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The overall damping of an offshore wind turbine during different operating conditions

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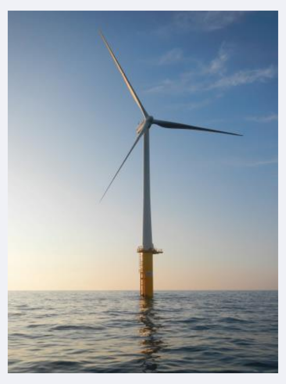
Motivation

Damping significantly **influences** the **dynamic response** of a wind turbine and thus also its **predicted lifetime**. A better understanding on the damping of offshore wind turbines can **improve design** and thus reduce the initial cost of future **substructures**. Damping ratios are very difficult to predict by numerical tools therefore measurements on existing offshore wind turbines are crucial to verify the existing design assumptions.

Overall Damping

The overall damping of the first bending modes in respectively the fore-aft (FA) and side-side (SS) direction of an offshore wind turbine consists of a combination of



- **structural damping**
- **soil damping**
- **hydrodynamic damping**
- **aerodynamic damping**

Additionally **damping due to constructive devices** can be present e.g. when a tuned mass damper is installed. The **overall damping** of an offshore wind turbine significantly **depends** on its **environmental** and **operational** conditions (EOCs).

Approach

The **objectives** of this research were :

- Set up a long term campaign to estimate damping over the full operational range of the offshore wind turbine.
- Classify damping according to the different operating and environmental conditions

The measurements were conducted at the **Belwind** offshore wind farm 46km outside the Belgian coast. One of the 55 **Vestas V90-3.0MW** turbines on **monopile foundations** was equipped with an array of accelerometers in 2011.

Step 1 : Automated Operational Modal Anlysis

In order to estimate damping for **an instrumented wind turbine**, there are two basic approaches.

- Damping is estimated after a rotor stop using the logarithmic decay approach.
- Damping is estimated during normal operation of the turbine using operational modal analysis.

The second approach is preferred as this will allow to estimate damping over the full operational range of the turbine and determine modal properties of all relevant modes. In order to do so an **Automated Operational Modal Analysis algorithm** has been developed in order to process long term datasets.

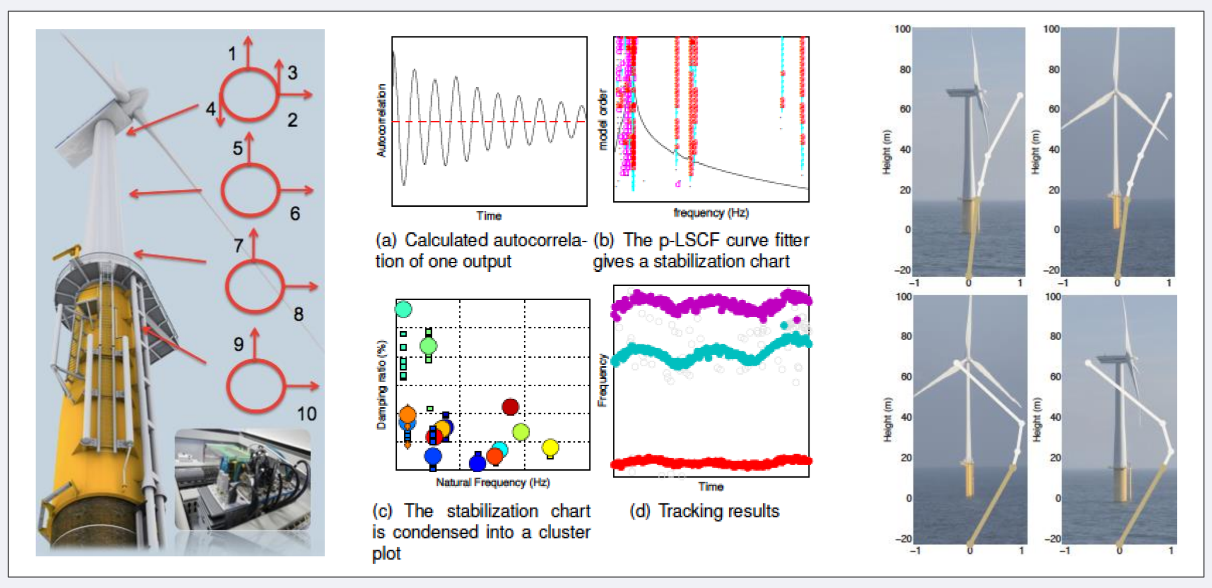


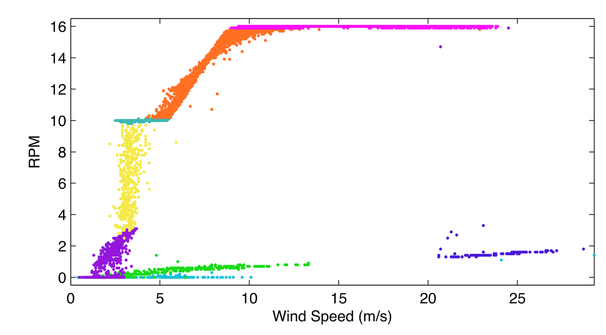
Figure 1: (left) locations accelerometers (middle) data-processing approach using automated operational modal analysis (right) 4 fundamental mode shapes of turbine

