Monitoring of offshore turbines for design and O&M - an overview of the activities of OWI-Lab

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Abstract

The **Offshore Wind Infrastructure Lab (OWI-Lab)** develops mid- and long-term **monitoring solutions** for offshore wind turbines. The **motivation** is gaining the insights that are crucial to **minimize construction and installations costs** of future offshore wind farms and to **extend the life time** of existing structures and **reduce** their **operation and maintenance costs**.

Offshore Wind Farms

The **Offshore Wind Infrastructure Lab (OWI-Lab)** has a mutual partnership with **Parkwind** to provide several **monitoring services** at both the **Belwind** wind farm and the **Northwind** wind farm.

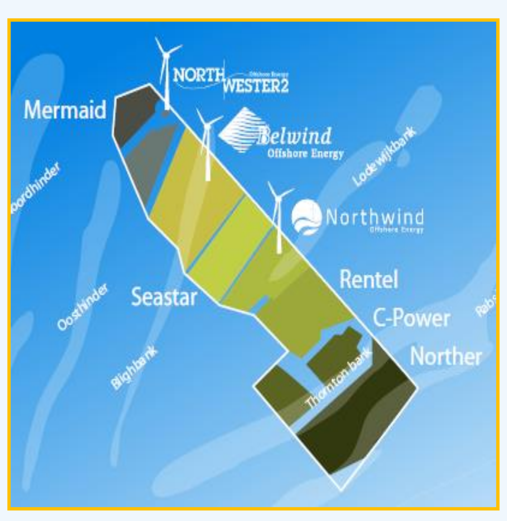


Figure 1: Belgian offshore wind-farm-concessions

Facts Belwind: 55 Vestas 3MW V90 turbines, Monopile foundations, 46 km offshore, Water Depths : 16 – 30m

Facts Northwind: 72 Vestas 3MW V112 turbines, Monopile foundations, 37 km offshore, Water Depths: 16 – 29m

Periodic Design Verification

Objectives: design verification, improved design assumptions, reduction in steel, scour monitoring

In **periodic design verification** the resonance frequencies of the fundamental tower modes are identified using a mobile measurement system and state-of the art operational modal analysis techniques.

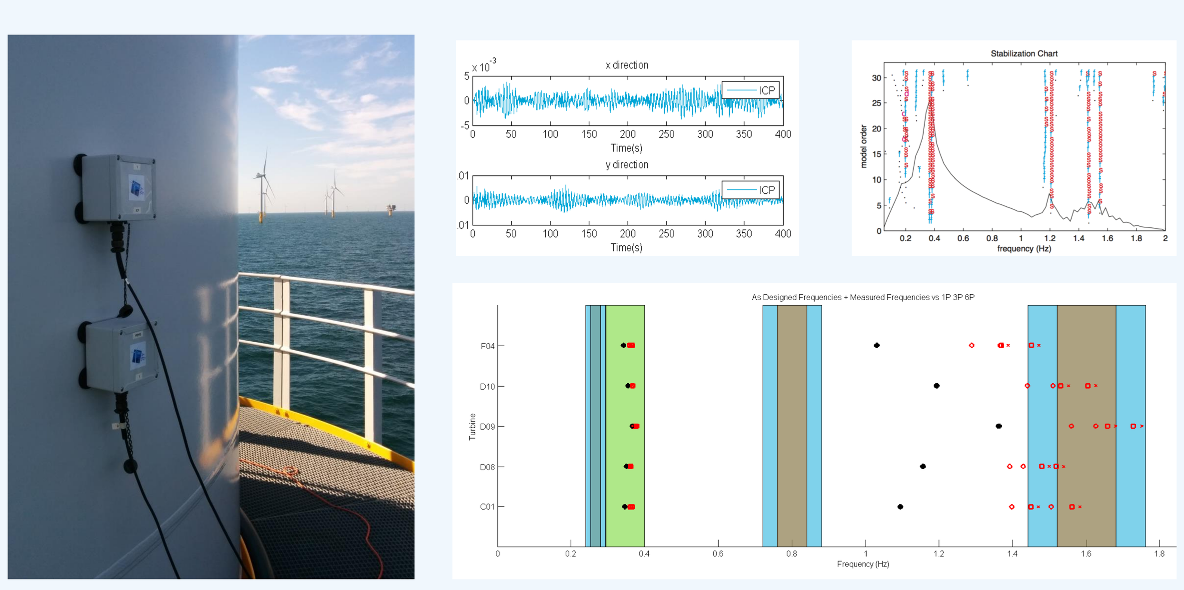


Figure 2: measurement setup (left) typical vibrations and modal analysis results (top right) As designed and measured frequencies vs 1P, 3P, 6P bands (bottom right)

Results indicate a general underestimation of the soil stiffness. The first resonance frequency is between 5% and 10% higher then designed. Different resonance frequencies can result in higher loads and therefore reduced life time. This inevitably results in the use of more steel and thus higher constructions and installation costs. With respect to scour monitoring bathymetry only shows the changes in the seabed but lacks information about the impact thereof on the turbine's dynamics.

