PO.ID 101

Life time assessment of offshore foundations using a virtual sensor approach

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Abstract

For offshore wind turbines (OWT) practical limitations prohibit to mount sensors at stress and fatigue hotspots. E.g. for a monopile foundation, the most popular design, the stress hot spot is at the mud line 30 m. below the water level. Installing a measurement system at these locations is unfavorable in terms of cost and maintenance. This limitation is overcome by reconstructing the full-field response of the structure based on the limited number of measured responses at easily accessible locations and a calibrated Finite Element Model (FEM) of the support structure. A modal decomposition and expansion approach is used for reconstructing the responses at all possible hot spot locations.

Approach

The proposed life time assessment approach of an offshore wind turbine includes the following 5 steps:

Figure 1: work-flow for life-time assessment

A modal decomposition and expansion approach is used as response estimation technique for response prediction. The approach is summarized in figure 2:

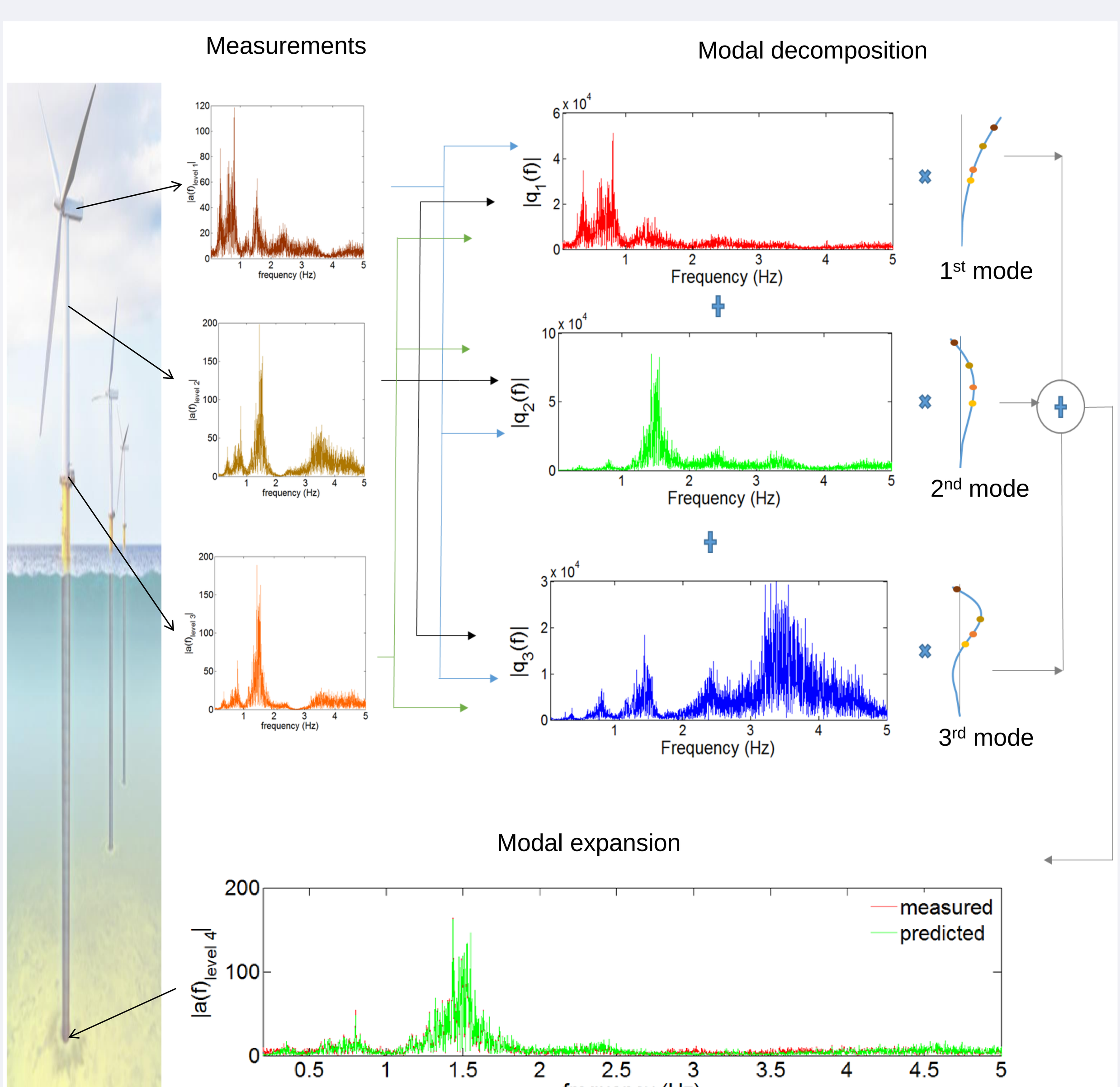

Figure 2: modal decomposition and expansion approach in a schematic representation

Offshore measurements

