1865 THE UNIVERSITY OF MAINE
Department of Mechanical Engineering

A Single-Axis Hybrid Modelling System for Floating Wind Turbine Basin Testing

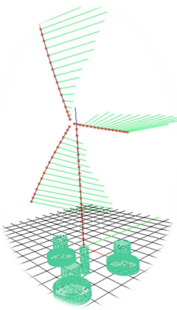
Matthew Hall and Andrew Goupee

Numerical Modeling

The Problem

An important part of floating wind turbine design is simulating the coupled system response. The numerical models built for a given design require experimental validation. Experiments however have difficulty matching the full-scale coupled behavior.

Simulations

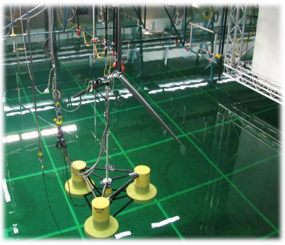


Medium fidelity coupled simulation tools are needed for iterative design processes and for loads analyses in support of certification. Engineering-level design codes like FAST[1] provide good approximations of the aero-hydro-elastic dynamics while being computationally efficient. Because of uncertainties in hydrodynamics modeling[2] and the use of empirical coefficients, model validation and tuning is crucial.

Physical Modeling

Experiments

Floating wind turbine designs are typically validated at near 1:50 scale in wind-wave laboratories. The necessity of Froude scaling results in reduced Reynolds numbers. Even with a high-quality wind tunnel and compensated rotor geometry, some aspects of the wind turbine performance have so far been unable to match the full scale values[3]. As a consequence, the aero-elastic response is altered and realistic blade-pitch controllers cannot be used.



A Hybrid Solution

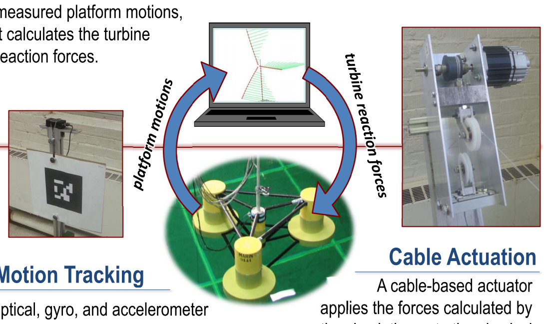
An alternative is to couple parts of the simulations and experiments together, an approach gaining popularity in offshore renewable energy research[4-7].

Hybrid modeling can offer wave-basin validation with more realistic wind loads by combining physical and numerical models:

- A Froude-scaled floating platform is tested in a wave basin.
- A full-scale wind turbine simulation runs beside the experiment.
- A sensor and actuation system couples the physical and numerical models together in real time. The requirements are demanding[8].

Numerical Model

A customized version of FAST models the full-scale wind turbine dynamics above the tower top at up to 15X real time. From the measured platform motions, it calculates the turbine reaction forces.



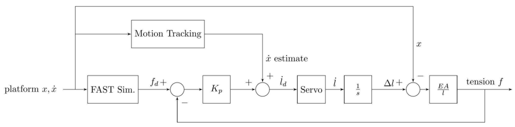
Motion Tracking

Optical, gyro, and accelerometer measurements of the floating platform motion are filtered and passed to the control system.

Cable Actuation

A cable-based actuator applies the forces calculated by the simulation onto the physical floating platform. Each winch unit incorporates force and motion feedback.

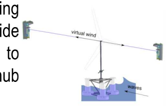
Controller



An "impedance" coupling scheme sees the actuator apply forces (calculated by the wind turbine simulation) in response to platform motions. A two-part controller deals with compensating for platform motions and ensuring the correct cable tensions.

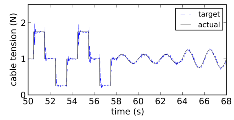
Single-Axis Prototype

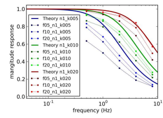
The first prototype of the hybrid coupling system uses two opposing cables to provide actuation along a single axis. It is sized to provide wind turbine thrust forces at hub height for up to 1:50-scale testing.



Tension Control Testing

Testing of a single winch unit in isolation allows tuning of the tension controller and quantification of system bandwidth.

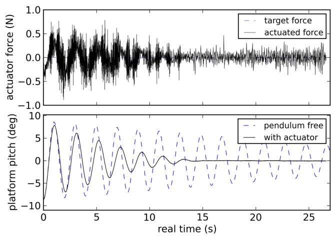




1:100-Scale Pendulum Test Rig

A 14 kg pendulum serves as a proxy floating platform and allows controlled testing of the coupling system. The pendulum approximates the DeepCwind Semisubmersible pitch response at 1:100 scale.

Free-decay tests with no numerical model (zero desired actuation force) show the actuator has a moderate effect on the pendulum, adding damping.



