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Assessment of wind turbines fatigue life consumption at the site

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Abstract

Wind turbines (WT) are normally designed for 20-25 years lifetime. However, actual (site) conditions under which turbines operate are usually milder than those considered during the design process, allowing for an extended service life that can be appreciated through theoretical analysis even before the wind farm construction. Service life extension of an asset has a positive impact on its economics. Furthermore, due to the liberalization of the electricity market, wind farm operators are obliged to participate in the daily market, thus having the opportunity to value their bidding prices and income against the real-time fatigue life consumption of their assets. It is therefore important to have the ability to reduce production in periods of low prices but high life consumption.

In this work, we present a comprehensive time domain methodology for estimating fatigue loading and expected service life of wind turbines in connection to their power production. The procedure comprises in-house tools for servo-aero-elastic calculations [1], micro-siting with CFD [2] and SCADA analysis, which feed-in a neural network-based regression algorithm to obtain fatigue loads, lifetime and power production estimates. The proposed methodology can also assess the effect of various operational or control parameters driving fatigue consumption (e.g. de-rated operation , sector management, soft shut down/storm control, peak shave).

Objectives

a. Build-up a comprehensive methodology for estimating fatigue loading and expected service life of wind turbines in connection with power production
b. Identify and assess critical for fatigue consumption inflow conditions
c. Suggest and assess i) specific control algorithms for mitigating fatigue consumption, ii) substitution of replaceable components to improve lifetime

Method

The developed Lifetime Estimation procedure comprises the following:

a. SCADA data analysis (when available) to obtain WT characteristics for tuning the generic aeroelastic model, WTs availability and inflow conditions
b. Definition of WT generic servo-aero-elastic model, based on available data (e.g. brochures, general specifications, drawings, SCADA)
c. Wind measurements analysis and estimation of inflow conditions per WT through CFD micro-siting
d. Build of fatigue loads (DELs) database for predefined “load sensors” along the WT’s components from aero-elastic calculations for various inflow conditions
e. Estimation of the expected lifetime per WT component based on Palmgren-Miner rule by comparing the actual (at the site) against the design damage. Fatigue damage is estimated through Neural Network-based regression of the DELs database for the full set of inflow conditions.
f. Uncertainty analysis, regarding the inflow conditions and the generic model
g. Suggestion of sector management schemes, if needed (optional)

Conclusions

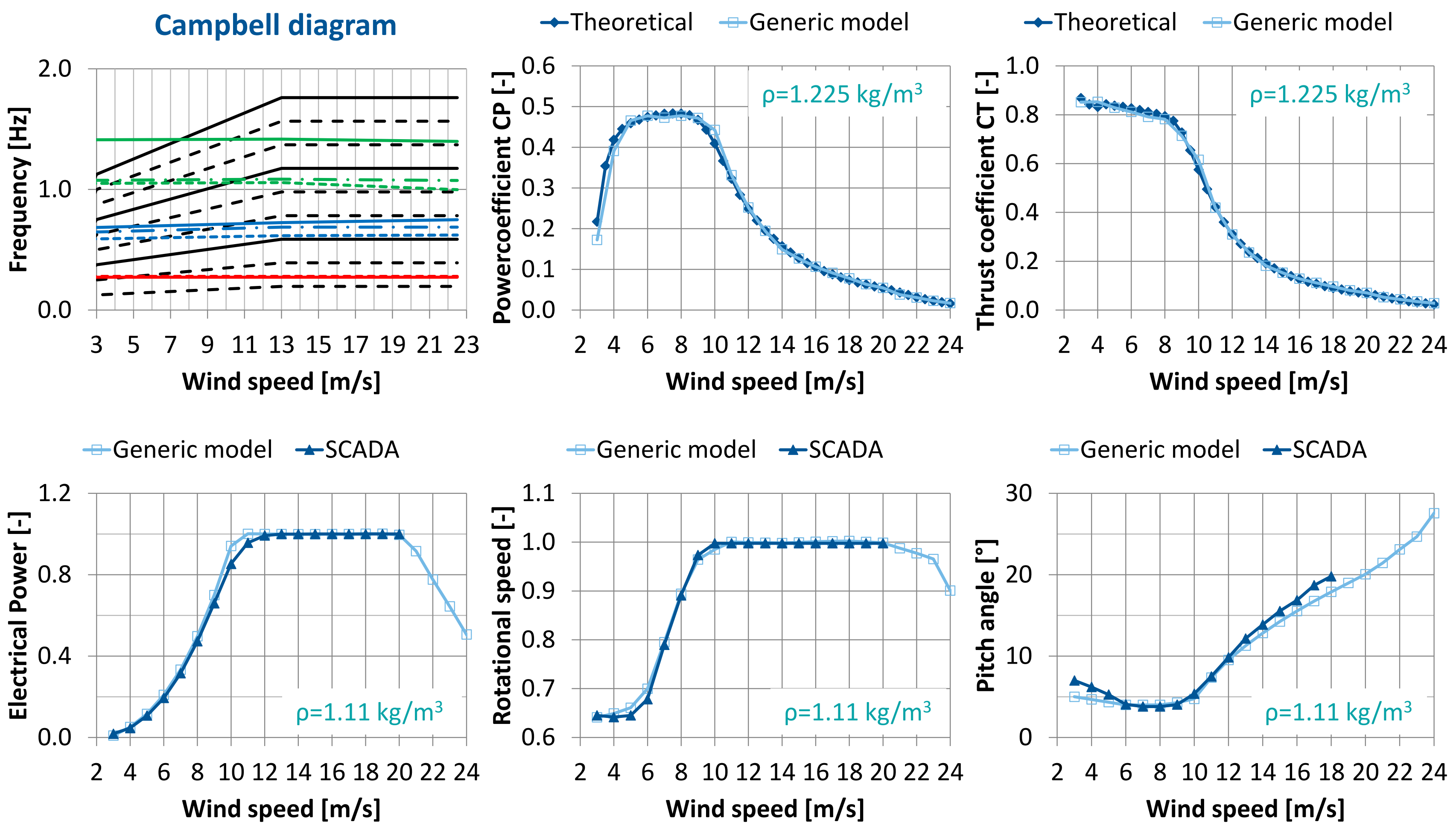
A comprehensive methodology for estimating fatigue loading and expected service life of wind turbines in connection to their power production is presented. The main output from the above analysis is the estimation of the actual fatigue life, based on a synthesis of measured and calculated wind inflow conditions. In complex terrains, fatigue lifetime may be consumed within a very limited inflow range (e.g. wind yaw direction) that may be effectively avoided with an almost zero penalty on power production through proper management schemes (defined through a cost-benefit analysis, i.e. life consumption vs power production). In addition, fatigue life of a turbine may be extended by substituting replaceable components such as bolts, bearings or even the blades.