The measurement campaign is performed at the Belwind wind farm, which consists of 55 Vestas V90 3MW wind turbines on monopile foundations. The wind farm is located in the North Sea on the Bligh Bank, 46km off the Belgian coast

Figure 3: location Belwind wind farm (left), measurement locations of the acceleration measurements (middle), fiber Bragg grating sensors for strain measurements installed above the flange connection on 4 locations (right)

The locations are chosen based on the convenience of sensor mounting, such as the vicinity of platforms. The chosen levels are 69 m, 41 m, 27 m and 19 m above Lowest Astronomical Tide Level (LAT)

Identification of modal parameters using OMA

State of the art OMA techniques have been automated and are applied for the continuous tracking of natural frequencies, mode shapes and damping values of the fundamental tower modes.

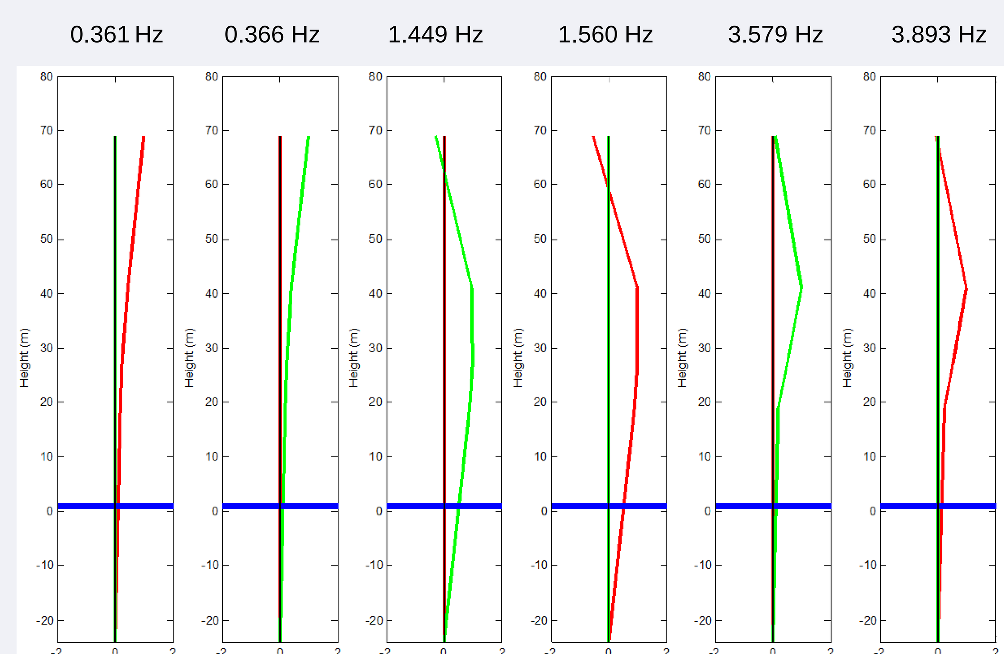

Figure 4: Fundamental tower/foundation modes in parked conditions with their corresponding frequencies: In red the modes in the FA-direction, with green lines the modes in the SS direction, blue line indicates the water level and the lowest point corresponds to the mudline level

Finite Element Model - FEM Modal Analysis

A finite element model of the offshore wind turbine is created using pipe elements. The soil pile interaction is modeled using a distributed spring approach. Also the ocean environment is considered in the model.

