FREE-SURFACE FLOW MODELING OF MULTIPLE TIDAL TURBINES

Allocation: Illinois/100 Knh
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EXECUTIVE SUMMARY

In this project, the PI simulated two back-to-back, full-scale, complex-geometry tidal turbines in free-surface flows using an in-house computational free-surface flow framework and the Blue Waters supercomputer. In addition, the PI investigated the wake and free-surface effects on tidal turbine performance in the downstream turbine through a case study. To quantify the free-surface effect, the researcher performed a pure hydrodynamics simulation and a free-surface simulation. He observed a significant drop in the thrust coefficient and production coefficient between the upstream and downstream turbines owing to the velocity deficit. Further, both simulations predicted almost the same thrust and production coefficients for the upstream turbine, while the pure hydrodynamics simulation predicted a noticeably higher thrust coefficient and production coefficient for the downstream turbine.

RESEARCH CHALLENGE

Although computational fluid dynamics simulations are widely used in the research and development of tidal energy, few of them consider the free-surface effect, which has been proven in experiments to have a significant influence on tidal turbine performance. In this project, the PI developed a computational framework that is able to simulate multiple tidal turbines in turbulent free-surface flows. This framework will ultimately facilitate the research and development of tidal energy farms.

METHODS & CODES

The PI developed an in-house MPI-based parallel free-surface flow simulation framework. In the computational framework, the level-set method was adopted to track the evolution of the air–water interface. The aerodynamics and hydrodynamics were governed by a unified two-phase incompressible Navier–Stokes equation in which the fluid density and viscosity are defined by means of the level-set function. The finite-element-based Arbitrary Lagrangian Eulerian Variational Multiscale formulation enhanced with weak enforcement of essential boundary conditions was employed to discretize the free-surface flow equations. The sliding-interface formulation was used to account for the presence of the tower and nacelle, thus enabling the so-called full-machine simulation. The sliding-interface formulation was also augmented to include level-set redistancing.

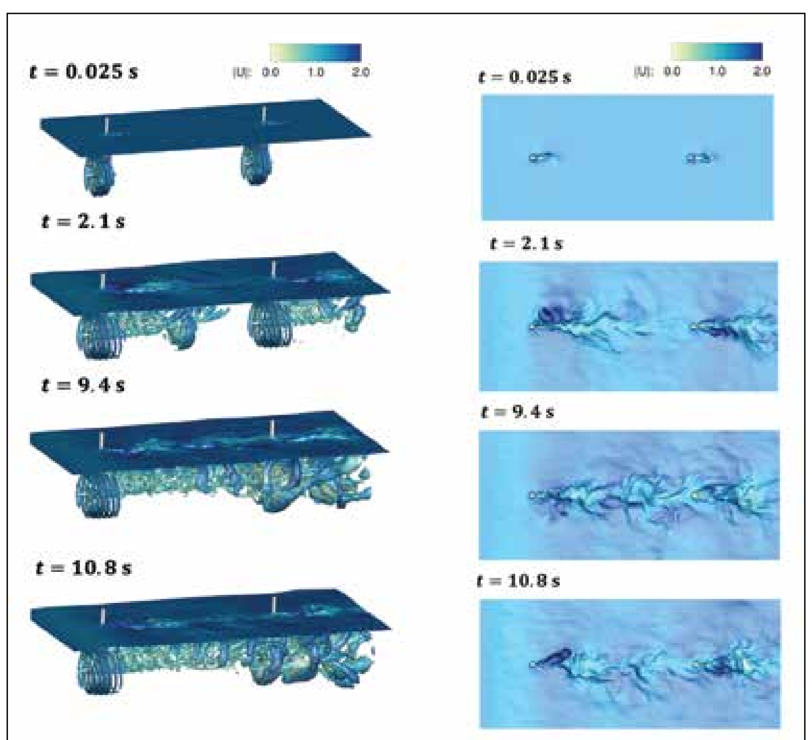

Figure 1: Free-surface deformation of two back-to-back tidal turbine simulations at four different time instances.

