Recommendations for load validation of an offshore wind turbine with the use of statistical data – experience from alpha ventus
Project Partners

A. Load analysis and probabilistic load description
B. Load-reducing control and load monitoring
C. Design conditions for future wind turbines
Introduction

Measurement campaigns for offshore wind turbines

• Once the design of the turbine has been certified a prototype can be built for testing.

IEC-61400 -13 Measurements of Mechanical Loads:

• “This standard is aimed at the test institute, the turbine manufacturer and the certifying body and clearly defines the minimum requirements for a mechanical loads test …”

Why do we need this?

• “In the design stage, loads can be predicted with aero-elastic models and codes. However, such models have their shortcomings and uncertainties, and they always need to be validated by measurement. “
Open questions for offshore

Measurements

• How do we take into account the offshore environment? How do you include oceanographic measurements into the capture matrix? Should they even be included into the capture matrix?

Simulations

• How do we set up the simulation to represent the measurements taken? Do the measurement load cases (MLC) lead to a good comparison possibility with the design load cases (DLC)?

Validation

• Is there a clear procedure for validation?
On the subject of validation

General recommendations from Söker et al.

- Consistency of environmental conditions
- Consistency of turbine dynamic behaviour (frequencies)
- **Consistency of turbine characteristic curves**
- **Consistency of behaviour of loads and operational parameters** (time series and statistics)
- Consistency of fatigue characteristic behaviour
Methodology
Validation of computer models

GENERAL IDEA

• Use measurement data and compare it to simulation data on a statistical basis

BUT

• There are many different offshore turbine concepts (support structures, towers) so a general procedure is useful and necessary

• There are more environmental effects to take into account offshore, this leads to large scattering

Figure: Fore-aft damage equivalent loads for case of power production
Methodology

How to go about the comparison?

Possible approaches

1. Carry out the IEC 61400-3 design load case (DLC 1.1 and 1.2) simulations for power production and show that the simulations are conservative (fatigue and maximums)

2. Use a design of experiments methodology with full factorial or Box-Behnken representation of the measured environmental statistics as input for simulations (Müller et al.¹)

3. Chose only specific range of measurement events within know boundaries and pick representative parameters as input for simulations

Screened Statistical Data Comparison Method
Methodology
Screened Statistical Data Comparison Method

Screening of the data:

1. **List all meteorological and oceanographic parameters** needed for the validation, along with other parameters such as marine growth thickness and density.

2. Define which parameters need to be **binned**.
   
   E.g. wind speed.

3. Define which parameters will be **constrained**.
   
   E.g. only data from 5-7% turbulence intensity

4. Define which parameters are, for the purpose of the validation, **constants**.
   
   E.g. marine growth thickness or mean sea level
Methodology
Screened Statistical Data Comparison Method

Simulation parameters need to be set based on the screened data.

1. Determine a **mean value** representative of the bin or constraint

2. In the case that a bin or constraint is large, divide the constrained parameter into different mean values.
   
   E.g. wind wave misalignment is filtered from +60 to -60 degrees, the simulated misalignment can be +45, 0 and -45 degrees.

3. Determine the **number of seeds** that are appropriate for each simulation
Application of methodology in alphaventus

Measurement campaign

AV7 – statistical & 50Hz data
- SCADA
- strain gauges
- accelerometers

 calibration
 plausibility checks

FINO1 – statistical data
Meteorological measurements
e.g. - wind speed
- wind direction
- air temperature

Oceanographic measurements
e.g. - current
- wave conditions (sig. wave height, wave length)
Modeling of the turbine

SWE-Flex5 coupled with Poseidon

SWE - Flex5
- dynamic simulation of onshore wind turbines with max. 28 degrees of freedom

Poseidon (University of Hannover)
- linear finite element code specially designed for wave loaded space frame structures

Flex5 + Poseidon
- Integrated approach
- Coupled turbine, substructure and foundation model
- Validation model of AV04 jacket mounted turbine by Kaufer²

