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Long-term floating wind turbine performance under met-ocean conditions influence

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Abstract

Under severe operating conditions, the motions of a floating wind turbine might exceed certain safety limits and thus impose the machine shutdown. This results in a loss of energy production. Here, a methodology for evaluating the effect of met-ocean conditions on the long-term dynamic response of such systems is proposed. Given a chosen offshore location, off the coast of Aguçadoura (Portugal), wind and wave data are extracted from reanalysis databases, for a window of twenty years with hourly resolution. The response of a sample floating wind turbine is simulated in the time domain for a subset of 1000 conditions, selected using a maximum dissimilarity algorithm (MDA). Results are then interpolated for the whole set of data using radial basis functions (RBF). This approach allows to drastically reduce the computational effort. Tower inclination and hub acceleration are selected as relevant operating parameters: when they exceed a given safety tolerance, the wind turbine is supposed to be shut down. The average capacity factor is 33.4% if no stops are considered, and reduces non-linearly as more restrictive tolerances are given. This approach may be helpful in evaluating a balanced tradeoff between energy production and reliable operation, bridging the design and operational phases of a wind energy project.

1. Objectives

- Quickly evaluate the **long-term** response of a floating wind turbine, i.e.:
  - Platform displacements
  - Nacelle acceleration
  - Mooring line tension
- Get information about static and **dynamic** loads acting on critical points of the system.
- Assess the influence of **operating thresholds** on the energy production

2. Methodology

- Extract met-ocean data from **reanalysis databases**, a known and reliable source of information [1], already used in a wide range of marine engineering applications [2] [3].
- Select a relevant subset of met-ocean data, by means of a **maximum dissimilarity algorithm** (MDA), able to represent the climate variability at the chosen offshore location.
- Simulate the behavior of the floating wind turbine, for the selected climate conditions, by means of a **time domain model**.
- Interpolate relevant results over the whole set of data using **radial basis functions** (RBF).

3. Results

3.1 DATA EXTRACTION

The location chosen is located 5 km off the coast of **Aguçadoura, Portugal** (Fig.1). The site presents a marked W-NW dominant wave direction (Fig. 2), which is associated also to extreme wave height events. The wind rose highlights a wider spreading for the wind speed direction (Fig.3), which still has N-NW as most probable valı

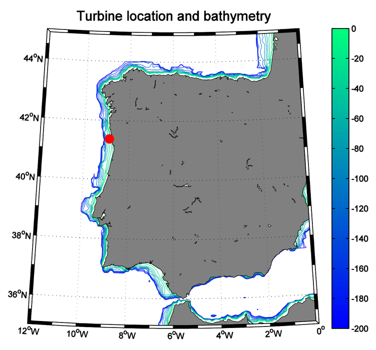

Figure 1. Turbine location and bathymetry

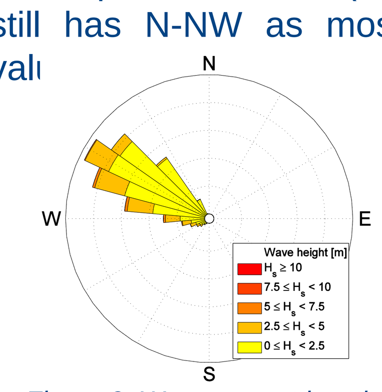

Figure 2. Wave rose at location.

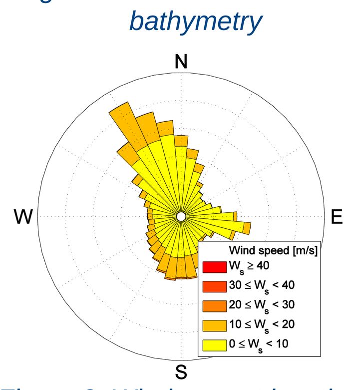

Figure 3. Wind rose at location.

3.4 RBF INTERPOLATION

In Figg. 6-8 it is possible to appreciate results of the RBF interpolation for **platform roll**, **hub acceleration** and **mooring line tension at fairleads**.

