The DTU 10MW Reference Wind Turbine

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DTU Wind Energy
Department of Wind Energy
Where do I come from?
Map of the Technical University of Denmark
Where do I come from?
DTU Wind Energy: Organization and activities
Where do I come from?

DTU Wind Energy: Research Facilities

Existing:
• Wind turbines at Risø Campus for research and courses;
• Test Station for Large Wind Turbines at Høvsøre;
• Test Station for “Very” Large Wind Turbines at Østerild;
• Risø met-mast
• Blade test Facility for Research;
• 1 MW drive-train test facility;
• Measurement stations and equipment, incl. Lidars;
• PC-clusters;
• Structural test laboratory;
• Material tests lab, incl. Microscopes etc
• Fiber lab
• Smaller wind tunnels; and
• The WindScanner facility.

Under development or in planning phase:
• Østerild Grid Test Facility;
• National Wind Tunnel and;
• Large Scale Facility (structural tests);
Agenda for today

- Why a 10 MW reference wind turbine?
- The DTU 10MW Reference Wind Turbine
- Integrated design complex
- Example of integrated design
- Summary
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Why a 10 MW reference wind turbine? Upscaling

Power $\sim$ rotor diameter$^2$
Mass $\sim$ rotor diameter$^3$

Upscaling rated power by $\times 100$ in 30 years

Source: International Energy Agency (IEA)
Why a 10 MW reference wind turbine? 

Upscaling

- The wind turbine is only a fraction of the total cost of an offshore farm (~30%-40%)

- The rotor is only a fraction of the total cost of a wind turbine (~20%)

- However, even though the rotor is a small fraction of the entire cost this component is a key component that makes a difference for the Annual Energy Production
Why a 10 MW reference wind turbine? The Light Rotor project

• The Light Rotor project was carried out 2010-2014
• Aimed at creating the design basis for next-generation wind turbines of 10+ MW.
• A collaboration with Vestas Wind Systems
• The project sought to create an integrated design process composed of:
  – Advanced airfoil design taking into account both aerodynamic and structural objectives/constraints,
  – Aero-servo-elastic blade optimization
  – Structural topology optimization.

• BUT: We needed a reference wind turbine to compare our designs against
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The DTU 10 MW Reference Wind Turbine

Objectives

• The purpose with the design is:
  – To achieve a design made with traditional design methods in a sequential MDO process
  – Good aerodynamic performance and fairly low weight.
  – To provide a design with high enough detail for use for comprehensive comparison of both aero-elastic as well as high fidelity aerodynamic and structural tools,
  – To provide a publicly available representative design basis for next generation of new optimized rotors.

• The purpose is not:
  – To design a rotor pushed to the limit with lowest weight possible,
  – To push the safety factors as much as possible,
  – Provide a design of a complete wind turbine – focus is on the rotor,
  – To provide a design ready to be manufactured; the manufacturing process is not considered.
The DTU 10 MW Reference Wind Turbine

The method

- FFA-W3-xxx airfoils. 24.1% to 36.0% relative thickness, 48% and 60% airfoil scaled from FFA-W3-360 and cylinder.
- 2D CFD computations using EllipSys at Re $9 \times 10^6$ to $13 \times 10^6$ and 3D corrected
- HAWTOPT numerical optimizations. Max tip speed = 90m/s, $\lambda = 7.5$, min relative airfoil thickness = 24.1%
- ABAQUS (6.11) FEM computations and BECAS. Uniaxial, biaxial and triaxial laminates were used together with balsa as sandwich core material
- HAWCSTAB2 (aero-servo-elastic stability tool) computations including controller tuning.
- HAWC2 (aeroelastic code) computations. Class IA according to IEC-61400-1 standard for offshore application
The DTU 10 MW Reference Wind Turbine
Aerodynamic Design: Geometry
The DTU 10 MW Reference Wind Turbine Aerodynamic Design: 3D CFD analysis

- Automated workflow from 2D blade definition/airfoil family -> 3D shape -> 3D volume mesh,
- 3D CFD validation of performance predicted using BEM,
- Blade performance in the root area was not satisfactory due to use of thick airfoils (t/c > 0.36 for r/R < 0.30).
- Gurney flap were used to remedy this, increase in CP of 1.2% at design TSR.
- Resulted in adjustment of airfoil data and new design iteration adopting the modified root layout.
- (Automated derivation of 3D airfoil data).
The DTU 10 MW Reference Wind Turbine
Structural Design: Basic design choice

• A “box-girder” design approach is used.
• For layup definition the blade is partitioned into 100 regions radially and 10 regions circumferentially.
• A complete description of the blade’s geometry and layup is generated in the form of a finite element shell model.
The DTU 10 MW Reference Wind Turbine Structural Design: Design loop

Geometry, material and composite layup definition

Automatic generation of ABAQUS input files

ABAQUS: layered shell model

Ultimate loads

Automatic generation of BECAS input files

BECAS: cross section analysis

Cross section stiffness properties

HAWC2: aeroelastic analysis

Local stress and failure

Buckling

<table>
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<tr>
<th>Load case</th>
<th>$\gamma_F$</th>
<th>$F_x$ [MN]</th>
<th>$F_y$ [MN]</th>
<th>$F_z$ [MN]</th>
<th>$F_{res}$ [MN]</th>
<th>$M_z$ [MNm]</th>
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<tr>
<td>max</td>
<td>dlc5.1</td>
<td>1.35</td>
<td>0.9551</td>
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<td>1.0163</td>
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<tr>
<td>$F_y$ max</td>
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<td>1.1873</td>
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</tbody>
</table>