Grout Monitoring

Objectives: input for design, evaluating the grouted connection, risk reduction and reducing bank guarantees

Grout Monitoring consists of measuring the relative displacements between the transition piece and the monopile. Also the loads taken by the installed brackets and bearings are monitored. An advanced grout monitoring system has recently been installed in the Northwind wind farm. This system will allow to measure the strains and stresses within the grouted connection using optical fiber Bragg sensors.

The monitoring system at Belwind confirmed that the transition piece was indeed slipping on the monopile foundation as a result of a failing grout-connection.


Figure 3: Picture of a transition piece in the Northwind wind farm (left) Installed displacement sensor (middle) optical fiber Bragg sensor embedded in a steel bar (right)

Dynamic Monitoring

Objectives: Input for design, understanding dynamics, structural health monitoring, scour monitoring

Dynamic monitoring consists of the continuous monitoring of the vibration levels, resonant frequencies , damping values and mode shapes of the turbine.

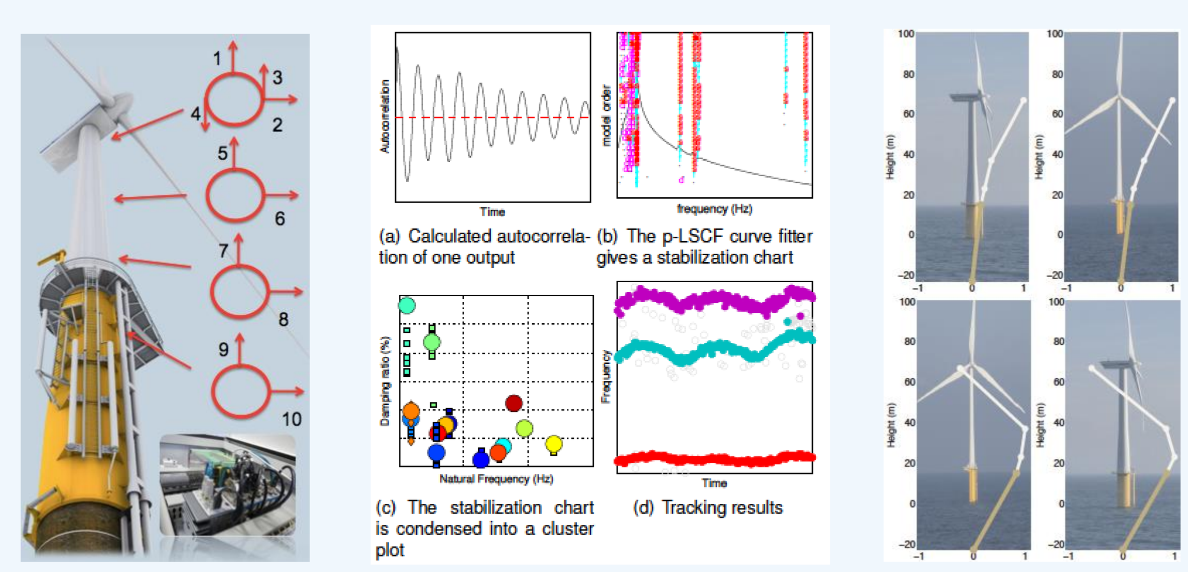


Figure 4: locations accelerometers (left) data-processing approach using automated operational modal analysis (right) 4 fundamental mode shapes of turbine

The monitored parameters strongly depend on the operational and ambient conditions of the wind turbine.

