Modal identification of time-varying systems using simulated responses on wind turbines

Mathieu BERTHA
Jean-Claude GOLINVAL

University of Liège

Novembre, 2012

Abstract

Wind turbines are good examples of time-varying systems as their modal properties depend on their instantaneous configuration. To catch the variations of modal parameters in time-varying systems, classical identification methods have to be adapted to the non-stationary nature of the recorded signals. In this paper, it is proposed to study the dynamic behavior of an offshore five-megawatt wind turbine. First, a numerical model of the wind turbine is created to serve as reference. Then, the time-varying behavior of the system is evaluated by simulating a large number of possible configurations. To this purpose, time responses are generated from the numerical model submitted to different environmental conditions. The wind is considered as the main non-measured external excitation force on the structure and the responses are recorded at several locations to simulate a real measurement process. Special care is brought to the accessibility of the measurement locations and to the limited number of available sensors in practice. Using these simulated measurements, output-only identification methods are used to extract varying dynamic properties of the structure. The final objective of this work is to pave the way to online condition monitoring of wind turbines.

Studied wind turbine

The complete wind turbine is described in the NREL technical report, 2009 [1].

Rating :	5 MW
Rotor diameter :	126 m
Hub height :	90 m

Wind speeds :

- Cut-in : 3 m/s
- Rated : 11.4 m/s
- Cut-out : 25 m/s

Rotor speeds :

- Cut-in : 6.9 r.p.m.
- Rated : 12.1 r.p.m.

Applied loads and identification method

Turbulent winds are generated based on a ***Kaimal*** wind model and applied on the structure.

Operational modal analysis is performed using the ***Stochastic Subspace Identification*** method [3].

Assumptions

- Linear time-invariant system
- Whiteness of the Gaussian process noise

Problem : these assumptions are not completely fulfilled.

Sensitivity of the method to the input parameters due to non constant operational conditions

Some tools are used to overcome these difficulties :

- Stabilisation diagrams with an automated clustering approach [4]
- Several simulations for different input parameters
- Projection channels used as references [5]

[1] Definition of a 5-MW Reference Wind Turbine for Offshore System Development.
Technical report, National Renewable Energy Laboratory, 2009.

[2] LMS International.
Samcef for wind turbines.
http://www.lmsintl.com/simulation/wind-turbines.

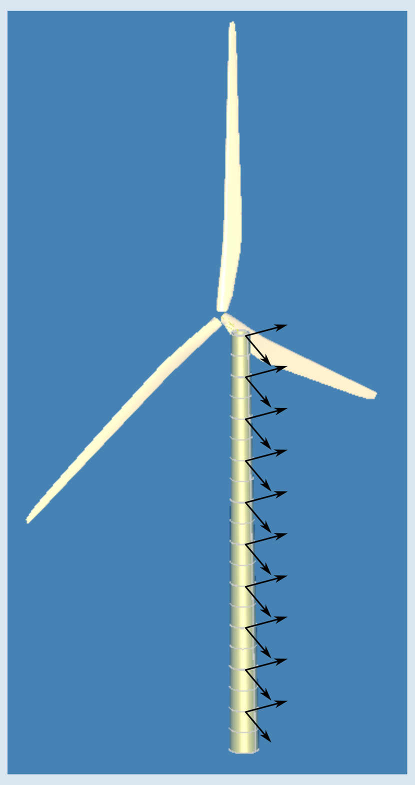
[3] Peter Van Overschee and Bart De Moor.
Subspace Identification for Linear Systems.
Kluwer Academic Publishers, 1996.

[4] Edwin Reynders, Jeroen Houbrechts, and Guido De Roeck.
Fully automated (operational) modal analysis.
Mechanical Systems and Signal Processing, 29 :228–250, May 2012.

[5] Niels-Jorgen Jacobsen, Palle Andersen, and Rune Brincker.
Applications of Frequency Domain Curve-fitting in EFDD Technique.
In *IMAC-XXVI*, 2008.

Numerical model

The wind turbine is modelled in the LMS–Samcef for wind turbine software [2].



Use of ***beam*** elements to model the tower and blades

Use of ***aero*** elements to compute aerodynamic loads on the blades

Use of ***Lumped masses*** to simulate the nacelle and the bedplate

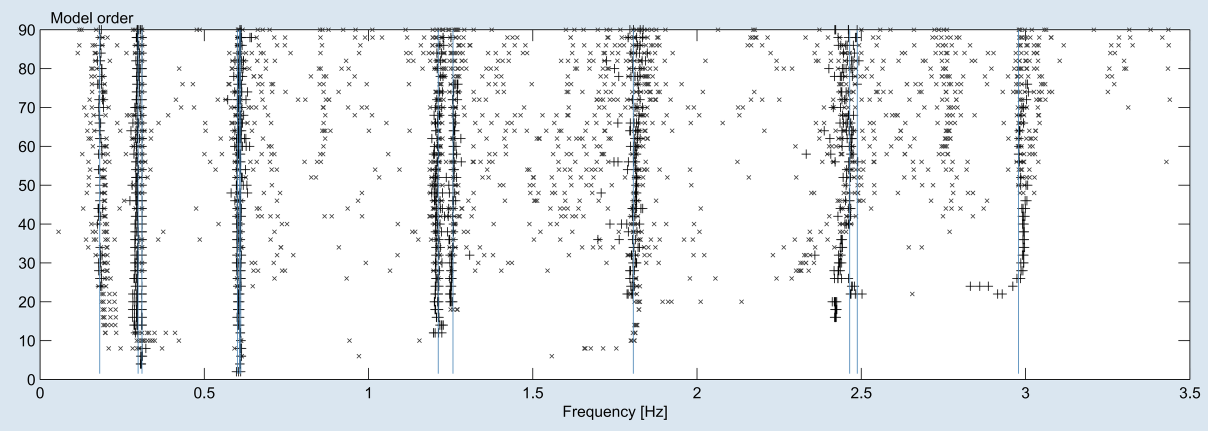
Use of ***Hinges*** in the rotor and yaw mechanism

10 measurement points are considered along the tower

Encountered difficulties

- The very low frequencies of the system require long time responses
- Due to high symmetry, the eigen modes are close in frequency
- The limited number of sensors causes high spatial aliasing
- The rotor speed and pitch angle slightly vary even under stationary winds

Identification results



(example in the case of a wind of 14 m/s)

Mean wind speed [m/s]	Mean rotor speed [r.p.m.]
4	7.4336
6	8.2786
8	9.9039
10	11.8921
12	12.1079
14	12.1091
16	12.1161
18	12.1240
20	12.1314