NREL

TEAMER Technical Support for Aquantis (Modeling)

Cooperative Research and Development Final Report

CRADA Number: CRD-21-17763

NREL Technical Contact: Thanh Toan Tran

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-91639
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Cooperative Research and Development Final Report

Report Date: October 10, 2024

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Aquantis, Inc.

CRADA Number: CRD-21-17763

CRADA Title: TEAMER Technical Support for Aquantis (Modeling)

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Water Power Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$75,000.00
Year 2, Modification #1	$0.00
Year 3, Modification #2	$0.00
TOTALS	$75,000.00

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Executive Summary of CRADA Work:

NREL will provide numerical modelling support to Requestor by completing four successive stages of numerical modeling effort which are capable of accurate predicting the performance of the Aquantis turbine. NREL will develop a baseline OpenFAST model (a couple model of AeroDyn and ElastoDyn solver) of the Aquantis turbine, subsequently couples this model to OrcaFlex or within OpenFAST framework to preliminarily design and explore a full floating tidal turbine system in a control co-design process.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope competencies, and/or
- Uses the laboratory's core competencies.

Summary of Research Results:

The intent of this project was to build a baseline OpenFAST model for the Aquantis floating turbine system so that preliminarily design and exploration during the design phases can be conducted. The NREL team successfully built the model based on provided inputs from the Aquantis team (e.g., TidalBladed model, OrcaFlex, Excel sheet, etc.). The coupling model of a full floating tidal turbine system built within OpenFAST code was tested under different simulation conditions such as free-decay analyses, and actual current and wave conditions. Below is a summary of the tasks outlined in the Statement of Work and the results that were generated.

PURPOSE

NREL will provide technical assistance to develop a robust and accurate numerical model of the Aquantis turbine using a coupling method between the OpenFAST rotor modeling capabilities and multibody dynamic modeling tools (i.e., OrcaFlex). Coupling open source OpenFAST code to the multibody dynamic tool will help Aquantis design and explore a floating tidal turbine system considering multiple key parameters (i.e., rotor loads, platform motions, and other relevant device performance parameters) in the early stages of the project in the design process. This is important to Aquantis because having a good numerical model helps Aquantis advance the understanding of the floating tidal turbine system as well as implement advanced rotor and system control strategies via the control co-design process.

STATEMENT OF WORK

For each task below, Requestor and NREL will have regular meetings to exchange the development status and relevant tasks. The high-level work described should be limited to the work the parties have identified funding to pursue at this point. If other work is identified in the future, then we would add it then via a Modification along with the associated funding.

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TASK DESCRIPTIONS

<u>NREL</u> shall complete the following tasks:

TASK 1:

Using the simulation data provided by the Requester, NREL will re-create a preliminary simulation model using developed OpenFAST's functionalities.

- A new AeroDyn model considering the tower shadow effect of extended structure of turbine tower will be adopted.
- A coupling model between AeroDyn and ElastoDyn considering the additional effect of added-mass and buoyancy forces exerted on tidal turbine blades and substructure system (i.e., tower, nacelle, and hub) will be developed.

Task 1 Results:

The first subsystem of the Aquantis turbine to be modeled in OpenFAST was the rotor. This allowed the team to ensure that rotor properties and simulation parameters were correctly translated from the original Aquantis model created in the commercial software Tidal Bladed to OpenFAST. This subsystem was modeled in OpenFAST's rotor aero/hydrodynamic module AeroDyn. The turbine was assumed to be fixed and rigid, so only rotor hydrodynamics were modeled, with no structural coupling. Airfoil coefficients, as well as blade shape and rotor geometry, were extracted from the Tidal Bladed model and used to create AeroDyn input files. Environmental and operating conditions were matched between the two simulations. A steady, uniform inflow was used to simplify comparisons. Blade element momentum theory was chosen as the wake/induction model, with a steady airfoil aerodynamic model, since the airfoil polars had been corrected for dynamic stall in a pre-processing step. Tower effects were neglected. The two marine turbine features activated in OpenFAST were a cavitation check, which checks for cavitation along the span of every blade, and buoyancy, which accounts for buoyant loads on the blades, hub, and nacelle. Buoyancy was also enabled in the Tidal Bladed model. The Prandtl tip and hub loss models were activated in OpenFAST. Simulations were run for a range of inflow speeds and a constant rotor speed of 12 rpm. These operating conditions corresponded to tip-speed ratios (TSR)s between 4.0 and 10.0. Power (C_P), thrust (C_T), and torque (C_Q) coefficients for the two models are shown in Figure 1. Good agreement was seen between the coefficients calculated in Tidal Bladed and those calculated in AeroDyn.

