Investigating the Relevance of Considering Structural Flexibility in Model Tests of Floating Wind Turbine Systems

Dr.Eng. Mareike Leimeister

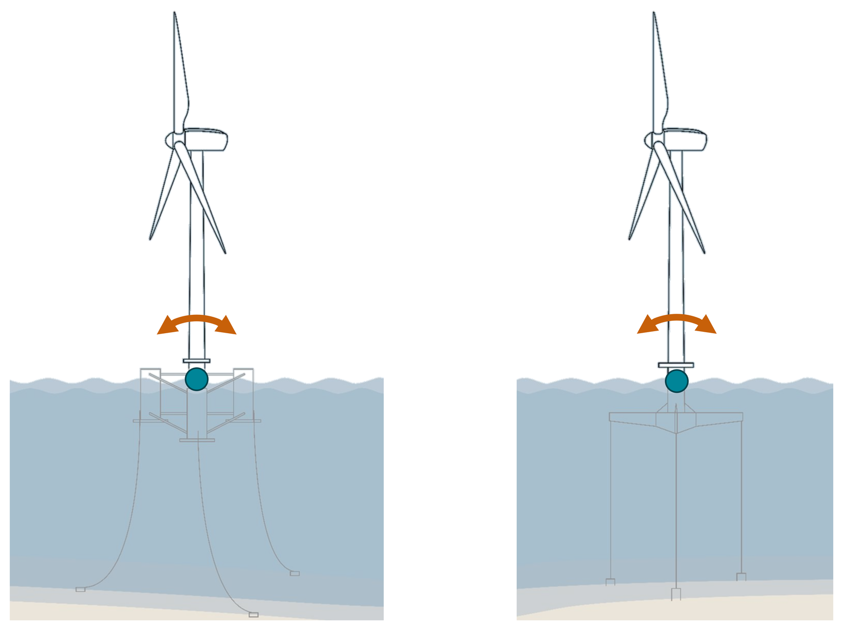
Fraunhofer IWES

The offshore wind market is developing rapidly towards very large turbines. This brings new challenges in numerical and experimental techniques to assess floating offshore wind turbine (FOWT) designs. With growing size of wind turbines, the inclusion of flexibility effects becomes more and more important. However, testing with small-scale models in wave basins is right now carried out with rigid models. It would be challenging to consider aero-elasticity, as the turbine's structural flexibility cannot be represented accurately enough in a physical small-scale model, or the aero-elastic numerical simulations are, based on the state-of-the-art, too slow for being incorporated into a small-scale model test through simulation-in-the-loop. Thus, the impact of the structural elasticity of blades and tower on the dynamic system responses of FOWT systems needs to be investigated. The main research questions are:

> ¿ Is it relevant to take structural elasticity into account during model-scale tests of FOWT systems?
>
> Which degree of structural flexibility needs to be considered? ?

Methodology

An extensive sensitivity study is performed based on numerical simulations in time domain. Increasing wind turbine MW-classes – utilizing the reference wind turbines NREL 5 MW, IWT 7.5 MW, DTU 10 MW, and IEA 15 MW [1-4] – and different degrees of structural flexibility are considered under typical dynamic motions of two floater configurations: a tension-leg platform (TLP) and a semi-submersible. Critical parameters (power, rotor speed, thrust, and loads at blade root, hub, tower base) are determined over the full operational wind speed range.



The sensitivity study is performed based on automated numerical simulations in time domain utilizing MoWiT [5] and PyWiT [6]. As the focus lies on dynamic motions of FOWT systems but not on specific floating platform designs, only the wind turbine is modeled, and the dynamic motion is imposed on it in form of a forced pitch oscillation at the tower base.

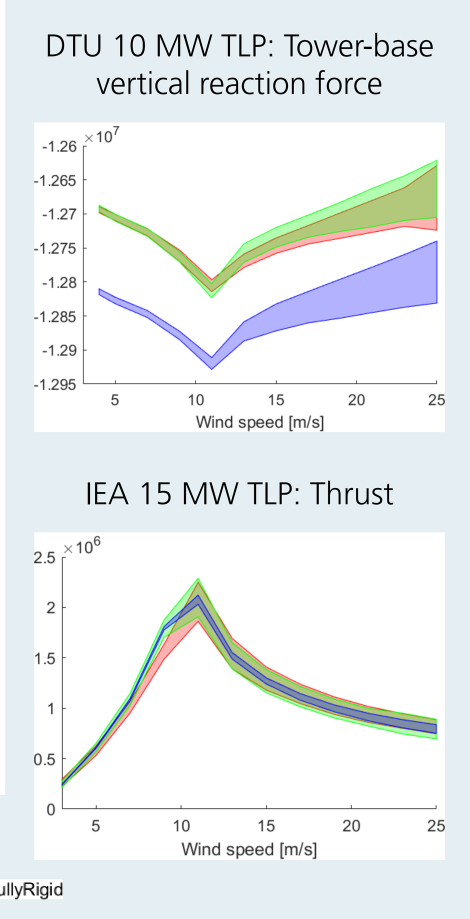
Results

Turbine performance and load parameters are compared in three respects:

General influence of different structural flexibility types

Each wind turbine and floater system is investigated individually and the development of the simulation results for the different parameterizations is evaluated over the full operational wind speed range.