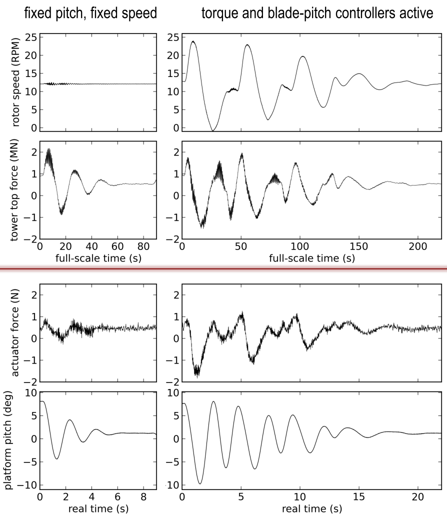
Coupled Results at 1:100 Scale

To measure and refine the coupling system's all-around performance before going to the basin, coupled tests are run in which the pendulum provides the platform dynamics and a FAST simulation provides the wind turbine dynamics. Free decay tests in steady wind give an idea of the system's performance under large platform motions and show the sensitivity of the motion to the details of the wind turbine controller. Tests in turbulent wind show the system's performance under more mild platform motion. The simulations use the NREL 5 MW reference turbine.

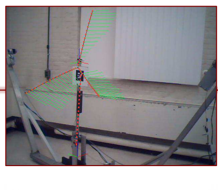
Numerical Results

Physical Results

Pitch free decay tests in steady 14 m/s wind

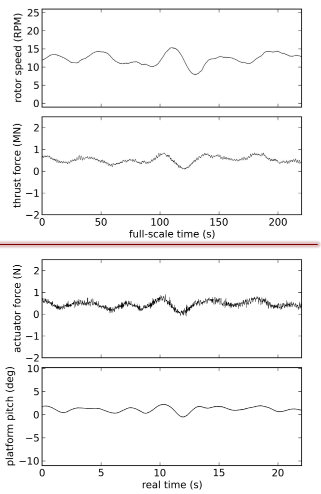


data recorded from full-scale FAST simulations running at 10X real time



data measured from 1:100-scale pendulum test apparatus

Test in 14 m/s class-A turbulent wind



The current system has difficulty applying the dynamic wind turbine forces from high-amplitude pitch free decay tests. Nevertheless, comparing the results with and without blade pitch control active in the simulation shows a clear impact on the behavior of the physical motion, consistent with the damping issues expected from a generic blade pitch controller operating in region III.

When turbulent wind is the only excitation on the hybrid system, platform pitching is moderate and the actuator is able to match the calculated forces closely.

Conclusions

The single-axis hybrid coupling system is approaching readiness for use in basin testing of a floating wind turbine platform. Results with a proxy platform show functional coupling and noticeable effects of the turbine behavior on the platform dynamics. The force control is very effective in low-motion conditions but deteriorates during large pitch motions. More control tuning is therefore still needed. Experience has shown coupling performance increases with the cube of scale, which is promising for testing at 1:50 scale.

Future Work

Future work will include improving performance with the test rig, wave-basin testing with a floating platform, and increasing the scale. If time allows the addition of more actuation axes, tests will be done using the mooring line model MoorDyn[9] to explore the potential of avoiding physical truncated moorings.

References

1. J. M. Jonkman, "Dynamics Modeling and Loads Analysis of an Offshore Floating Wind Turbine," PhD Thesis, University of Colorado at Boulder, 2007.
2. A. Robertson, J. Jonkman, W. Musial, F. Vorpahl, and W. Popko, "Offshore Code Comparison Collaboration, Continuation: Phase II Results of a Floating Semisubmersible Wind System," in *Proceedings of EWEA Offshore 2013*, Frankfurt, Germany, 2013.
3. R. W. Kimball, A. J. Goupee, M. Fowler, E.-J. de Ridder, and J. Helder, "Wind/Wave Basin Verification of a Performance-Matched Scale-Model Wind Turbine on a Floating Offshore Wind Turbine Platform," in *Proceedings of OMAE*, San Francisco, California, 2014.
4. J. Azcona, F. Bouchotrouch, M. González, J. Garciandía, X. Munduate, F. Kelberlau, and T. A. Nygaard, "Aerodynamic Thrust Modelling in Wave Tank Tests of Offshore Floating Wind Turbines Using a Ducted Fan," *J. Phys.: Conf. Ser.*, vol. 524, no. 1, 2014.
5. V. Chabaud, S. Steen, and R. Skjetne, "Real Time Hybrid Testing of Marine Structures: Challenges and Strategies," in *Proceedings of OMAE*, Nantes, France, 2013.
6. S. J. Beatty, M. Hall, B. J. Buckham, P. Wild, and B. Bocking, "Experimental and numerical comparisons of self-reacting point absorber wave energy converters in regular waves," *Ocean Engineering*, vol. 104, Aug. 2015.
7. G. Bracco, E. Giorcelli, G. Mattiazzo, V. Orlando, and M. Raffero, "Hardware-In-the-Loop test rig for the ISWEC wave energy system," *Mechatronics*, vol. 25, pp. 11–17, Feb. 2015.
8. M. Hall, J. Moreno, and K. Thiagarajan, "Performance specifications for real-time hybrid testing of 1:50 scale floating wind turbine models," in *Proceedings of OMAE*, San Fransisco, California, 2014.
9. M. Hall. MoorDyn. Available at www.matt-hall.ca/MoorDyn.

Acknowledgements

I'm grateful to many people for their support and advice with this research, especially my advisor Andrew Goupee, and Giacomo Vissio and colleagues. Collaborations with Vissio et al. were assisted by an INORE International Collaboration Incentive Scholarship and my PhD studies are supported by the Natural Sciences and Engineering Research Council of Canada.
NSERC CRSNG