Lifetime extension for large offshore wind farms: Is it enough to reassess fatigue for selected design positions?

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Introduction

Lifetime extension becomes soon important as the first larger offshore wind farms reach a mature age. For lifetime extension, a reassessment of structural integrity of the support structure is needed. Environmental conditions vary within **large wind farms** and lead to location-specific loading. This study addresses if reassessment must be performed for each turbine when **hydrodynamic parameters** change uniformly in the wind farm – or if trends can be derived from **design positions**? In this study, **time-domain simulations** were performed to reassess fatigue loads for monopile support structures located at five positions within a fictive wind farm. Results are presented for **turbine operation;** idling was not addressed at this stage of the project.

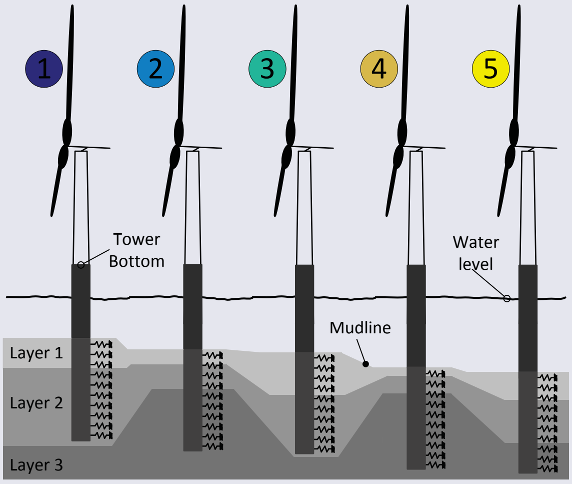
Numerical Model

OFFSHORE WIND TURBINE

- Monopile with NREL 5MW reference turbine atop (used in Phase II of the OC3 project)
- Soil-pile interaction is modelled with lateral springs distributed along the pile
- Implemented in the flexible multibody simulation tool Fedem WindPower (Version R7.2)

GENERIC OFFSHORE WIND FARM

- Reference values from UpWind Design Basis[1] with variations in water depth and soil conditions
- Length of monopile adjusted to water depth (no changes in dimensions of monopile)
- Unidirectional wind and waves
- Wake effects are taken into account using Frandsen wake model[2]



Pos	water depth [m]	f_{nat} [Hz]
1	15	0.246
2	20	0.237
3	22	0.232
4	26	0.226
5	30	0.217

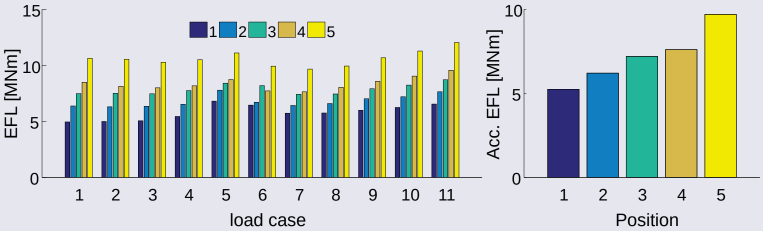
Load Simulations and Equivalent Fatigue Load Calculation

Load analyses were carried out under combined aero- and hydrodynamic loading in time-domain. In total 11 operational load cases with wind speed in the range between 4m/s and 24m/s were performed. Each load case with a duration of 3600 seconds (excluding transients). Wind turbines located at five different positions with variations in terms of soil conditions, water depth and neighboring wind turbines (wake effect) are selected. Load simulations were performed for each position individually. Bending moments at tower bottom are extracted and used to calculate an Equivalent Fatigue Load (EFL):

$$EFL = \left(\sum_{i=1}^{N} \frac{S_i^m}{N} \right)^{\frac{1}{m}}$$

Fatigue Assessment for Design

Results are shown for EFLs per load case and position and the accumulated EFL per position.



