Damping of an offshore wind turbine: classification and comparison between simulations and measurements

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Motivation

For offshore wind turbines fatigue life is a design driver. Damping plays a crucial role in estimating and modeling for fatigue life. Damping is inversely proportional to the vibration amplitude and consequently the more damping the better the fatigue life.

However, current design standards employ a crude estimate of the total structural damping. In particular as there has been little empirical validation of these damping assumptions.

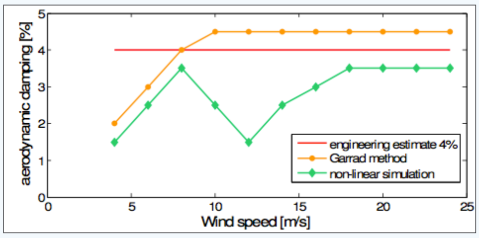


Figure 1 : Current design standards use simple models for aerodynamic damping. [1]

For design it is important to update this damping model 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.

Objective

To improve the general knowledge of damping for the first order tower modes in order to improve fatigue life calculations.

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**
- **Tune a numerical model** w.r.t. the measured turbine
- **Compare simulation and measurements**

Step 1 : Damping estimation @ Belwind

In order to estimate damping for **an instrumented wind turbine**, with accelerometers at different levels, there are two basic approaches.

- Damping is estimated from the vibration amplitude decay after a serious event (e.g. overspeed stop)
- Damping is estimated during operation of the turbine

The second approach is preferred a this will allow to estimate damping over the full operational range of the turbine and determine modal properties of all relevant modes. This will require **an automated Operational modal analysis algorithm** in order to process long term datasets.

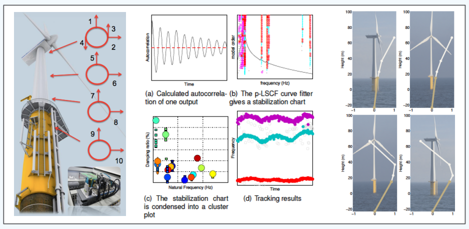
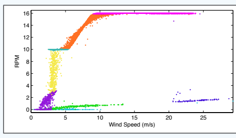


Figure 2: (left) locations accelerometers (middle) data-processing approach using automated operational modal analysis (right) 4 fundamental mode shapes of turbine

Applying the automated operational resulted in a database spanning nearly three years worth of damping estimates. Each data-point is attributed to one of eight different operational cases.



	Wind speed (*m/s*)		rpm		Pitch angle (*deg*)	
	Min.	Max.	Min.	Max.	Min.	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 3: (left) RPM vs. wind speed with colors indicating the different operational cases (right) Definitions of the different operational cases

This allows to investigate damping values for different operational cases of the wind turbine.

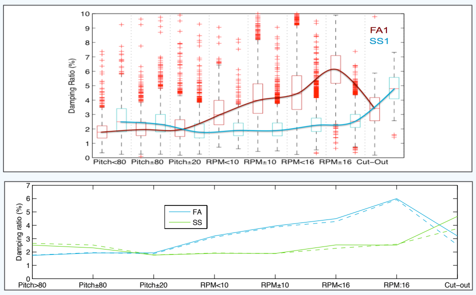


Figure 4 : Damping overview for the first Fore-Aft (FA) and Side-Side (SS) modes for (top) 2012 with box plots to indicate the spread. (bottom) Results for 2012 (full) and 2013 (dashed) are consistent. The x-axis represents different operational conditions or states of the offshore wind turbine

Several physical relations popped up from these analysis. E.g. the stronger damping for the Side-Side mode during parked conditions.
The found values can be used for design to model damping during a particular operational condition, e.g. max RPM.

Step 2: Tuning the numerical model

The numerical simulations have been carried out using **HAWC2** aeroelastic code developed at DTU.

In order to compare measurements with a model it is necessary to properly tune the damping parameters within the HAWC2 model.

The overall damping of the first FA mode of the model has been tuned to be in agreement with the measurements obtained during ambient excitations, respectively 1.6%. This damping value was obtained during low wind speeds while the wind turbine was in parked conditions and the mass tuned damper was switched on.

The overall measured system damping (D_{tot}) of an offshore wind turbine can be approximated as a linear combination of following damping sources:

$$D_{tot} = D_{struc} + D_{soil} + D_{aero} + D_{hydro} + D_{mass.damp}$$

D_{struc} = structural damping = 1.09%

D_{soil} = soil damping due to inner soil friction = 0.39%

D_{aero} = aerodynamic damping = 0.05%

$D_{mass.damp}$ = tower tuned mass damper (TMD), included in structural damping

D_{hydro} = $D_{radiation}$ + D_{vis}, hydrodynamic damping which consists of two terms = 0.06%,

$D_{radiation}$ = damping from wave creation due to structure vibration;

D_{vis} = viscous damping due to hydrodynamic drag

$\rightarrow$ D_{tot}= 1.59% for the FA mode

Step 3 : Comparing Simulation and Measurements

With the tuned numerical model it becomes possible to compare results from the simulations with actual measurements.

All simulations are conducted by simulating time series responses to wind and waves in HAWC2. These time series are processed using the same OMA algorithm used for the measurements.

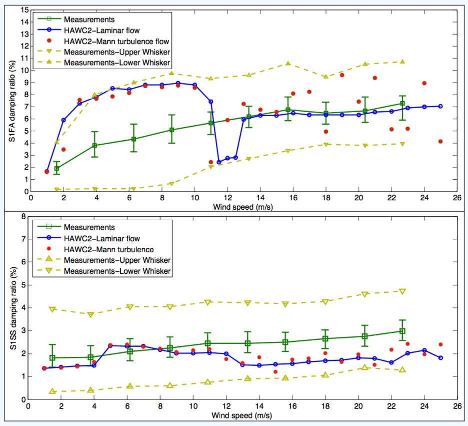


Figure 5 : Damping ratios of the first Fore-Aft (top) and Side-Side (bottom) modes versus wind speed for a turbine in operation

For the Fore-Aft mode the model initially is at the upper limit of the measurement results just within the top whisker (thus not considered an outlier). However, for higher wind speeds the model closely matches the measurements. Interestingly a decrease in damping is predicted by the model around 12 m/s. This decrease was also observed in [1]. However, in measurements it is not observed. Note, that simulations are obtained during one particular set of environmental conditions, while the measurement correspond with a long term period of varying environmental conditions which partially explains the spread on the results.

For Side-Side modes a better match between model and measurements is obtained over the full wind speed range with the model just dropping below the measurements at higher wind speeds.

Conclusions

It was shown that it is possible to identify the damping values of the first FA and SS for different operational 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. Secondly it was shown how for a numerical model damping can be tuned and time domain simulations can be processed using the same operational modal analysis techniques in order to obtain the actual damping in the simulations. A comparison with the measurements was done.

References

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

Acknowledgements

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