DeepWind-from idea to 5 MW concept

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DTU Wind Energy
Department of Wind Energy

DeepWind

Contents

- DeepWind Concept
- 5 MW design
- Optimization process results
- Conclusion

  – Controller part: grid compliance

DeepWind

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- DeepWind Concept
- Baseline 5 MW design
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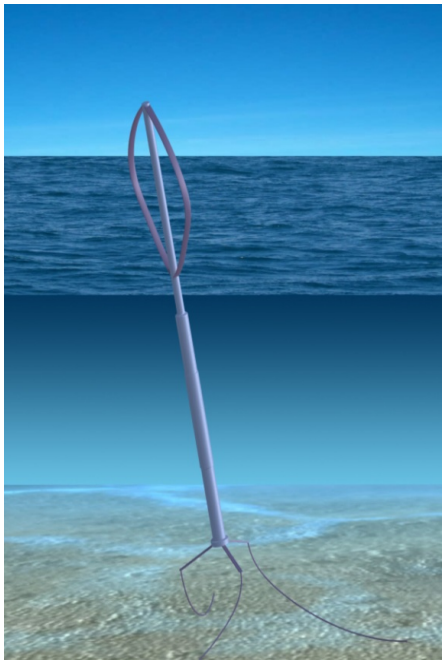

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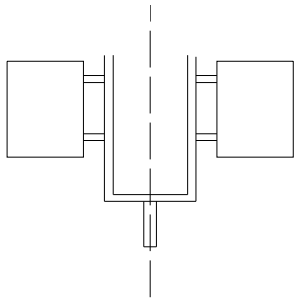
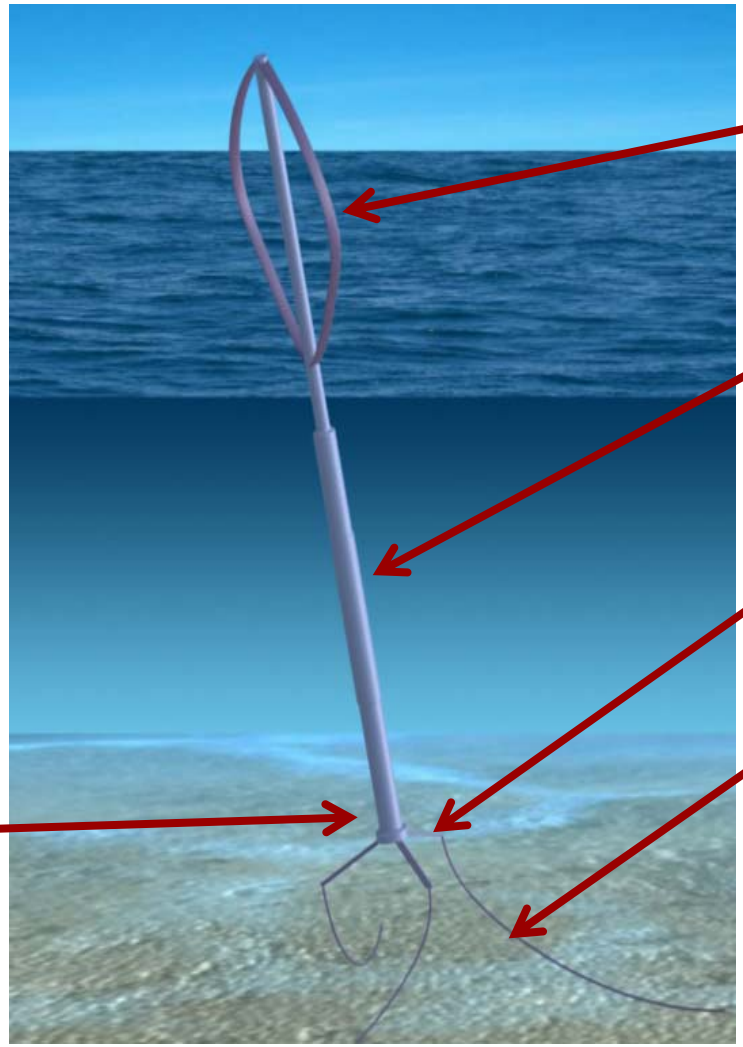
The Concept

- No pitch, no yaw system
- Floating and rotating tube as a spar buoy
- C.O.G. very low – counter weight at bottom of tube
- Safety system