Overall, the degree of structural flexibility impacts the oscillation amplitude and, in some cases (cf. top figure), also the mean of the system responses. Mostly, the oscillation amplitude is increased with more structural flexibility considered (cf. bottom figure). However, for some parameters, the fully flexible system reveals the lowest oscillation amplitudes. There are also different impacts perceived with deviating behavior depending on the wind speed.



At 15 s and 2° pitch oscillations

Impact of the pitch oscillation characteristics

A varying period or amplitude of the excitatory pitch oscillation is not affecting the responses of a fully-rigid system.

Considering structural flexibility, the pitch period influences the oscillation amplitude of the system parameters. The degree of impact is mainly driven by the floater and environmental characteristics, with a higher relevance of the wave spectrum represented by pitch periods of 7.4 and 9.2 s.

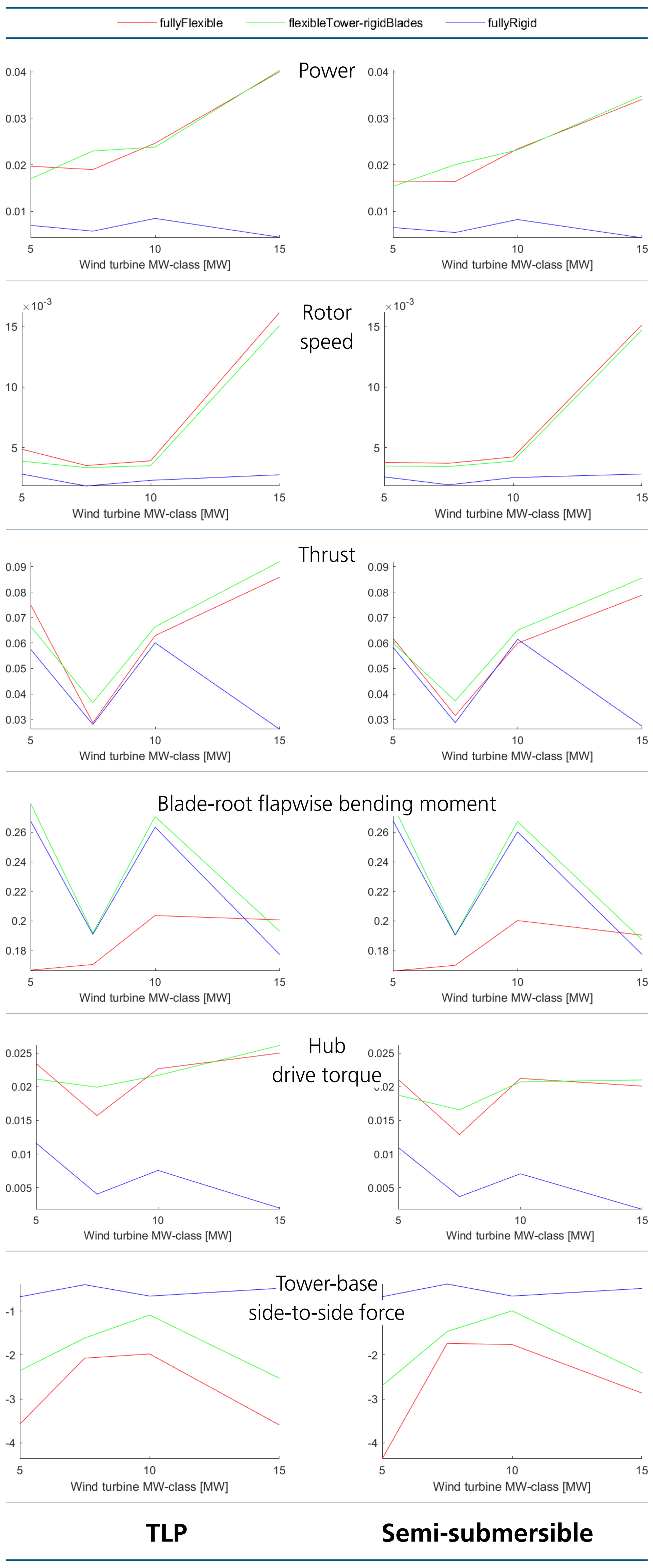
With higher pitch amplitudes, higher oscillation amplitudes of the system parameters are obtained. The degree of increased oscillation amplitudes varies for the different system parameters investigated as well as for the three flexibility types considered.