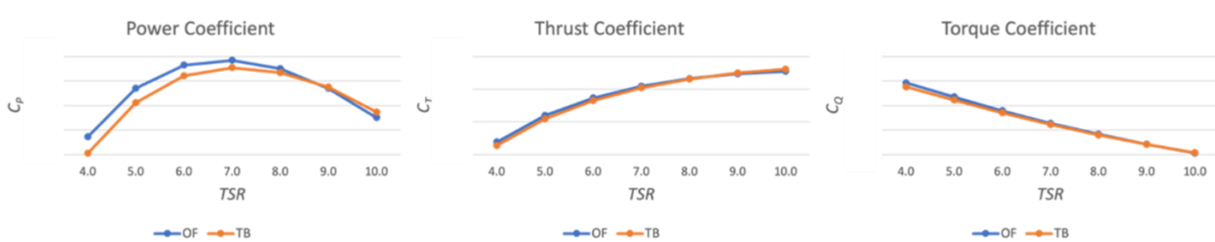

Figure 1. Power, thrust, and torque coefficients for the OpenFAST (OF) and Tidal Bladed (TB) models

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In addition to the re-built AeroDyn model, the NREL team also supported for fluid-structure coupling between AeroDyn and ElastoDyn modules. To do so, the structure properties of AQ10's tidal turbine blade was re-built in ElastoDyn format. This ElastoDyn input format was then used for BModes code which is used to find natural frequencies of the turbine blade. As shown in Table 1 below, the discrepancy between BModes (or ElastoDyn) and TidalBladed showed excellent agreement.

Table 1: Natural frequency comparison between Tidal Bladed vs. BModes (ElastoDyn)

	RPM	Bmodes (ElastoDyn)			Tidal Bladed	
TSR	V= 1m/s	F1 (Hz)	F2 (Hz)	F3 (Hz)	F1 (Hz)	F2 (Hz)
4	5.73	75.285	77.344	238.444	73.95	79.775
5	7.16	75.285	77.344	238.445	**1.8%**	**-3.0%**

TASK 2:

NREL will develop a coupling model between OpenFAST and the multibody dynamic tool, OrcaFlex (and/or OpenFAST's modules itself) to consider multi-physical loads exerted on the Aquantis floating tidal turbine system. Specifically, NREL will:

- Create and compute hydrodynamic coefficients using open source NEMOH or commercial WAMIT (licensed by NREL) boundary element method codes for a submerged spar-buoy structure.
- Build a hydrodynamic model of the submerged spar-buoy structure including mooring system in the commercial multibody dynamic solver, OrcaFlex (licensed by NREL).
- Build a coupling model between the preliminary OpenFAST model (Task 1) and the commercial multibody dynamic solver, OrcaFlex (licensed by NREL) or OpenFAST code itself.

Task 2 Results:

Figure 3 displays an original CAD model (left) and different mesh resolutions (right) of the AQ10's supporting platform which was used for WAMIT simulation to obtain hydrodynamic coefficients. The hydrodynamic coefficients were then used as an OpenFAST simulation input. As shown in Figure 4, the convergence of hydrodynamic coefficients was conducted.