Step 2 : EOC-classification

Applying the automated operational modal analysis resulted in a database spanning nearly three years worth of damping estimates. **Over 50000 damping values per year have been identified.**

These results are then put next to a subset of the turbine **SCADA** data and **meteorological** data. This allows classifying each damping ratio to an **environmental** and **operational** condition of the wind turbine (**EOC**).

Each data-point is attributed to one of the eight operational cases as defined in the following figure.



	Wind speed (m/s) Min.	Wind speed (m/s) Max.	rpm Min.	rpm Max.	Pitch angle (deg) Min.	Pitch angle (deg) Max.
Pitch : >80	n/A	n/A	n/A	n/A	80	100
Pitch : ±80	0	20	n/A	n/A	70	80
Pitch : ±20	n/A	n/A	n/A	n/A	19.5	20.5
RPM : <10	n/A	n/A	2.5	9.8	n/A	n/A
RPM : ±10	n/A	n/A	9.8	10.2	n/A	n/A
RPM : <16	n/A	n/A	10.2	15.9	n/A	n/A
RPM: ±16	n/A	n/A	15.9	17	n/A	n/A
Cut-Out	20	n/A	n/A	n/A	70	80

Figure 2: RPM vs. Wind Speed with colors indicating the different operational cases (OC) (left) Definition of the different used operational cases

Results

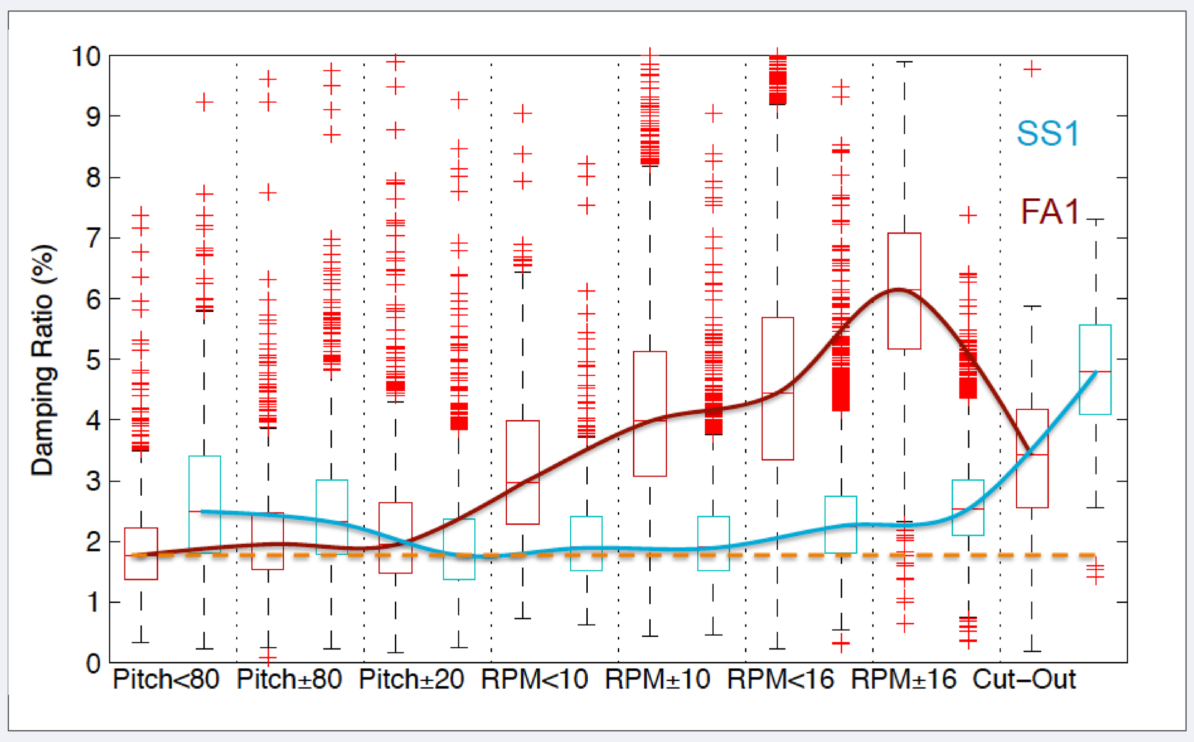


Figure 3 : Damping overview for the first Fore-Aft (FA) and Side-Side (SS) modes for (top) 2012 with box plots to indicate the spread. The x-axis represents different operational conditions or states of the offshore wind turbine

