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Design and Analysis of Mooring System for Semi-submersible Floating Wind Turbine in Shallow Waters

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Abstract

From the view of cost efficiency, floating wind turbine becomes more competitive than bottom fixed wind turbine when the water depth comes above 50 m. Semi-submersible floater concepts have been proposed to be deployed in shallow waters (50-100 m) because of its smaller draft compared to other floater types.

However, mooring system design is extremely challenging for floating structures in shallow water. The relationship between mooring line tension and offset becomes nonlinear after an initial linear part for small offsets [1], which could lead to extreme large tension during harsh environment when the floater motions have large offsets. Moreover, the nonlinear response of the platform in shallow water becomes more critical than deep water.

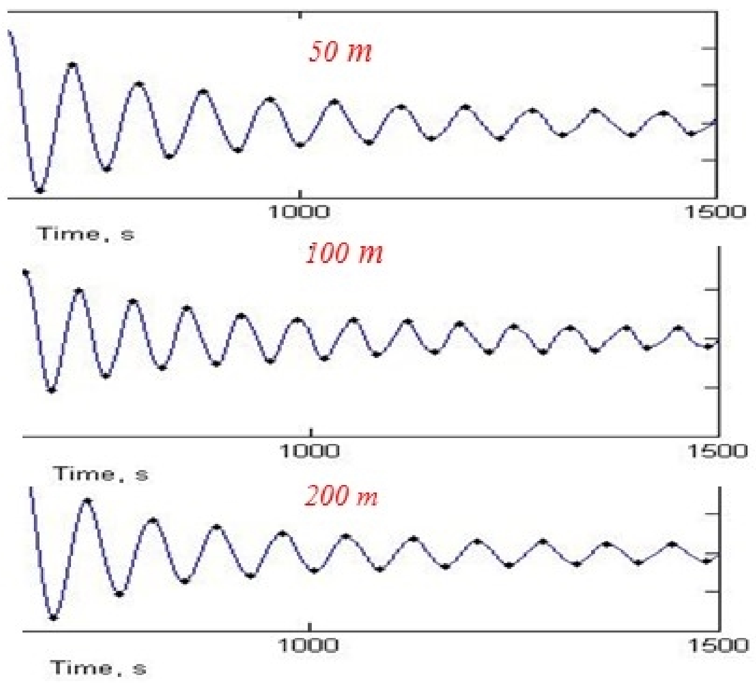
The present thesis focuses on the mooring system design and analysis for the 5-MW-CSC semi-submersible floater [3], [2] in 100 m and 50 m water depth using the mooring system design concept in 200 m water depth as a reference. Natural periods of the platform, horizontal and vertical mooring line stiffness, ultimate strength and fatigue life of mooring lines and tower are basic factors that have been considered and examined. Initially static design has been carried out in SIMA for determining the optimal mooring system design and afterwards fully coupled time-domain dynamic analysis was performed with the tool Simo-Riflex-AeroDyn to study and check the mooring system performance.

Objectives

- Define key properties of mooring lines for 50 m and 100 m water depth.
- Achieve similar horizontal stiffness as the reference model in 200 m.
- Guarantee the natural periods of all motions are on safe side.
- Calculate the mooring line extreme responses under survival condition and make sure they do not exceed the design limit.
- Calculate the mooring lines accumulated fatigue damage for 20 years under operational conditions and check with appropriate regulations.
- Calculate the tower base fatigue damage and generated power of the wind turbine under operational conditions.

