Design and Analysis of a Model Wind Turbine Blade for Wave Basin Test of Floating Wind Turbines
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ABSTRACT
In the wave basin test of wind turbines, rotor thrust of a Froude scale model blade is far less than the target value due to reduction of Reynolds number (scale effect). Rotor thrusts of both the prototype and the model are calculated and analyzed by using blade element momentum method (BEM method). In order to alleviate the scaling effect, original airfoil selections of the NREL 5-MW blade cross section (DU series) are replaced by low-Reynolds number airfoil (NACA 4412). On basis of the airfoil-adjusted blade model, this paper further builds an optimization model for the rotor thrust by choosing the blade chord length and twist angle as optimization variables.

KEY WORDS: Floating wind turbines; wave basin test; scale effect; rotor thrust; blade optimization.

NOMENCLATURE

- \( R \) = radius of the rotor
- \( t \) = wave period
- \( T \) = rotor thrust force on the airfoil section
- \( U \) = wave celerity
- \( U_r \) = rotational speed behind the turbine
- \( V \) = incoming free stream velocity
- \( V_{rel} \) = axial wind speed flowing across the turbine
- \( \alpha \) = angle of attack
- \( \theta \) = twist angle of the airfoil section
- \( \omega \) = rotational speed
- \( \varphi \) = relative flow angle
- \( \lambda \) = geometry scale factor
- \( \nu \) = kinematic viscosity
- \( \rho \) = air density

INTRODUCTION
Wind energy plays an important role among the renewable energies because it’s clean and widely available in many regions. As the water depth increases, different types of support structures for offshore wind turbines should be adopted. In the shallow water zone (less than 20 meters), fixed monopole structures are most feasible; in the transitional water depth zone (water depth between 20 meters to 50 meters), a jacket or tripod structure is usually used; in the deep water zone (greater than 50 meters), floating wind turbine (FWT) foundations are economically suitable (Roddier et al, 2010).

There are various types of FWT foundations, including spar-buoy, TLP and semi-submersible (Roddier et al, 2009). Typical FWT foundations are shown in Fig.1. On the top left is the Hywind spar-buoy floating foundation by Statoil Hydro supporting a 2.3 MW Siemens wind turbine, which was tested in Marintek in Norway (Skaare et al, 2006). On the top right is a tension leg platform (TLP) FWT foundation WindStar designed to accommodate a 5 MW HAWT by State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University (Zhao et al, 2012). On the bottom left is a semi-submersible floating foundation WindFloat by Principle Power. It is designed to support a 5 MW or larger wind turbine on one of three columns (Roddier et al, 2010). On the bottom right shows the wind and wave basin model test of WindFloat foundation at UC Berkeley before it was deployed in November, 2011 (Cermelli et al, 2010). In the test, a sized actuator disk was used to attract proper wind loads corresponding to the design wind