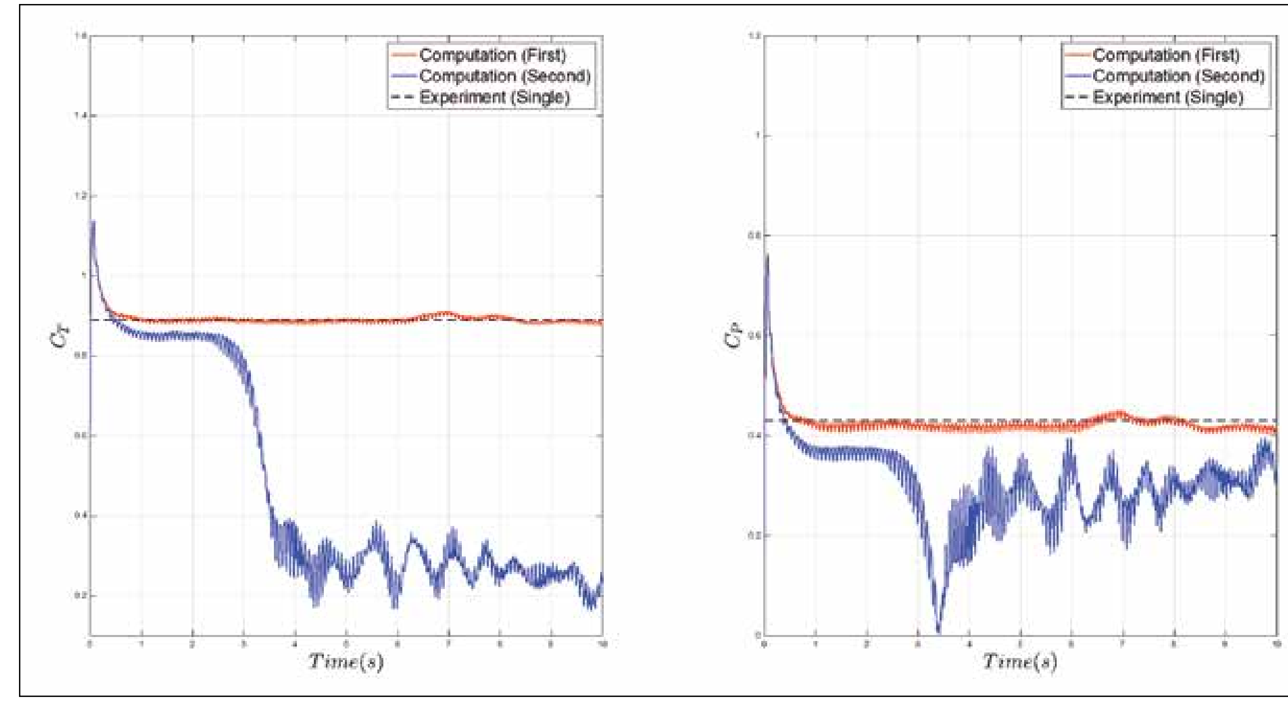

Figure 2: Time history of power and thrust coefficients of the two back-to-back tidal turbine simulations.

RESULTS & IMPACT

In this project, a computational free-surface flow framework was used to simulate two back-to-back tidal turbines in free-surface flows. The simulations were carried out at full scale and with the full complexity of tidal turbine component geometry. Without any empiricism, the simulations were able to accurately capture the effect of the free surface on the rotor hydrodynamic loading and the interaction between the upstream and downstream turbines.

For the deep-immersion operating conditions considered in this work, the free-surface simulation predicted a drop in the thrust coefficient of 70% and a drop in the production coefficient of 38.7% between the upstream and downstream turbines. By comparing the results of the pure hydrodynamics simulation and the free-surface simulation, the team found that the free surface does not affect the upstream turbine but does significantly change the performance of the downstream turbine.

This work is a first step toward using free-surface flow simulations of multiple full-scale tidal turbines with complex geometry. The proposed framework will help improve the efficiency of tidal farms by better understanding the combined wake and free-surface effects on turbines. In the future, the PI will conduct a parametric study of the distance between the upstream turbine and downstream turbine. He also plans to extend the current methodology to simulate multiple tidal turbines arranged in arrays and will consider both the fluid–structure interaction effect and cavitation.

WHY BLUE WATERS

The 3D, time-dependent, full-scale, full-geometry, multiscale, and multiphysics simulations of tidal turbines are computationally expensive, requiring supercomputers such as Blue Waters. In addition, the Blue Waters staff and technicians are knowledgeable and always willing to provide support.

PUBLICATIONS & DATA SETS

J. Yan, X. Deng, F. Xu, and S. Xu, "High fidelity numerical simulations of two back-to-back horizontal axis tidal stream turbines in free-surface flows," *Appl. Energy*, in review, 2019.