References

1. D. I. Manolas, V. A. Riziotis, and S. G. Voutsinas, Assessing the importance of geometric non-linear effects in the prediction of wind turbine blade loads, *Computational and Nonlinear Dynamics*, 2015, 10, 041008, https://doi.org/10.1115/1.4027684.
2. E. S. Politis and P. K. Chaviaropoulos, “Micrositing and Classification of wind turbines in complex terrain,” in Proceedings of *2008 European Wind Energy Conference and Exhibition*, Brussels, Belgium, 2008.

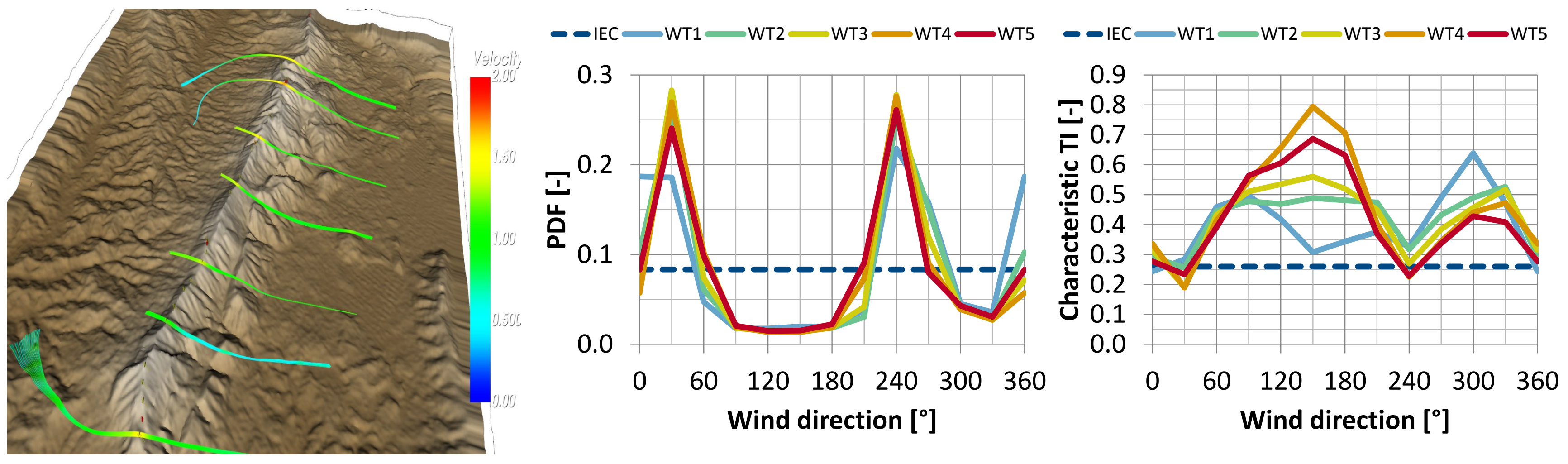
Results

Generic aero-elastic model



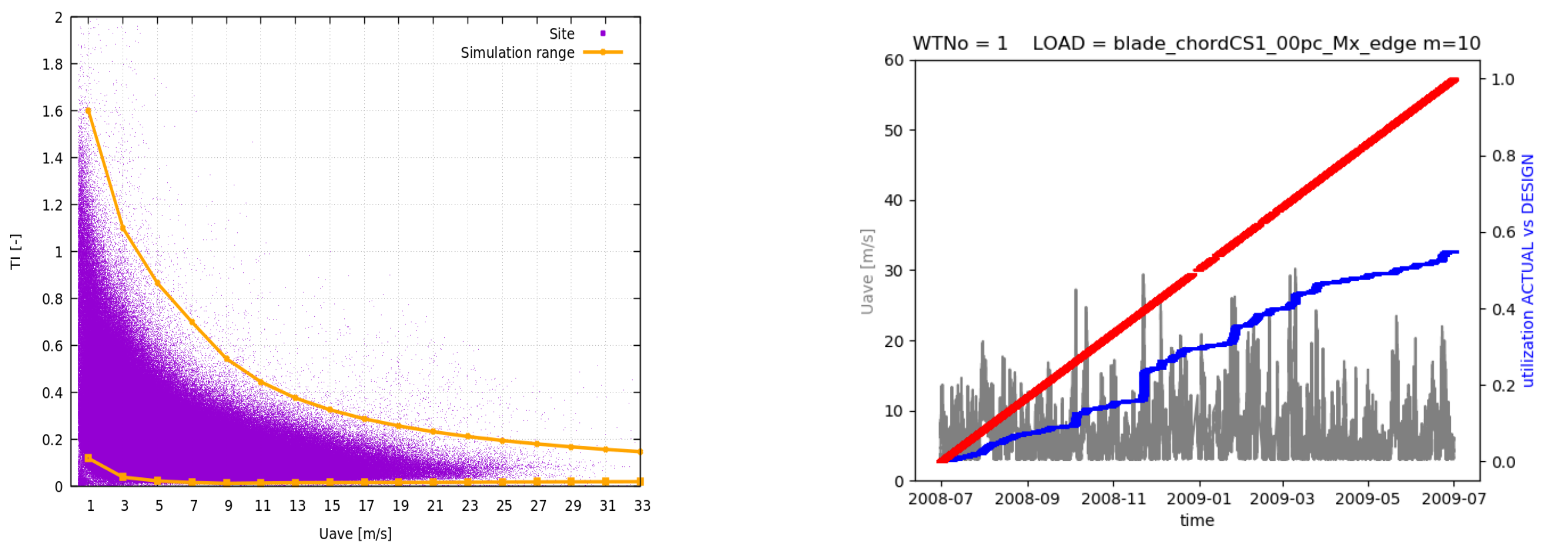
Generic model’s Campbell diagram, power and thrust coefficients (top) and verification against SCADA recordings for power, rotor speed and blade pitch (bottom).

CFD-based micro-siting



Speed-ups and stream-ribbons (left), PDF of wind direction (middle) and Characteristic turbulence intensity per direction (right).