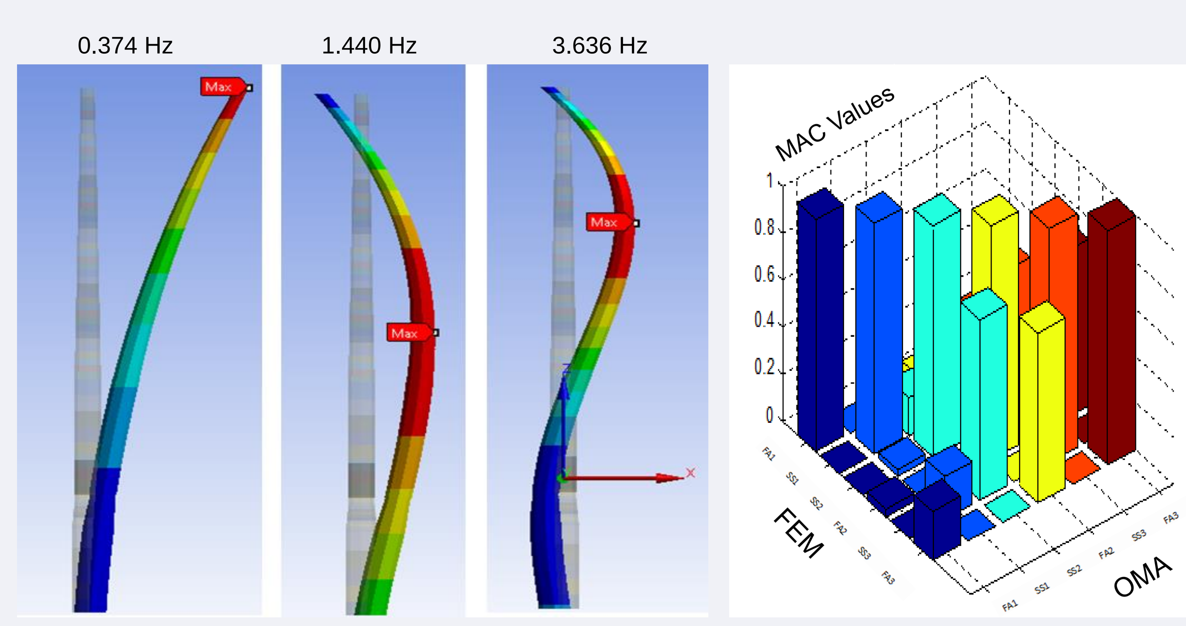

Figure 5: fundamental FA tower/foundation modes with their corresponding frequencies obtained through modal analysis (left). Graphical illustration of the MAC values of the 6 fundamental tower/foundation modes (right).

Response prediction

The response prediction algorithm has first been validated based on accelerations measured during parked conditions, rotating conditions as well as during an over-speed stop of the OWT. Indicative acceleration response estimations in time and frequency domain for each state are shown in figure 6.

