Light Rotor: The 10-MW reference wind turbine

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Light Rotor: The 10-MW reference wind turbine

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Background

• Wind turbines and rotors are growing in size
• Several investigations have been carried out to reveal the result of upscaling
• Wind turbine mass will with direct upscaling increase with \((\text{rotor radius})^3\)
• The power will only increase with \((\text{rotor radius})^2\)
• The gravity will have an increasing impact on the loads

• An obvious question is therefore:
  – How should the \textbf{power of 3 for the wind turbine mass} be reduced in the process of upscaling?
  – More specifically: How should the \textbf{power of 3 for the blade mass} be reduced?

• That is the reason for establishing a project to investigate this issue.
Background

- The “Light Rotor” project is a cooperation between DTU Wind Energy and Vestas.
- The objective is to develop the basis for design of wind turbine blades for use on 10MW rotors with lower weight, tailored aeroelastic response and optimized aerodynamic efficiency.
- This will be achieved by developing and applying a combination of thick airfoils, blade sweep and optimized structure.
This presentation

• This presentation is about the development of a 10MW reference wind turbine, where future “light weight” designs can be compared
• This 10MW reference wind turbine is not expected to be an exceptional light weight construction, but rather a fair upscaling of an existing wind turbine
• The presented turbine is iteration #2 in the design process and not the final design
Outline

• Basic considerations
• The method
• Results from the LR10-MW turbine
  – Aerodynamic design
  – Structural design
  – Aeroelastic stability
  – Loads
• Conclusions
Basic considerations

Rotor diameter [m] vs RNA mass [ton]

- V90-3.0MW: 472 W/m²
- V112-3.0MW: 305 W/m²
- V164-7.0MW: 331 W/m²
- Artificial 5MW reference: 407 W/m²

Turbine

RNA mass = 629 tons

R = 89.17 m
The method

Airfoil choice
- FFA-W3-xxx airfoils. 24.1% to 36.0% relative thickness, 60% airfoil scaled from FFA-W3-360 and cylinder.

Airfoil characteristics
- XFOIL computations at \( Re = 9 \times 10^6 \) to \( 13 \times 10^6 \) 3D corrected

Aerodynamic design
- HAWTOPT numerical optimizations. Max tip speed \( = 80m/s, \lambda = 8.06 \), min relative airfoil thickness \( = 24.1\% \)

Structural design
- ABAQUS (6.11) FEM computations. Uniaxial, biaxial and triaxial laminates were used together with PVC foam as sandwich core material

Aeroelastic design
- HAWCSTAB2 (aero-servo-elastic stability tool) and HAWC2 (aeroelastic code) computations. Class IA according to IEC-61400-1 standard for offshore application

Final design
- Iteration #2 is presented
The LR10-MW turbine: Aerodynamic design

HAWTOPT
The LR10-MW turbine: Structural blade design

ABAQUS

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<tr>
<th>Mode Number</th>
<th>Frequency [Hz]</th>
<th>Remark</th>
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<tr>
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<td>0.5210</td>
<td>First flapwise</td>
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<tr>
<td>2</td>
<td>0.8820</td>
<td>First edgewise</td>
</tr>
<tr>
<td>3</td>
<td>1.6142</td>
<td>Second flapwise</td>
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<tr>
<td>4</td>
<td>2.8173</td>
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<tr>
<td>5</td>
<td>3.4027</td>
<td>Third flapwise</td>
</tr>
<tr>
<td>6</td>
<td>5.0342</td>
<td>First torsional</td>
</tr>
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</table>

17 April 2012 EWEA Conference, 2012
The LR10-MW turbine: Blade mass

\[ \text{Mass}_{\text{glass}} = 0.0024 \times \text{Length}^{2.16} \]

\[ \text{Mass}_{\text{carbon}} = 9\times10^{-5} \times \text{Length}^{2.95} \]

- 73.5m blade upscaled with \( x^3 \)
- 73.5m blade upscaled with \( x^{2.16} \)
- Glassfiber
- Carbonfiber
- Upscale from 40m blades with \( x^3 \)
- Power (Glassfiber)
- Power (Carbonfiber)

LR10MW blade
Mass = 47.9 tons
The LR10-MW turbine: Aeroelastic stability

HAWCSTAB2

![Graphs showing modal frequencies and damping ratio vs. wind speed for different parts of the turbine](image-url)
The LR10-MW turbine: Aeroelastic stability

HAWCSTAB2
The LR10-MW turbine: Loads

HAWC2

Blade Root Flapwise Bending

Blade Tip Deflection

Tower Root Side-Side Bending

Blade Root Edgewise Bending

Resulting tower bottom moment

Tower Root Fore-Aft Bending
Conclusions

- A rotor and a wind turbine for a 10-MW wind turbine are designed with the shown results for Iteration #2 in the design process.
- The design process will need more iterations between aerodynamic, structural and aeroelastic design.
- It is of primary importance to design the rotor together with the entire system: Foundation, tower, drivetrain and rotor.
- Several issues were highlighted:
  - Selecting the specific power is not trivial. For this rotor it was chosen to maintain the specific power of the artificial 5-MW wind turbine.
  - The mass of the LR10-MW blade seems to be somewhat too high compared to a blade directly upscaled from e.g. LM73.5P.
  - Estimating the drive train mass is not trivial
  - The mass of the turbine is highly depending on concepts/technology

- In the further work, the challenges in the control needs to be solved.
- Also, the balance between power performance, loads and structural layout will be investigated further resulting in changes in the present design.
Availability

• The final design incl. aeroelastic model and blade layout will be available on:
  – www.vindenergi.dtu.dk
  – under the menu Research
  – from July 1, 2012
Acknowledgements

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Thank you for the attention!