DeepWind-An Innovative Offshore Wind Turbine Concept

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Innovative Concepts and new Technologies

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DTU Wind Energy
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Contents

• DeepWind Concept
• DeepWind instruments and goals
• Results in the project
• Conclusion
So far, offshore wind energy has been mainly based on onshore HAWT technology moved in shallow waters. In order to reduce the cost, offshore wind energy needs new concepts specifically designed for offshore conditions. Key issues for a successful offshore concept are:

- Simplicity
- Up-scaling potential
- Suitability for deep sites
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DeepWind Concept

• Genuine offshore concept
  – Simple
  – Scalable
  – For deep sea sites
• Floating offshore based on VAWT technology
• Cost difference allows room for design space
• A priori: Tech Range 100-1000 m depth
• So far
  – demonstrator
  – exhibition model
  – paper work results

• Contributions to reduce risk(selected list):


  V. L. Offshore floating vertical axis wind turbines with rotating platform Risø DTU, Roskilde, Denmark, PhD dissertation PhD 80, 2011

  Stefan Carstensen1 Xerxes Mandviwalla, Luca Vita and Uwe Schmidt Paulsen Lift of a Rotating Circular Cylinder in Unsteady Flows ISOPE June2012
DeepWind
The Concept

• No pitch, no yaw system

• Light weight rotor with pultruded blades
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The Concept

- No pitch, no yaw system
- Floating and rotating tube as a spar buoy
- Light weight rotor with pultruded blades
- Long slender and rotating underwater tube with little friction
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The Concept

• No pitch, no yaw system

• Floating and rotating tube as a spar buoy

• C.O.G. very low – counter weight at bottom of tube

• Light weight rotor with pultruded blades

• Long slender and rotating underwater tube with little friction with little friction
DeepWind
The Concept

• No pitch, no yaw system

• Floating and rotating tube as a spar buoy

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• Safety system

• Light weight rotor with pultruded blades

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DeepWind
The Concept

• No pitch, no yaw system
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• Light weight rotor with pultruded blades
• Long slender and rotating underwater tube with little friction
• Torque absorption system
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The Concept

- No pitch, no yaw system
- Floating and rotating tube as a spar buoy
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- Safety system
- Light weight rotor with pultruded blades
- Long slender and rotating underwater tube with little friction
- Torque absorption system
- Mooring system
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**The Concept - Generator configurations**

- The Generator is at the bottom end of the tube; several configurations are possible to convert the energy.

- Three selected to be investigated first:
  1. Generator fixed on the torque arms, shaft rotating with the tower.
  2. Generator inside the structure and rotating with the tower. Shaft fixed to the torque arms.
  3. Generator fixed on the sea bed and tower. The tower is fixed on the bottom (not floating).
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The Concept- Blades technology

- The blade geometry is constant along the blade length

- The blades can be produces in GRP or similar

- Pultrusion technology:
  - Presently block up to approx 1 m units
  - outlook- 11 m chord several 100 m long blade length

- Pultrusion technology could be performed on a ship at site

- Blades can be produced in modules
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The Concept- Installation, Operation & Maintenance

• INSTALLATION
  ✓ Using a two bladed rotor, the turbine and the rotor can be towed to the site by a ship. The structure, without counterweight, can float horizontally in the water. Ballast can be gradually added to tilt up the turbine.

• O&M
  ✓ Moving the counterweight in the bottom of the foundation is possible to tilt up the submerged part for service.
  ✓ It is possible to place a lift inside the tubular structure.

- A new basis for cost cutoff in installation procedures
- Redistributing the costs
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The Concept Upscaling

- Pultrusion technology allows for very long and fail-free manufactured blades
- Concept simplicity
- Few components with less down time failures

- Cost-effective different materials for large structure
- Specific requirements to maintain the underwater components
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Instruments and goals

WP10 Project Management
WP-leader: RISØ DTU

WP1. Aero-elastic code and simulation of performance, dynamics and loads
WP-leader: RISØ DTU

WP2. Blades technology and design
WP-leader: DTU MEK

WP3. Generator concepts
WP-leader: AAU

WP4. Turbine system control
WP-leader: SINTEF

WP5. Mooring floating and torque absorption system
WP-leader: MARINTEK

WP6. Exploration of lift, drag and friction on a rotating cylinder
WP-leader: DHI