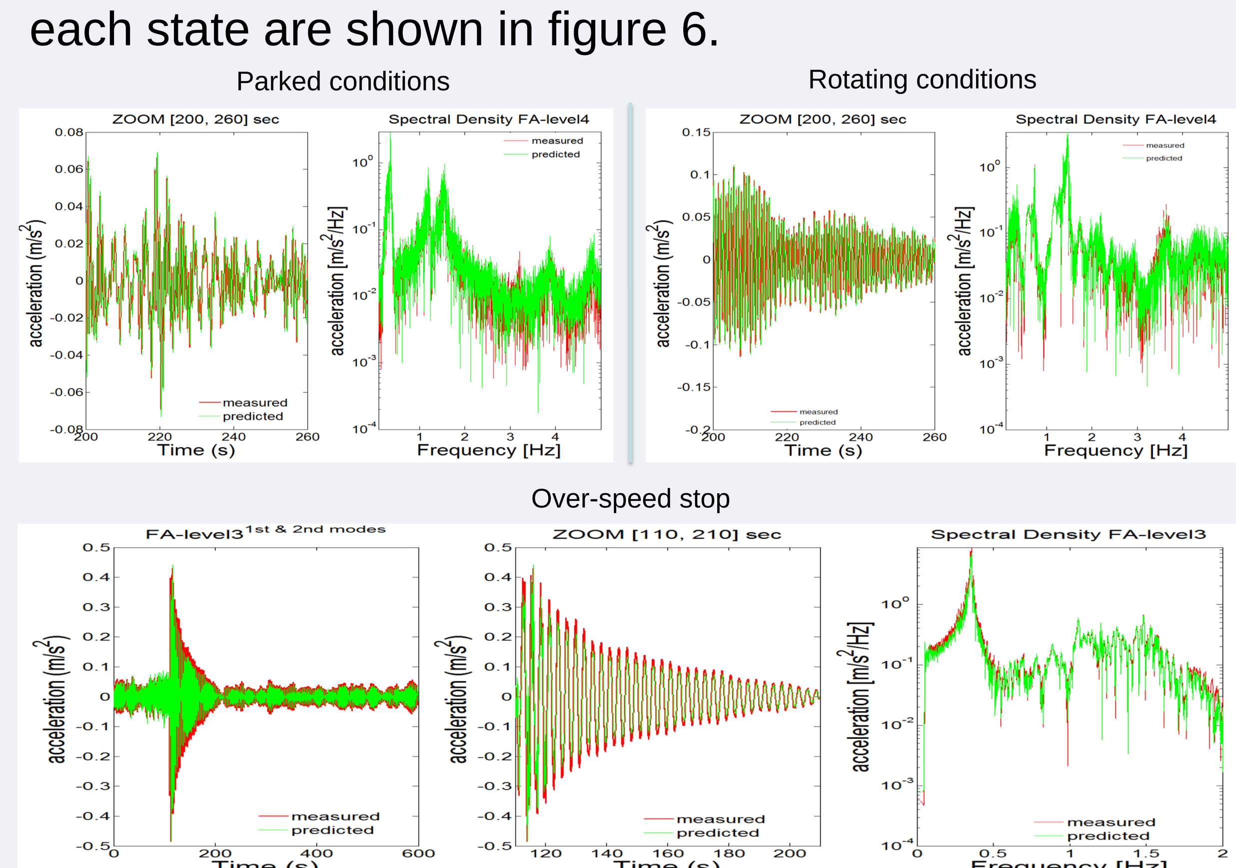

Figure 6: Time domain and frequency domain comparison of predicted (green) and measured accelerations (red) at sensor level 4 [parked/rotating conditions] and sensor level 3 [over-speed stop].

A full day of parked and a full day of rotating conditions are then analyzed. A total of 144 ten-minute files were analysed in order to obtain the predicted accelerations. The results of the full-day predictions are shown in figure 7. As shown, in parked conditions, the dynamic behavior can almost be completely described by the first two modes and thus 2 sensor levels, whereas in rotating conditions 3 modes and 3 sensor levels are necessary for more precise and accurate predictions.

