Simulation Methods for Floating Offshore Wind Turbine Farms with Shared Moorings

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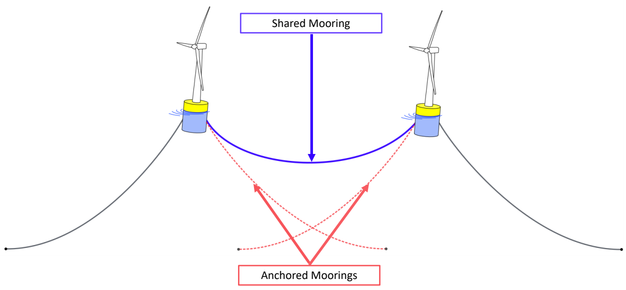
Shared Moorings

One of the largest challenges to the development floating offshore wind turbines (FOWTs) is their capital cost [1]. For this reason, cost reduction is a research area which deserves particular interest. The concept of shared moorings (pictured right) seeks to reduce cost of a FOWT farm by reducing the total material cost of mooring lines and anchors used. It has been shown that cost savings are possible in pilot-scale farms that incorporate shared moorings [2].

Despite representing cost benefits, using shared mooring lines also complicates the dynamics of the FOWT farm. Each shared mooring line in a farm serves as a coupling link between two FOWTs and the effect of using many shared moorings is to couple many degrees of freedom (DOFs) of the complete FOWT farm.



Research Objectives

To better understand how the use of shared moorings may impact FOWT farms, the following research objectives have been identified:

- **Develop methods of analyzing the dynamics of FOWT farms with shared moorings**
- **Verify the results of these methods in the limiting case of a single FOWT**
- **Incorporate these methods in an optimization scheme with the main objective of minimizing total farm cost**

The end goal of this research is to create a tool to determine cost optimal FOWT farm designs that use shared moorings, for a given set of inputs defining the site characteristics. The optimization routine will make use of the analysis methods described here.

Methodology

Eigenvalue Analysis:

For preliminary estimates of the natural frequencies of FOWT farms with shared moorings, an eigen-analysis method was developed. This method calculates natural frequencies from a linearized equation of motion for the farm:

$$[M + m_a(\omega_n)]\{\ddot{x}\} + [K]\{x\} = 0$$

Here the matrix [M + $M_a(\omega_n)$] represents the combined mass and added mass matrix and [K] represents the linearized stiffness matrix. By determining the eigenvalues of the above system of equations the natural frequencies (ω_n) are also determined. This method is limited to degrees of freedom in surge and sway, but includes the degrees of freedom for many FOWTs. This method also makes the assumption of linear mooring lines and zero damping.

Frequency Domain:

A frequency-domain method was developed to determine response amplitude operators (RAOs) for FOWT farms with shared moorings. The RAO is determined using frequency-dependent added-mass (m_a) and damping coefficients (B) as well as linear mooring stiffnesses (K):

$$F_{ex}(\omega) = \left[-\omega^2\big(M + m_a(\omega)\big) + i\omega B(\omega) + K\right]q(\omega)$$

This method assumes that the platform response (q) in any degree of freedom is harmonic, and therefore would ignore any transient behavior. Determining the RAO is useful since it allows for comparison of platform response independent of environmental factors such as the sea state.

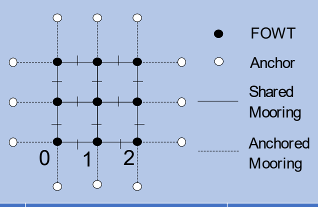
Time Domain:

A time- domain method is useful because it is higher fidelity and can generate time-series results for platform motions and line tensions. This leads to results which are In general, a time-domain method uses an equation of motion which integrates all forces acting on each FOWT in a farm through time:

$$F_{Platform} = F_{Wind} + F_{Lines} + F_{Hydro}$$

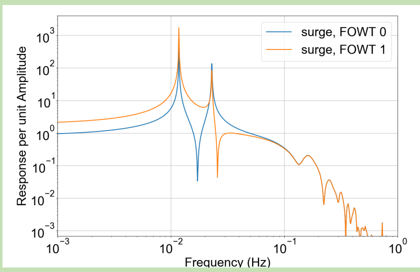
The method used here uses an actuator disc method to determine wind thrust force, a quasi-static model for mooring forces, and a time-domain representation of linear hydrodynamics to determine hydrodynamic forces. From integrating the forces, a time-series for the position of each platform can be determined. Also of importance for shared mooring concepts is the time-series of the tension in the mooring lines.