WP7. Concept testing
WP-leader: RISØ DTU

WP8. Integration of technologies and upscaling, evaluation
WP-leader: RISØ DTU

WP9. Dissemination and exploitation
WP-leader: RISØ DTU

Validation

Numerical code implementation

Main parameter investigation

Dissolution Programme

Verification Programme

Validation Programme
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Results 1st Design Assumptions

- Dynamic stall neglected
- Atmospheric turbulence not considered
- Evaluation of loads with 3 DOF
- No mooring
### DeepWind

**Results 2MW VAWT vs HAWT**

<table>
<thead>
<tr>
<th></th>
<th>Deep Wind</th>
<th>HyWind*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td>2 MW</td>
<td>2.3 MW (+15%)</td>
</tr>
<tr>
<td><strong>Rotor Diameter</strong></td>
<td>67 m</td>
<td>82.4 m (+23%)</td>
</tr>
<tr>
<td><strong>Rotor Height</strong></td>
<td>75 m</td>
<td>65.0 m (-13%)</td>
</tr>
<tr>
<td><strong>Chord (blades number)</strong></td>
<td>3.2 m (2)</td>
<td>N/A (3)</td>
</tr>
<tr>
<td><strong>Rotational speed at rated conditions</strong></td>
<td>15.0 rpm</td>
<td>16.0 rpm (+7%)</td>
</tr>
<tr>
<td><strong>Radius of the rotor tower</strong></td>
<td>2.0 m</td>
<td>3.0 m (+50%)</td>
</tr>
<tr>
<td><strong>Maximum radius of the submerged part</strong></td>
<td>3.5 m</td>
<td>4.15 m (+19%)</td>
</tr>
<tr>
<td><strong>Total tower length (underwater part)</strong></td>
<td>183 m (93m)</td>
<td>165 (100)</td>
</tr>
<tr>
<td><strong>Displacement</strong></td>
<td>3000 tons</td>
<td>5300 tons (+77%)</td>
</tr>
</tbody>
</table>

*“HYWIND, Concept, challenges and opportunities”, Statoil

Uwe Schmidt Paulsen - *Prospects of Large Floating Vertical Axis Wind Turbines* - Proceedings in Deep Sea Offshore R&D Conference Trondheim(NO) 2011
DeepWind

Results 1st BaseLine 5 MW Rotor Design

Paulsen US, Vita L, Madsen HA, Hattel J, Ritchie E, Leban KM, Bertheisen PA, Carstensen S 1st DeepWind 5 MW baseline design
Energy Procedia 00 (2011) 000–000

Geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor radius (R)</td>
<td>m</td>
<td>63.74</td>
</tr>
<tr>
<td>Rotor height (H)</td>
<td>m</td>
<td>129.56</td>
</tr>
<tr>
<td>Chord (c)</td>
<td>m</td>
<td>7.45</td>
</tr>
<tr>
<td>Solidity (σ = Nc/R)</td>
<td>-</td>
<td>0.23</td>
</tr>
<tr>
<td>Swept Area</td>
<td>m²</td>
<td>10743</td>
</tr>
</tbody>
</table>

Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>kW</td>
<td>5000</td>
</tr>
<tr>
<td>Rated rotational speed</td>
<td>rpm</td>
<td>5.26</td>
</tr>
<tr>
<td>Rated wind speed</td>
<td>m/s</td>
<td>14</td>
</tr>
<tr>
<td>Cut in wind speed</td>
<td>m/s</td>
<td>5</td>
</tr>
<tr>
<td>Cut out wind speed</td>
<td>m/s</td>
<td>25</td>
</tr>
</tbody>
</table>

![Graph showing power and lift coefficient vs. wind speed]
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Results 1st BaseLine 5 MW Design Blades

- blade weight 154 Ton
- blade length 187 m
- Blade chord 7.45 m, constant over length
- All GRP
- NACA 0018 profile
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Results 1\textsuperscript{st} BaseLine 5 MW Design Generator

- 5 MW mechanical power at estimated 5.26 rpm and 9.1 MNm shaft torque renders a 400 pole 17.53 Hz design with a pole pitch of around 7.85 cm

- This corresponds to an air-gap diameter of around 10 m outer diameter of around 10.5 m, with a core length of around 1.4 m.