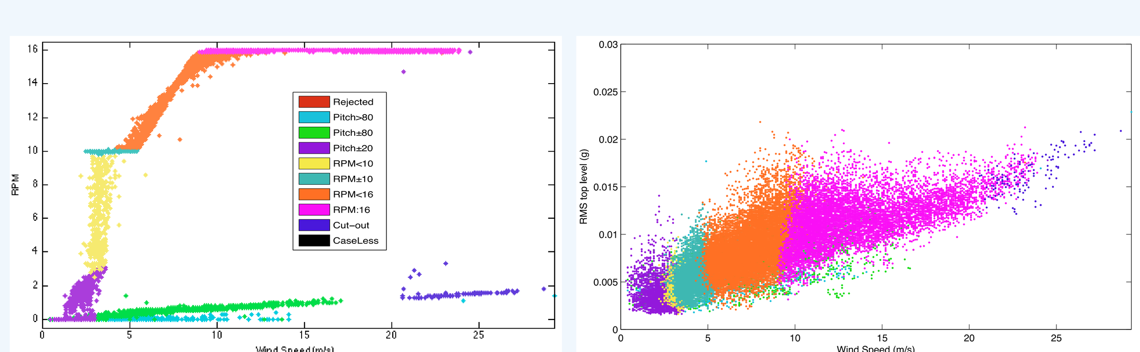


Figure 5: RPM vs. Windspeed with colors indicating the different operational cases (OC) (left) Vibration levels vs windspeed for the diifferent operational cases

Damping ratios are crucial for life time predictions and are very difficult to predict by numerical tools.

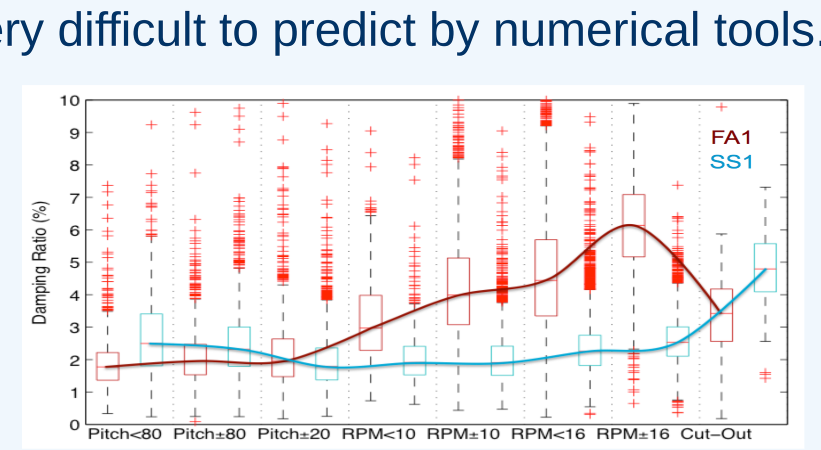


Figure 6: Damping values of the first for-aft and side-side mode for different OCs

Without data normalization the onsets of scour or other structural changes remain obscured by the natural variations in the resonance frequencies and early detection is impossible. Preliminary results over a period of 2 years indicate a global stiffening

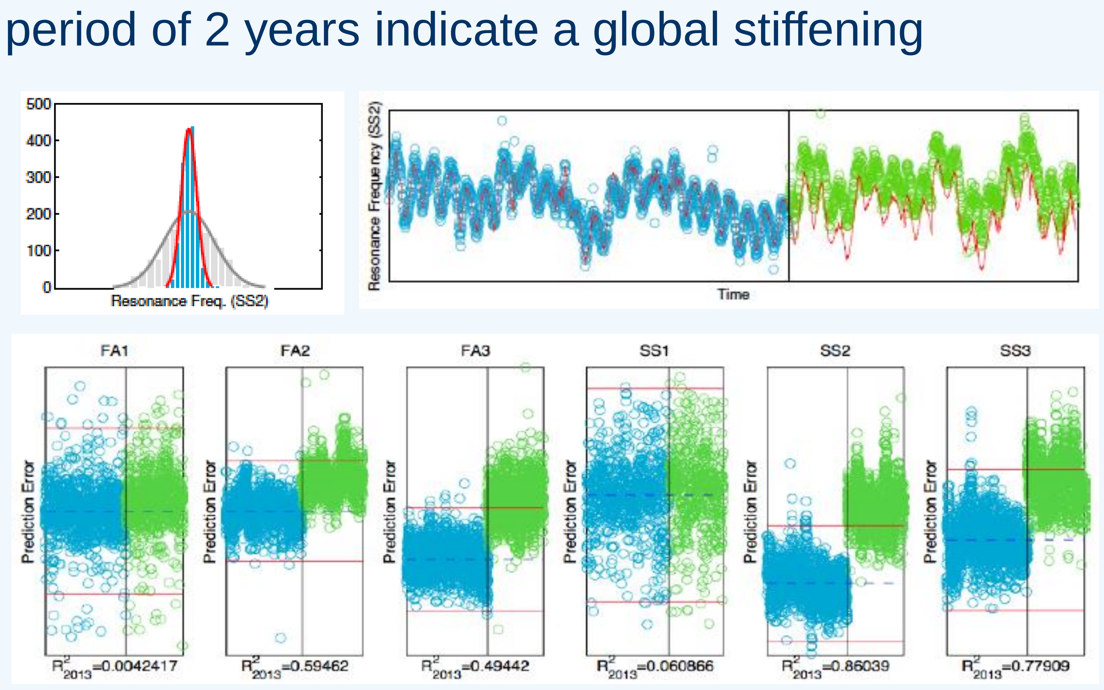
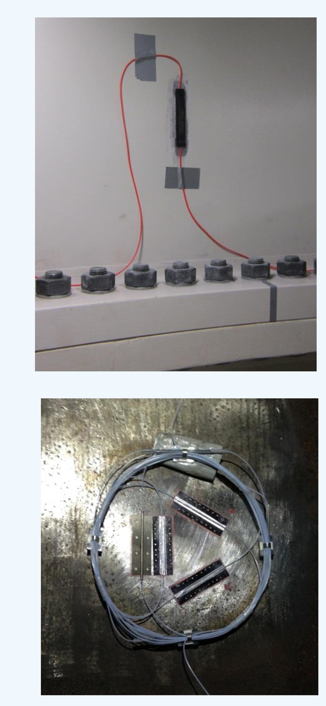