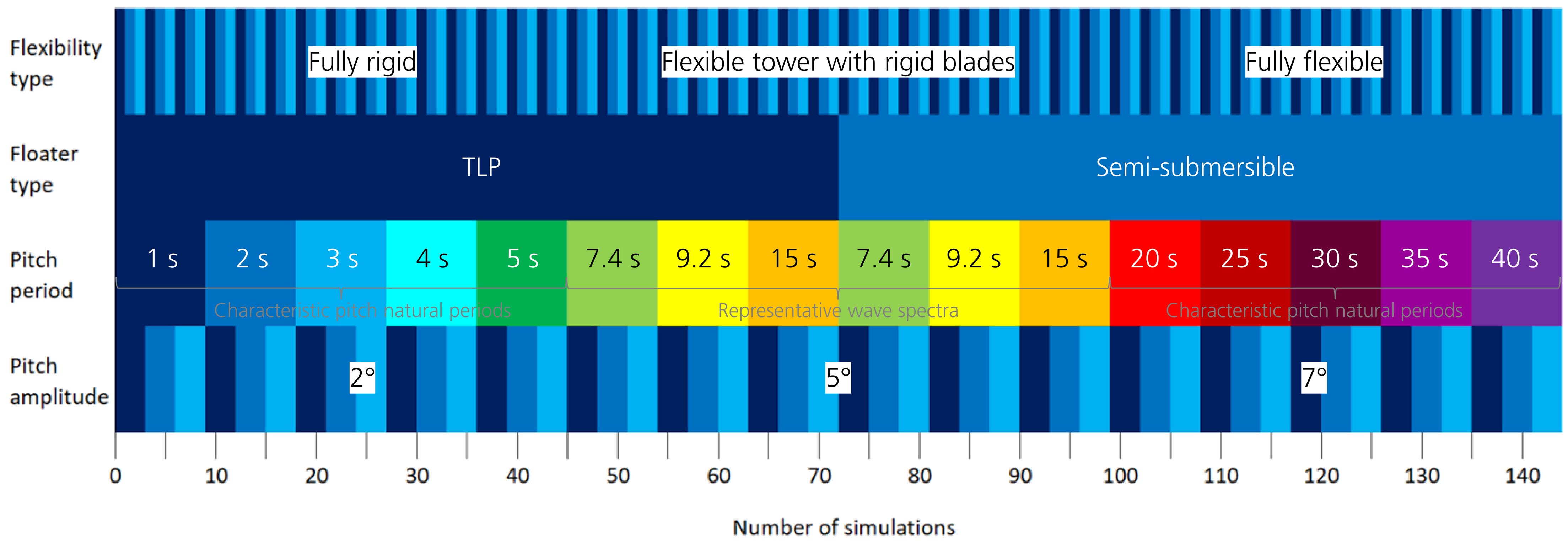
Development of the influence of different structural flexibility types over the wind turbine MW-class

For a better comparison of the influences of different structural flexibility types on critical system parameters over varying wind turbine sizes, the results are analyzed in a normalized manner. This means that the ratio between amplitude and mean of the oscillatory system response is computed and then averaged over the operational wind speed range. The impact of the wind turbine MW-class on critical system parameters is shown in the figures on the right.

For most of the system parameters, the consideration of structural flexibility becomes significantly important when going beyond 10 MW, while the difference between considering just a flexible tower or additionally also flexible blades is less relevant.

Development of the ratio between amplitude and mean of system parameters over the turbine size





Design of experiments for each wind turbine MW-class.

Conclusions

The relevance of taking account of structural flexibility during model-scale tests of FOWT systems is investigated by means of an extensive numerical sensitivity study. Wind turbines of different MW-classes are assessed, and with different degrees of flexibility. Simulations are run to represent the effects on either a TLP or a semi-submersible floater.

For wind turbine systems of 10 MW and higher, structural flexibility has a noticeable impact on the system responses, especially on the parameters' oscillation amplitudes. Thus, it is concluded that ultimate loads may be less affected by flexibility, and that the rigid models may be considered conservative as they tend to give higher loads. The motion amplitude, however, is larger for the flexible systems, so the effect on fatigue would be substantial, and hence, the consideration of structural flexibility is recommended for larger wind turbine systems. However, the need for considering the blades' flexibility in addition to the tower's flexibility should be carefully weighed against additional efforts (e.g., financial and temporal expenditures as well as degree of complexity) and assessed based on the blades' flexibility impact on specific system parameters.

1 Jonkman et al., 2009. *Definition of a 5-MW Reference Wind Turbine for Offshore System Development*. NREL/TP-500-38060
2 Popko et al., 2018. *IWES Wind Turbine IWT-7.5-164 Rev 4*. doi:10.24406/IWES-N-518562
3 Bak et al., 2013. *Description of the DTU 10 MW Reference Wind Turbine*. DTU Wind Energy Report-I-0092
4 Gaertner et al., 2020. *Definition of the IEA Wind 15-Megawatt Offshore Reference Wind Turbine*. NREL/TP-5000-75698
5 Fraunhofer Institute for Wind Energy Systems, 2023. *The MoWiT (Modelica for Wind Turbines) Library*. http://mowit.info/
6 Fricke et al., 2021. *Python Framework for Wind Turbines Enabling Test Automation of MoWiT*. doi: 10.3384/ecp21181403

EERA DeepWind Conference, January 17-19, 2024,
Radisson Blu Royal Garden Hotel, Trondheim, Norway