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PERFORMANCE EVALUATION OF DYNAMIC HV CABLES WITH AL CONDUCTORS FOR FLOATING OFFSHORE WIND TURBINES

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ABSTRACT

Floating Offshore Wind turbine installations will require HV dynamic power cables to be connected to the of longer length static export power cables. Experience from offshore wind installations has highlighted the criticality of power cables, underlining the need for high integrity, yet cost effective cable solutions. This paper will assess the mechanical performance and load parameters for an Aluminum power conductor cable. Whilst copper is the conventional choice due to its lower resistive losses, Aluminum cores are increasingly used for static power cables, due to their benefits regarding overall cable weight and material cost. The work presented adopts a coupled aero-elastic and hydrodynamic modelling approach to simulate the behavior of the well-documented OC4 semi-sub platform, together with the 5MW NREL wind turbine. The model allows a direct comparison between the two cable types, maintaining the overall system and environmental conditions.

The results inform the design envelope regarding the ultimate load conditions a for the two principle cable designs, providing global load estimates, such as effective tension and bending stresses, to inform the local stress analysis. Furthermore, the results will form the basis for future physical demonstration and validation tests.

This paper will be of interest to technology developers and practitioners concerned with submarine dynamic power cables, offer a methodology to directly compare and evaluate different cable design options, and providing some design guidance for and aluminum conductor cables.

Keywords: Floating Offshore Wind; Dynamic Submarine Power Cable, Aluminum Conductor, Numerical Modelling.

1. INTRODUCTION

1.1 Current state and market outlook Floating offshore Wind

Floating Offshore Wind (FOW) technology has become a feasible technical solution, with a number of prototype deployments around the world. Whilst the floating platform type has been variable, all deployments have opted for a horizontal-axis, three-bladed wind turbine. The floating platform types that have been demonstrated through full-scale deployments are the Spar-buoy, barge and semi-submersible concepts [1].

Key FOW markets are globally distributed, including Europe, Japan and the West Coast in the US. Estimates for the technical FOW potential are ~7 GW installed capacity in Europe, the USA and Japan combined. The Hywind consortium states Japan (3.5 GW), France (2.9 GW), the US (2 GW) and Ireland/UK (1.9 GW) ad prospective market with substantial deployment opportunities leading up to 2030 [2].

One of the critical components that floating installations rely on is the dynamic power cable. These dynamic submarine power cables cross the water column, from the floating platform to the seabed, where they typically connect to a static subsea inter-array / export power cable. These cables must maintain the highest

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possible integrity to ensure uninterrupted power generation is the dynamic power cable.

In FOW applications, power cables must be designed to operate in highly dynamic conditions with cyclical axial loading sequences and continuous bending cycles due to both, environmental loads, and the relative motion of the device system components. The Hywind SPAR project and the WindFloat Semi-submersible design are two examples where dynamic cables have been deployed in relatively shallow waters. Increasingly deeper water depth will increase the design demands for dynamic cables. In particular, cable weight will be a governing design parameter in deeper water.

In order to reduce cable weight, alternative core materials can be explored, namely copper can be replaced with aluminum or aluminum alloy as conductor material for the dynamic cable. This design option would allow to lower weight and potentially cost, as the ‘expense of a larger cross-sectional area, owing to the lower electrical conductivity of aluminum compared to copper.

This paper will explore the possibility to considerably reduce cable weight by replacing the cable conductor material with aluminum or aluminum alloy, instead of copper. The study focusses on suitable cable configurations and seeks to estimate the expected cable tension and Minimum Bending radius.

Following the introduction, the paper will briefly set out the modelling approach and method, followed by a presentation of the main results. The discussion will give insight into some of the ongoing and future work in order to progress the Al conductor design.

1.2 Technology Readiness Levels (TRL) and the Innovation Cycle

Technology Readiness Levels (TRLs) are a widely used metric of technology maturity and risk, and has been readily applied to offshore engineering. The TRL range from 1 (Basic principles observed) to 9 (actual system proven in operational environment; commercial availability) with incremental steps / stage gates in between to structure and manage the often long (typical several years for offshore engineering) and costly innovation process.

The floating offshore wind technology has different concepts at all stages of the ‘TRL ladder’. The majority has reached scaled experimental tank test (TRL 4), moving to validation and technical demonstration in relevant offshore environments (TRL 5/6). TRL 7 is a significant step in demonstrating the technology in operational environments. Several technologies and concepts have achieved TRL7 and are progressing and performing projects for both pilot and pre-commercial (i.e. relying on public investments/incentives) at TRL 8. If projects can successfully demonstrate their technical and economic viability at TRL8, they will progress to commercial deployment projects. Pilot projects such as Hywind and Kincardine are in the pre-commercial TRL phase (TRL 8). The challenge for the research, development and innovation activities is how the innovation cycles of individual, often critical sub-systems, can be integrated and aligned with the overall system demonstration and commercial progression. Whilst pilot projects can demonstrate the technical feasibility, future market trends and competitiveness demand both lower cost and further innovation in order to meet specific market needs, such as deep-water installations.

