Offshore & Dredging Engineering

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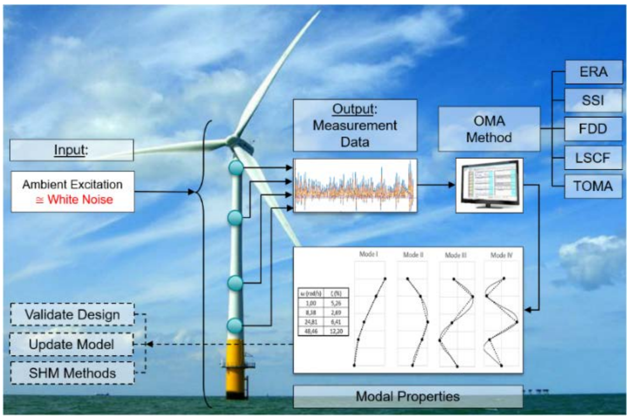
A benchmark study on operational modal analysis system identification algorithms for operating Offshore wind turbines

Recently, Offshore Wind Turbines (OWT) have attracted great attention in an effort to make a shift from fossil-based energy sources towards an enhanced sustainable and renewable energy production. In order to achieve the renewables targets and reduce the cost of wind energy, OWTs are consistently increasing in size. Therefore, research has targeted the optimization of OWT design. For many years, System Identification has played a central role in obtaining the actual modal properties of existing structures. Operational Modal Analysis (OMA) is a subset of these technique that applies on measurement data obtained from a structure loaded by ambient excitation. In the case of an OWT, such methods would be highly important in validating and/or updating the design and monitoring the structural health of the structure, which includes damage identification and fatigue damage estimation and would potentially lead into lifetime extension.

In practice, however, using OMA techniques on operating OWT is not a straightforward procedure. In fact, most of these techniques assume that the excitation is a white-noise process, which is not the case when waves and operational loads (e.g. rotational sampling) are present. Apart from that, the system itself is considered to be Linear Time-Invariant. Unfortunately, the modal properties of the system are highly affected by the varying rotational speed of the rotor and in general do violate the LTI assumptions. Given these challenges, the use-ability of existing methods need to be further investigated through application on OWTs under different operational conditions. Also, it is vital to asses and if possible eliminate the impact of the limitations related to loading on the identification.

Thus, a benchmark study of OMA algorithms has been performed on simulated data obtained from two models. The first model is a simplified OWT numerical model in Matlab, which can be used to validate the algorithms, and the second is the NREL 5-MW baseline offshore wind turbine in FAST that was used to simulate multiple different operational conditions. Using the simulated responses, at first, the Eigensystem Realization Algorithm (ERA) and the Natural Excitation Technique (NExT) were applied. Secondly, the widely used Stochastic Subspace Identification (SSI), has been included in this study. In Addition to these time domain techniques, the frequency-domain algorithms, Frequency Domain Decomposition (FDD) and the Least-Squares Complex Frequency-domain (LSCF) estimator were examined. In the end, Transmissibility-based Operational Modal Analysis (TOMA) was developed aiming in removing the influence of the external loading.



Through this study several parameters used in each algorithm as well as the robustness against harmonic excitation and measurement noise were investigated, providing the user with guidelines for each method. Then in the application on simulated data obtained from FAST, the results showed that all the algorithms were able to derive several stable modes, even when theoretically fundamental assumptions are violated. In general, the algorithms performed better for low wind speeds, while at high wind speeds the algorithms leaded in poorer identification (smaller number of stable modes). The greatest deviation compared to analytically obtained modal properties was observed in the damping ratios of the flapwise blade bending modes, where none of the algorithms was able to obtain such large damping ratios (>30%). However, most of them were still able to obtain two fore-aft tower modes and an accurate damping estimation. TOMA did remove the influence of external loading from the identification, but faced difficulties in obtaining blade modes. Finally, this benchmark study revealed the strengths and weaknesses of each technique when the core assumptions are violated.

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