Methods

Fig1. Surge Decay Test



Tab2. Decay Test Result – 6 DOFs

Natural Period			
Water Depth (m)	200	100	50
Surge (s)	79.43	78.97	64.13
Sway (s)	79.43	74.97	66.77
Heave (s)	25.34	25.27	24.92
Roll (s)	31.14	30.80	30.34
Pitch (s)	31.08	30.74	30.29
Yaw (s)	57.55	61.68	78.43

Fig2. Mooring Line Tension Spectrum
Hs=13.4 m, Tp=13.1 s, Uw=41.86 m/s

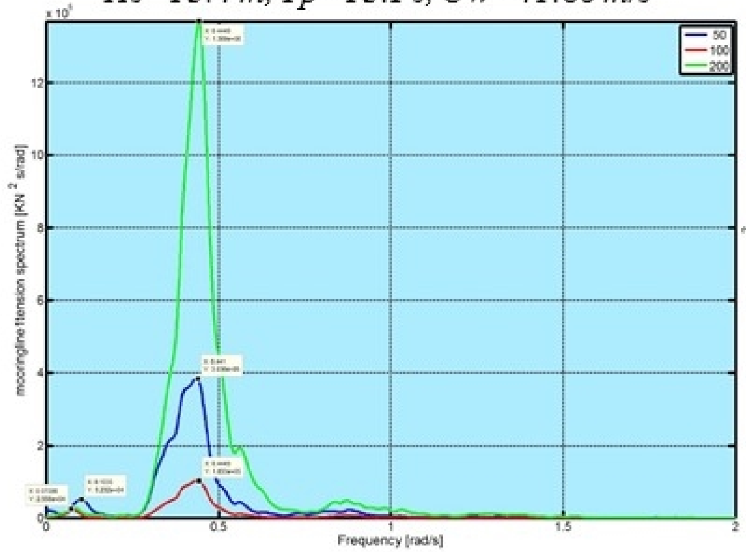


Fig3. Floater Surge Motion Spectrum
Hs=13.4 m, Tp=13.1 s, Uw=41.86 m/s

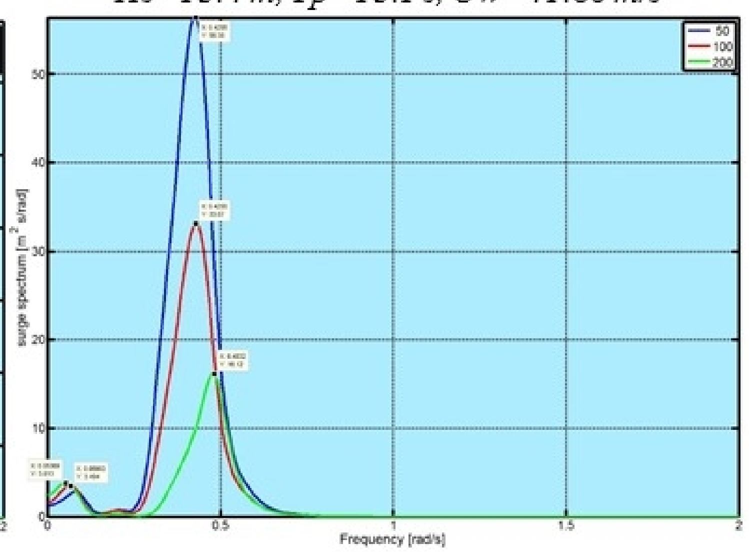


Fig4. Mooring Line Fatigue Damage

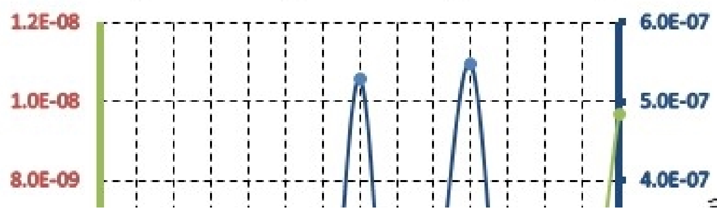
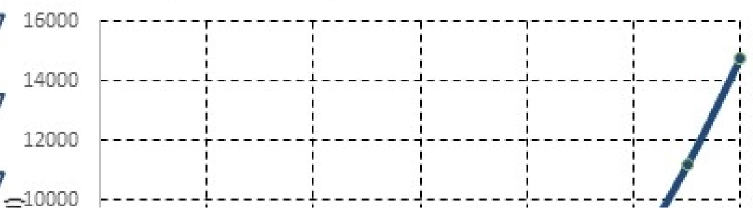
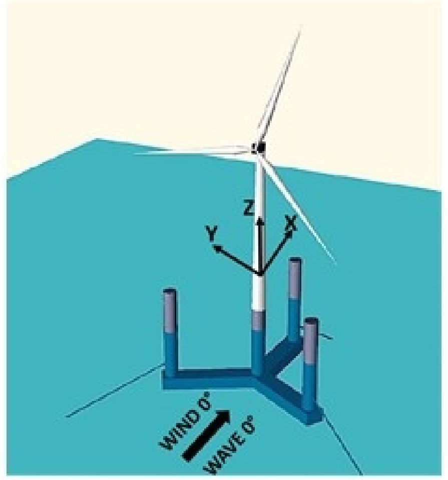