Equivalent Fatigue Loads per load case and accumulated fatigue damage

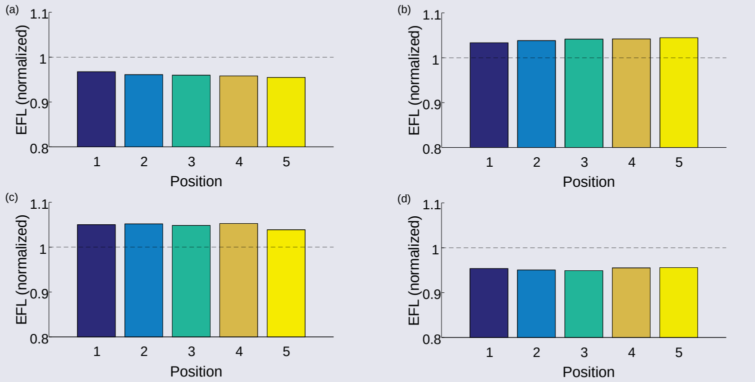
- Load cases are weighted with the probability of occurrence
- Increase of total EFL with increasing water depth

Fatigue Reassessment

In order to account for discrepancies between environmental data used for the design and the actual environmental conditions that the offshore wind turbine was exposed to during operational life, the significant wave height (H_s) and peak period (T_P) were changed in a range of 5% around their original value. Structural loads were recalculated using the same numerical models, but updated environmental data. The fatigue assessment is performed in the same manner as it was done for the design phase, allowing a comparison between design and reassessment phases.

Single Parameter Variations

H_s and T_P are varied individually, while keeping the remaining parameters constant.



Accumulated EFL for (a) H_s -5%, (b) H_s +5%, (c) T_p -5%, and (d) T_p +5%. Results are normalized to the design case.

Peak period:

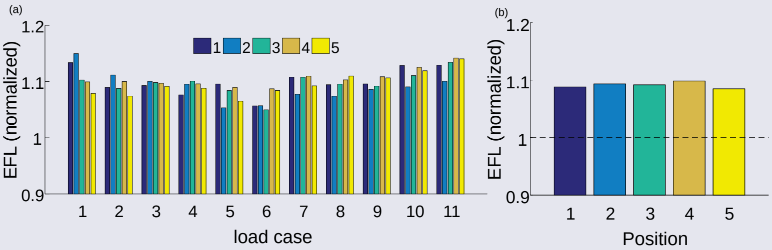
- A decrease of T_P moves the wave excitation frequencies closer to the fundamental frequency of the models, thereby increasing the fatigue loads on the structure
- Nearly linear behavior: a 5% change in T_P value leads to changes in accumulated EFL in the range between 4.4% and 5.2%

Significant wave height

- Similar to T_P, the accumulated EFL shows a nearly linear behavior for the changes within the range of +/- 5% for H_s

Combined Parameter Variations

For the case shown the parameters were simultaneously varied as follows: H_s+5% and T_p-5%.



(a) EFLs for the full set of load cases and all positions and (b) accumulated EFL. Results are normalized to the design case

- The combined variation shown in the figure above leads to higher EFLs for each load case in comparison to the initial design
- The accumulated EFL increases for all five positions in a similar range (8.5% - 9.5%)

Conclusions

- **Design:** Fatigue loads increase for deeper water and lower support structure natural frequency. This is in line with previous studies[3]
- **Reassessment:** Preliminary results indicate that an extrapolation from one position to others might be feasible. Results should be treated carefully as several limitations apply.
- **Limitations:** Idling load cases are missing (count up to 20% of fatigue life); other environmental and operational parameters apart from hydrodynamics must be assessed (wind speed, turbulence intensity, corrosion, turbine downtime, etc.)
- **Future work:** Include turbine idling and extend the study for other load-driving parameters

References

1. Fischer T., De Vries W., Schmidt B. (2010). UpWind Design Basis (WP4 : Offshore Foundations and Support Structures).
2. Frandsen S.T., Barthelmie R., Pryor S., Rathmann O., Larsen S., Højstrup J., Thøgersen M. (2006). Analytical Modelling of Wind Speed Deficit in Large Offshore Wind Farms. Wind Energy, 9(1-2), 39-53.
3. Ziegler, et al. (2015). Sensitivity of wave fatigue loads on offshore wind turbines under varying site conditions. Energy Procedia, 80, 193-200.

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