Uncertainties in Turbulent Wind Modelling for Offshore Wind Turbines

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Outline

- Motivation & Background
- Uncertainty in the turbulence models in the IEC standards
- Uncertainty in the standards versus site specific models
- Uncertainty due to changing atmospheric stability
- Future work
Turbulence models in the standards

- Kaimal spectrum and exponential coherence model (TurbSim):
  - Spectral densities and coherence explicitly given
- Mann model (DTU Mann64 generator):
  - Three-dimensional velocity spectral tensor and coherence tensor

- Both models are based on neutral atmospheric conditions and developed using onshore measurements only
Atmospheric Stability

UNSTABLE
Parcel has positive buoyancy and will continue to rise

NEUTRAL
Parcel has no net buoyancy and will remain at that height

STABLE
Parcel has negative buoyancy and will return to original level
Variation in Atmospheric Stability Offshore

FINO 1

FINO 3

FINO 2
Simulations

- **OC3-Hywind**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine</td>
<td>NREL 5MW</td>
</tr>
<tr>
<td>Cut-in, rated, cut-out wind speed</td>
<td>3, 11.4, 25 ms⁻¹</td>
</tr>
<tr>
<td>Hub height</td>
<td>90 m ASL</td>
</tr>
<tr>
<td>Cut-in, rated rotor speed</td>
<td>6.9, 12.1 rpm</td>
</tr>
<tr>
<td>Water depth</td>
<td>320 m</td>
</tr>
<tr>
<td>Draft</td>
<td>120 m</td>
</tr>
<tr>
<td>Mooring line</td>
<td>3 lines, 120° apart from each other</td>
</tr>
</tbody>
</table>

- **SIMO-RIFLEX®** - A coupled simulation tool available in Simulation Workbench for Marine Application (SIMA). This coupled tool is able to perform aero-hydro-servo elastic simulations. SIMO models the flexible multibody system and RIFLEX performs finite element method to slender bodies to get forces and deflections of body members.
The Mann Model in the IEC has higher spectral energy for the along wind component and also higher levels of coherence.
Uncertainty in the two spectral models in the standards

- Wind turbine class C (12% TI at hub height)

<table>
<thead>
<tr>
<th>Component</th>
<th>DEL Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower top torsion</td>
<td>40%</td>
</tr>
<tr>
<td>Tower base fore-aft</td>
<td>10%</td>
</tr>
<tr>
<td>Blade root flap-wise</td>
<td>17%</td>
</tr>
<tr>
<td>Blade root edge-wise</td>
<td>12%</td>
</tr>
</tbody>
</table>
Standard Spectral Model versus Site Specific Model

- Up to 50% difference in DEL prediction
- Input:

<table>
<thead>
<tr>
<th>Uhub (m/s)</th>
<th>TI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>9.61</td>
</tr>
<tr>
<td>11.4</td>
<td>6.90</td>
</tr>
<tr>
<td>15</td>
<td>5.25</td>
</tr>
</tbody>
</table>

Max difference in DEL*:

- Tower base fore-aft: 7.8%
- Blade root flap-wise: 12%
- Blade root edge-wise: 0.5%
Højstrup spectral model – unstable conditions

- Højstrup spectral model: derived based on Kaimal spectral model, especially developed for unstable diabatic conditions:

\[ S(n) = S_L(n) + S_M(n) \]

Low-frequency part \quad High-frequency part (Kaimal spectral model)

- Parameters: boundary layer height \( z_i \), Obukhov-length \( L \), height \( z \)
- In combination with Davenport coherence:

\[ Coh_i(n) = \exp \left[ -\frac{n}{u} \sqrt{(C_i^y d_y)^2 + (C_i^z d_z)^2} \right] \]

- Developed for unstable conditions but using onshore data
Højstrup Results – DEL’s

Up to 65% difference for yaw between neutral (Kaimal) and very unstable (Højstrup L=-50m)

Up to 37% difference for tower base side-side

Up to 24% difference for blade root flap-wise bending

Up to 7% difference for tower base fore-aft bending

Up to 3% difference for blade root edge-wise bending
Pointed-Blunt Model fitted to FINO 1 data

