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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Development of new strategies for optimized structural monitoring of wind farms: description of the experimental field" *by* João Pacheco et al.

João Pacheco et al.

ec11142@fe.up.pt

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The authors thank the detailed and helpful comments. We have considered the feedback in the revised manuscript. Each comment is further addressed below.

- Comment 1: Section 3.1 needs more detail on the simple model as results are presented later. Some more specifics on thing such as how elements are modelled, what boundary conditions are used and what assumptions are made would be useful.

- R1: In order to better interpret the experimental results, a numerical model of the wind turbine was developed using Robot structural analysis software (Autodesk, 2016), fol-

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Discussion paper

lowing the technical drawings provided by the manufacturer. It is a simplified model, in which the operation of the turbine is not modelled. Rotational movement of the rotor and all control systems are disregarded, being the main purpose the simulation of the dynamic behaviour of the tower under the test conditions presented in the following section. It is considered that the foundation does not allow any kind of relative movements and is not considered the opening of the door (a specific numerical model for this detail has shown that it has a reduced influence on global behaviour). Thus, for the modelling of the tower was based on 3D bar elements to which the corresponding cross sections were assigned. Regarding blade modelling, at the time very detailed information was not available. Alternatively, starting from the NREL 5 MW reference wind turbine (Jonkman, Butterfield et al., 2009), the characteristics of the blades were scaled to be compatible with the wind turbine under study. The blades are modelled by 3D bar elements, divided into multiple sections to which the average mass, stiffness and inertia characteristics have been attributed. Since there is no rotation of the rotor, the blades were modelled with the pitch angle observed during the ambient vibration tests. The nacelle and hub are presented by concentrated loads applied at their centres of gravity. The connection between the tower, blades and the geometric centres of the nacelle and hub is modelled with rigid links of negligible mass.

Autodesk: Robot Structural Analysis Professional (Version 29.0.05650(x64)), 2016.
Jonkman, J., Butterfield, S., Musial, W., and Scott, G.: Definition of a 5-MW Reference Wind Turbine for Offshore System Development: National Renewable Energy Laboratory (NREL), 2009.

- Comment 2: It's not clear how much data was used to construct the frequency tables in figure 8. Are these single observations of frequency or are they averages of multiple observations? It would also be good to know how much deviation is observed to give context to the level of difference between 'non-operational' and 'operational'.

- R2: The values of the natural frequencies presented in figure 8 were obtained from single observation (10 minutes time series of accelerations) under operating and nonoperating conditions. In the experimental campaigns conducted for a first estimation of the modal properties, several 10 minutes setups were measured, but in this paper only the values of one of the observations are presented. The number of datasets collected during the described ambient vibration tests is not enough for a reliable statistical characterization The evaluation of the variation of the modal parameters of the structure within the various operating regimes is still being performed.

- Comment 3: Line 129: it's mentioned that turbine 5 behaves 'differently' to the other turbines. Although a difference can be seen in figure 9 it would be clearer for the reader to say in the text what this difference is.

- R3: It is verified that the wind turbine 5 presents a different dynamic behaviour due to the differences observed at the values of the natural frequencies of the first and second tower bending modes associated with the side-side direction (1SS lower than the others and 2SS higher than the others).

- Comment 4: In section 4.2, I don't think it's ever mentioned what the sampling rate of any of the sensors are. Since a comparison is generally invited between the different sensors, such as that strain gauges can be used for an OMA purpose, it would be useful for the reader to know how comparable these sensors are regarding aspects such as the sampling rates.

- R4: Samples rates of:

Force-balance accelerometers = 20 Hz;

Strains and rotations tower monitoring systems = 50 Hz;

MEM accelerometers (blades and tower) = 62.5 Hz;

Blades strains monitoring system = 100 Hz

Some of these sampling rates resulted from hardware constrains. For the application of OMA algorithms, a sampling rate of 20Hz is already quite conservative taking into account the natural frequencies of the most relevant modes.

- Comment 5: Line 242: It's mentioned that a model is conducted in FAST, also mentioned before in section 3.1, and the results are compared to the measurements. This is all moved on from too quickly. Why is a FAST model used? How important for that purpose is the difference from the measured results? Please give a bit more of the pertinent details on this and explain the aspects of this which might be of interest to the reader.

- R5: The main goal of the WindFarmSHM research project is the development, validation and optimization of a monitoring strategy to be applied at the level of the wind farm, suitable to both bottom fixed and floating solutions, which should be able to evaluate the structural condition of wind turbines and their consumed fatigue life. Since there are still very few floating wind turbines in operation and due to the confidentiality associated with this very promising technology, during the course of the project it is unlikely to have access to real monitoring data. Therefore, the development and validation of the monitoring strategy to be proposed for this type of offshore wind turbines will be based on artificial experimental data generated by numerical models. Firstly, numerical models of the instrumented onshore wind turbine in Tocha Wind Farm, taking into account their aerodynamics, control systems and flexibility of structural elements, are being constructed and tuned to replicate the experimental data. Then, these will be converted to floating wind turbine models including the hydrodynamics effects. The numerical models to be developed will also be used to simulate damage scenarios for both bottom fixed (e.g. stiffness reduction in the tower-foundation connection) and floating wind turbine (e.g. damage of a mooring line) to validate the algorithms that will be proposed for damage detection.

- Comment 6: Figure 1 is good for expressing the process, but the bottom three rows are confusing, what do the bars to the right of 'Blades', 'Tower' and 'Foundation' mean?

- R6: The bars represent in a simplistic fashion the damage detection check for the structural elements (blades, tower and foundation) and the colour scale of the bar is related to the severity of the respective damage. The bars corresponding to the life-time prediction are related to the fatigue assessment of the structural elements (blades and tower) and indicate the percentage of useful life consumed up to the moment of analysis.

- Comment 7: Figure 9, it would help the reader to state in the caption that these measurements were from the non-operational condition.

- R7: Figure caption corrected for: Figure 9. Comparison of the natural frequencies of four wind turbines in non-operational condition (1st and 2nd pairs of bending modes).

- Comment 8: The description in the text of figure 17 (line 246) doesn't quite match the figure. It seems the results for 'Force-balance accelerometers' was added without updating the text.

- R8: Figure 17 shows the average spectra of the six force-balance accelerometers (first row), longitudinal deformations recorded by sensors A, B, C and D (second row) and clinometer 3 (third row), considering the rotor parked (left) and in operation (right).

- Comment 9: Line 122: please define the acronym ANPSD before using it.

- R9: ANPSD: average normalized auto-spectral density function

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