Fatigue damage & lifetime estimation



Turbulence intensity values corresponding to site conditions and aeroelastic simulations (left) and time series of fatigue utilization factor of edgewise moment at the blade root (right).

Lifetime estimation

	Component	WT1	WT2	WT3	WT4
Cat.1 (P90)	Tower	>40.0	>40.0	>40.0	>40.0
	Nacelle Welded	>40.0	>40.0	>40.0	>40.0
	Nacelle Cast	29.7	>40.0	>40.0	>40.0
	Hub	34.4	39.0	35.5	35.3
Cat.2 (P75)	Blade Flap	23.5	>40.0	>40.0	>40.0
	Blade Edge	27.6	>40.0	28.5	33.9
Cat.3 (P75)	Pitch mechanism	>40.0	>40.0	>40.0	>40.0
	Blade/Hub interface	26.8	29.7	29.4	29.7
	Hub/Shaft interface	>40.0	>40.0	>40.0	>40.0
	Yaw mechanism	>40.0	>40.0	>40.0	>40.0
	Nacelle/Tower interface	>40.0	>40.0	>40.0	>40.0
	Minimum Lifetime	**23.5**	**29.7**	**28.5**	**29.7**
	Extended Lifetime	**29.7**	**39.0**	**35.5**	**33.9**

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