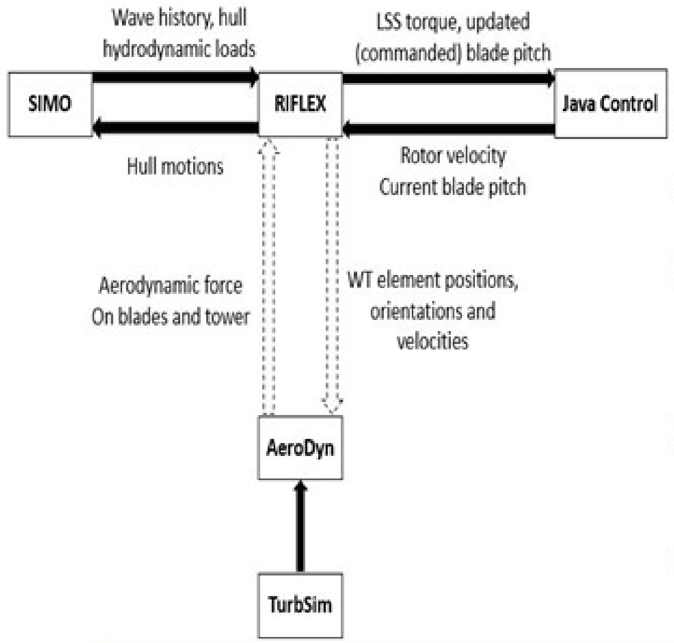
Fig5. Mooring Line Tension VS Offset





Static Design and Analysis in SIMA

- Study 5-MW-CSC 200 m mooring system properties as a reference.
- Define mooring line properties for 50 m and 100 m in SIMA.
- Perform static analysis to check horizontal tension and offset relationship and maximum mooring line tension.
- Determine optimum mooring line design concepts for 100 m and 50 m.