Figure 7: Distribution of normalized frequencies (top left) A model (-) trained on the data (o) of Period 1 (blue) is used to predict the values in Period 2 (green) (top right) Prediction Error for all 6 tower modes showing a global stiffening (bottom)

Life Time Assessment

Objectives : Quantify the consumed life time of existing turbines for repowering and life time extension.



With sensor access limited or unfeasible virtual sensing is required to have an assessment of consumed life time at critical locations. Response estimation techniques allow to estimate the stresses at unmeasured locations by combining a limited set of response measurements (accelerations, strains, etc.) and a Finite Element (FE) model. The FE model is updated based on the dynamic properties identified by the dynamic monitoring system.

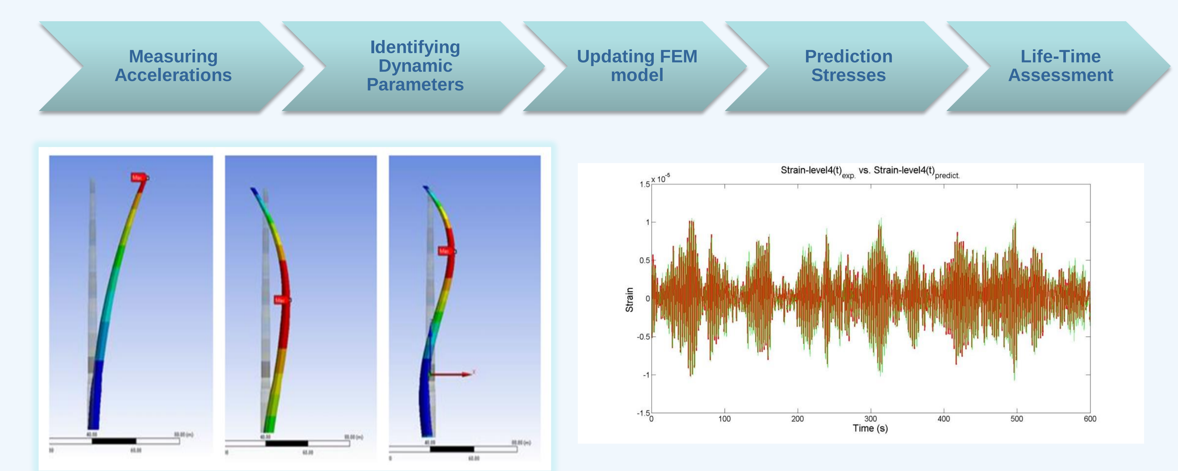


Figure 8: workflow for life time assessment (top) First 3 tower modes from FE-model (bottom left) measured vs predicted stress time-history (bottom right)

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.