Reference: Elastic, Shear, Mass - Ax. 1, Ax. 2.
The DTU 10 MW Reference Wind Turbine
How the blade compares to existing ones

\[ \text{Mass}_{\text{glass}} = 0.0023 \times \text{Length}^{2.16} \]

\[ \text{Mass}_{\text{carbon}} = 9 \times 10^{-5} \times \text{Length}^{2.95} \]

Blade mass [tons] vs. Blade length [m]

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

15 September 2015
The DTU 10 MW Reference Wind Turbine
Aero-servo-elastic analysis

- HawcStab2 used to analyze the modal properties of the wind turbine:
  - frequencies, damping ratios, and mode shapes.
- The DTU Wind Energy controller was revised and tuned specifically for the DTU 10 MW RWT.
- To avoid tower mode excitation from 3P frequency, minimum RPM = 6.
- Report and source code on controller available.
The DTU 10 MW Reference Wind Turbine

Load calculations: HAWC2

- DTU 10MW RWT: IA according to IEC-61400-1 (3rd edition)

- The suggested load cases by IEC standard must be verified in order for withstanding all loading situations during its life time.

- Most of design load cases are considered except DLC8, which is for transport, assemble, maintenance, and repair cases, and DLC 1.4, DLC 2.2, DLC 3.1, DLC 3.2, and DLC 3.3 which are very depending on controller.
The DTU 10 MW Reference Wind Turbine
Load calculations: HAWC2

Tower Bottom Fore-Aft Bending

Tower Bottom Side-Side Bending

Blade Root Flapwise Bending

Blade Tip Deflection hub coord between 175 and 185 deg
# The DTU 10 MW Reference Wind Turbine Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
<td>Nominal power</td>
<td>10.0 MW</td>
</tr>
<tr>
<td>Rotor configuration</td>
<td>Upwind, 3 blades</td>
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<tr>
<td>Control</td>
<td>Variable-speed, collective pitch</td>
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<tr>
<td>Drivetrain</td>
<td>Medium speed, Multiple stage gearbox</td>
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<td>Rotor diameter</td>
<td>178.3 m</td>
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<td>Hub height</td>
<td>119.0 m</td>
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<td>Cut-in/rated rotor speed</td>
<td>6RPM/9.6RPM</td>
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<tr>
<td>Rated tip speed</td>
<td>90 m/s</td>
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<td>Blade pre-bend</td>
<td>3.3 m</td>
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<tr>
<td>Tower mass</td>
<td>628.4 tons</td>
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<tr>
<td>Nacelle mass</td>
<td>446.0 tons</td>
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<tr>
<td>Rotor mass</td>
<td>230.7 tons</td>
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<tr>
<td>Blade mass</td>
<td>41.7 tons</td>
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</table>
The DTU 10 MW Reference Wind Turbine
Some of the lessons learned

• Transition from laminar to turbulent flow in the boundary layer of the airfoils:
  – The result is uncertainty of the aerodynamic performance and thereby on loads and especially the power

• The efficiency of thick airfoils, i.e. airfoils with relative thickness greater than 30%, is significantly better when using Gurney flaps,
  – The result is an increase of the power of several percent

• To reduce the blade weight, the blade design needs to be “stress/strain” driven rather than “tip deflection” driven.
  – The result is a pre-bend design,

• The control of the rotor must take several instability issues into account, e.g. coinciding frequencies from the tower eigen frequency and 3P at low wind speeds,
  – The result is determination of the minimum rotational speed

• Blade vibrations in stand still
  – Vibrations at 90 degrees inflow direction can probably be avoided by pitching each blade differently
  – Vibrations at 30 degrees inflow direction can be reduced by ensuring “smooth” airfoil characteristics
The DTU 10 MW Reference Wind Turbine
Is it public?

• It is important for R&D that there are common designs so that the performance of simulation tools, solutions to problems etc. can be discussed.

• This was the reason to make the turbine public

• The DTU 10 MW RWT is used in the European InnWind project and many other projects.

• Available as a comprehensive release

• Go to: dtu-10mw-rwt.vindenergi.dtu.dk
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Integrated Design Complex
FUSED-Wind

- Framework for Unified Systems Engineering and Design of Wind Turbine Plants

- Go to: fusedwind.org
- Based on OpenMDAO developed by NASA

- Collaboration with NREL
- The framework includes pre-defined interfaces, workflows and I/O definitions that enables easy swapping of codes.

- DTU and NREL will each release separate software bundles that target specific usages, i.e. airfoil, turbine, and wind farm optimization.
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Example of integrated design
Case: Shape and structural optimization

41.7 ton
37.5 ton
33.4 ton
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Summary and future work

- You have heard about:
  - The DTU 10MW RWT
  - Integrated blade design

- It is the hope that persons, projects and organizations will use the DTU 10MW RWT
- It is also the hope that it will be detailed and optimized further and uploaded to our site as a new “branch”

- In the future the integrated design complex will be developed further to take more degrees of freedom into account.
- Also, more detailed cost models will be included
- In this way we will try to decrease the CoE further
Thank you for your attention!

DTU 10MW Reference Wind Turbine: dtu-10mw-rwt.vindenergi.dtu.dk

Integrated design complex: FUSED-Wind fusedwind.org