many electrons at many different energy levels (orbits). The colour of light that each electron will produce depends on how much energy it loses if it falls from one orbit to an inner one. The electrons in different materials have specific and predictable reactions when they are stimulated by an outside energy source and move between energy levels. They have a characteristic colour or colours that can be repeatedly produced by outside energy stimulation. These characteristic colours are associated only with that particular material.

With this special coloured fibre material, atoms absorb high-energy light of one colour, and almost immediately release the energy as light of another colour. Many substances fluoresce when ultraviolet light strikes them. We cannot see ultraviolet, but we can see the lower energy light that fluorescence produces. The red- and green-coloured fibres contain a central core that includes a material with fluorescent properties as shown in Figure 3. The fluorescent core absorbs blue and ultraviolet light from all directions. It then re-radiates the energy in the form of red or green light (depending on the material in its core). The cladding on the outside of the fibre core traps the radiated light and guides it toward the ends.



(a)

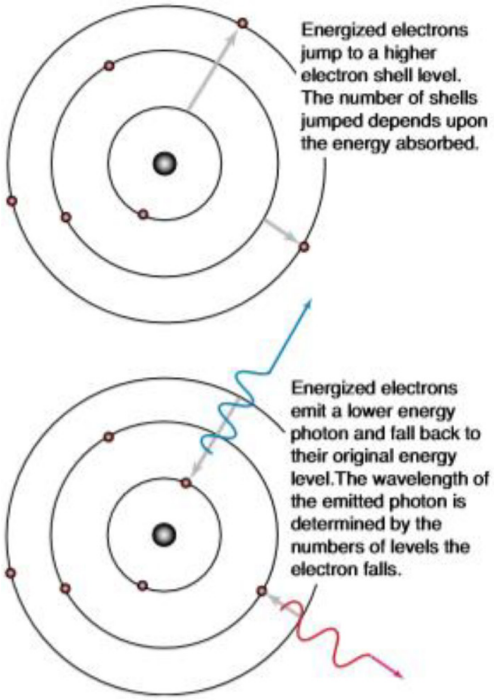


Figure 2. **(a)**, **(b)** and **(c)** Phenomenon of fluorescence.

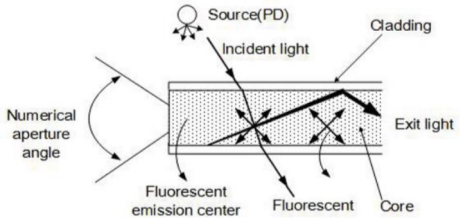


Figure 3. The principle of fluorescent fibre.

3. Optical PD Measurement System

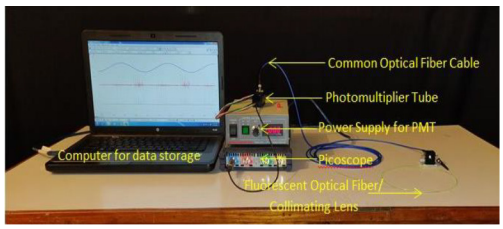


Figure 4. Optical PD measurement system.

Optical PD measurement system consisting of fluorescent optical fibre, mating sleeve, common optical fibre and photomultiplier tube module. Fluorescent fibre absorbs the light emission from partial discharge. The mating sleeve couples fluorescent fibre and common fibre which transmits the optical signal to the photomultiplier tube module. A photomultiplier tube converts the light intensity into an electrical signal.

4. Experimental Setup

XLPE cable of length 10 m, 3x300 sq. mm., rated voltage 12.7/22 kV (E) was used for partial discharge measurement. At the end of cable termination, the anti-tracking sleeve and stress cone tube were cut open and a fluorescent optical fibre probe was placed near the interface of the semiconductor layer and termination. The cable was placed in a shielded room creating an interference-free dark environment suitable for optical partial discharge measurement. An optical system was used for the measurement and simultaneously PD detection was made by conventional electrical method (IEC 60270). The system was calibrated at 10pC and background noise was <1 pC. The cable was connected to a 200 kV, 200 kVA partial discharge-free transformer and measurements were carried out. Figure 5 shows the experimental setup used.

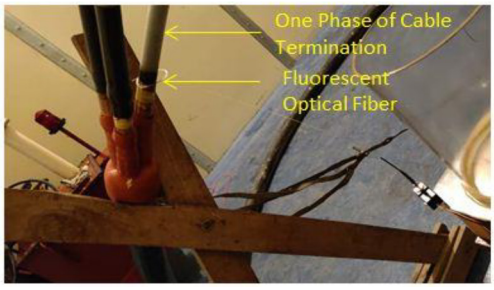


Figure 5. PD measurement at cable termination.

5. Results and Discussion

Figure 6 shows the PD trace obtained on the cable. The top trace in the figure shows the applied sinusoidal voltage, middle and the bottom traces indicate partial discharges by electrical and optical methods respectively. The PD inception occurred at 10.6 kVrms. The measured PD magnitude at 10.6 kV was 30 pC. The applied voltage was increased up to 16 kVrms for PD measurement. The measured PD magnitudes were 7500 pC to 10000 pC at 16 kVrms.

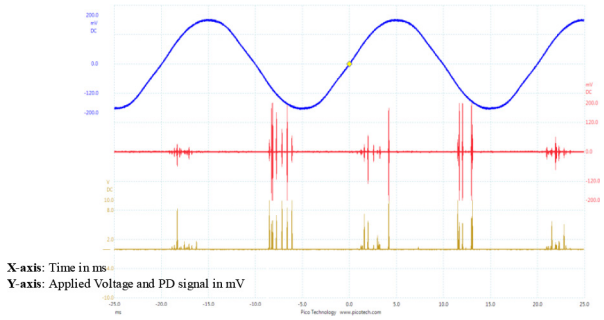


Figure 6. Electrical (Red) and optical (Yellow) partial discharge measurement in cable termination.

Further from Figure 6, it can be inferred that the electrical and optical PD are correlating well in magnitude, phase and number. The maximum values of electrical and optical PD signals were 200 mV and 10V respectively. The optoelectronic system is capable of detecting PD in cable terminations operating in a dark environment. Figure 7 shows the PRPD pattern obtained on the cable termination.

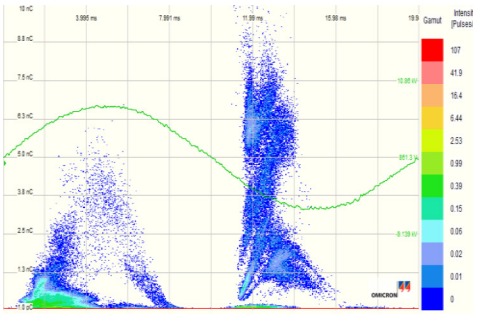


Figure 7. PRPD pattern obtained for the cable termination.

6. Conclusion

From the experimental investigations, it is concluded that fluorescent optical fibre along with a suitable optical transducer is capable of detecting partial discharges

in cable termination. It is a promising tool for online partial discharge monitoring of cable terminations and it will be another feather on the cap of sensored cable terminations.

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