Field experiences with distributed fiber optic sensing in power cable monitoring of complex windfarms

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ABSTRACT

Distributed Fibre Optic Sensing, featuring temperature, acoustic or deformation measurement is now commonly deployed in the field, monitoring complex windfarms or long interconnectors. The mature technology, together with advanced data processing and modelling allows for the computation of the cable conductor temperature, the estimation of the cable depth of burial and the evaluation of cable protection system condition or of termination connector condition. Learnings gathered in the field over thousands of kilometres of instrumented power cable, both onshore and offshore are discussed in this paper.

KEYWORDS

Distributed Fibre Optic Sensing, Distributed Temperature, Acoustic and Strain sensing systems (DTS, DAS, DSS), Real Time Thermal Rating (RTTR), Depth of Burial (DoB), power cable, monitoring, windfarm, offshore wind.

INTRODUCTION

Distributed Fibre Optic Sensing (DFOS) is now commonly deployed in the power cable industry as a monitoring tool, as a management tool, and as a fault-finding tool.

The DFOS family is made of Distributed Temperature, Acoustic and Strain sensing systems (DTS, DAS, DSS), each having its own particularities and preferred applications. Different models using DFOS data allow extracting meaningful information from the sensors, for instance to dynamically manage the load using a Real Time Thermal Rating approach (RTTR), to evaluate the cable Depth of Burial (DoB) or to identify cable protection systems (CPS) condition.

Comprehensive monitoring is only possible when all technologies (sensing and data processing) are proprietary and well mastered such that the best combination can be used regardless of any other consideration.

In this paper, following a short reminder of the physics underlying fibre sensing, we review how DFOS solutions were deployed in the field along large offshore windfarms featuring complex cable routes, or on long interconnectors. The different experiences demonstrate that an optimized solution is designed solely with respect to the application, and not to the availability of a particular type of interrogator, and that it requires a good understanding of the field.

The examples reported in this paper are related to multiple installation sites and correspond to 1000's of kilometres of permanently instrumented power cable, forming a huge track record for the technology and its applications.

THE DFOS FAMILY

Distributed Fibre Optic Sensing (DFOS) is based on the measurement of backscattered light from optical fibres [1]. A powerful pump light pulse (intensity modulated, frequency modulated) is launched in the fibre. The returning backscattered light, created by local non-homogeneities, and spread over three different spectral components, is acquired, and processed as a function of time and distance.

The combined intensity and phase measurement of Rayleigh backscattering is used by the Distributed Acoustic Sensing (DAS) system. A DAS is sensitive to the thermally or mechanically (elongation) induced phase changes along the fibre. The result is relative and features a temperature gradient $\frac{\Delta T}{\Delta t}$, respectively an elongation gradient $\frac{\Delta \varepsilon}{\Delta t}$ or directly a temperature difference ΔT, respectively an elongation difference $\Delta\delta\varepsilon$, depending on the technology [2], [3].

The measurement of either the Raman backscattering [4] or of the Brillouin backscattering [5] results in Distributed Temperature Sensing (DTS). Brillouin scattering is also used to address Distributed Strain Sensing (DSS) [5]. Both Raman and Brillouin measurements can be calibrated and, unlike DAS, provide an absolute measurement of the local temperature or the local elongation.

Different technical bodies have worked on issuing guidelines or standards for the qualification and test of DTS; DAS and DSS, amongst which are SEAFOM™ MSP-01 (DTS) and MSP-02 (DAS), IEC 61757-2-2 (DTS), 61757-3-2 (DAS) and the to be released 61757-1-2 (DSS). The IEC 61757-2-2/MSP-01 defines the key DTS parameters, in particular the distance measurement range, measurement time, spatial resolution, temperature repeatability, and temperature measurement error (calibration error on absolute measurement). The documents also describe the corresponding test setups. Similarly, the IEC 61757-3-2/MSP-02 defines the key DAS (ϕ-OTDR, coherent-OTDR excluded) parameter, in particular the dynamic range, frequency response, fidelity, self-noise, spatial resolution, crosstalk, and loss budget. Test setups are also described. Note that those documents target the instrument only and neither the fibre nor the sensing cable used in real life applications.

In addition, CIGRE study committee B1.80 is working on technical guidelines for Site Acceptance Tests (SAT) which purpose is to define meaningful and realizable test methods to ensure a proper "end-to-end" test of DTS or DAS in an efficient and cost-effective manner.

DEPLOYING DFOS WITHIN COMPLEX WINDFARM

In a complex windfarm, featuring an export cable and a large wind turbine array, a single interrogator is not anymore the solution. For DTS only, multiple interrogators, potentially providing sequential measurement over multiple