Mooring System Design for a Large Floating Wind Turbine in Shallow Water

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equinor

Introduction

In the recent years, the offshore wind turbine market has increased significantly. Due to the large available areas, the high wind velocity, and the low noise and visual impact issues offshore, this has been a good alternative to onshore wind turbines. The low draft of the floating wind turbines makes it possible to locate them in shallow water. In order to make the offshore wind turbines commercial feasible, it is important to have a novel mooring system. To do this, several different mooring line materials, different anchor types, installation methods and mooring line lengths can be investigated in order to find the best solution.

Objective and scope

The aim of the thesis is to look at a floating 10 MW offshore wind turbine at 70 m water depth, having different mooring systems. In addition, the possibility of simplifying the model by removing the modelled tower and wind turbine is investigated. The scope of the Master thesis is:

- Literature study regarding offshore wind turbines, mooring, mooring line types, mooring line failure modes, and design and analysis of mooring systems.
- To implement a 200 m water depth floating semi submersible wind turbine SIMA model to 70 m water depth using two different catenary chain systems, and a taut polyester system.
- Perform decay tests, constant wind tests, find the RAOs and do an ULS analysis of the systems.
- Compare the different models with regard to the performed tests. See if a simplified model, where the effects of the tower and wind turbine is implemented in the sub-structure, works and saves time.

Conclusion

- The initial system satisfies the ULS criteria (DNV-OS-J103 (2013)), but the mooring lines go into slack
- The Hywind system does not satisfy the ULS criteria, and the mooring lines also go into slack
- The simplified Hywind model is in acceptable agreement with the original Hywind model
- The polyester system satisfies the ULS criteria, but the mooring lines go into slack

References

[1] C. Bak et al.: *Design and Performance of a 10MW Wind Turbine.* J. Wind energy (2013)
[2] Q. Wang: *Design and Dynamic Analysis of a Steel Pontoon-Type Semi-Submersible Floater Supporting the DTU 10MW Reference Turbine.* Master's Thesis, Delft University of Technology and NTNU (2014)
[3] Equinor: *Mooring: Detail Design.* Company presentation (2014)

Modelling

Four different floating wind turbine (FWT) models have been examined in SIMA at 70 m water depth. They all have the same DTU 10MW reference wind turbine [1] and a semi-submersible sub-structure developed in Qiang Wang's Master thesis [2] (figure 1). The models are:

- An initial catenary chain mooring system (figure 2)
- The Hywind Scotland mooring system [3], which is smaller and lighter than the initial system
- A simplified Hywind Scotland mooring system modelled without the tower and the wind turbine. The effects of the removed parts are included in the sub-structure
- A taut fiber rope system (figure 3)

The FWTs are assumed to be located at Equinor's Scotland Hywind floating wind turbine pilot park at Buchan Deep, with its environmental conditions. Both NPD turbulent wind and TurbSim turbulent wind has been used for the extreme conditions.