The general form of the PB model

\[
\frac{nS_i}{u_x^2} = \frac{a_i f}{(1 + b_i f)^{5/3}} + \frac{a_2 f}{1 + b_2 f^{5/3}},
\]

Where \(a\) & \(b\) are empirical coefficients

The form of the PB model for stable conditions

\[
\frac{nS_i}{u_x^2} = \frac{a_i f}{(1 + b_i f)^{5/3}} + \frac{a_2 f}{1 + b_2 f^{5/3}} + a_3 f^{-2} + a_4 f^{-2/3}.
\]

Spectral & coherence model was derived in the study of (Cheynet et al., 2018) using data from FINO1 measurement platform. This is only verified for vertical separations.
Platform PSD – yaw motion (below rated)

![Platform PSD diagram]

- **Platform yaw**
- **Wave**
- **Controller low-pass filter**
- **3P**

<table>
<thead>
<tr>
<th>U = 8 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Very unstable (L=-41)</td>
</tr>
<tr>
<td>- Unstable (L=-90)</td>
</tr>
<tr>
<td>- Weakly unstable (L=-180)</td>
</tr>
<tr>
<td>- Near unstable (L=-300)</td>
</tr>
<tr>
<td>- Neutral (L=Inf)</td>
</tr>
</tbody>
</table>
Platform PSD – yaw motion (above rated)
Tower top Torsion using BPM model fitted to FINO 1 data

Pointed-Blunt (max. DEL difference)

- Tower top torsion: 24%
- Tower base fore-aft: 2%
- Blade root flap-wise: 6%
- Blade root edge-wise: 1%
Conclusions

- The IEC Mann model is the most conservative spectral model used in our studies so far.
- The tower top yaw appears to be very sensitive low frequency input and coherence.
- The tower top torsion DELs were most affected, however significant uncertainty was also observed for the tower base side to side and blade root flap DEL’s.
- Atmospheric stability has a very important effect on the DELs of a spar floating offshore wind turbine.
- A recent JIP also found that unstable conditions are dominant (>60%) offshore which is contrary to onshore sites, where neutral conditions are prevalent.
- The Mann model has been fitted to measurements offshore but it is known to fit poorly under unstable conditions, especially in the low frequency range. Very sensitive to the low frequency cut-off chosen.
Future Work

- New measurements from the COTUR project will hopefully provide new information on coherence for horizontal separations.
- Simulations using modified Mann spectral tensor model (Chougule et al., 2018) – with the possibility of deriving parameters from offshore data into the models. This model is known to be poor at simulating unstable conditions.
- Comparing various floater models and rotor sizes (Bachynski & Eliassen, 2018).
- Rather than trying to fit neutral based onshore models to offshore data maybe we need to start from scratch and develop a specific model that can properly describe unstable conditions offshore?
Breaking and Extreme Wave Loads on OWT

WAVESLAM PROJECT
Wave tests in the Large Wave Flume FZK.

DeRisk Project: De-risked extreme wave loads for offshore wind energy – DTU Oxford UiS DHI Statkraft Equinor

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Full Scale Measurements of Wind Turbulence
for structural engineering and wind energy applications

Illustration of the floating bridge concept
(Foto: SVV / ViaNova / Baezeni)

Deployment of a long range LIDAR at a bridge site
(UiS, UiB, CMR, 2014)


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Dynamic Analysis of Floating Offshore Wind Turbines

Analysis of Floating Horizontal and Vertical Axis OWTs

Installation of Bottom-fixed and Floating Wind Turbines
Computational Fluid Dynamics

Wind-wave interaction

Turbulence modelling

Wind turbine on a fish feeding barge

Associate Prof. Knut Erik Giljarhus
Failure Analysis and Monitoring of Mechanical Components

Bearing of a land-based wind turbine

Wear evolution monitoring at UiS

Healthy case

Faulty case

Associate Prof. Idriss El-Thalji
Any Questions?