# EXTREME STRUCTURAL DYNAMIC RESPONSE OF A SPAR TYPE WIND TURBINE


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## Abstract

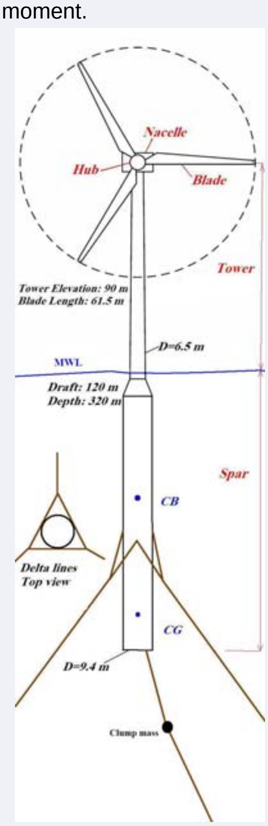

Proper performance of structures requires among other things that its failure probability is sufficiently small. This would imply design for survival in extreme conditions. The failure of a system can occur when the ultimate strength is exceeded (Ultimate Limit State) or fatigue limit (Fatigue Limit State) is passed. The focus in this paper is on the determination of extreme responses for ULS design checks. The present paper deals with coupled wave and wind induced motion and structural response in harsh condition up to 14.4 (m) significant wave height and 49 (m/sec) 10-min average wind speed (at top of tower, 90 m) for a parked floating wind turbine. In survival condition the wind induced resonant responses (mainly pitch resonance) are dominant. Due to resonant motion responses the structural responses are close to Gaussian. The dynamic structural responses show that the process is wide banded. The critical structural responses are determined by coupled aero-hydro-elastic time domain simulation. Based on different simulations (20 1-hour, 20 2-hours, 20 3-hours and 20 5-hours) the mean up-crossing rate has been found in order to predict the extreme structural responses. The most probable maximum and bending moment for up-crossing level of 0.0001 for present study are very close. The minimum total simulation time in order to get accurate results is highly correlated to the needed up-crossing level. The 1-hour and 2-hours original values cannot provide any information for 0.0001 up-crossing level. Comparison of different simulation periods shows that the 20 1-hour simulations can be used in order to investigate the 3-hours extreme bending moment if the proper extrapolation of up-crossing rate used.


## Theory

While analytical models are used for determining the linear response, the distribution of nonlinear response in general need to be treated in a semi-empirical manner by modeling the distribution of the response peaks or up-crossing rates.

Extreme value statistics for 1 or 3 hours period can be obtained taking into account the regularity of the tail region of the mean up-crossing rate. The mean up-crossing rate is instrumental in obtaining statistics of extremes. As the up-crossing of high levels are statistically independent event, we can assume a Poisson distribution for extreme bending moment.

To limit the computational efforts to determine the 100-year extreme response value a contour surface method is applied based on a joint distribution of wind speed, significant wave height and wave period. The 100-years return period environmental condition has been set in order to get 100-years response of the floating wind turbine in harsh environmental condition. A systematic study for choosing the turbulent wind intensity and scaling the mean wind velocity has been carried out.



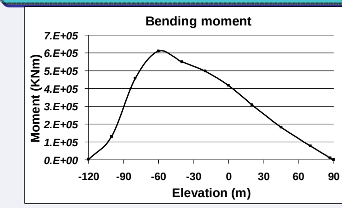

Catenary Moored Deep Spar Floating Wind Turbine

## Model

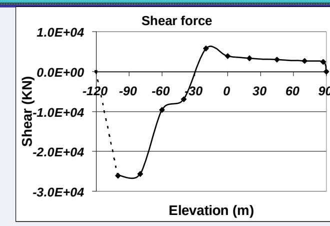
Floating Wind Turbine Properties (CMS)

