# A new time-domain model-based diagnosis method for assessing the offshore floating wind turbine umbilical state of health

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## ABSTRACT

*This paper investigates a new low-cost method for the in-situ diagnosis of floating wind turbine umbilicals. We propose to assess the cable electrical health state by monitoring estimated capacitances of multi-wire transmission line models. A pulse generator and a high frequency acquisition system have been specially designed in order to efficiently sensitize the model parameters in operating conditions. The output-error identification approach is exploited to select the "best" model structure, i.e. to optimize its parameterization and its granularity, using experimental data obtained with an 8 MW 500-m long submarine power cable. Then, a sensibility analysis shows that the proposed method allows to detect and localize a breakdown of the cable moisture barrier dealing with a relative increase of more than 8% of the cable distributed capacitance.*

## KEYWORDS

Umbilical, subsea power cable, XLPE, Insulation testing, Insulation condition monitoring, Predictive maintenance, Multi-wire transmission line, Output-error method, Model-based diagnosis.

## INTRODUCTION

Deep-water Floating Offshore Wind Turbine (FOWT) is a promising technology for the production of renewable electricity: not only it provides access to the powerful and steady wind blowing offshore, but above all FOWT has a far better social acceptability than that of near shore fixed-foundation wind turbines. The counterpart is its higher capital and operational expenditures and the reduction of the cable installation and maintenance costs remains one of the main challenges for the development of offshore wind energy [1-2]. This concerns the static cable buried beneath the seafloor and the so-called umbilical power cable linking the floating turbine to its substation.

For each of them, the insulation system between the phase conductor and its screen is designed to withstand the operational voltage and the maximum temperature - typically of 90°C continuously for XLPE material [3]. But contrary of static cables, the umbilicals are subjected to continuous movements over their service life. Their insulation layer and water barrier consequently endure thermal, mechanical and electrical stresses which coupling may accelerate aging phenomena. Although aging of static power cables has been largely studied for several decades [4-5], the monitoring of high-voltage high-power umbilical is yet an open research topic. Indeed, even if oil & gas industry has a huge experience in the design and maintenance of low-power umbilical subsea cables, its economical model is radically different from that of marine renewable energy framework that requires low-cost technological bricks [1-2]. Moreover, it is well known that the presence of water is the necessary condition for water-trees to be initiated. Whatever the cable design (dry, semi-wet or wet), an abnormal increase of moisture content in the cable cross-section represents a potential upcoming insulation problem. Monitoring this moisture along the 300 to 800 meter long dynamic cable is therefore a key issue for the predictive maintenance of an offshore farm [6].

We propose to address this challenge by the in-situ identification of a continuous-time state-space model structures dealing with multi-wire transmission lines. The underlying idea is to use the screen-screen or conductor-screen distributed capacitances as fault sensor. For this, the cable is divided into $N_c$ elementary *Pi*-cells with the same values of distributed resistances, capacitances and self/mutual inductances. Only one cell presents a different capacitance value revealing either the local concentration of water-trees or the moisture content increase resulting from the rupture of the cable water barrier. This article presents the first results obtained with a classical Transmission Line (TL) modelling only one phase. For each cell, a $P$-stage $R-L$ network is optimized in order to accurately simulate the TL resistive behaviour in the range [0 – 10 MHz]. By default, the model presents too many unknown parameters for in-situ system identification. Several physical considerations and simulations by Finite Element Method (FEM) allow to limit this number to 4, which in practice remains within a classical range in model-based diagnosis framework. The cable diagnosis is then performed by the identification of $N$ different faulty-models, each one considering the faulty cell at a different position: the *n*th model that presents – amongst others - the lowest energy of the output error between measured and simulated currents (whereas the system/model input is the voltage applied to the transmission line end) reveals the fault position and its severity. Finally, the underlying principle of the proposed method is more or less the same as for the classical reflectometry; the main difference is that we use here a model that explicitly explains the default. The proposed model has been successfully validated with a submarine power cable and we have shown that it allows to detect and localize a $1$-meter long faulty cell for a variation of more than 8% of its distributed capacitance. This value must be compared, for example, with the doubling of the TL distributed capacitance for a water tree growth of 60% across the XLPE phase insulation [7].

## 1. EXPERIMENTAL SETUP

Fig. 1 shows the subsea power cable used for experimental data acquirements. It is a $500$-meter long sample from the $8$ MW 25 km long static export cable connecting the $1$ km$^2$ offshore test site to the French grid, near Le Croisic (see https://sem-rev.ec-nantes.fr/ and [9]). A low-cost system has been specially designed with high-frequency components (mosfet switches, sensors, etc.)