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Structural load validation for wake situations using alpha ventus measurement data

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WINDFORS Windenergie Forschungscluster

Motivation

Offshore load validation in wake conditions

Wake Effects

- Increase of turbulence intensity
- Wind speed deficit
- Wake meandering



Downstream wind turbines

- Less power production
- Higher structural loads



Motivation

Offshore load validation in wake conditions



FAST.Farm Model

- Mid-Fidelity tool for simulating wind farms developed at NREL with modifications by SWE
- Aero-hydro-servo-elastic interactions in a wind farm

Wind farm dynamics

- Wake calculation based on dynamic wake meandering model (DWM)
- Wake merging by superposition
- Wake added turbulence (implemented by SWE)
- Supercontroller



Wind turbine dynamics

- OpenFAST simulation
- Aerodynamics (BEM)
- Structural Dynamics (MBS)
- Hydrodynamics (Strip theory)
- Turbine Controller

Measurement Data Analysis

Data Basis



- Meteorological measurement at Fino 1 met mast
- Turbine load measurements at AV4 and AV5
 - Senvion 5M turbines
 - 5MW rated power
 - Diameter = 126m

Measurement Data Analysis

Turbine measurements



- SCADA measurements (Generator power / speed, Yaw – position, Blade pitch)
- Strain gauges: tower base, blade root
- Sampling frequency: 50 Hz
- Investigated period: 01/2016 07/2018

Fullscale Validation Uncertainties Match? **Measurements Simulation Model Uncertainties Reducing Uncertainties** Meteorological Conditions met mast 126 m rotor diameter (Calibration necessary) Hub height at LAT +92 m Hub **Turbine Load** - Calibration with Nacelle Nacelle **Measurements** Rotation, Idling Rotor Tower - Sensor redundancy **Turbine Dynamics** Model tuning with TP (asymmetric system: pitch measurements LAT error, mass imbalances (frequency response) Jacket subetc.) structure Seabed at LAT -28m Simulation methodology Model tuning with measurements (e.g. modal damping)

Results: Selected simulation case

Environmental conditions: Co-simulation approach

	Measurement	Simulation
Wind speed	6.5 – 7.5 m/s	
Turbulence intensity	3 – 15 % (mean: 6%)	
Power law shear exponent	0 – 0.2 (mean: 0.03)	
Atmospheric stability	unstable (52 %), neutral (29 %), Stable (19 %)	
Sea state: significant wave height	1.1 – 3.2 m	

Validation results

Power deficit



- 50 % less power production in full wake conditions
- Power deficit well captured by FAST.Farm



Validation results

Tower base: damage equivalent loads (DEL)

290° AV1 AV2 AV3 Rotor Diameters [-] -10 -12 AV4 AV5 Fino 1 AV6 272° 272° 6.7 D 3.2 D 250° AV7 AV8 AV9 AV10 AV11 AV12 -20 -5 0 5 10 15 20 Rotor Diameters [-]

- Up to 2.5x increase in loads during full wake conditions (measurements)
- Trends are captured with FAST.Farm in good agreement





Conclusions

- 1. Strong wake deficit and increase in structural loads observed in wake conditions
- Accurate predictions of turbine performance and structural loads possible with FAST.Farm
- 3. Very careful data treatment and simulation setup necessary
 - \rightarrow RAVE data basis proved to be very valuable

 \rightarrow Stay tuned: Journal publication aimed including more details

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Thank you!



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