| | |
|---|---|
| Total Draft | 120 m |
| Diameter Above Taper | 6.5 m |
| Diameter Below Taper | 9.4 m |
| Spar Mass, Including Ballast | 7593,000 kg |
| Total Mass | 8329,230 kg |
| Centre of Gravity, CG | -78.61 m |
| Pitch Inertia about CG | 2.20E+10 kg•m^2 |
| Yaw Inertia about Centerline | 1.68E+08 kg•m^2 |
| Rating | 5 MW |
| Rotor Configuration | 3 Blades |
| Rotor, Hub Diameter | 126 m, 3 m |
| Hub Height | 90 m |
| Cut-In, Rated, Cut-Out Wind Speed | 3 m/s, 11.4 m/s, 25 m/s |
| Rotor Mass | 110,000 kg |
| Nacelle Mass | 240,000 kg |
| Tower Mass | 347,460 kg |

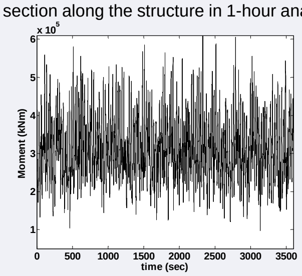
## Results



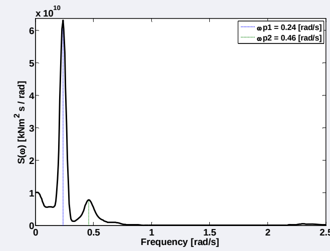

Maximum bending moment in each section along the structure in 1-hour analysis




Maximum shear force in each section along the structure in 1-hour analysis



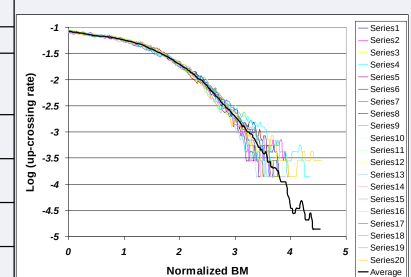

Bending moment time history at z= -60 m




Bending moment spectrum at z= -60 m

Dynamic response Statistics (1-hour simulation)

| Response | Mean | STD | Skewness | Kurtosis |
|---|---|---|---|---|
| Nacelle Surge (m) | 78.64 | 10.69 | 0.002 | 2.63 |
| Pitch (deg) | 12.35 | 3.23 | -0.116 | 2.32 |
| BM at interface (kNm) | 2.18e+5 | 6.14e+4 | -0.026 | 2.98 |
| BM at tower top (kNm) | 1.90e+3 | 2.24e+3 | 0.039 | 3.04 |
| BM at blade root (kNm) | -1.24e+4 | 2.30e+3 | -0.260 | 3.19 |
| Shear at interface (kN) | 1.32e+3 | 674.9 | -0.120 | 3.10 |
| Shear at tower top (kN) | 1.05e+3 | 405.7 | -0.002 | 3.12 |
| Shear at blade root (kN) | 436.53 | 78.29 | 0.260 | 3.20 |




Up-crossing rate for 20 2-hours simulations and the average up-crossing rate (40 hours)

## Conclusions

Extreme values for severe environmental conditions have been obtained based on 20 1-hour, 20 2-hours, 20 3-hours and 20 5-hours simulations. Since the response is governed by resonance the response is close to Gaussian. The process is wide banded. The up-crossing rates based on time series have been obtained.

The minimum total simulation time (number of simulations multiply by simulations period) in order to get accurate results is highly correlated to the needed up-crossing level. The 1-hour and 2-hours original values cannot provide any information at the 0.0001 up-crossing level. The extrapolation of 1-hour period in order to capture the up-crossing level of 0.0001 can be used. The Naess approach gives more reasonable results. If up-crossing of higher levels is needed the total simulation time should be increased. The most probable maximum and bending moment for up-crossing level of 0.0001 for present study are very close. Comparison of different simulation periods show that the 20 1-hour simulations are sufficient for predicting the 3-hours extreme bending moment if the up-crossing rate is based on reasonable extrapolation.

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