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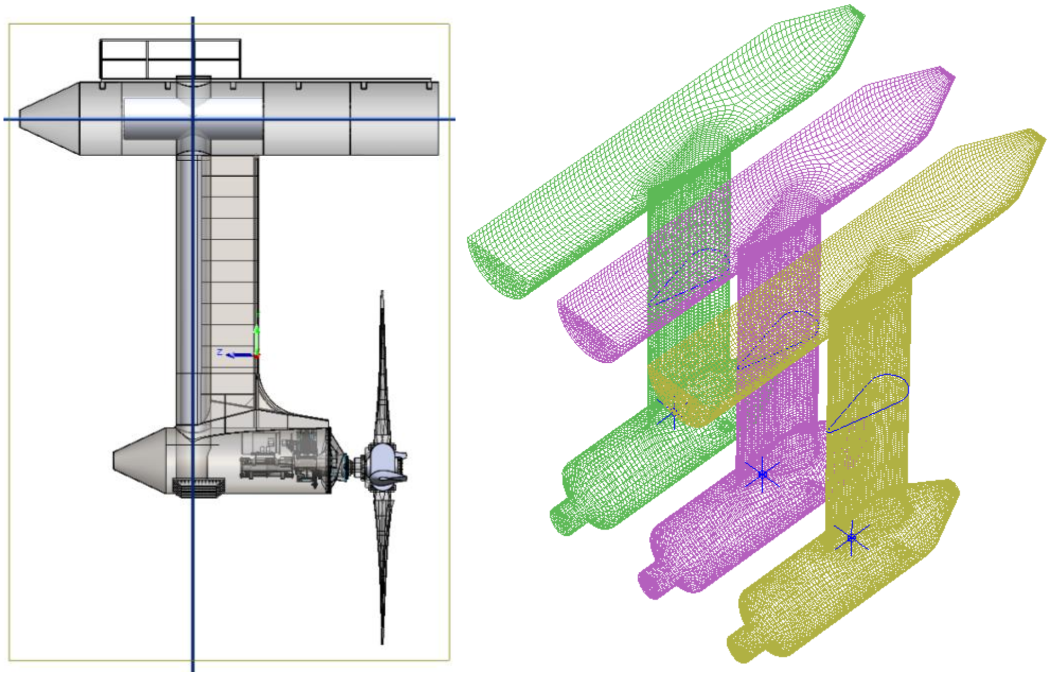

Figure 3. Platform CAD and its mesh resolutions for WAMIT solution

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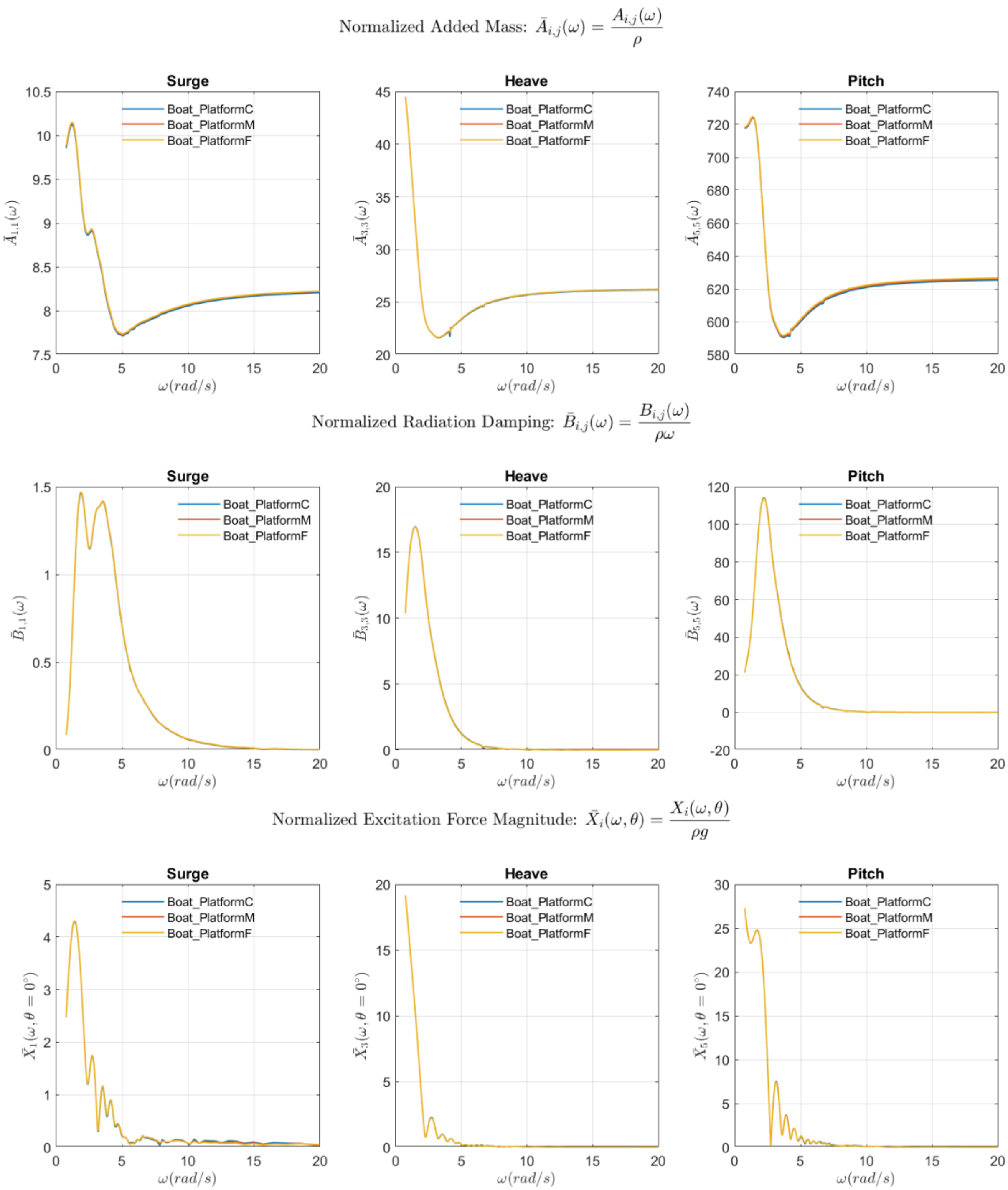