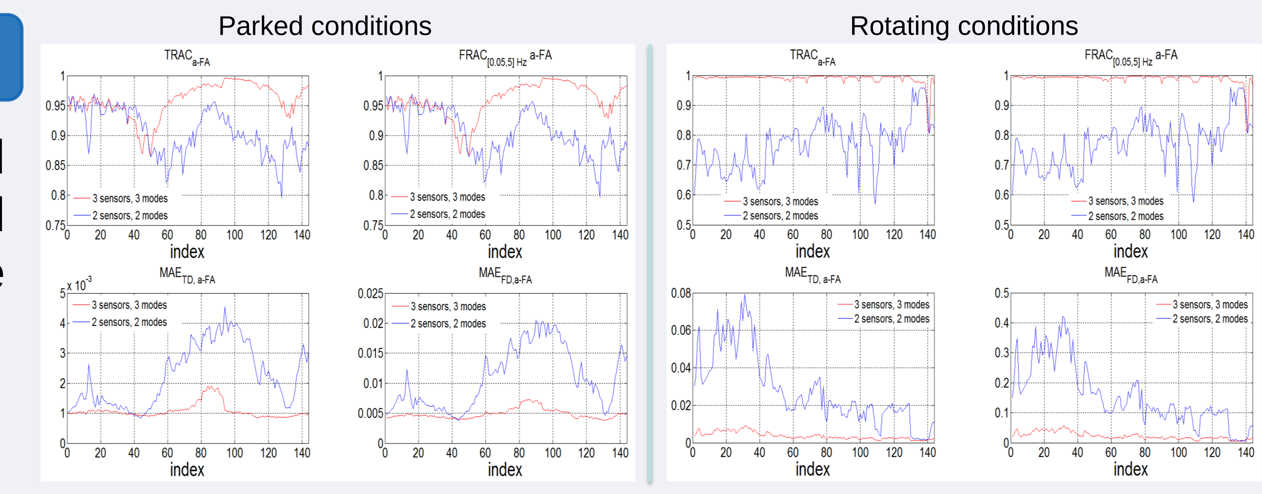

Figure 7: Time Response Assurance Criterion, Frequency Response Assurance Criterion and mean absolute error indexes as tools to quantify the quality of acceleration predictions at the lowest sensor level for a full day of parked/rotating conditions of the wind turbine. Results in FA direction notifying the impact of using a 2sensor-2mode or 3sensor-3mode determined system to predict the vibrational response at the lowest sensor level.

Finally the method has been validated for the prediction of strains. In the first step only parked conditions have been considered.