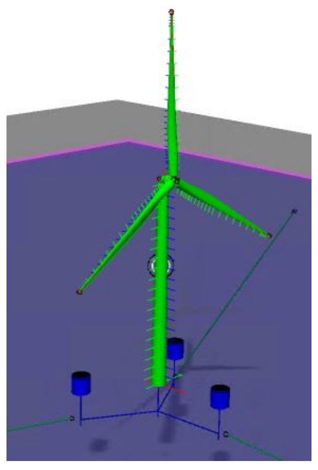

Figure 1: SIMA model

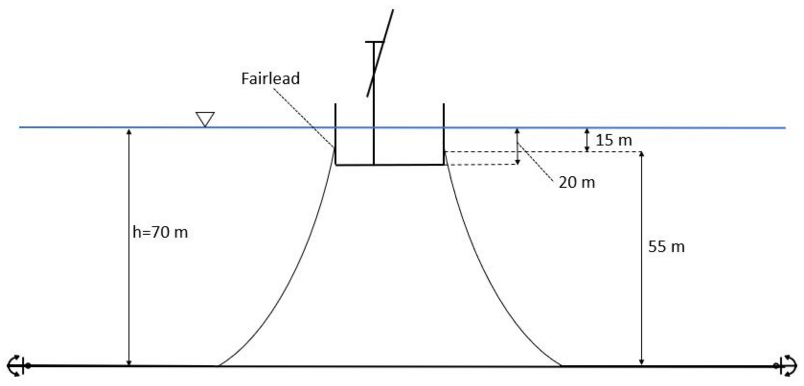

Figure 2: Catenary mooring system

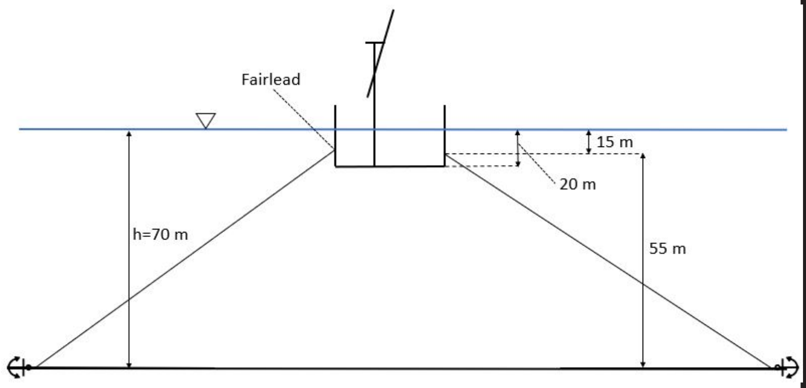

Figure 3: Taut mooring system

Results and Discussion

Some of the results are presented below. Figure 4 shows that the mean pitch for the original and simplified model in constant wind is similar. The damping of pitch in the simplified model is lower than for the original model.

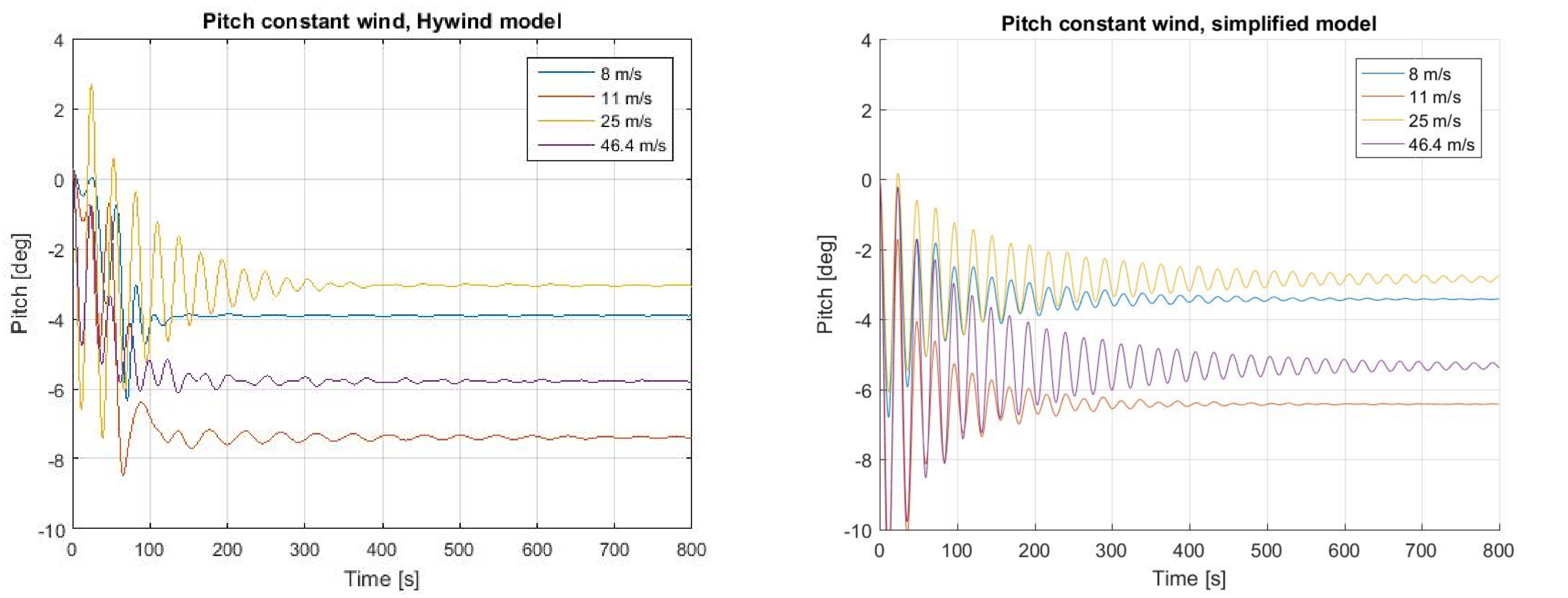

Figure 4: Pitch of the structure in constant wind (at hub height) for the the original Hywind model (*left*) and the simplified Hywind model (*right*)