Figure 4. Hydrodynamic coefficients of Aquantis's supporting platform with different mesh resolutions

In this project, instead of using a coupling model between OpenFAST and the multibody dynamic tool, OrcaFlex, we used OpenFAST's module itself to consider multi-physical loads exerted on the Aquantis floating tidal turbine system. This effort was changed during the project period. Figure 5 displays an example of the AQ10's floating tidal turbine system under a wave condition. All major structures of the system were able to be modeled by the current OpenFAST model.

To test the coupling of the whole floating tidal system, we preliminarily tested free decay analysis of six- degree-of-freedoms (6-DOFs) of the system. Figure 6 illustrates the free-decay response of heave and pitch DOFs which indicates that the natural frequency of these DOFs is close to wave frequencies in the real world. This finding informed the Aquantis team to re-consider floating design.

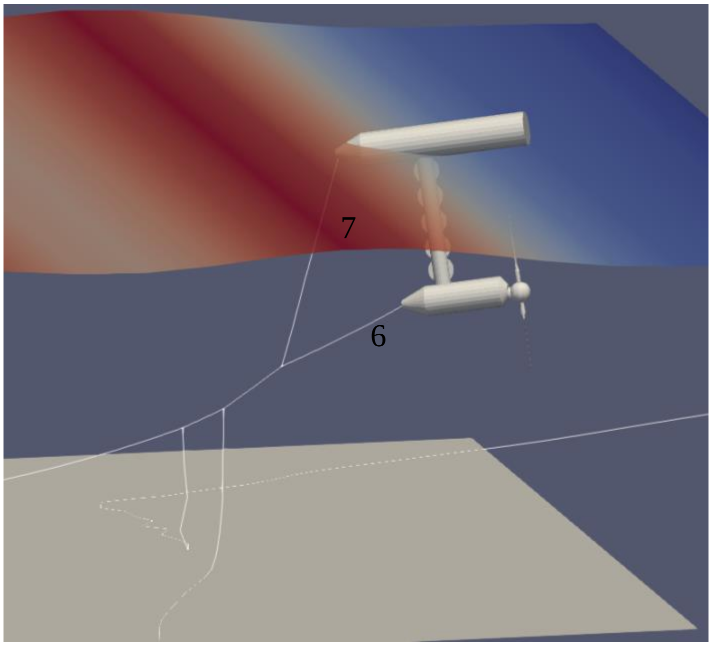

Figure 5. An illustration of the AQ10's floating tidal turbine system in OpenFAST visualized by Paraview