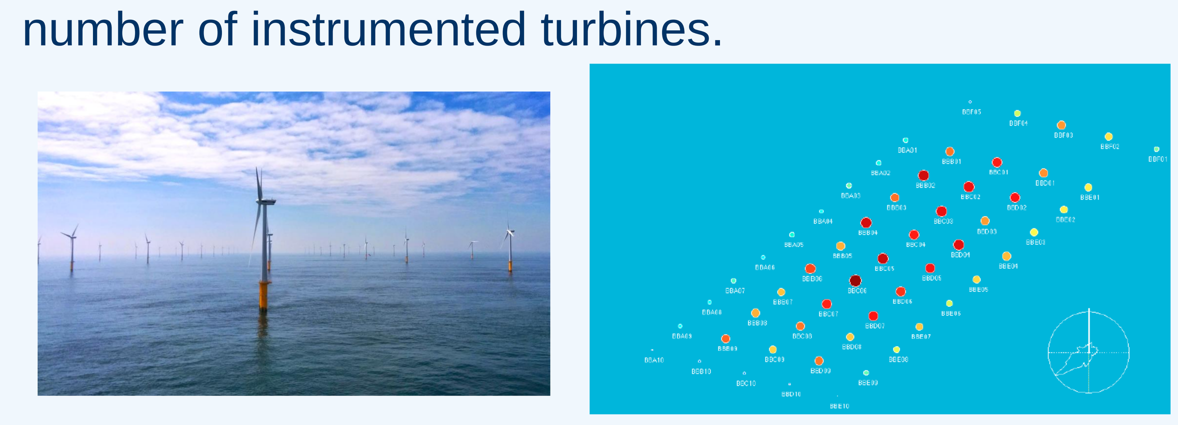


Figure 9: View on the wind farm (left) Wind farm overview of consumed life time for a given wind sector (right))

Performance Monitoring

Objectives: Assess the overall performance of the wind farm, detect underperforming turbines and quantify the lost revenue

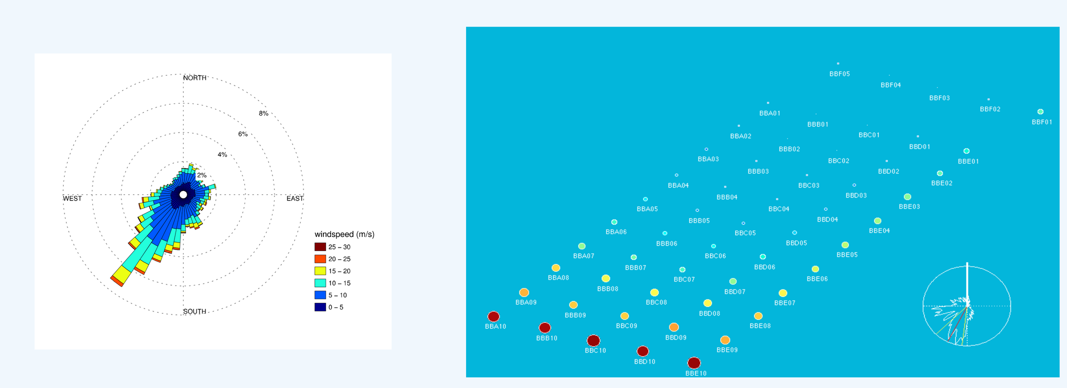


Figure 10: Wind Rose (left) Wind farm overview showing averaged produced power and wake loses for a given wind sector

Performance issues in individual turbines can be detected by continuously estimating and monitoring the power curves of all turbines within a farm. Early detection in deviations from the expected power curve or deviations between sensors will allow to plan maintenance and improve overall farm performance

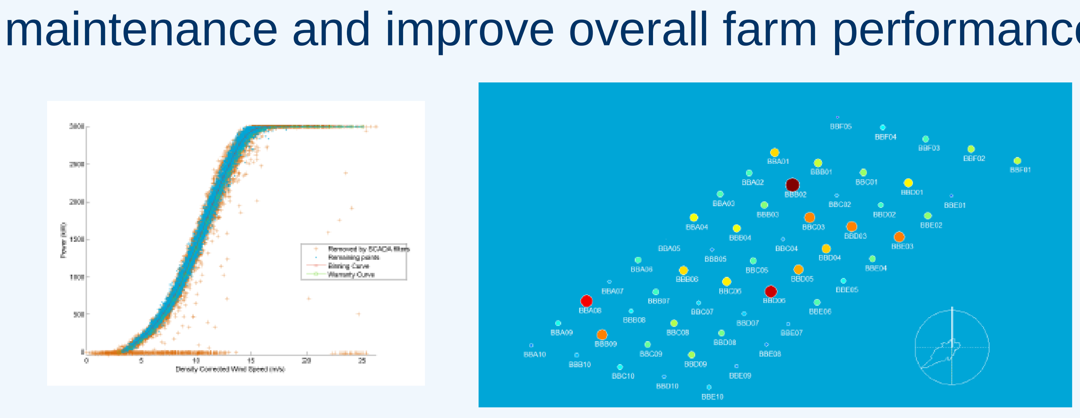


Figure 11: Estimated power curve vs waranty power curve (left) Wind farm overview of power curve deviation for a given wind sector

Acknowledgements

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