FAST Code Verification of Scaling Laws for DeepCwind Floating Wind System Tests

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ABSTRACT

This paper investigates scaling laws that were adopted for the DeepCwind project for testing three different floating wind systems at 1/50 scale in a wave tank under combined wind and wave loading. The 1/50 scaling of the full-scale 5-MW wind turbine system is performed based on Froude scaling laws, which are commonly used for offshore structures. The scaling approach adopted is verified through FAST, an aero-hydro-servo-elastic dynamic modeling tool, by comparing the consistency of simulation results between model and full scale. The Froude scaling approach does not maintain proper Reynolds number scaling and the implications of this issue are discussed.

KEYWORDS: Froude scaling; offshore floating wind turbine; NREL FAST; DeepCwind; model testing

NOMENCLATURE

\[ C = \text{wave celerity} \]
\[ C_g = \text{frictional force coefficient for mooring line and sea floor} \]
\[ D = \text{diameter of the structure} \]
\[ E = \text{Young's modulus} \]
\[ EI(z) = \text{distributed structural rigidity} \]
\[ EA = \text{longitudinal axial stiffness} \]
\[ F_r = \text{Froude number} \]
\[ g = \text{acceleration due to gravity} \]
\[ H_F = \text{mooring line fairlead tension along horizontal axis} \]
\[ I = \text{moment of inertia} \]
\[ J = \text{mass moment of inertia} \]
\[ L = \text{unstretched length of mooring line} \]
\[ m = \text{mass of the structure} \]
\[ r = \text{distance between reference point and center of gravity} \]
\[ R = \text{radius of the rotor} \]
\[ Re = \text{Reynolds number} \]
\[ t = \text{time} \]
\[ TSR = \text{tip-speed ratio} \]
\[ u = \text{fluid velocity} \]
\[ u(z,t) = \text{out-of-plane deflection} \]
\[ V_F = \text{mooring line fairlead tension along vertical axis} \]
\[ V = \text{total wind speed} \]
\[ x_F(H_F, V_F) = \text{mooring line fairlead to anchor distance along horizontal axis} \]

INTRODUCTION

Model testing is used to facilitate technological advancement of systems, where prototype testing is not economically feasible. It is a proven methodology for research and development of ocean and offshore engineering systems, and is used to better understand the system dynamics and responses. To estimate the dynamic properties of a full-scale prototype, the empirical data from the model tests or simulations is scaled up by introducing fundamental and derived scaling laws. This paper discusses the implementation of a similar approach to better comprehend the dynamics of floating offshore wind systems through model testing. Though the testing of offshore structures and wind turbines at model scale has been used extensively, combining both systems in one test complicates the methodology of the commonly used scaling laws and introduces new terms.

The DeepCwind consortium is a group of academic and research organizations that share a common goal of advancing floating offshore wind development in the United States. The offshore wind energy research led by DeepCwind commenced with the 1/50-scale model testing of several 5-MW floating offshore wind turbines (FOWT) at the Maritime Research Institute Netherlands (MARIN). The model tests were conducted to identify the system response of three different design concepts of floating wind systems and to generate high-fidelity system response data needed to validate tools used for modeling these systems (De Ridder et. al., 2011). To perform the model tests, a set of scaling laws was developed to scale the 5-MW systems to a size that could be tested in the wave basin. To do this experiment, DeepCwind chose to scale the geometry by a factor of \[ \lambda = 1/50 \] by utilizing the proven