Evaluation of the extreme and fatigue load measurements at alpha ventus

Ricardo Faerron, Sarah Lott, Kolja Müller, Prof. Dr. Po Wen Cheng

Stuttgart Wind Energy (SWE), University of Stuttgart

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Project Partners

Work Packages

OWEA LOADS

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

Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Projektträger

Koordination
Presentation Content

Extrapolation
1. What are the procedures for extrapolation of ultimate loads from measurements?

Fatigue in Wake
2. What is the deviation measured in the fatigue loads of two turbines in a wind park?

IEC Simulations
3. What are the effects of the stochastic environmental conditions which are not considered in the design guidelines?
Part 1

Extrapolation

1. What are the procedures for extrapolation of ultimate loads from measurements?

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General Idea of Extreme Load Extrapolation

For DLC 1.1 the characteristic value of load shall be determined by a statistical load extrapolation and correspond to an exceedance probability, for the largest value in any 10-min period, of less than or equal to $3.8 \times 10^{-7}$, (i.e. a 50-year recurrence period) for normal design situations. For guidance see Annex F.

No detailed information about the extrapolation procedure is given
→ room for interpretation

Methods were developed for simulation data
→ unique opportunity to apply the methods to offshore measurement data
Load Extrapolation Procedure

- load data
  - global maximum method
  - block maximum method
  - peak over threshold method

- extreme load samples
  - distribution function, e.g.
    - Gumbel
    - Weibull
    - GEV
    - Lognormal
    - Gamma
  - fitting method, e.g.
    - method of moments
    - maximum likelihood
    - least squares

- extreme load estimation for a specific return period

- short-term and long-term distribution
Database for Extrapolation

Restrictions:
- Status signal: Production, Power > 200kW
- Freestream

5MW wind turbine
AD 5-116

3 years of measurement data
The estimated extreme load essentially depends on the choice of the distribution function.
Conclusion and Outlook

Which distribution function fits the evaluated measurement data best?

Goodness of fit tests for all wind bins
→ Lognormal distribution

Conclusion:
• Load extrapolation with measurement data results in plausible extreme loads.
• Lots of processing of the data is necessary.

Outlook:
• Further investigation of different extrapolation methods.
• Comparison to simulation data.
Part 2

Extrapolation

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IEC Simulations

3. What are the effects of the stochastic environmental conditions which are not considered in the design guidelines?
Two cases can be analysed

**Case A**
AV8 in wake of AV7

**Case B**
AV7 in freestream

**Data sorting**
- 13 Months – Data from 01-Oct-2010 to 31-Oct-2011
- 10 min time series
- Power production
- No curtailment

Edge and flap strain gauge sensors

Adwen 5MW
AD 5-116
Case A: AV8 in Wake
Damage equivalent loads (DEL) on the blades

Turbine AV8 in Wake
Normalized DEL

Turbine AV7 in Freestream
Normalized DEL

DEL Edgewise

DEL Flapwise

Fino1 WdSpd @ 90m
Comparing the damage on the blades based on linear damage accumulation and the Palmgren-Miner Rule
Case B: Freestream vs Wake
Comparing Damage of Flap Measurements

Turbine AV7 in freestream
Turbine AV8 in wake
Rated wind speed = 12.4 m/s
Case B: Freestream vs Wake
Outliers for flap sensors

**Conclusion:**
- A better understanding of outliers is needed to properly characterize damage and fatigue of measurement data.
Part 3

Extrapolation
1. What are the procedures for extrapolation of ultimate loads from measurements?

Fatigue in Wake
2. What is the deviation measured in the fatigue loads of two turbines in a wind park?

IEC Simulations
3. What are the effects of the stochastic environmental conditions which are not considered in the design guidelines?
Validation of IEC 61400-3: DLC 1.2 (fatigue + production)

1. What is the scatter range of IEC simulations?
2. Can load scatter be captured with simulation model?
Scatter range of loads from IEC simulations

SWE Computer Model

- 100 simulations
  - Per wind bin

Weibull dist.

- 100 simulations
  - Take DEL of 6 simulations per bin

Damage

- Over lifetime (20 yrs)

Repeat 10,000 times

→ scatter included in IEC assumptions low in comparison to measurements
→ damage scatter around rated wind critical

Graph 1: Comparison of damage scatter from IEC DLC 1.2 simulations to measurements

Graph 2: Damage over lifetime (20 yrs) for 100 simulations per wind bin

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Capture load scatter through consideration of scatter of environmental conditions

Design of Experiment: 3 step, Full Factorial = 4374 simulations
Box Behnken = 738 simulations

Consider scatter of:
- Wind speed
- Turbulence intensity
- Wind shear
- Wave height
- Wave period

Based on 5 year Fino1 data

Conclusion:
- Stochastics of measured loads can be simulated when considering scatter of environmental conditions
- Turbulence intensity major contributor to scatter of DEL (MyTB)
Summary

- Extrapolation of measurements show how the extrapolated load depends heavily on the distribution function used.

- Characteristic behaviour of fatigue on blades has been shown. While a better understanding of outliers is necessary to understand measurement of loads.

- Scattering of load measurements can be captured through consideration the stochastic environmental condition in the simulations.
Thank you for your attention
The damage caused by a load spectrum of \( n \) cycles with ranges \( S_{r,i} \)

\[
D = \sum_{i=1}^{n} \frac{1}{k \cdot S_{r,i}^{-m}}
\]

\( Sr = \) is the range of a load cycle
- \( 1/m = \) is the slope of the S-N line on log-log scale

Case B: Freestream vs Wake
Comparative Damage Edge Sensors

AV7 in freestream
AV8 in wake
Rated wind speed = 12.4 m/s