Control development for floating wind

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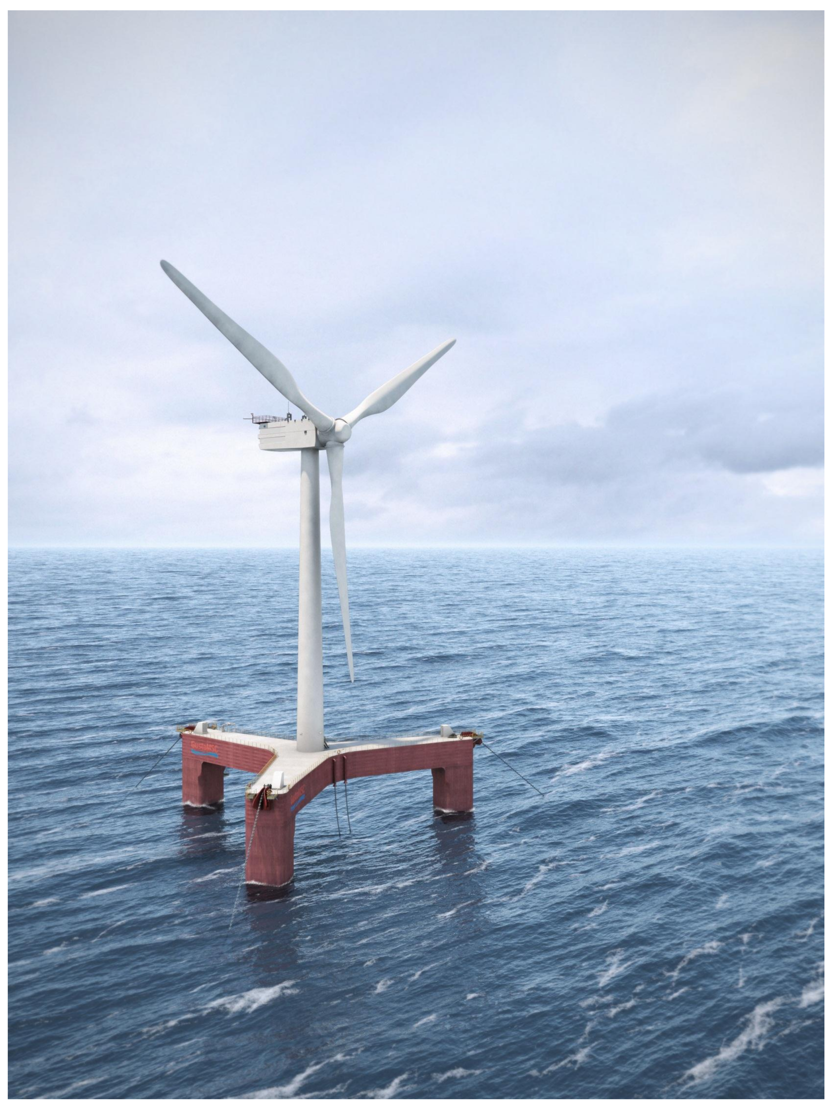
Abstract

Control of a floating wind turbine has proven to be challenging, but essential for lowering the cost of floating wind energy. Topic of a recent joint R&D project by GustoMSC, MARIN and ECN, is the concept design and verification with coupled simulations and model tests of the GustoMSC Tri-Floater. Only using an integral design approach, including mooring and control design, a cost effective system can be obtained.
In this project, ECN developed a general floating wind turbine control strategy and applied this to the GustoMSC Tri-Floater equipped with the NREL 5MW RWT. The designed controller ensures stable operation, while maintaining proper speed and power regulation. The motions of the floating support are reduced and substantial load reduction has been achieved.

Approach

Method
Due to their strong interaction, integral design of the floater, mooring and control is needed [4]. Short intermediate design loops with simplified models take care of subsystem design, such as the wind turbine control system. The design is verified by stability analysis, coupled time domain simulations and model tests [5].

System definition
Figure 1 shows the floating wind turbine system consisting of the NREL 5MW RWT [1] on the GustoMSC Tri-Floater [2&4], along with a specification of its main properties.



