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Final Report of CROWN - Part 1/3: Summary Report

Subproject: Motion Reduction

Within the Eurostars Project
E!113443 CROWN Motion Reduction
Joint Project: Motion Reduction of a Concrete Reduced-draft spar for the Offshore floating Wind iNdustry

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Summary

This report presents the project *Motion Reduction of a Concrete Reduced-draft spar for the Offshore floating Wind iNdustry (CROWN)* of the partners Seaplace, USTUTT and sowento GmbH.
Sowento was in charge of the motion reduction sub-project.

As part of the overall project, Seaplace designed a Floating Offshore Wind Turbine (FOWT) with Reduced Spar Design (RDS) platform for a multi-megawatt turbine. The reduction of turbine motion is achieved by integrating an Anti-Heeling and Ballast System (AHBS), Anti-Roll Tanks (ART) and a turbine controller. In addition, a proof-of-concept of a real-time observer was realised within the framework of CROWN. This is used to reconstruct or observe system states that cannot be measured or that are too complex to measure. In cooperation with the IH Cantabria (IHC), a 1:36 scaled test model was designed and built. This was tested and validated as a HIL system in the wave tank of IHC. The term HIL is used to refer to the test model as a system that is embedded in a control system via its inputs and outputs (see Fig. 1).

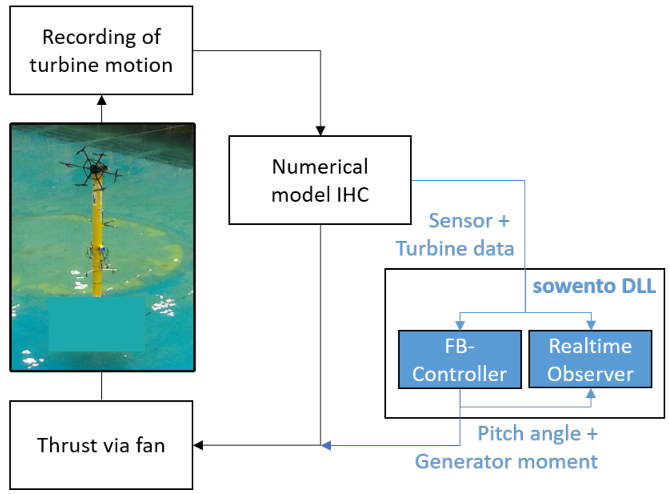

Abbildung 1: Hardware-In-the-Loop (HIL)-System by IH Cantabria (IHC) with integrated sowento-Dynamic-Link-Library (DLL).

Original task and scientific and technical status on which the project based

One of the most pressing needs in the development of FOWTs is to reduce the uncertainty of structural, operational and extreme loads, which increases the reliability of the design methodology and thus increases affordability and insurability. These are key factors in terms of cost reduction of the FOWT technology. A combination of advanced sensors and a digital twin that simulates system response at any point in time offers the prospect of understanding and monitoring FOWT behaviour under operational, extreme, but also temporary transport and installation conditions. The approach of the digital twin as a real-time observer has not yet been tested in any known concept, or one that has become known during the project. The real-time observer developed in CROWN is intended to lay a foundation for further developments.

The tasks associated with this goal included

- The set up and validation of a higher order OpenFAST model and a controller design model with Simplified-Low-Order-Wind-Turbine (SLOW). SLOW is an in-house, reduced-order nonlinear simulation model for FOWTs, which in its linearised form is particularly suitable for the development of tubine controllers and real-time observers. SLOW was developed together with University of Stuttgart (USTUTT) and has already been validated in many research and industrial projects.
- The development of a baseline feedback controller to reduce the turbine movement, loads and to optimise turbine performance.
- The development of a real-time observer.
- The validation of the simulation model, feedback controller and real-time observer against measured data.

Process of the project

The steps to achieve the project objectives are listed below:

- Set up of the OpenFAST simulation model and comparison with Seaplace's FOWT model.
- Construction of the SLOW model and verification with OpenFAST, linearisation of the SLOW model.
- Development of a baseline feedback controller with generator torque controller and blade pitch controller.
- Construction of a framework for the development of the real-time observer: The interfaces between the numerical model of the IHC and the sowento software were defined, so that the measurement data can be made available to the sowento software in real time.
- Development of the real-time observer. Here, a Luenberger observer for linear models was implemented, which is based on the linearised SLOW model. This allows states to be observed that are represented in the SLOW model.
- Integration of the real-time observer and feedback controller into a sowento Dynamic-Link-Library (DLL) which was integrated into the HIL system of the IHC (Fig. 1).
- Performance of the tests with different configurations in the wave tank of the IHC.
- Validation of the simulation model characteristics by comparing simulation results and measured data without wind and waves.
- Validation of the feedback controller and real-time observer by comparing simulation results and measured data in wind and waves.

Main results

With a focus on the evaluation of the measurements, the most important results for sowento are summarised below:

- *Validation of the reduced model SLOW*. During the measurement campaign of the scaled FOWT prototype, the SLOW model could be validated. Hereby, the reliability and robustness of the model could be confirmed under consideration of aerodynamics, structural dynamics, hydrodynamics and control.
- *Validation of the turbine controller*. The controller concept with feedback controller of the RDS platform was developed, tested and proven to contribute to the reduction of turbine motion.
- *Proof-of-concept of the real-time observer*. The measured and observed states (Fig. 2) showed good agreement. Through the scaled test of the RDS-FOWT, the effective functionality of the real-time observer could be shown. In this context, conducting real tests is a significant step to move from a concept level to an implementation level.

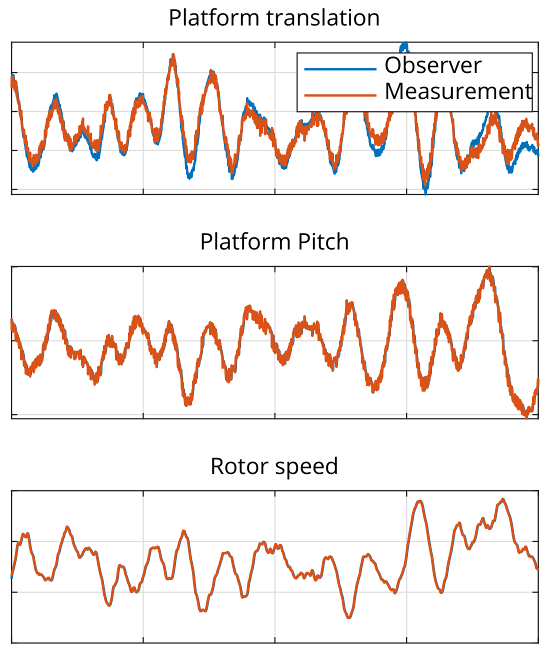

Abbildung 2: Measured and observed states

sowento will build on the results to commercialize the digital twin as a platform solution for FOWT load and condition monitoring. It will be combined with a flexible number of sensors, including a nacelle-based lidar for a low-uncertainty reconstruction of the FOWT behavior in every instance of time.