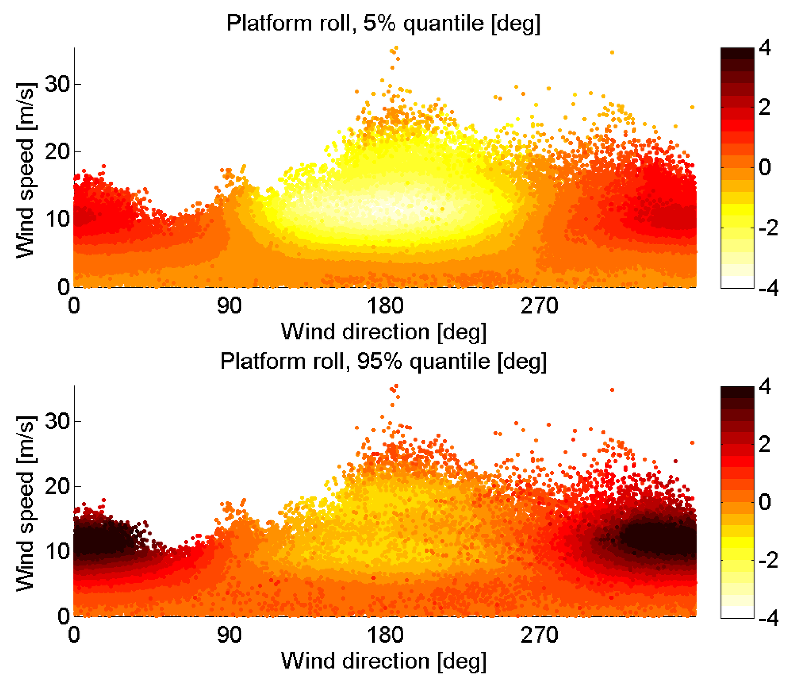

Figure 6. Roll displacement (5% and 95% quantile) as function of wind speed and direction.

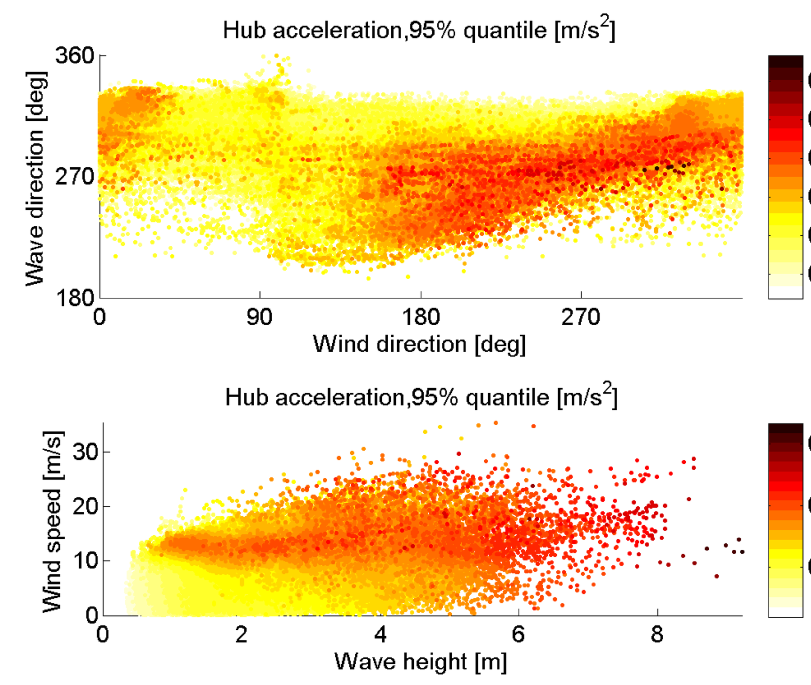

Figure 7. Hub acceleration (95% quantile) as function of a) wind and wave directions, b) wind speed and wave height.

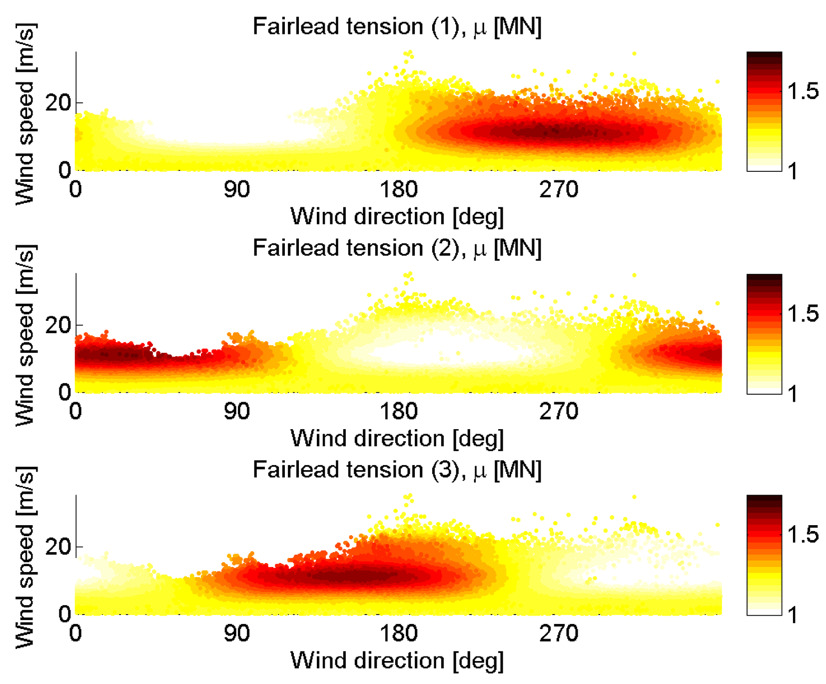

Figure 8. Mooring tension (95% quantile) fairlead for three catenary lines, as function of wind speed and direction.

3.2 DATA SELECTION

Met-ocean data come from reanalysis databases developed at IH Cantabria [1], for a time span of 20 years with 1 hour resolution. A subset of **1000 met-ocean conditions** has been selected (see Fig. 4) by means of MDA.

