University of Stuttgart

Damage Assessment of Floating Offshore Wind Turbines Using Response Surface Modeling

Kolja Müller[a], Martin Dazer[b], Po Wen Cheng[a]
[a]Stuttgart Wind Energy (SWE), University of Stuttgart
[b]Institute of Machine Components (IMA), University of Stuttgart

Problem Description

Fatigue assessment for floating wind turbines is commonly established by comprehensive simulation studies of integrated time-domain simulations. Procedures which incorporate simplifications of the environment in order to limit the number of simulations typically lead to more conservative designs. An alternative approach is proposed here based on response surface modeling using Latin hypercube sampling and artificial neural networks (ANN). The presented method takes into account the statistical characteristics of environmental parameters during the systems life time (resulting in more realistic and accurate damage calculations) while keeping the numerical effort to a minimum.

Considered System and Environment

The considered system is the **DTU10MW** reference turbine positioned on the **SWE TripleSpar**. The turbine's characteristic wind speeds are:

$v_{cut-in} = 4\,\frac{m}{s}, v_{rated} = 11.4\,\frac{m}{s}, v_{cut-out} = 25\,\frac{m}{s}$

Simulations are carried out in time domain using **FAST8**, using BEM for aerodynamics, first-order potential-flow theory for hydrodynamics and a quasi-static model with dynamic relaxation for mooring line forces (MoorDyn).

The environment is set up based on **LIFES50+ site A** (mild environmental conditions) design load case (DLC) 1.2 [1]. Measurement data based on the ANEMOC and CANDHIS buoy network is used as well as FINO1data for turbulence intensity.

Figure 1: considered system

The variations of **wind speed, turbulence intensity, wave height and wave period** are considered in this study. Three **load ranges** are defined for differentiating between fundamentally different system behavior based on the controller mode: partial load range below rated wind speed (PLR), transitional load range around rated wind speed (TLR) and full load range above rated wind speed (FLR)

A reference case was established for comparison based on conservative assumptions of environmental conditions.

Response Surface Modeling (RSM)

The overall procedure used in this study is as follows:

1) Define simulation points using **Latin hypercube sampling (LHS).** We considered 3 different sample sizes for each load range: 50, 100 and 150

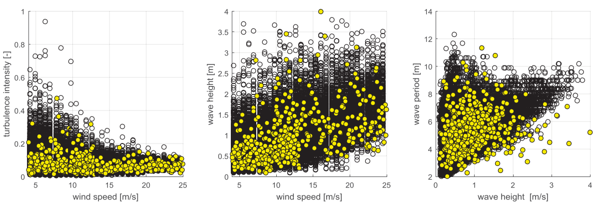

Figure 2: Environmental conditions. Original data from measurements (black) and determined from LHS-algorithm (shown here are the version with 150 samples per load range resulting in a total of 450 data points to be evaluated for the complete power production load case).

2) Carry out simulations, calculate damage equivalent loads (**DEL**)

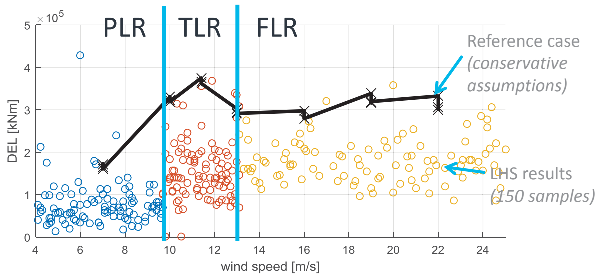

Figure 3: Tower base fore-aft DEL results for all load ranges (PLR: blue, TLR: red, FLR: yellow) from LHS simulations based on 150 samples.

3) Based on the simulation results, determine a **response surface using artificial neural network (ANN) regression.** Then, evaluate the regression model at defined bin centers of the environmental model. As the regression results change with each run, 20 regression evaluations were performed and the statistics of the results are analyzed.

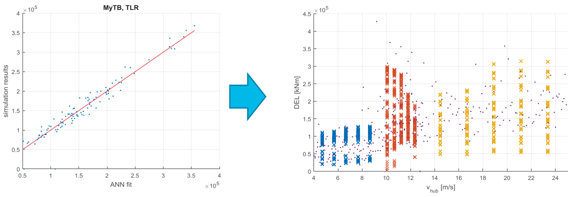

Figure 4: Performance of ANN describing damage equivalent load of tower base fore-aft bending moment. Simulation results vs. ANN fit- results (left plot) and
Exemplary comparison of LHS simulation results (dots) and RSM evaluation at grid center points (150 samples, all load ranges. PLR: blue x, TLR: red x, FLR: yellow x). (right plot)

4) Weight all bin-center DELs according to the related bin occurrence probability. Then calculate the **resulting DELs over lifetime.**

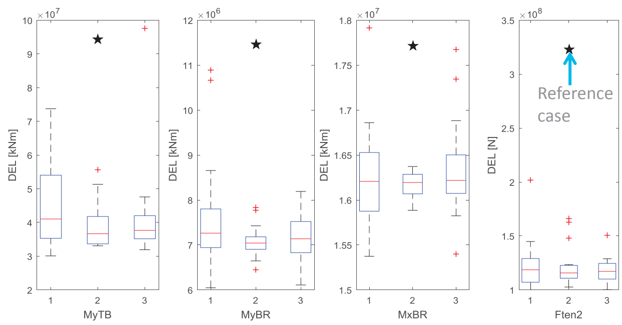

Figure 5: Box plots of predicted overall DELs from RSM evaluations for different positions (tower base, blade root, fairlead mooring line) based on different numbers of samples (1:50, 2:100, 3:150). Plot indicating median, 25th and 75th percentiles (boxes) and 0.35th and 99.65th percentiles (whisker). DELs from reference calculation indicated by ★.

Conclusions and Outlook

The first results of this initial, hypothetical study promise that a fully stochastic approach for fatigue assessment is possible and indicate the potential for a significant reduction of the fatigue load estimate. Future studies will focus on more accurate regression models and include more environmental conditions (e.g. wind direction, wind-wave misalignment, etc.).

Acknowledgements and References

The research leading to these results has received partial funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 640741 (LIFES50+).

[1] Antonia Krieger, Gireesh K. V. Ramachandran, Luca Vita, Pablo Gómez Alonso, Joannès Berque and Goren Aguirre, "LIFES50+ D7.2 Design Basis" DNVGL, Tech. rep. 2015.

SWE Stuttgart Wind Energy @ Institute of Aircraft Design

www.ifb.uni-stuttgart.de/windenergie