Anomalous Condition Detection for Subsea Cables using Distributed Temperature Sensing Measurements

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ABSTRACT

This paper proposes a unique approach to utilize Distributed Temperature Sensing (DTS) data for detecting anomalies in underground/submarine cables. The idea is to establish a set of system identifiers by correlating the load and temperature in space and time. These parameters can be utilized as indicators of cable health, that can reveal changes in system behaviour by appropriate trend analysis. The proposed method is applied to a case study involving an onshore/offshore cable, showing the ability to identify an anomalous period. This way of analysing monitoring data shows potential for further utilization of cable characterization to facilitate predictive maintenance.

KEYWORDS

DTS, data-driven analysis, subsea export cable, condition monitoring, thermoelectric equivalent model, curve fitting, anomaly detection.

INTRODUCTION

Offshore wind power, a key to meeting ambitious net-zero emissions, is expected to grow tenfold in capacity worldwide by 2035 [1]. An increase in interest, investment, size and the number of offshore wind farms brings the challenge of efficient and cost-effective maintenance and condition monitoring of the assets. High-voltage underground and subsea export cables are difficult to monitor and localize faults because of the challenges associated with accessibility. Owing to the heavy cost of installation and repair of the submarine export cables, connecting offshore plants to the onshore substations can be a bottleneck of the system. This emphasizes the need of utilizing available monitoring data to its full potential to predict, prevent and most importantly identify fault location in a given cable.

The conductor temperature of a loaded cable is a result of conductor current and the conductive heat transfer through cable and environment. Changes in the environment can be deducted from the temperature response to the changes in the line loading. This correlation is often exploited to model an electro-thermal equivalent of a cable. IEC 60287 utilizes this correlation to calculate the continuous current rating of cables [2]. Enescu et al have overviewed several thermal models for power cables and indicated their effectiveness in identifying soil dimensions, cable current ratings and their applications in FEM analysis [3]. These models can be utilized to understand the dynamic rating of submarine cables using a thermal ladder network equivalent to improve cable ratings [4]. Another application could be to identify changes developed with time to predict performance anomalies. In the current work, the relationship between current and temperature is studied to understand the cable laying characteristic along its whole length.

Fibre optic-based Distributed Temperature Sensing (DTS) is now an established method enabling identifying spatially distributed temperatures of a cable. They provide the thermal profile of the cable at a given time and space, subject to the resolution of the measuring device. The underlying principle for the DTS system utilizes the Raman back-scatter optical time-domain reflectometry, which is resistant to residual strain effect and delivers self-checking, real-time fibre degradation adjustment [5].

Traditionally DTS data is used directly as a trigger to set off for alarming high-temperature values. Correlating the variations in temperature with corresponding load current variation can be utilized as a powerful tool to characterize the cable condition. DTS monitoring can generate a wealth of in-service temperature data which can seed a number of data-based empirical modelling and fuel a wave of highly competitive research and development that could facilitate enhanced condition assessment of cables. Research indicates that DTS data can also be effectively used for real-time depth of burial analysis using an appropriate thermal model of the cable [6]. Kazmi et al have shown the possibility of debottlenecking offshore windfarm export cables by utilizing the DTS-load current correlation and by identifying critical cable sections [7].

This paper investigates the possibility of characterizing a cable and using the features for detecting anomalies. Any significant change in the established normal characteristic behaviour can be considered as an indication of anomaly making it worth investigating. An anomaly for an underground cable can be an indication of one or more of the following scenarios:

- Re-surfacing of the cable due to marine-bed disturbances
- Damage of cable insulation leading to an insulation breakdown/fault (the associated decreased thermal conductivity in a localized spot would not mean anything, due to longitudinal heat equalization).
- Issues concerning link box/ faulty connections of grounding/cross-bonding leads/link cables
- Cross-bonding errors for an underground cable
- Mechanical threats to the cable integrity
- Partial discharges/defect conductor joints causing heat accumulation at a stressed cable section

The first section of the paper explains the electro-thermal model establishing the cable equivalent. The second section explains a case study used to validate the model. The third section discusses the results obtained and the fourth section includes a discussion that includes the potential of the proposed method in real time. While dealing with identifying anomalies, the commonly faced challenge