NREL 5MW RWT
- three bladed rotor of 126m diameter
- rated power 5MW, rated speed 12.1rpm
- variable speed, pitch regulated
- hub height of 90m
- geared drive train with ratio 1:97

GustoMSC Tri-Floater
- three-column semi-submersible
- heave plates
- catenary mooring, three lines
- draft of 13.2m
- water ballast of 972t
- total displacement 3627t
- natural period surge/sway about 70s
- natural period pitch/roll about 30s

Figure 1: Artist impression and specification of the GustoMSC Tri-Floater (source: GustoMSC)

Algorithm development

1) Control of a floating wind turbine is not trivial; placed on a floating support, the system can become unstable [3]. The problem to stabilise the system, while maintaining proper speed and power regulation is solved with an active floating support damping algorithm, based on observer and state feedback. This approach results in:
- stable operating wind turbine with good tracking performance
- reduction of the standard deviation of the floater motions
- reduction of fatigue loads in the wind turbine components

2) The motion of the floating support due to wave excitation contributes to the wind turbine loads, both directly as gravity and inertia loads, as well as indirectly as component of the apparent wind on the rotor. Estimating this wind-from-waves component allows a 'pseudo' feedforward on the pitch control loop that:
- reduces fatigue loads in the wind turbine components
- reduces the power and speed fluctuations as well as the blade pitch control activity

Acknowledgement

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Control design

Linking the two new algorithms to the baseline ECN controller allows dedicated floating wind turbine control design for the GustoMSC Tri-Floater. The baseline control includes, amongst others: peak shaving, QN shifting and (scheduled) pitch actuator limitation.
Frequency domain analysis indicated stability throughout the operating range. Time domain simulations were performed to verify tracking performance (see figure 2).

