Smart rotor

Lars O. Bernhammer
FLOW PhD day 2-10-2013
Research Partners
# Planning

## Time line

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<th>ID</th>
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**Challenge the future**
Load Alleviation in Wind Turbine Components

- Locations investigated:
  - Blade root
  - Shaft
  - Nacelle
  - Tower root
  - Tower top
  - Tip displacement
## Load Cases evaluated

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<thead>
<tr>
<th>Design Situation</th>
<th>DLC</th>
<th>Wind condition</th>
<th>Type of analysis</th>
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<td>ECD ( V_{hub} = V_{r} \pm 2 \text{m/s}, V_{in}, V_{out} )</td>
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<td>Normal shut down</td>
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Not considered: Emergency and Failure cases
Fatigue Load Alleviation in Wind Turbine Components

- Locations investigated:
  - Blade root
  - Shaft
  - Nacelle
  - Tower root
  - Tower top

- 3 forces & 3 moments per location
Extreme Load Alleviation in Wind Turbine Components

- Locations investigated:
  - Blade root
  - Shaft
  - Nacelle
  - Tower root
  - Tower top
  - Tip displacement

- Lower reduction potential as for fatigue loads
Extreme Tip Displacements

- Below and around rated speed: reduction of tip deflections
- Above rated: Increase of tip deflections
- Ultimate: 6% reduction flapwise
Non-linear modal based structure

- Start with full finite element model
- Reduce to structural backbone
- Break into segments
Model assumptions

- Segmentation of structure
- Large rotations and deformations are achieved by rigid body motion
- Local deformations are obtained by modal formulations
Fictitious masses

- Concentrated masses larger than segment mass
- Used to create a set of rigid body modes and fix-fix modes
- Boundary grid points are loaded by fictitious mass
- After calculation of modes, the fictitious masses are removed by:
  \[ \bar{M}_{removed} = \phi^T [\bar{M}_{full} - \bar{M}_{ficticious}] \phi \]
- Stiffness matrix and mode shapes are not changed
Assembly of compatibility matrix

- From root to tip, incremental construction

\[
T = \begin{bmatrix}
-\phi_{11}^{-1} \phi_{12} & 0 & 0 \\
\phi_{21}^{-1} R_{11} \phi_{1, \text{end}} T_1 & -\phi_{21}^{-1} \phi_{22} & 0 \\
0 & I & 0 \\
\vdots & \vdots & \vdots \\
[\phi_{n1}^{-1} \phi_{n-1, \text{end}} F_{n-1} \cdot T_{n-1}] & -\phi_{n1}^{-1} R_{n-1,1} R_{n-2,1}^{-1} \phi_{n2} & I
\end{bmatrix}
\]

- The global deformation is obtained by

\[
\begin{aligned}
&u_{\text{deformed}, i} = R_1^{-1} u_{\text{undeformed}, i} + R_1^{-1} \phi_i \begin{bmatrix} \xi_{i1} \\ \xi_{i2} \end{bmatrix} + \delta_i
\end{aligned}
\]
Non-linear static deflection

- 2 segments capture moderate amplitudes (<30% tip deflection)
- More segments are needed for high deflections
- 3 segments provide results within 7% of non-linear finite element model for 70% tip deflection
Dynamic response - Vertical and horizontal tip displacement

- Maximum vertical displacement captured
- Horizontal displacement more poorly captured, 3 segments needed
- Local vibration due to step input
- Overestimation of non-linear stiffening
Concept of flap design

- Free-floating flap
- Can be used for energy harvesting i.e. for sensors
- Can be used for control
- Internal actuator controlling trailing edge tab

![Power vs. R graph](image_url)
Work in progress

- Re-design of NREL 5MW turbine for Smart rotor
- Cost modelling of smart turbine
- Design of a free-floating wind turbine flap section for OJF
Thank you

Questions?