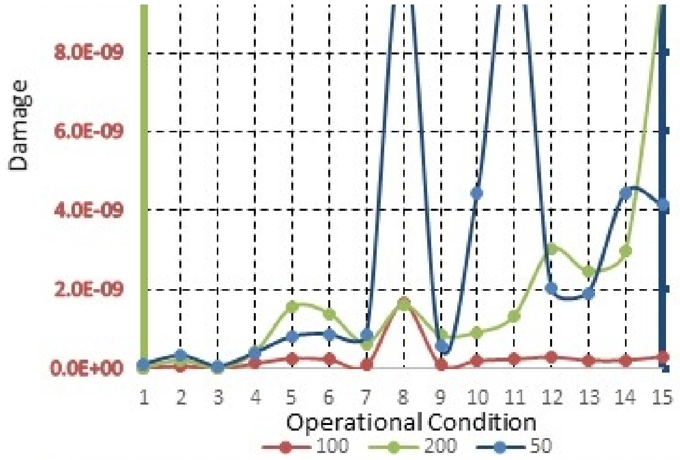
Dynamic Analysis in Simo-Riflex-AeroDyn

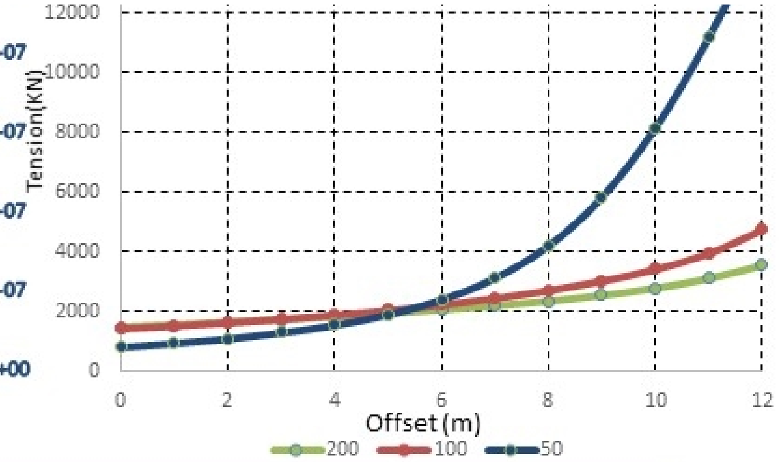
- Calculate hydrodynamic loads for 50 m and 100 m.
- Carry out decay tests to check natural periods for floater motions in six degree of freedom.
- Calculate floater motions and mooring lines response under two survival conditions with four wave incoming directions and ten different wave/wind random seeds.
- Calculate mooring line and tower base fatigue damages under fifteen operational conditions with six wave/wind random seeds.
- Document wind turbine performance of rotor speed and generated power.

Results

Tab1. Mooring System Static Configuration

Water depth (m)	200	100	50
Number of mooring lines (m)	3	3	3
Angel between adjacent lines (deg)	120	120	120
Radius to anchors from platform center (m)	884.36	698	600
Unstretched mooring line length (m)	873.11	671.66	566.65
Pretension (KN)	1683.1	1710.91	1295.35
Mooring line Type	Spiral rope with plastic sheathing	Spiral rope with plastic sheathing	Chain Studless R4-RQ4
Mooring line nominal diameter (m)	0.1365	0.1365	0.18
Mooring line unit mass in water (kg/m)	115.02	115.02	648
Mooring line axial stiffness (N)	3.08E+09	3.08E+09	2.92E+09
Catalogue Breaking Load (KN)	16769	16769	26278
Clump weight (t)	17.253	60	60





Conclusions

- Two new mooring system designs have been proposed for 100 m and 50 m water depth with two different mooring line materials: wire rope for 100 m and chain for 50 m.
- The transition from linearity to nonlinearity between mooring line tension and offset occurs at a larger offset for 200 m and 100 m (10 m offset) and smaller offset for 50 m (6 m).
- The natural periods of mooring system for 100 m and 50 m are achieved close to those for 200 m, sufficiently larger relevant wave period.
- The extreme responses in 200 m are larger than those in 100 m and 50 m because of smaller pretension in latter two cases.
- All the mooring line responses and floater motions under extreme condition are on safe side.
- For 50 m water depth, the mooring line fatigue damage is relatively higher than in 100 m and 200 m even though the stress ranges do not show big difference, it is because of the different mooring line types used and consequently the S-N curve.
- All 20 year fatigue damage results for the three water depths are acceptable.

References

[1] DNV-OS-J101-Design of Offshore Wind Turbine Structures, May 2014.
[2] Luan, C., Michailides, C., Gao, Z., and Moan. T., "Modeling and analysis of a 5 mw semi-submersible wind turbine combined with three flap-type wave energy converters".
[3] Luan, C., Gao, Z., and Moan. T., "Conceptual designs of a 5-MW and a 10-MW semi-submersible wind turbine with emphasis on the design procedure". (to be submitted)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"The stone age came to an end, not because we had a lack of stones, and the oil age will come to an end not because we have a lack of oil." - Sheikh Ahmed Zaki Yamani