Electrical Diagnosis of Dynamic Subsea Power Cables for Floating Offshore Wind Farms Using a Model-Based Approach

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ABSTRACT

Dynamic subsea power cables or their accessories failure can result in significant economic consequences on floating offshore wind farms (FOWFs). Their monitoring as well as their predictive maintenance are crucial for the viability of FOWFs. This study explores an original model-based approach that uses the convolution between the temporal response of a faulty cable and that of a transmission-line model to locate faults at unknown positions. The study focuses on the early diagnosis of a fault initiation resulting in a slight deviation in the distributed resistance of the core metallic screen or conductor. By analyzing experimental signals, the study demonstrates the possibility of detecting and locating the fault position caused by a distributed resistance variation of at least 30%.

KEYWORDS

Dynamic power cable, model-based diagnosis, floating offshore wind farm, system health monitoring, reflectometry, time-domain analysis.

INTRODUCTION

Offshore renewable energy (ORE) sources hold great promises as future clean energy enablers to reduce greenhouse gases and limit climate changes. Offshore wind energy represents one of the main sources of ORE that uses wind turbines to convert the air kinetic energy into electricity. As fixed offshore wind farms suffer from the Not-In-My-Backyard (NIMBY) syndrome [1], floating offshore wind farms (FOWFs) are gaining popularity as alternatives as they can be situated further offshore.

High-voltage (HV) and medium-voltage (MV) dynamic cables are one of the key components of FOWFs. While in service, these cables along with their accessories are vulnerable to a range of electrical, mechanical, thermal, and environmental stresses, which can cause them to malfunction and eventually fail [2-3]. Specifically, these stresses can give rise to several anomalies, including but not limited to mechanical damage of metallic parts, partial discharges (PDs), water trees, insulation system degradation, overheating, etc., which evolve over time and can end in cable breakdowns [4-8]. Therefore, it becomes essential to detect and locate these faults in the shortest time and to take preventive measures.

Nonetheless, the industrial sector has little experience with the aging, in-service behavior, and failure risks of dynamic cables [9-11]. The reflectometry-based methods, in addition to other methods (such as the optical distributed sensing, PD measurements, acoustic detection, etc.), are some of the techniques used to diagnose faults in power cable systems [12-14]. Although these methods are relatively efficient, they have shown to be less reliable when identifying faults in challenging marine environments. For instance, reflectometry-based techniques have demonstrated efficiency in the diagnosis of hard faults, namely open or short circuits, which require the temporary shutdown of the system for technical interventions. However, given the considerable expenses associated with offshore maintenance activities, it is evident that early detection of degradation, well before it precipitates a shutdown of the installation, is of paramount significance. Predictive maintenance is clearly a key challenge.

For this reason, scientists and engineers merged the reflectometry-based techniques with data-driven approaches (such as big data, neural networks, teaching–learning-based optimization, continuous wavelet transform, etc.) or model-based approaches using identification genetic algorithms, inverse scattering, etc. to analyze the complex signatures of the faults [15-17]. Although data-driven approaches are well-suited for handling large data sets, model-based approaches based on continuous time modeling remain interesting in the context of power cables, particularly in instances where the available database for data-driven methods is deemed insufficient to deliver accurate and reliable results. Generally speaking, continuous-time modeling offers several benefits, including a direct relation between model parameters and the physical properties of the system.

Recently, the *in-situ* identification of a continuous-time state-space model that characterizes the high-frequency behavior of the cable over a wide frequency range has been utilized in power cables. This approach employs an explicit model of the cable system and the fault to analyze the measured signals. The model was used in [18] to monitor moisture and water barriers by detecting a local variation of the distributed capacitance in a cable core, which can be modeled using a distributed circuit under certain hypotheses. In reality, a fault in the cable core has the potential to alter not only the distributed capacitance but also the other electrical distributed parameters (resistance, conductance, and inductance), or even a combination of them. In this paper, we move a step further and explore the potential of the continuous-time state-space model to diagnosing cable cores by detecting and locating a local