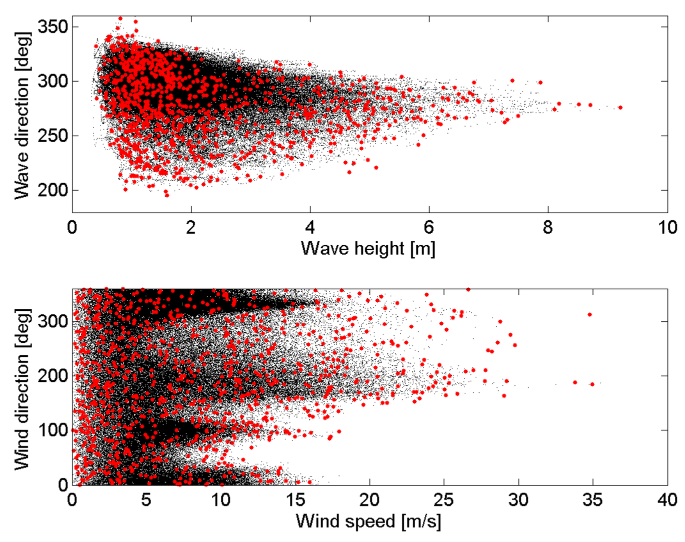

Figure 4. Selection of 1000 met-ocean conditions by means of MDA algorithm (black: 20 years data, red: selected)

3.3 TURBINE RESPONSE SIMULATION

Irregular wave and turbulent wind time histories were input to a time domain floating turbine model, which includes:

- Linear hydrodynamics modelling.
- Quasi-static mooring formulation.
- Quasi-static thrust force modelling, based on instantaneous relative wind speed calculation (see Fig. 5).

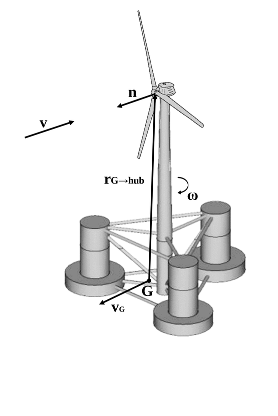

Figure 5. Sketch of the OC4 semi-submersible platform.

The system under consideration is the OC4 platform [4], which mounts the NREL 5 MW wind turbine.

3.5 CAPACITY FACTOR ESTIMATION

Safety tolerances are strictly related to platform motions since they may affect severely the system reliability and performance [5]. Here, the operating parameters chosen are:

- **Tower tilt**, since it is directly related to tower base bending moment (nacelle hanging mass), and may alter gearbox lubrication and bearing loading.
- **Hub acceleration**, since it is directly related to dynamic nacelle and tower base loading (nacelle accelerating mass).

When any of these parameters exceeds its safety value, the machine is supposed to be shutdown. The average, 20 years capacity factor of the wind turbine is **33.4%**. As the safety tolerances are decreased, the capacity factor decreases **non-linearly**, as shown in Fig. 9.

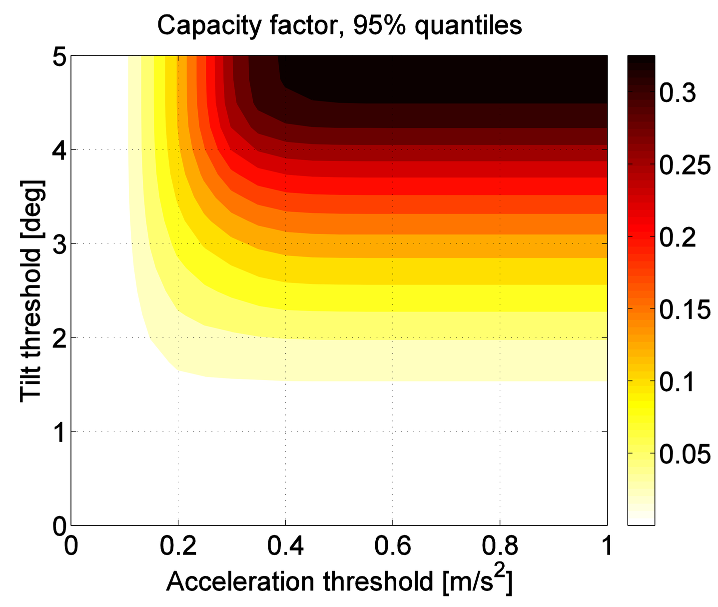

Figure 9. Capacity factor of the wind turbine, as function of tower inclination and nacelle acceleration safety thresholds.

Conclusions

- The presented methodology is flexible and can quickly assess the **response** of a floating wind turbine, **independently** of its platform geometry or mooring configuration.
- The results can give valuable information at the design stage, regarding **long-term** dynamics of the floating system (i.e. **fatigue loading**) and at the operating stage, helping in rapidly forecasting the turbine behavior based on the weather predictions.
- Safety tolerances may be adjusted to optimize the **tradeoff** between energy production and reliable operation. For the studied case, the thresholds may be as low as 4.75 deg and 0.7 ms^{-2} (respectively, for tower tilt and hub acceleration), without affecting the turbine capacity factor.

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