The Gumbel distribution of the maximum tension in the extreme weather condition (3h simulations of 50 year return period extreme wind and waves, and 10 years return period of extreme current) in the left figure in figure 5 shows that 10 runs are enough to obtain sufficient accuracy of the results. From the right figure in figure 5, it can be seen that the lee side polyester mooring lines will go into slack in an extreme condition.

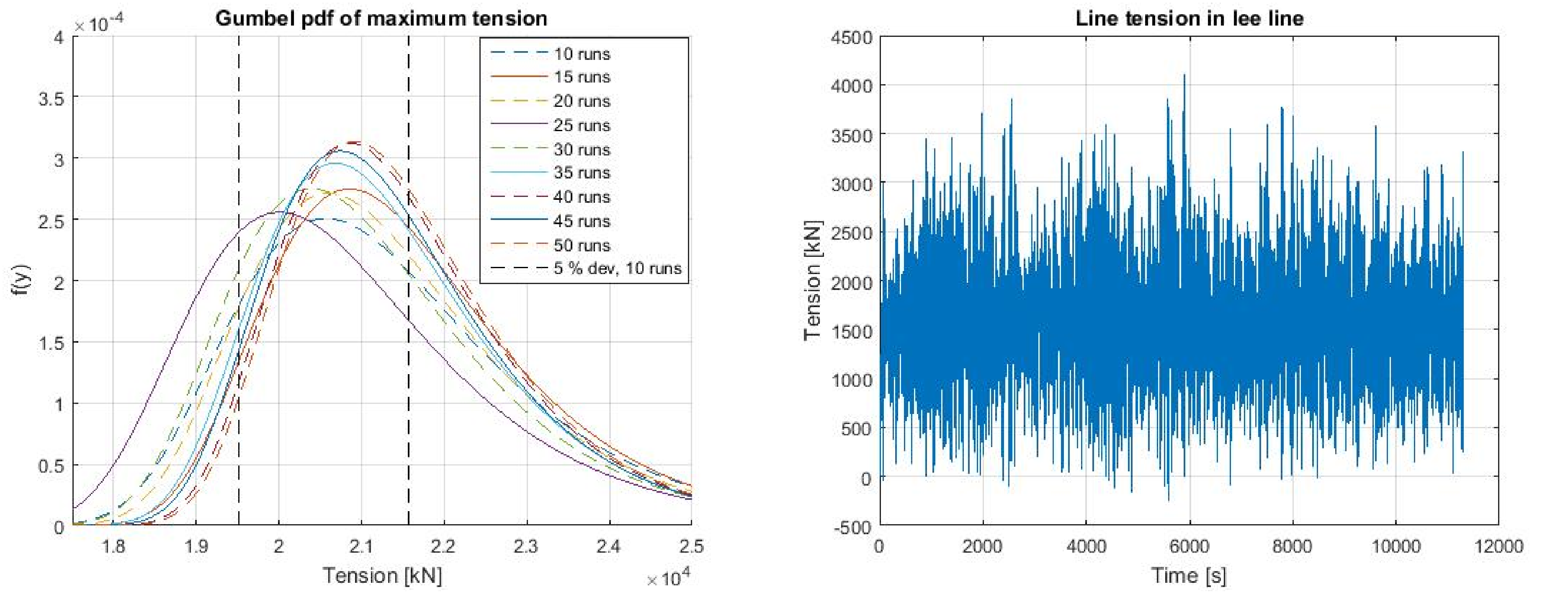

Figure 4: *Left*: Gumbel distribution of the maximum line tension in the most exposed line for the Hywind model in ULS condition. *Right:* Axial tension in leeward line for polyester system in extreme condition.