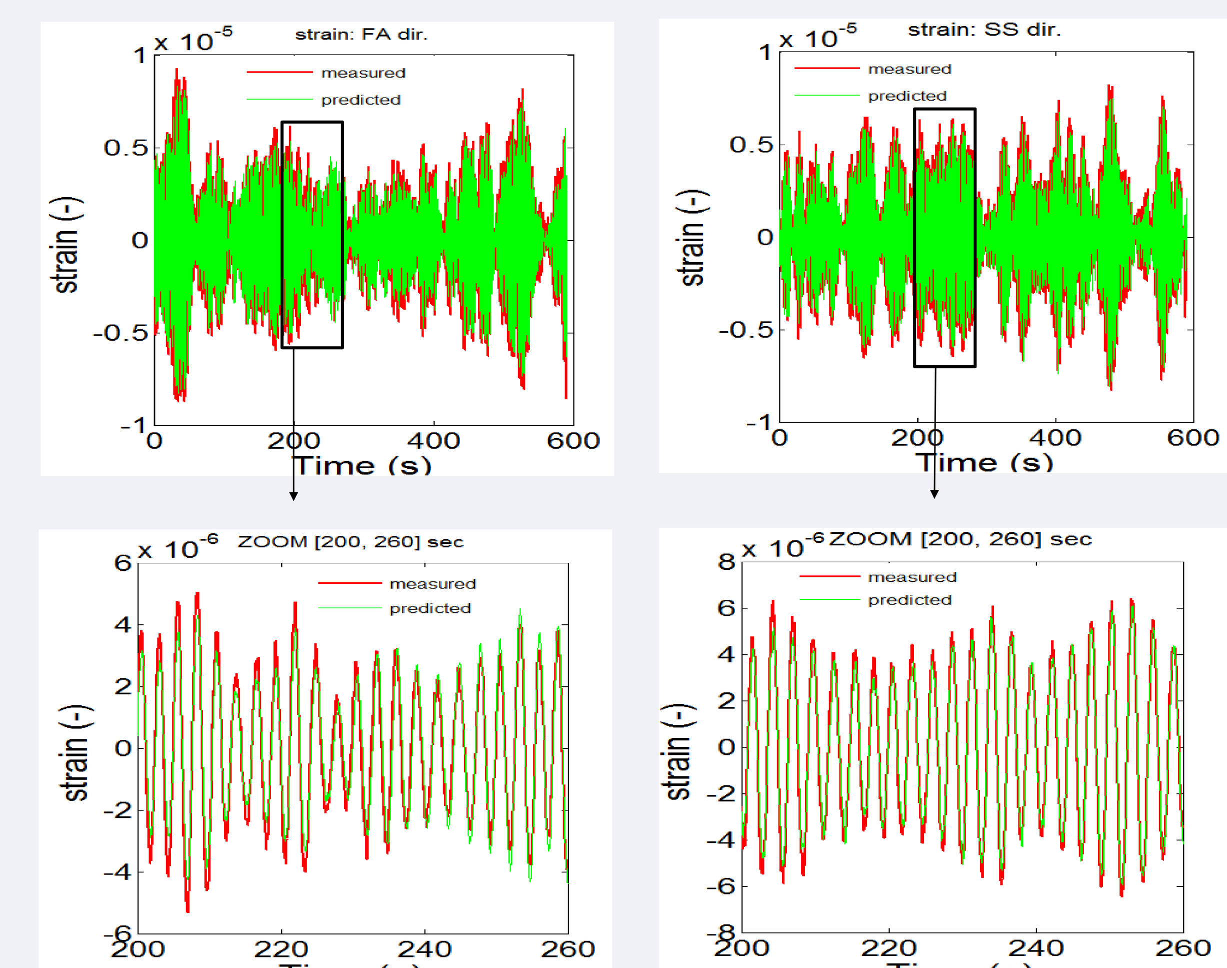

Figure 8: Time domain comparison of predicted (green) and measured strains (red) at sensor level 3 (Z=41 m LAT) for parked conditions of the wind turbine both in FA and SS

Conclusions

The results of a dynamic response prediction method applied on an offshore wind turbine on a monopile foundation were presented. The proposed method is based on a modal decomposition and expansion approach that is used to estimate the response at unmeasured fatigue hotspot locations by combining a limited set of acceleration response measurements and a Finite Element Model. The method has proven to be fast, easy to implement, reliable and effective for the prediction of responses (accelerations/strains). It is imperative to use 3 sensor levels and 3 modes for accurate response predictions under rotating conditions of the OWT.

Life Time Assessment at Park Level

Linking consumed life time to SCADA parameters and environmental parameters will allow to determine the park-wide consumed life time with only a limited number of instrumented turbines.

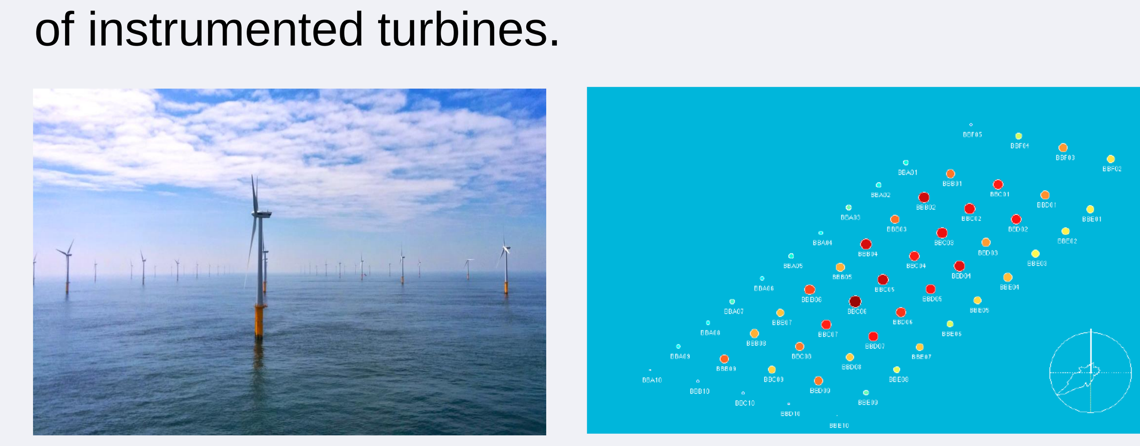

Figure 9: View on the wind farm (left) Concept plot for wind farm overview of consumed life time for a given wind sector (right)

Acknowledgements

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