Targeted R&D funding is one pathway to develop, pilot and possibly integrate sub-system and component level innovations into established FOW concepts. The work presented here is part of a EU Horizon 2020 project, FLOTANT, to develop an innovative and integrated Floating Offshore Wind solution, optimized for deep waters (100-600m), targeting 10+MW wind turbine installations.

The project seeks to develop prototypes of novel mooring, anchoring and dynamic cable components, as well as a hybrid offshore floating wind platform. The work presented here focusses on the dynamic power cable.

2. METHODOLOGY AND MODELLING APPROACH

The mechanical load analysis for dynamic submarine power cables is commonly carried out in two distinctive steps:

1. Global load analysis: The forces and motions acting on the power cable, induced through the combined effect of the metocean environment and the aero-hydrodynamic response of the floating structure are estimated.
2. Local analysis that seeks to determine the local stresses (within the cross-section) of the cable.

This paper only presents the global load analysis, as an initial assessment for Aluminum conductor cables. It should be noted that a full cable design would have to incorporate and satisfy the design conditions of step 2 As well.

FOW installations are modelled through a combined model of that simulates both the aerodynamic and hydrodynamic load conditions. The aerodynamic-hydrodynamic coupling described in [3, 4] and has been applied to dynamic power cables in [5]. The main features and parameters for both models are briefly described here:

The aerodynamic model employs the open access code FAST [6]. The aerodynamic and structural properties of the wind turbine are represented through a suite of sub-models in order to estimate the wind turbine loads in time-domain simulations. The work presented here also employs the 5 MW NREL reference turbine.

The hydrodynamic modelling is facilitated through the commercial code OrcaFlex [7], following a lumped mass, finite element approach and has been previously applied to dynamic mooring and power cable problems [8, 9]. The analysis has been performed for the semi-submersible platform (OC4), as described in [10].

Fig. 1 depicts a wireframe overview of the main system components, including the floating semi-submersible platform, maintaining station through three mooring lines at 120 degree spread and the dynamic cable in a Lazy Wave configuration. Table 1 summarizes the cable properties for the Aluminum core design. Table 2 shows the three modelled load cases, which were chosen to allow a comparison with the copper conductor cable simulated in [5]. All cases were performed in a sea state with a significant wave height of Hs = 9m, Tp = 15s, whilst varying the wind speed between 9-25 m/s to capture lower, medium and higher operational wind speeds.

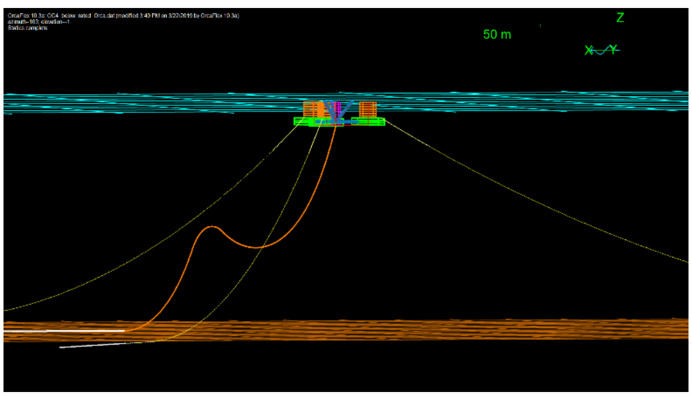

FIGURE 1: OVERVIEW OF PLATFORM, CABLE AND MOORING CONFIGURATION

TABLE 1: ALUMINIUM CABLE PROPERTIES

Parameter [unit]	Symbol	Value
Static axial strength [kN]	F_{max}	56
Rated axial strength [kN]	F_{rated}	279
Minimum bending radius [m]	MBR	2.3

TABLE 2: OVERVIEW OF MODELLED ENVIRONMENTAL LOAD CASES. EACH LOAD CASE IS MODELLED FOR 3600S.

Load case	Hs [m]	Tp [s]	V [m/s]
Low rated wind speed	9.0	15	8.0
Medium wind speed	9.0	15	15.0
Upper limit rated wind speed	9.0	15	25.0
Water depth, D = 200m			

3. RESULTS

The results are presented with a view towards the Minimum Bending Radius (curvature) that the cable has to withstand and the effective tension along the length of the cable. Both parameters indicate, whether the cable design and configuration are suitable, comparing cable design properties and modelled load conditions.

Fig 2 depicts the minimum, mean and maximum tensions along the entire length of the cable. Throughout the simulated load case the cable is not subject compression (i.e. negative minimum tensions), satisfying an important design criterion. It can also be observed that the highest tension is located at the cable hang off point at the platform (arc length = 0). The tension peak mid-arc (~220m) aligns with the location of the Lazy Wave arc. The visible discrete steps mid-arc, are caused by the discrete floatation buoy elements. The rated axial strength (56 kN (static) and /279 kN (dynamic)) is not reached at any point during the ULS case (F_{max} = 36kN), with a mean cable tension of (F_{mean} = 30kN).

