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

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Outline of the presentation

Description of the problem
Numerical model for simulations
Choice of an identification method
Encountered difficulties
Numerical results
Problem statement
The considered wind turbine (NREL technical report, 2009)

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.
A numerical model is built to simulate structural response

**Beam** elements model the tower and blades

**Aero** elements compute aerodynamic loads on the blades

**Lumped masses** simulate the nacelle and the bedplate

**Hinges** are used in the rotor and yaw mechanism

10 measurement points are considered along the tower
The wind is simulated with the *TurbSim* simulator coupled with *S4WT*.

The wind is generated based on the *Kaimal* model.

A set of load cases is generated considering different mean wind speeds.
Operational analysis requires output-only identification method

Some techniques are suitable for output-only modal analysis:

- (E)FDD
- $p$-LSCF (PolyMAX)
- SSI
The working assumptions of the *SSI* methods are not completely fulfilled

Assumptions of:

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

Because of the dynamic properties of the system and the deviation from working assumptions, some difficulties appear
The dynamic properties of the structure

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.

Tower bending modes are well identified.

Blade modes are seen as tower bending modes.
The method becomes sensible to the input parameters due to non constant operational conditions.

The rotor speed and pitch angle slightly vary even under stationary winds.
One can use some tools to try to overcome these difficulties

Stabilisation with an automated clustering approach (Reynders et al., 2012)

Several simulations for different input parameters

Projection channels used as references (Jacobsen et al., 2008)
The automated stabilisation diagram does not require thresholds any more.

The method in three steps:

- Separation between *possibly physical* and *certainly spurious* modes
- Grouping of similar modes
- Selection of a representative mode
The number of criteria to distinguish modes is more substantial

Classical stabilisation:
- Frequency deflection
- Damping deflection
- Mode deflection

Automated stabilisation:
- ... 
- Pole deflection 
- Mode shape complexity
The automated method adaptively selects the physical modes.
The use of projection channels reduces the CPU time

- Reduction of the size of correlation blocks in the Hankel matrix
  - Choice of the number of projection channels
  - Selection of the first one
  - Selection of the others
### Results

<table>
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<th>Mean wind speed [m/s]</th>
<th>Mean rotor speed [r.p.m.]</th>
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<tbody>
<tr>
<td>4</td>
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<td>12.1240</td>
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<tr>
<td>20</td>
<td>12.1314</td>
</tr>
</tbody>
</table>

![Graph showing frequency vs. wind speed]

- **Second fore−aft bending mode** of the tower caused by edgewise bending of the blade
- **Edgewise and flapwise bending modes** of the blades
- **Third harmonic of the rotor**
- **First bending modes** of the tower
- **Gyroscopic effect**

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Conclusions

A series of load cases were generated and applied on a numerical model.

Identifications were performed with the SSI method.

Some difficulties were pointed out in such an application.

Some tools were used to try to overcome these difficulties.

One can conclude that the traditional SSI method is not accurately applicable to such an application.
Thank you for your attention