Toward acoustic detection of partial discharges in high voltage cables

Tadeusz **CZASZEJKO**, Jarman A. D. **STEPHENS*;** Monash University, Melbourne, Australia
tadeusz.czaszejko@monash.edu
* Currently with ABB Australia

ABSTRACT

The concept of partial discharge (PD) detection using acoustic methods, for the use in high voltage cable systems, is being developed. A photonic acoustic sensor based on a fibre Bragg grating (FBG) has been shown to detect acoustic emission from PDs. The sensitivity of a generic FBG appears insufficient for practical applications. An improved FBG photonic acoustic sensor has been developed which exhibits a 50-60 dB gain in sensitivity when compared with a generic FBG. This article describes the design process and test results of the improved FBG-based PD photonic acoustic sensor.

KEYWORDS

Partial discharge, acoustic monitoring, fibre optics, fibre Bragg grating sensor, high voltage cable systems.

INTRODUCTION

Partial discharge detection through observation of acoustic emissions is a known supplement to classical electromagnetic (EM) PD detection techniques. However, electro-acoustic (EA) sensors, such as piezoelectric sensors, still require electrical connections to the PD monitoring system. As such, traditional EM and EA methods are not amenable to PD monitoring of live insulated cables that often span long distances. Even off-line PD tests can be cumbersome to arrange for all joints and terminations simultaneously using traditional methods. Conversely, photonic acoustic sensors can exclusively transmit optical signals within optical fibre and thus avoid any electrical coupling between the PD sources and monitoring equipment. This electrical isolation and no need for electrical supply to the sensor cause photonic acoustic sensor systems to be the technology of choice in this context.

Partial discharge detection and source localisation using acoustic emissions (AE) is a well-established practice in power transformers. There is ample information in literature about the various properties of acoustic signals emitted from PDs in paper-oil insulation. These signals are recorded using ultrasonic sensors, which are typically piezoelectric. Early attempts to detect AEs from PDs in cables and cable accessories were reported in the early 1990's [1][2]. Oscillation modes of acoustic signals from cavities in solids were investigated in [1]. The detection and localisation of PDs using AEs in prefabricated cable joints is described in [2]. This work concentrated on the feasibility of this PD detection technique and rudimentary discrimination between PD acoustic signals and ambient acoustic noise. Somewhat more detailed investigations of AE signals generated from partial discharges began to appear in the late '90s [3][4][5][6][7]. The AE signals detected were typically dominated by the mechanical resonant frequency of the electro-acoustic sensors, which was 150 kHz in [3] and [4] and as high as 1 MHz in [6]. Additional literature, such as [7], concentrated on pulse counting and didn't consider the signal bandwidth.

A different PD detection method using acoustic signals, based on the corona gun and supplemented by a fibreglass probe as a wave guide, was proposed in [8] for testing medium voltage cable terminations. This method produced a good level of PD detection sensitivity, ranging between 5 – 50 pC. Subsequently, electrical utilities in Norway implemented this detection method in practice, presumably as a pass/fail test because they did not record any characteristics of the acoustic signal recorded.

Attempts were made to characterise AEs from typical defects, such as in joints due to poor workmanship [2]. Insulation cavities with simple geometries were investigated in [1][3][4][5], whereas AEs generated from electrical treeing were reported in [7] and [9]. However any information obtained from these acoustic signals, which were generated by PD, was limited because the signals were constrained to a narrow frequency band centred around the resonance of the piezoelectric sensors used.

This brief review shows representative examples of research in which 'classical' EA sensors were used for PD detection. These sensors operate within the ultrasonic range of frequencies. Cross-linked polyethylene (XLPE) and cured liquid silicon rubber (LSR) are two popular electrical insulation materials which were tested more recently for their acoustic properties in the region of 200-600 kHz [10].

Our own computer simulations and preliminary tests have shown that sound waves emitted by small cavities in solids can be within the audible range [11][12]. The prospective photonic acoustic sensors are not restricted to the ultrasonic range of frequencies like their electro-acoustic counterparts. The aim of this paper is to show how our previous findings have helped to develop a photonic acoustic sensor for PD detection.

ACOUSTIC SIGNALS FROM PD IN SOLIDS

Photonic sensor

The photonic acoustic sensor is based on FBG technology. An FBG is a filter embedded in an optical fibre that reflects light but only the wavelengths of light specific to the filter. The filter's characteristic wavelength is called Bragg wavelength, λ_B. The Bragg wavelength is affected by strain exerted on the fibre. When wavelength of light from a narrow-bandwidth laser is tuned on to a slope of the reflection spectrum of FBG, near λ_B, strain variations exerted on the FBG from impacting sound waves shift the FBG's spectral response and thus vary the amount of light reflected.

Fig. 1 and Fig. 2 illustrate the principle of optical signal modulation that can be achieved with the use of a narrow-bandwidth laser and an FBG. The π-phase shifted grating (πFBG) has a steep notch in its spectral characteristic that helps to achieve higher sensitivity in comparison with a standard FBG.