Results: Farm Scale

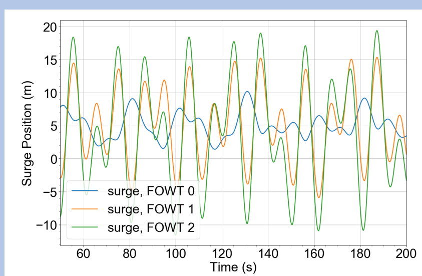


	Frequency (Hz)	Degeneracy
ω_1	0.0139	6
ω_2	0.0256	6
ω_3	0.0271	6

RAO for a 3-by-3 square grid farm layout



Surge position time-series for a 3-by-3 square grid farm layout



Verification: Single Turbine

All 3 methods are compared in the case of a single-turbine. Specifications were used for the DeepCWind semi-submersible, and results of the methods were compared against results of the OC4 Phase II meta-analysis [3].

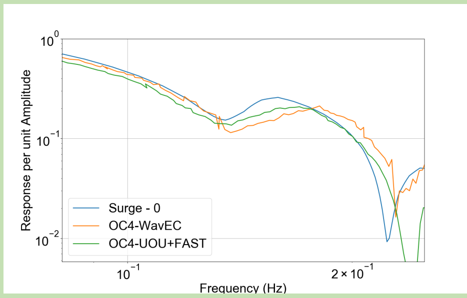
The natural frequency in surge calculated by the eigen-analysis method used here was:

$$\omega = 0.00902\ Hz$$

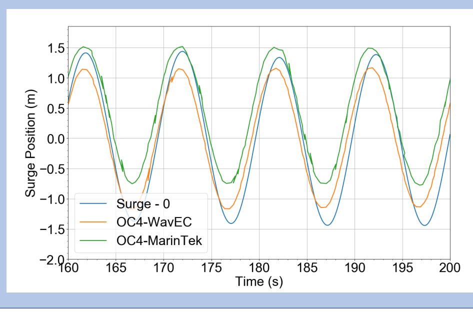
Which falls in the range of natural frequencies calculated by other independently developed method for the OC4:

$$\omega_1 = [0.00858, 0.0114]Hz$$

Surge RAO verification against OC4 Phase II Results [3]



Regular wave surge time-series verification against OC4 Phase II Results [3]



Method Improvements

The results from the developed methods do not yet adequately match published results for the DeepCWind semi-submersible. More tweaking and debugging will be done with the methods to achieve better agreement. As well, there may be significant second-order wave forcing near the natural frequencies of the FOWT farm system [4]. These frequencies are very low (<0.1Hz) and so difference-frequency terms may be important to add to one or more of the analyses.

Optimization

Once fully developed and verified, these methods will be used in an optimization scheme. The parameter space of the optimization will include parameters defining the layout and properties of the mooring system. The main objective function will be a cost function, and constraints will be made on the dynamics of each farm. The analysis methods developed will ensure that all trial configurations are dynamically feasible.

References

[1] T. Stehly, D. Heimiller, and G. Scott, "2016 Cost of Wind Energy Review," National Renewable Energy Laboratory, Technical Report TP-6A20-70363, Dec. 2017.
[2] P. Connolly and M. Hall, "Comparison of pilot-scale floating offshore wind farms with shared moorings," *Ocean Engineering*, vol. 171, pp. 172–180, Jan. 2019.
[3] A. Robertson *et al.*, "Offshore Code Comparison Collaboration Continuation Within IEA Wind Task 30: Phase II Results Regarding a Floating Semisubmersible Wind System," in *Proceedings of the 33rd International Conference on Ocean, Offshore and Arctic Engineering*, San Francisco, California, USA, 2014, p. V09BT09A012.
[4] S. Gueydon, T. Duarte, and J. Jonkman, "Comparison of Second-Order Loads on a Semisubmersible Floating Wind Turbine," p. V09AT09A024, Jun. 2014.