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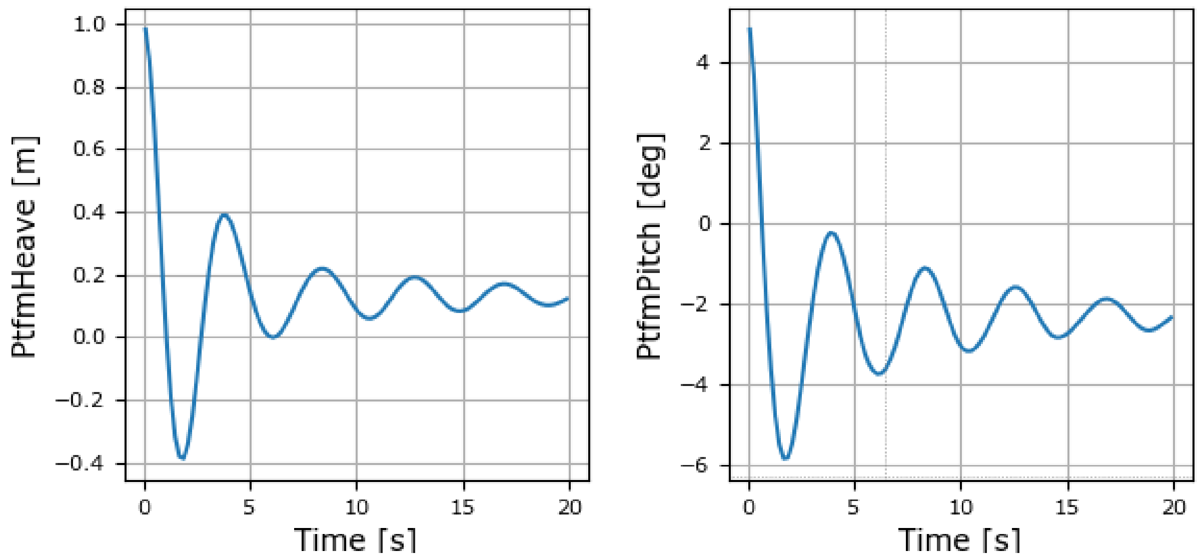

Figure 6. Free decay analyses of the AQ10's floating tidal turbine system using the OpenFAST tool

TASK 3:

- Run the coupled model considering multiple operating conditions based on design standards to optimize key parameters (rotor loads, platform motions, and other relevant device performance parameters)
- Demonstrate/handover the developed simulation model to the Requestor so that they can replicate the simulation model and results for their own purposes in control co-design process.
- Collaborate with Aquantis team to incorporate their developed closed-loop controller into the coupled model

Task 3 Results:

To further test the full coupling model of the AQ10's floating tidal turbine system, we ran more simulations under different input conditions and accessed some interesting design outputs such as rotor hydrodynamic performance and load, 6-DOFs platform motion, and mooring line tensions. Figures 7 and 8 display these outputs of the AQ10's floating tidal turbine system under an inflow current of 1.5 m/s, wave period of 8 s, and wave height of 2 m. As shown in Fig. 8, there are very high nonlinear floating motions as well as a strong coupling among platform DOFs. That results in highly dynamic rotor performance and load prediction shown in Fig. 7. This initial OpenFAST model will help the Aquantis team further investigate interesting design outputs during the design process.

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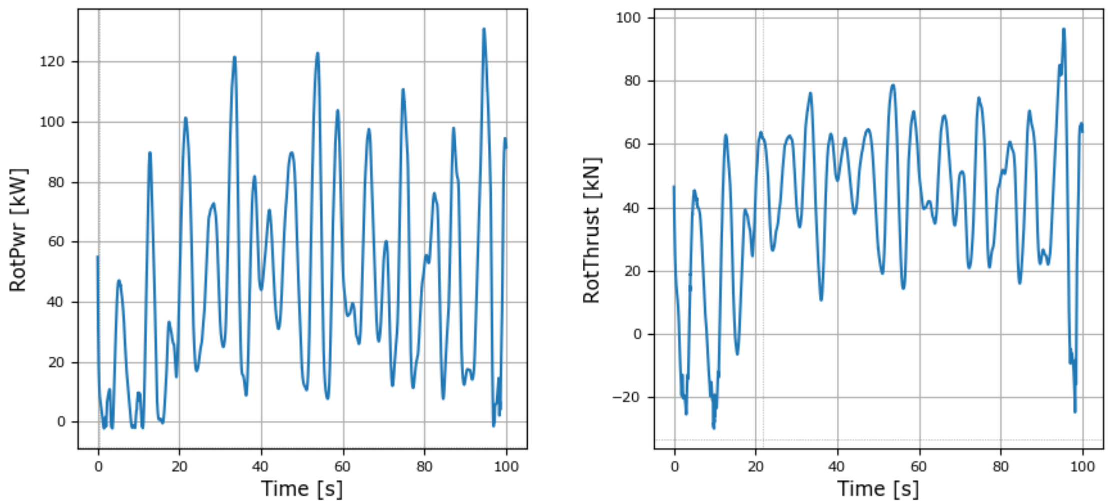