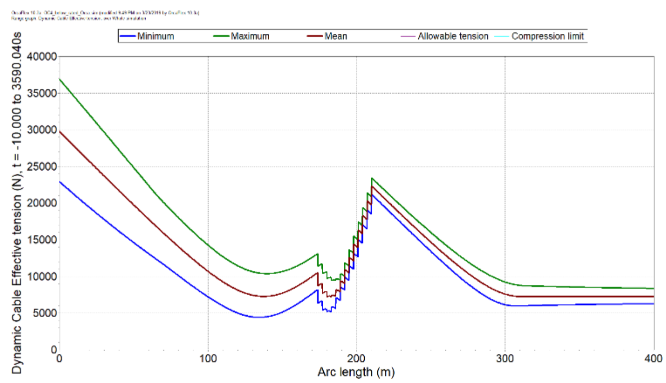

FIGURE 2: RANGE GRAPH PLOT SHOWING MINIMUM, MEAN AND MAXIMUM CABLE TENSIONS FOR CONFIGURATION II) DURING ULS SIMULATION (HS = 9 M, TP = 15S). ARC LENGTH = 0 CORRESPONDS TO THE CABLE HANG OFF AT THE PLATFORM.

Fig 3 displays the cable curvature along the cable length, showing the min/mean/max curvature the cable is subjected to. The highest curvature is located at the physical Lazy Wave peak (0.195 rad/m), but is a factor of 2.2 below the rated cable curvature (0.43 rad/m).

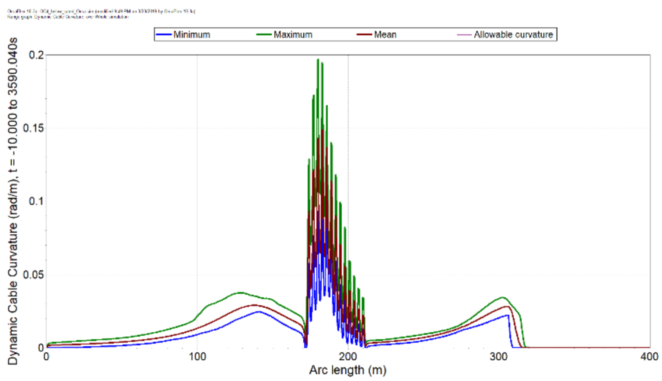

FIGURE 3: RANGE GRAPH PLOT SHOWING MINIMUM, MEAN AND MAXIMUM CABLE CURVATURES DURING ULS SIMULATION (HS = 9 M, TP = 15S). ARC LENGTH = 0 CORRESPONDS TO THE CABLE HANG OFF AT THE PLATFORM. THE ALLOWABLE CURVATURE IS K =0.195 RAD/M

4. DISCUSSION

The results indicate that the cable design criteria regarding tension, compression and MBR constraints are met for the chosen configuration and the modelled selection of load cases.

The objective for this work was to compare the copper and aluminum conductor cable behavior for the same floating offshore wind installation. A direct comparison of key parameters is given in Table 3.

TABLE 3: COMPARISON OF ALUMINIUM AND COPPER CABLE LOAD PARAMETERS FOR SELECTED SIMULATIONS, WATER DEPTH *= 200m.*

Parameter [unit]	Symbol	Aluminium conductor	Copper conductor [5]
Max cable tension [kN]	F_{max}	36	48
Mean cable tension [kN]	F_{rated}	30	41
Minimum bending radius [m]	MBR	5.1	6.25

Keeping all model parameters constant, including a fixed water depth of D = 20m, it can be seen that the Aluminum cable, configured for the same voltage capacity (66kV) is able to reduce the max cable tension at the hang off (-25%) and the mean cable tension (-27%). The necessary trade-off in the design is an increased cable diameter. The modelled MBR that the cable has to withstand is also lower for the Al conductor cable.

The results are however encouraging that, the design envelope can be achieved for Al conductor cables, offering benefits in intermediate water depth, as modelled.

Increased water depth will hold additional benefits for Al conductor cables, relieving both maximum and mean tension at the hang off point.

Ongoing and further work are under progress regarding more detailed local load analysis, as well as electrical design of the cable cross-section.

5. CONCLUSION

The paper has offered a summary of the main results regarding the load performance of a dynamic power cable with Aluminum conductor, seeking to reduce the cable weight to facilitate increasingly deeper water FOW installations. Based on the selected load cases and coupled aerodynamic-hydrodynamic load modelling a reduction of the ULS tensions was found, both regarding the maximum tension at the hang-off, as well as the mean cable tension. This is encouraging, as any load reliefs can propagate into the design of hang-offs and connectors. Thus, the design, testing and demonstration of Al conductor cable for FOW applications has the potential to contribute to a reduction in Levelized cost of electricity for this technology.

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