The 5 MW Deepwind Floating Offshore Vertical Wind Turbine Concept Design - Status And Perspective

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The 5 MW Deepwind Floating Offshore Vertical Wind Turbine Concept Design - Status And Perspective

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DeepWind

- A radical new design- aiming for better COE and a more reliable wind turbine
  - Few components-less failures at less cost
  - Pultrusion-less failures; cost approximately 30% of conventional blade
  - Operation not influenced by wind direction
  - New airfoil profiles available for better efficiency
  - Simple stall control with overspeed protection
- Rotating spar with high Aspect ratio-Less displacement than existing concepts
- No nacelle-low center of gravity - high stability
- Upscaling potential
- Insensitive to wind turbulence

Vita L, Paulsen US, Pedersen TF, Madsen HA, Rasmussen F *A Novel Floating Offshore Windturbine Concept* in Proceedings of the European Wind Energy Conference (EWEC), Marseille, France, 2009


Larsen TJ, Madsen HA. *On The Way To Reliable Aero-elastic Load Simulation On VAWT’s. Proceedings of EWEA 2013 Wind Energy conference Vienna; 2013*

Vita L *Offshore floating vertical axis wind turbines with rotating platform* Riso DTU, Roskilde, Denmark, PhD dissertation PhD 80, 2011
Design suites(1)

- General FE model
- Wind
  - Atmospheric Turbulence
  - Shear
- Aerodynamics
  - Dynamic stall
  - Actuator Cylinder
- Hydrodynamics
  - Magnus force
  - Morrison forces
  - Friction
- Mooring lines
- Generator control
Design suites(2)

- Generator design tool
- CAD design tool

✔ Optimization
✔ Simulation
✔ Visualization
Bearing design-test rig
Preconditions-Site (Karmøy, No)

- **Latitude:** 59° 8'44.88"N,
- **Longitude:** 5° 1'25.66"E

DHI’s Hindcast model

### Significant Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity of the water currents at the surface</td>
<td>[m/s]</td>
<td>0, [0.35,0.7]</td>
</tr>
<tr>
<td>Maximum significant wave height $H_s$</td>
<td>[m]</td>
<td>14</td>
</tr>
<tr>
<td>Maximum peak wave period $T_p$</td>
<td>[s]</td>
<td>16</td>
</tr>
<tr>
<td>Wind speed (limit wind speed of the design)</td>
<td>[m/s]</td>
<td>&lt;25</td>
</tr>
</tbody>
</table>
Sketch of the concept

- Modified rotor shape
  - $|\varepsilon| < 5000 \times 10^{-6}$ m/m
  - Sectionized NACA 0018,0025 profiles
  - Light rotor with pultruded blades
- Simple conical support tower
- Floater design implemented
- Generator at end of rotating spar
Airfoil development

LTT WT TUDelft
**Blade Design**

**Pultrusion:**

- Constant chord over length
- Low manufacturing cost +
- Structural strength for thin profiles -

**Rotor shape:**

- Structural stiffeners to improve strength in blade cross section
- Gravity and centrifugal loads are important for VAWT rotor blade shape design
- Present design fully shape optimized

5 MW blade section, 1st baseline
Blade shape optimization

Loading: Sea state 3, 24 m/s no turbulence

“Pultrusion is one of the most cost-efficient composite manufacturing methods to produce constant cross sectional profiles at any length”.

DeepWind—from idea to 5 MW concept Energy Procedia (2014)
Industrial joints solution

• Gravity stability: vertical distance between COG and BC

• If Rotation around COG and weak Pitch-Surge coupling:
  \[ T_{n_5} = 2\pi \sqrt{I_{55} + a_{55}/k_{55}} \]

• Avoid resonance
  - \( T_n > \) wave periods with significant energy contents
  - \( (I_{55} + a_{55}) \) increase or decreasing \( k_{55} \)
Floater

![Graph showing variation of centre of gravity blades.](image)

<table>
<thead>
<tr>
<th>COG [m]</th>
<th>Natural Period [s]</th>
<th>Static heel (tilt) Angle [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>29</td>
<td>11</td>
</tr>
<tr>
<td>90</td>
<td>16</td>
<td>16</td>
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</tbody>
</table>

**Pitch**

**tilt**

*Floating wind farm layout*

- 20 turbines
- 60 mooring lines
- 17 anchor points
Safety system

Demonstrator testing blades hitting water

Before hit after
Safety system

Idea from Demonstrator testing blades hitting water

Huge Rotor Inertia
Slow rpm 0.6 rad/s

Max sinking depth to avoid mooring line twisting is 65 m
≈ 50 deg twist

To be verified
Results Blade shape-modified Troposkien shape

- Blade length ≈ 200 m
- Blade weight ≈ 45 T
- Less bending moments at blade root and predominantly tension
Results-Electrical system

Direct Drive
Permanent Magnet
Radial Flux
Height x Dia ≈3m x 6m
Weight (core material) ≈ 90 T
Results-Electrical system

Grid integration
4 quadrant inverter

All active turbine control via generator torque

2p damping with notch filter and PI controller

![Diagram of electrical system](image)
Results-power curve

Blue SS1 Red SS2 Green SS3
Results-pitch

Blue SS1 Red SS2 Green SS3
Results-roll

Blue SS1 Red SS2 Green SS3
Results-moments

![Graph showing results moments vs. wind speed](image-url)
Conclusions

- Demonstration of an optimized rotor design with pultruded, sectionized GRP blades
- Aerodynamic stall control, a robust and simple electrical controls
- 2 Blades with 2/3 less weight than 1st baseline 5MW design, and Less bending moments in root, and tension during operation
- Potential for less costly light weight rotor
- Use of moderate thick airfoils of laminar flow family with smaller CD₀ and good Cₚ, increase efficiency and increase structural rigidity
- Floater: successful design in harsh environment
- Industrial solutions available for joints, underwater generator and mooring system
- No show stopper- the concept can be developed further in an industrial optimization process
- COE/LCOE: DeepWind technology in a steep learning curve
- The 20 MW is far beyond current wind turbine sizes
Acknowledgement

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