Figure 7. AQ10's hydrodynamic power and thrust under a uniform inflow speed of 1.5 m/s and irregular wave condition (Hs = 2 m and Tp = 8s)

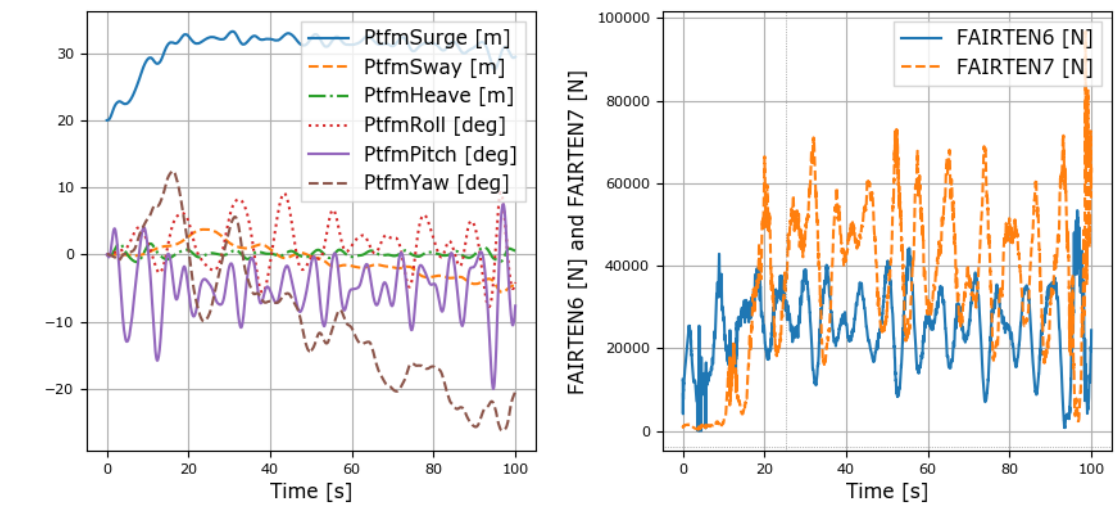

Figure 8. AQ10's dynamic responses and mooring tensions under a uniform inflow speed of 1.5 m/s and irregular wave condition (Hs = 2 m and Tp = 8s)

TASK 4:

- NREL to provide the following reports to DOE Office of Scientific and Technical Information (OSTI):
- An initial abstract suitable for public release at the time the CRADA is executed.
- A Final report, within 30 days upon completion of termination of this CRADA to include a list of Subject Inventions.
- Other scientific and technical information in any format or medium that is produced as a result of this CRADA.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Task 4 Results:

This report serves to meet the requirement for the public release abstract (Executive Summary) and the CRADA Final Report with preparation and submission to OSTI in accordance with the agreement's Article X.

REQUESTOR shall complete the following tasks:

TASK 1:

- Coordinate with NREL team to exchange/update necessary design information related to the project.
- Demonstrate/handover existing numerical simulation model of a spar buoy-based tidal turbine design (and all relevant device data/required input data – i.e., aerodynamic inputs, turbine specification, submerged spar-buoy structure, mooring specification, etc.). Specifically, Requestor will provide preliminary modeling simulations conducted by the Tidal Bladed code.

Task 1 Results:

The Aquantis team provided necessary design inputs of the floating turbine system to the NREL team. They included a TidalBladed model, Excel sheet of all model properties, as well as simulation output for the comparison. (See in NREL's Task #1)

TASK 2:

- Develop a closed-loop controller using Matlab/Simulink for control co-design framework.
- Collaborate with NREL team to integrate developed controller to coupled numerical model.

Task 2 Results:

Both teams discussed control co-design frameworks either developed by a third-party partner in this project or NREL's CT-Opt toolset. The NREL team also exchanged the pathway of a coupling between OpenFAST and Matlab/Simulink for control design and integration.

Subject Inventions Listing:

None.

ROI #:

None.

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