Several interesting observations can be made from these analysis. During parked conditions, Pitch:>80deg and Pitch:80deg., the SS damping exceeds the FA damping. With the blades pitched out, i.e. facing away from the wind, most blade surface is facing the SS direction. Or otherwise put, the SS mode has a larger contribution of aerodynamic damping. At Pitch:20 both directions are approximately equally damped. With increasing rotational speeds, and smaller pitch angles, the damping of the FA mode increases and far exceeds the SS damping. At the maximum rotational speed, RPM:16, the damping of the FA mode reaches a median value of 6%. The orange dashed line corresponds more or less with the overall damping of the turbine while the aerodynamic damping is negligible. Only during parked condition the damping in FA direction corresponds with this value. However in SS direction even for the operational cases RPM<10 and RPM=10, that correspond with small pitch angels, the overall SS damping does almost not exceed this value. Finally the figure below shows the stability of these damping estimate over two years

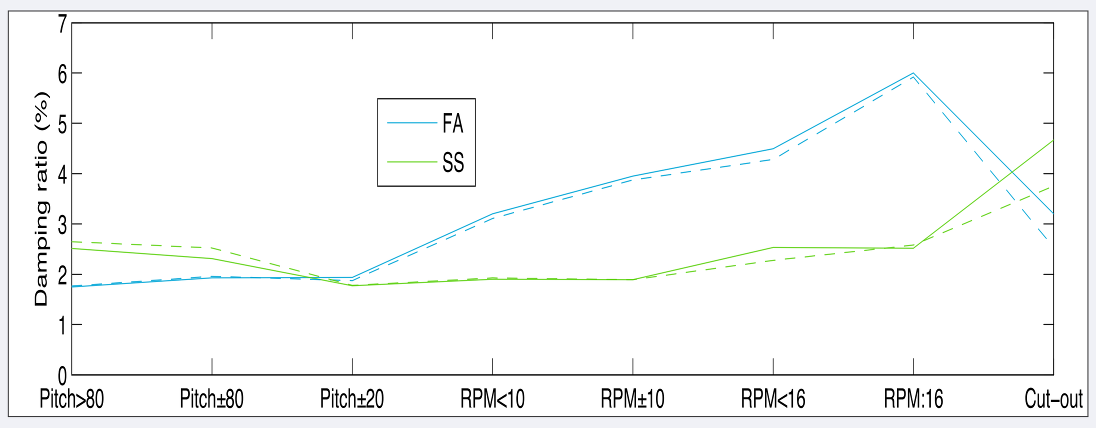


Figure 4 : Comparing the damping values for 2012 (full) and 2013 (dashed) for the first Fore-Aft (FA) and Side-Side (SS) modes. The x-axis represents different operational conditions or states of the offshore wind turbine.

Aerodynamic Damping

Current design standards employ a crude estimate of the aerodynamic damping. For design it is important to validate these damping models with real life data. Not only will this increase the accuracy of the predicted life time. Ultimately, it can result in a cost reduction for future wind farms.

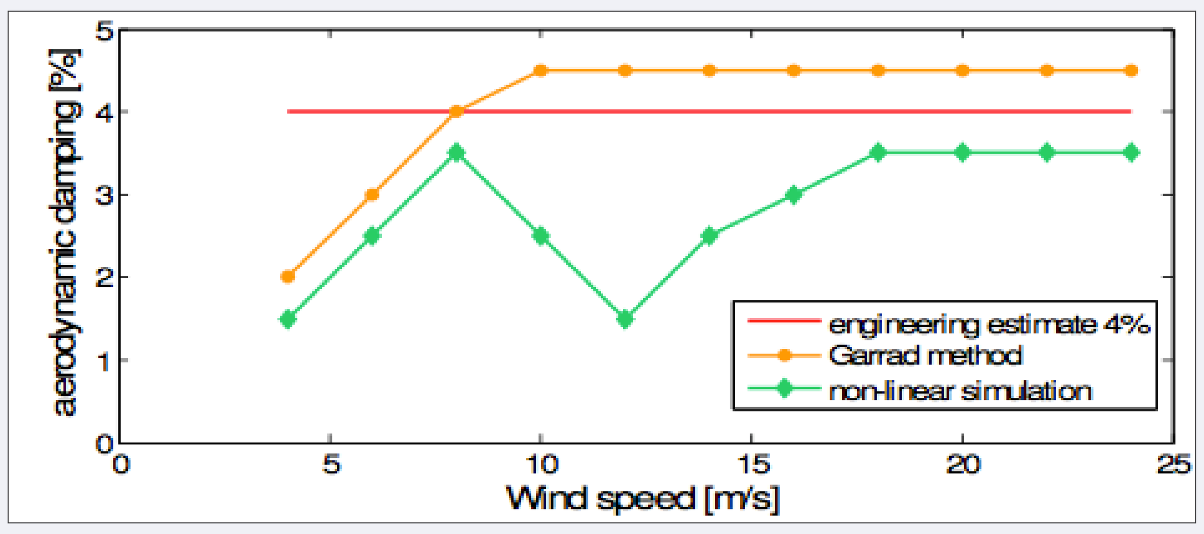


Figure 5 : Existing models for aerodynamic damping. [1]

