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Coupled Dynamic Modeling of Floating Wind Turbine Systems

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Abstract

This article presents a collaborative research program that the Massachusetts Institute of Technology (MIT) and the National Renewable Energy Laboratory (NREL) have undertaken to develop innovative and cost-effective floating and mooring systems for offshore wind turbines in water depths of 10−200 m. Methods for the coupled structural, hydrodynamic, and aerodynamic analysis of floating wind turbine systems are presented in the frequency domain. This analysis was conducted by coupling the aerodynamics and structural dynamics code FAST [4] developed at NREL with the wave load and response simulation code WAMIT (Wave Analysis at MIT) [15] developed at MIT.

Analysis tools were developed to consider coupled interactions between the wind turbine and the floating system. These include the gyroscopic loads of the wind turbine rotor on the tower and floater, the aerodynamic damping introduced by the wind turbine rotor, the hydrodynamic damping introduced by wave-body interactions, and the hydrodynamic forces caused by wave excitation.

Analyses were conducted for two floater concepts coupled with the NREL 5-MW Offshore Baseline wind turbine in water depths of 10−200 m: the MIT/NREL Shallow Drafted Barge (SDB) and the MIT/NREL Tension Leg Platform (TLP). These concepts were chosen to represent two different methods of achieving stability to identify differences in performance and cost of the different stability methods.

The static and dynamic analyses of these structures evaluate the systems' responses to wave excitation at a range of frequencies, the systems' natural frequencies, and the standard deviations of the systems' motions in each degree of freedom in various wind and wave environments. This article explores the effects of coupling the wind turbine with the floating platform, the effects of water depth, and the effects of wind speed on the systems' performance.

An economic feasibility analysis of the two concepts was also performed. Key cost components included the material and construction costs of the buoy; material and installation costs of the tethers, mooring lines, and anchor technologies; costs of transporting and installing the system at the chosen site; and the cost of mounting the wind turbine to the platform.

The two systems were evaluated based on their static and dynamic performance and the total system installed cost. Both systems demonstrated acceptable motions, and have estimated costs of \$1.4−\$1.8 million, not including the cost of the wind turbine, the power electronics, or the electrical transmission.

1. Introduction

A rich wind resource lies untapped off the coasts of the United States with an estimated capacity near 1 TW. This resource is available 5−50 miles off the coast in water depths mostly greater than 30 m. At these depths, the current practice of installing wind turbines on monopiles that are driven into the seabed becomes economically infeasible. The deployment of wind power technology on floating platforms offers a promising solution for offshore wind power at these depths, and a potential alternative to monopiles in shallower water. Previous simulation studies by J. E. Withee [16], K. H. Lee [8] and [9], and K. C. Tong [13] show promising results for the behavior of floating wind turbine systems. However the full coupling between the wind turbine and the floating platform has been observed only to a limited extent, and the optimal design concept for these systems remains unknown. Furthermore, the chore of installing a wind turbine onto a floating platform at sea may make the cost of this technology prohibitive.

This study, therefore, has four goals: (1) to make a first step toward coupling proven codes from the wind power and oil and gas industries to create a tool to model and analyze the behavior of coupled wind turbine and floating platform systems; (2) to study and understand the behavior of these systems in various wind and wave environments; (3) to identify the most cost-effective structures that will provide a solution to the deep water problem; and (4) to avoid the need to install the wind turbine on the platform while at sea.