²: Kaufer D. 'Validation of an Integrated Simulation Method using High Resolution Measurements from Alpha Ventus', ISOPE 2013, Anchorage, Alaska
Screened Statistical Data Comparison Method

$1^{\text{st}}$ step: examples of screening of measured data

- Wave height
- Turbulence Intensity
- Free flow sector
## Example from alpha ventus

| Parameters            | Constraint or Binning                      | Values for data screening | Value for simulations | Seeds                  |
|-----------------------|--------------------------------------------|---------------------------|-----------------------|------------------------|
| **Wind condition**    |                                            |                           |                       |                        |
| Wind direction        | Free stream                                | 207-275 degrees           | 270 degrees           |                        |
| Mean hub wind speed   | 1m/s bins                                  | 3.5-23.5 m/s              | 4-23 m/s              |                        |
| Turbulence intensity  | Constrained                                | 5.5%-6.5%                 | 6%                    |                        |
| Wind shear            | Not binned or constrained                  | none                      | 0.14 power law exponent|                        |
| **Wave conditions**   |                                            |                           |                       |                        |
| Significant wave height| Constrained as function of wind speed      | Bin is defined as a function of the fitting curve of significant wave height vs wind speed. The bin will be +/- 0.5 m of the fitted significant wave height value for a given wind speed | For each wind speed bin, a significant wave height value is given by the best fit curve |                        |
| Peak spectral period  | Constrained                                | 6-8 seconds               | 7 seconds             |                        |
|**Wind and wave**      |                                            |                           |                       |                        |
| Misalignment          | Constrained                                | -30 to +30 degrees        | -30, 0, +30 degrees   | 3                      |
| **Sea currents**      |                                            |                           |                       |                        |
| Current velocity      | Not binned or constrained                  | none                      | 0 m/s                 |                        |
| Direction             | Not binned or constrained                  | none                      | -                     | -                      |
| **Water level**       |                                            |                           |                       |                        |
| Mean sea level        | Not binned or constrained                  | none                      | 27 m design basis     |                        |
| **Air Properties**    |                                            |                           |                       |                        |
| Density               | Not binned or constrained                  | none                      | 1.225 kg/m^3          |                        |
| **Marine growth**     |                                            |                           |                       |                        |
| Thickness             | Not binned or constrained                  | none                      | 0.05 m                |                        |
| Density               | Not binned or constrained                  | none                      | 1325 kg/m^3           |                        |
| **Wind/Yaw**          |                                            |                           |                       |                        |
| Misalignment          | Not binned or constrained                  | none                      | -5.0, +5 degrees      | 3                      |
| **Soil parameters**   |                                            |                           |                       |                        |
| Scour                 | Not binned or constrained                  | Not available             | None                  |                        |
| Stiffness and Damping | Not binned or constrained                  | Not available             | Provided by manufacturer |                        |
Example Results

Power production

Losses dependant on location of measurement point
Example Results

Generator speed

Screening without wave period restriction

University of Stuttgart, Stuttgart Wind Energy (SWE) @ Institute of Aircraft Design
Example Results

Fore-aft tower base bending moment

Good agreement of comparison
Example Results
Blade flapwise bending moments

Model dependant limitations of the standard deviation and DEL
Conclusions

• The simple methodology shows to be useful for the validation of statistical data
  The designer or validation engineer can therefore better understand the capabilities of the simulations
  Limits appearance of outliers and scattering when comparing data

• We need computer models we can trust but models themselves will always have limitation
  Careful interpretation of results necessary
Outlook

• **Importance of wake**: this also needs to be analysed as fatigue loading can be driven by this situation
  • but difficulty determining inflow wind speeds and turbulence intensities

• **Effects of other parameters**: by using the same *Screened Statistical Data Comparison Method* but changing the screening parameters, other effects can be investigated,
  • E.g. high turbulence intensities, hydrodynamic loads
Thank you for your attention

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