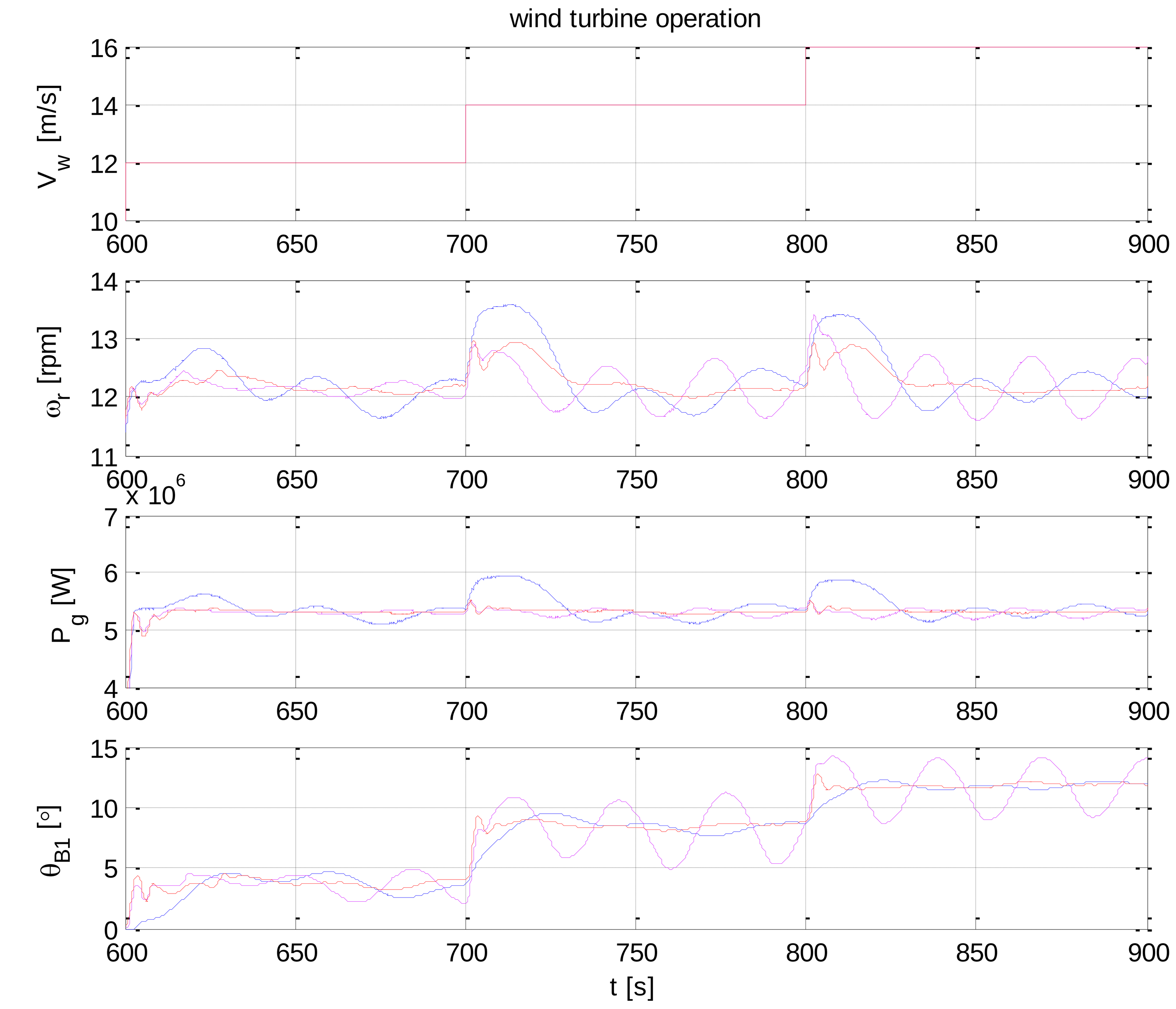

Figure 2: Wind turbine operation for step response above rated (b: OC3float, m: ECNland, r: ECNfloat)

Control evaluation

Evaluation of the designed controller with the nonlinear fully coupled simulation tool AQWA-PHATAS showed stable operation with good tracking performance, as well as reduction of floater motions and wind turbine loads. Results have been compared to a land based controller and the floating controller developed for the OC3 benchmark [6]. For typical above rated conditions (stochastic wind and irregular waves), the following has been achieved:
- good tracking performance (normal turbulence and gust response)
- large reduction of floater pitch motion standard deviation (see table 1)
- about 38% reduction of tower base bending fatigue
- about 12% reduction of blade root bending fatigue

motion σ in [m] or [deg] | controller	OC3float	ECNland	ECNfloat
surge	2.809	2.293	2.293
heave	0.261	0.250	0.253
pitch	1.687	3.085	1.129

Table 1: Standard deviation of floater motions for typical above rated conditions

Conclusion

The developed ECN floating wind turbine controller ensures stable operation, while maintaining good tracking performance. The floater motions are significantly reduced, as well as loads on the wind turbine components. Using an integrated design approach, this allows for a more cost effective floating wind turbine system.

References

1. Jonkman J, Butterfield S, Musial W and Scott G. *Definition of a 5MW Reference Wind Turbine for Offshore System Development*. Technical Report NREL/TP-500-38060, NREL, USA, 2009.
2. Bulder BH, et al. *Floating offshore wind turbines for shallow waters.* European Wind Energy Conference, Madrid, 2003.
3. Jonkman J. *Influence of control on the pitch damping of a floating wind turbine*. In Proceedings of the ASME Wind Energy Symposium in Reno, Nevada, USA, 2008.
4. Huijs FA, Mikx J, Savenije FJ and Ridder E de. *Integrated design of floater, mooring and control system for a semi-submersible floating wind turbine foundation.* EWEA Offshore, Frankfurt, 2013.
5. Ridder E de, Otto W, Zondervan G, Huijs FA, Savenije FJ. *State of the art model testing techniques for floating wind turbines.* EWEA Offshore, Frankfurt, 2013.
6. Larsen TJ and Hanson TD. A method to avoid negative damped low frequent tower vibrations for a floating, pitch controlled wind turbine. In Proceedings of the Science of making torque from wind conference, 2007.