Monitoring of smart HV cable joints with embedded fiber optic-based acoustic partial discharge sensors

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ABSTRACT

This study presents a novel approach to detecting partial discharges (PD) in high-voltage (HV) cable joints using embedded fiber optic-based acoustic emission PD sensors, known as OptiFender sensors. Three OptiFender sensors were embedded on a defective HV joint body, and the joint was encapsulated in a clamshell vessel and filled with a compound. All sensors survived the embedding process, and they measured PD down to 10 pC and at voltages from 20 kV to 180 kV, providing a continuous monitoring of the PD in the joint.

KEYWORDS

Partial Discharge, Acoustic Emission, Continuous Monitoring, Acoustic Sensors, Fiber Optic Sensors, OptiFender, High Voltage, Joints, Terminations.

INTRODUCTION

Electrical pulses referred to as Partial discharges (PDs) occur in the insulation of medium and high voltage equipment, which includes cable accessories, transformers, and switchgears. These pulses are typically caused by physical damage to the insulation materials, aging, corrosion, or production errors of the cable accessories. PDs are now recognized as the leading cause of premature deterioration in electrical equipment and are responsible for the majority (85%) of substations failures [1].

The industry has developed various techniques to detect partial discharges (PDs), one of which is periodic inspections of high voltage (HV) assets to measure PDs or assess other physical parameters like temperature, voltage, or current at the asset. However, there has been an increased demand for continuous online monitoring of assets in recent years instead of periodic inspections. This shift is driven by the need for higher grid reliability and the evolving nature of modern smart grids, which puts components under more significant stress and causes earlier degradation. To meet this requirement, various sensing technologies used in periodic inspections are now incorporated into continuous monitoring systems. Nonetheless, challenges such as interfering electromagnetic noise, the absence of power sources in the field, and the remote location of assets make it difficult to deploy conventional sensing technologies permanently and restrict their effectiveness as monitoring solutions.

In order to overcome the drawbacks of traditional sensing technologies, alternative methods have been investigated, and fiber optic sensing has been found to have a distinct set of benefits for continuous partial discharge (PD) monitoring. These sensors are immune to electromagnetic interference, require no power at the sensing location, and can be positioned in remote areas without difficulty. This article explores the potential of fiber optic sensing for PD detection using the OptiFender system. OptiFender can detect ultrasonic acoustic signals from partial discharges and trace their progression over time. OptiFender sensors are passive and can be easily attached and retrofitted to various high voltage assets, as well as being integrated into HV electrical joints and accessories, which enables the detection of internal and surface partial discharges in close proximity.

In this study, the capabilities of the OptiFender system are demonstrated by inspecting a high-voltage cable joint with internal PD. A reference calibrated capacitive PD sensor was used throughout this test as a reference for all the electrical PD measurements.

FIBER-OPTIC SENSING TECHNOLOGY

The OptiFender system employs interferometry, which involves configuring two fibers of equal length in a Michelson interferometry setup. Both sensing and reference arms are wound around cores. To prevent vibrations and mechanical disruptions, the reference fiber is coiled around a damper, while the sensing fiber is coiled around a mandrel with a flat bottom. To ensure the most efficient transmission of the surface acoustic wave to the sensing fiber, the sensor is placed on the structure's surface, with the sensitive mandrel in direct contact (refer Figure 1). The sensor can be secured in position on different materials using various methods such as with a magnetic clamp, a rubber clamp, or an adhesive substance.

As an acoustic wave travels through the fiber optic sensor, its vibration is transferred to the sensing mandrel and subsequently to the coiled fiber encircling it. This generates an interferometric signal that is measured by the OptiFender data acquisition unit (DAQ), where the signal is acquired, and the acoustic emission signal is demodulated. The OptiFender data acquisition unit then transmits the signal to a computer operating OptiFender software for the detection of acoustic events and additional processing. Comparisons conducted in the past between Optics11 acoustic emission (AE) sensors and piezoelectric-based AE sensors have confirmed the same levels of sensitivity and functionality [2].

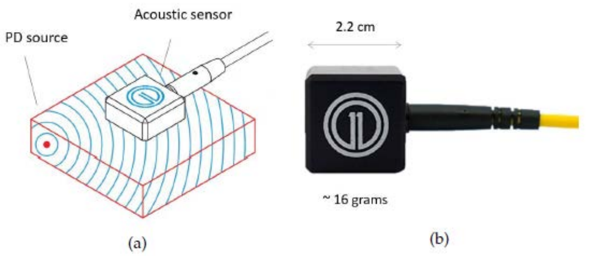

Figure 1 (a): Transfer of the PD-generated acoustic signal to the OptiFender sensor. (b): The OptiFender PD sensor.