Investigation of the biofouling thermal effects on offshore wind turbine power cables

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ABSTRACT

The dynamic submarine cable supplying power from the turbine to its electric substation is subject to motion of the floating structure, waves, and marine currents. Its XLPE electric insulation system, designed to continuously support 90°C, is therefore highly stressed by coupled thermal-mechanical-electrical constraints, which can be worsen by the biofouling growth affecting its hydrodynamic, drag and cooling. This article is intended to evaluate the risk that biofouling will lead the XLPE material to exceed 90°C under normal operating conditions. The study shows significant temperature increases in the cable, depending on the thickness, density and the length of the mussel layer distribution.

KEYWORDS

Marine renewable energy (MRE), floating wind turbine, dynamic cable, biofouling, homogenization, thermal analysis, IEC, XLPE.

INTRODUCTION

Offshore floating wind turbines represent a promising technology to produce renewable electricity at a competitive cost compared to other MRE [1]. Indeed, thanks to their floating foundations, these turbines can be anchored on the seabed farther from the shore than bottom-mounted turbines, where the wind blows stronger and steadier than on land or near shore. The world's largest utilities involved in offshore wind farms claim that this technology is more economical than the use of bottom-fixed foundations [1], and that it reduces the impact on marine environment as well as the use conflicts with other sea activities. But the counterpart is the complexity of the floating structure anchoring and of the electrical connection. For example, many recent studies have highlighted that cable installation remains the top industrial challenge for the majority of utilities [2-5]. This concerns the static cable flowing the farm power to the shore and the dynamic cable transmitting the electric power from the floating turbine structure to the fixed farm substation. This so-called umbilical cable is a key component for offshore operators: firstly because cable manufacturers have only few feedbacks about these new products (unlike the case of static submarine cables) and secondly because a dynamic cable is designed on a case-by-case basis, depending on each new MRE farm project specifications. Generally speaking, dynamic cable are designed to face coupled mechanical-electrical-thermal constraints: its armor is sized to withstand the mechanical constraints, the phase conductor is sized in relation to its current carrying capacity [6-7] and the XLPE insulation system (between each phase conductor and its screen) is designed to endure both the electric and the thermal constraints.

It is well-known that the dynamic cable is generally

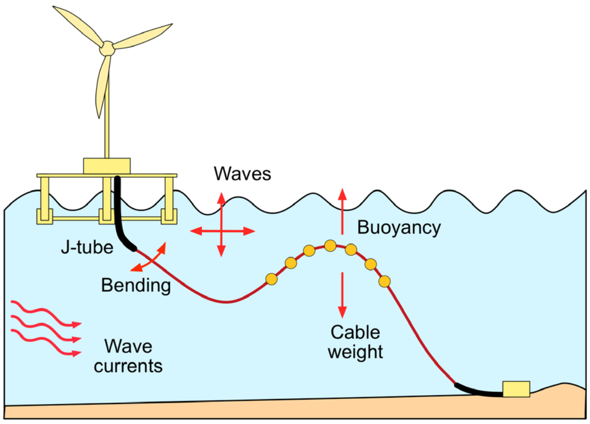

Fig. 1: Floating wind turbine and its dynamic cable.

oversized in order to support the hot spot that can appear in the J-tube (see Fig. 1) due to its bad cooling conditions [8-9]. But another problem that can accentuate the coupled mechanical-electrical-thermal constraints is the biofouling growth that strongly affects 1) the cable linear mass locally, 2) the apparent diameter and 3) the surface roughness (see Fig. 2). Several previous studies have been conducted to characterize and measure the phenomenon of colonization and its hydrodynamic effects. Sarpkaya in [10] demonstrates through experiments that biofouling may double drag and inertia coefficients for a cylinder. Yang et al. [11] investigated the fouling assemblages on chain catenary mooring lines for a wave energy converter (WEC) and the study concluded that marine growth decreased by 20% the fatigue life of the mooring lines. Achenbach and Heinecke [12] showed that biofouling reduces the value of the critical Reynolds, which characterizes the fluid flow (laminar to turbulent).

Moreover, the biofouling, and particularly the mussel growth, can affect the cable cooling by adding a thermal resistance which reduces the heat transfer between the core and the sea water. Considering this, one could wonder how much the biofouling growth can impact the temperature gradient in the cable cross section, knowing that umbilicals are dimensioned to remain below a temperature of 90 °C into the conductor and XLPE insulation in normal operating conditions, according to the IEC 60287-1 standard [13]. To our knowledge, no prior studies have examined the impact of biofouling on the thermal behaviour of a dynamic cable. The answer to this question requires to consider the non-homogenous distribution of marine growth along the dynamic cable which requires a 3D model to compute the heat flux within the cable, which is then transmitted to its environment. Unfortunately, the 3D numerical simulation of a power cable of about 300 meters long requires very high computational power and times. This paper presents an original approach based on the section homogenization to