The following figure gives the overall FA damping estimates during production, not considering parked conditions and cut-out, for 2012. With increasing wind speeds the damping of the FA mode increases from 1.8% to 6.5-7%, thus an increase of 4.7-5.2%

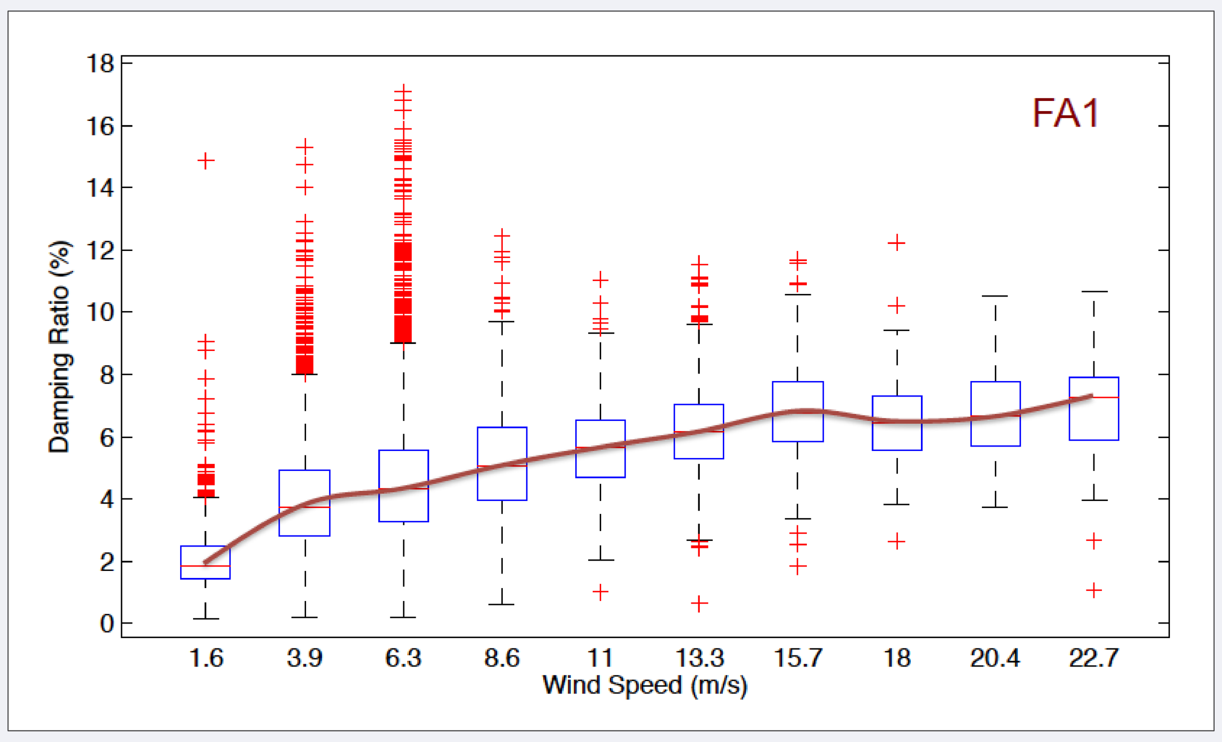


Figure 6: Boxplots for the overall FA damping estimates vs the wind speed during production cases only

The rapid increase in FA damping can be attributed to the increase of aerodynamic damping. Eventually the FA damping stagnates around 6.5-7%. This stagnation of the damping values was also predicted by theory for similar turbines [1]. However, more dedicated simulation models suggested that the damping would again drop after a given wind speed [1]. The current results do not indicate such a drop. Note, that simulations are obtained during one particular set of environmental conditions, while the measurements correspond with a long term period of varying environmental conditions which partially explains the spread on the results.

Conclusions

It was shown that it is possible to identify the damping values of the first FA and SS for different operational and environmental conditions using state-of-the art automated operational modal analysis techniques. This is an industry first result and can improve current standards for damping of offshore wind turbines.

References

[1] J. v.d. Tempel. *Design of support structures for offshore wind turbines*. PhD Thesis, TU Delft 2006

Acknowledgements

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