- Mass of Copper, Iron and permanent magnet materials of around 90 metric tons

- Design fits reasonable with the platform design
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Results 1st BaseLine 5 MW Design Floater

Hywind site + 6DOF:
~4900 tons mass 0.9k€/ton
~35/60 sec natural periods in yaw/surge
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Results LTT Windtunnel tests (July 2012)

Analysis of advanced airfoils developed for VAWTs
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Results Modelling of Pultrusion Process

Studies already done:
- Process optimization studies by using gradient based and/or genetic algorithms
  - Optimal heater configuration
  - Increase productivity i.e. increase pulling speed while satisfying the desired cure degree

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Results Physical Model Experiments


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Results Physical Model Experiments

Picture

\[ U = U_m \sin(2\pi ft + \phi) + U_c \]

Carstensen et al. Lift of a Rotating Circular Cylinder in Unsteady Flows ISOPE June 2012

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Results Physical Model Experiments Forces

(a) Morison formulation, waves and current:

\[ F_X = \frac{1}{2} \rho C_D D U |U| + \rho C_m A \frac{dU}{dt} \]
\[ F_Y = 0 \]

(b) Cylinder rotating in steady current:

\[ F_X = \frac{1}{2} \rho C_D D U |U| \]
\[ F_Y = \frac{1}{2} \rho C_L D U |U| \]

(c) Cylinder rotating in unsteady flow (Ideal Fluid):

\[ F_X = \rho C_m A \frac{dU}{dt} \]
\[ F_Y = \rho \Gamma U = \rho 2 A \omega U = \rho C_T A \omega U \]
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Results Physical Model Experiments
Oscillatory Lift Force

\[ KC \text{ small: } (1 < KC < 8) \quad KC = \frac{2\pi a}{D} = \frac{U_m T}{D} \]

\[ KC \text{ large: } (12 < KC < 24) \quad F_y = \frac{1}{2} \rho C_L U|U| + \rho C_{mY} A \frac{dU}{dt} \]

Carstensen et al. Lift of a Rotating Circular Cylinder in Unsteady Flows ISOPE June 2012
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Results 2nd Design Assumptions

✓ Actuator cylinder model*
✓ Dynamic stall
✓ Atmospheric turbulence
✓ Evaluation of loads 6 DOF
✓ Mooring system

*Madsen HA, Larsen T, Paulsen US Adoption of the aeroelastic code HAWC2 for vertical axis turbines using the actuator cylinder flow model 51st AIAA conference Dallas Texas(USA) Jan 2013
## DeepWind

### Results 2\textsuperscript{nd} iteration 5 MW Design Rotor

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor radius (R0) [m]</td>
<td>58.5 (-8%)</td>
</tr>
<tr>
<td>Rotor Height (H) [m]</td>
<td>143 (+10.4%)</td>
</tr>
<tr>
<td>H/(2R0) [-]</td>
<td>1.222 (+22%)</td>
</tr>
<tr>
<td>Solidity ((\sigma = Nc/R0)) [-]</td>
<td>0.15 (-33%)</td>
</tr>
<tr>
<td>Swept Area (Sref) [m(^2)]</td>
<td>12318 (+15%)</td>
</tr>
</tbody>
</table>

![Graph](image)
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Results $C_p$ vs dimensionless flapwise Inertia
(bending stiffness)

©DeepWind,TUDelft
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Results case-2+ 1iteration

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Conclusion

✓ Established a full design tool and verification code integrating VAWT concept
✓ Established a full model for blade pultrusion and preparation of advanced thick airfoils of laminar flow family with smaller CD₀ and good Cₚ
✓ Design tool for PMG subsea generators; 1ˢᵗ design of a 5 MW generator
✓ Design tool and verification tool for VAWT controls
✓ 1ˢᵗ Floater for 5 MW design
✓ Verified Fluid dynamics for rotating cylinders
✓ Iteration from a 1ˢᵗ 5 MW floating concept to a 2ⁿᵈ iteration towards a light weight 5MW rotor with low bending moment

• Continuation of iterations for improved design and for Cost analysis
• 1ˢᵗ campaign of Demonstrator tests conducted
• Next tests to be carried out in Ocean lab
Conclusion

Thank You for Your Attention

Thanks to EU FP7 and the members of DeepWind consortium: DTU(DK), AAU(DK), TUDELFT(NL), TUTRENTO(I), DHI(DK), SINTEF(N), MARINTEK(N), MARIN(NL), NREL(USA), STATOIL(N), VESTAS(DK) and NENUPHAR(F).