Design and Assessment of Hybrid Catenary Mooring Systems with Steel Wire and Polyester Ropes for a 10 MW Semi-submersible, Spar buoy and TLP Wind Turbine at 1,000 and 200 m Water Depth

Abstract

This work presents a detailed design and comparative assessment of hybrid catenary mooring systems for a 10 MW semi-submersible floating wind turbine at a deep-water site of 1,000 meters and shallow water site of 200 meters. The study evaluates the technical feasibility and cost benefits of using steel wire ropes (SWR) versus polyester ropes (PR), as well as versus their combined configurations (SWR-PR). Four distinct mooring system designs –each featuring a 3x2 redundant layout with chain segments – are developed and analyzed under both harsh (OA-class, North Sea) and mild (OB-class, Mediterranean) environmental conditions using a fully coupled hydro-servo-aero-elastic time-domain tool. The four different mooring layouts are alternatively studied in combination with 3 different conventional floating designs (Semi-sub, Spar buoy and TLP). All systems satisfy the ABS-195 design requirements, with mooring chains governed by fatigue and ropes by ultimate limit states. The SWR configuration provides better station-keeping performance, exhibiting the smallest platform offsets under both intact and accidental conditions. Conversely, the PR system reduces material costs by approximately 15% in harsh environments and alleviates fatigue loads on the chains, permitting smaller diameters. The hybrid SWR-PR systems offer an effective engineering compromise, balancing cost savings with improved motion characteristics. Under OB-class conditions, cost differences between all designs are marginal, within a 2-4% range.

Introduction

In floating offshore wind turbines, comparative analyses of mooring systems available in the literature have further elucidated the fundamental differences in design and performance requirements between shallow and deep-water applications, where cost and stability considerations vary considerably based on water depth and selected mooring chain size (Wang et al., 2023). Furthermore, the implementation of multi-component mooring lines has been proposed to address the pronounced dynamic effects that intensify with increasing water depth, emphasizing the necessity for fully coupled dynamic analysis to accurately predict the global responses of floating structures (Hermawan & Furukawa, 2020).

Against this extensive and detailed technical background, the present study investigates the design and comprehensive performance assessment of three distinct hybrid catenary mooring configurations for a semi-submersible, spar buoy and TLP floating offshore wind turbines at a 1,000- and 200 meter water depth. The proposed configurations combine chains with either steel wire ropes (SWR), polyester ropes (PR), or a composite chain-SWR-PR system. All designs rigorously follow prevailing industry standards for a 25-year operational lifetime and are systematically assessed under both harsh (representative of the North Sea) and mild (representative of the Mediterranean Sea) environmental conditions.