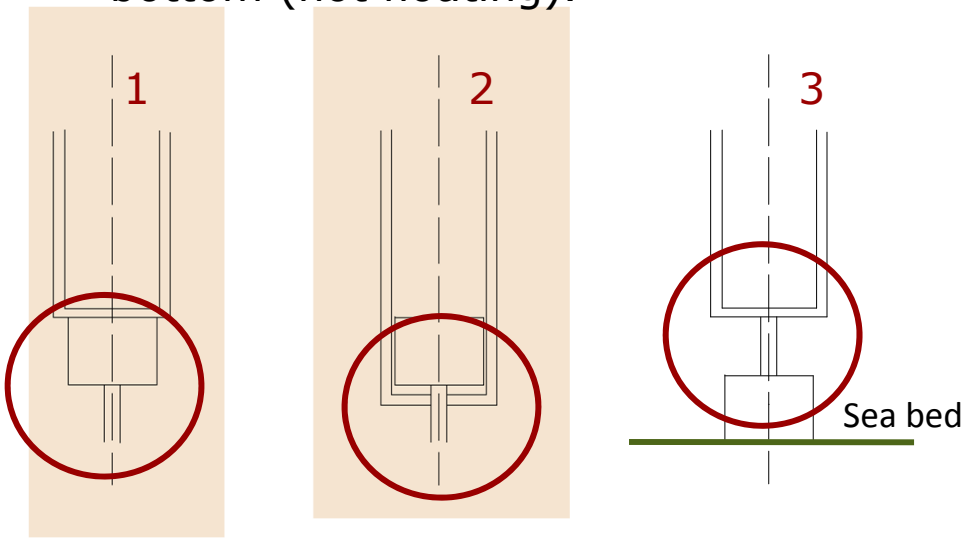


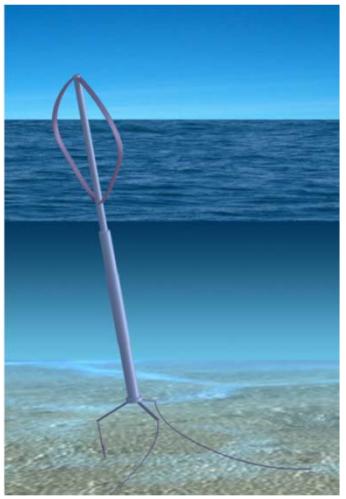
- Light weight rotor with pulltruded blades, prevailing loads from aerodynamics
- Long slender and rotating underwater tube with little friction
- Torque absorption system
- Mooring system

DeepWind

Concept- Generator configurations

- The Generator is at the bottom end of the tube; several configuration are possible to convert the energy
- Robust integrated bearing technology
- 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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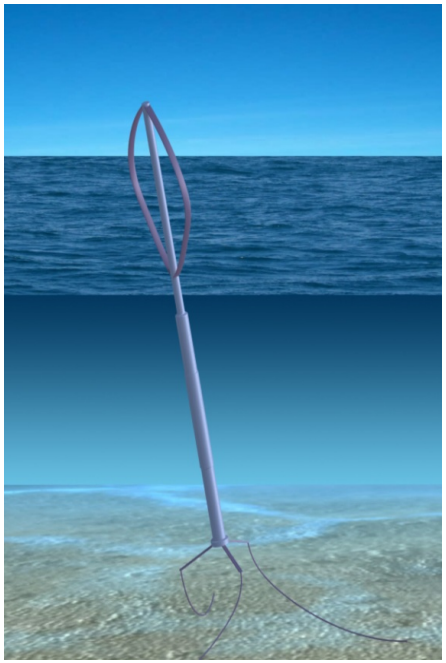
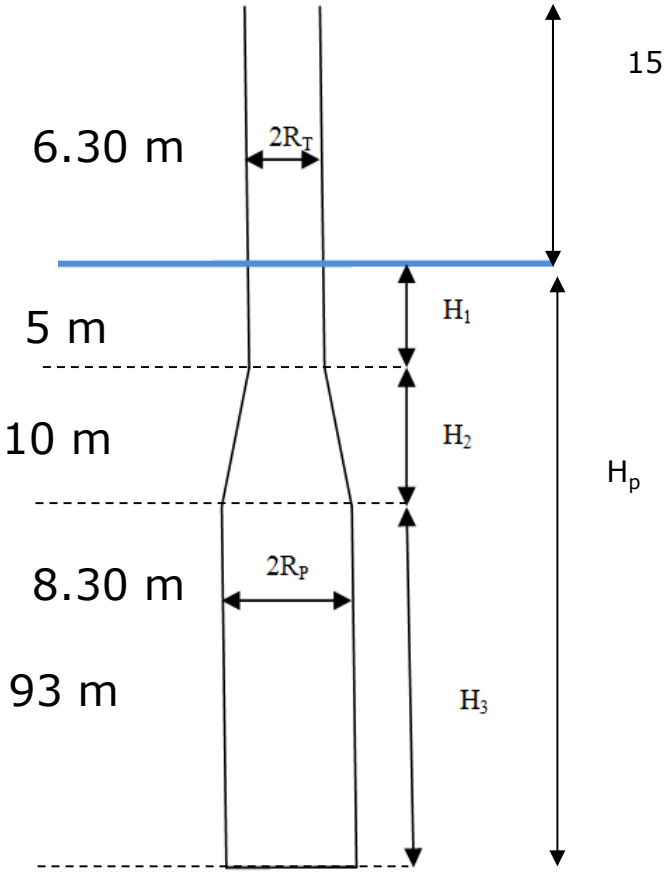
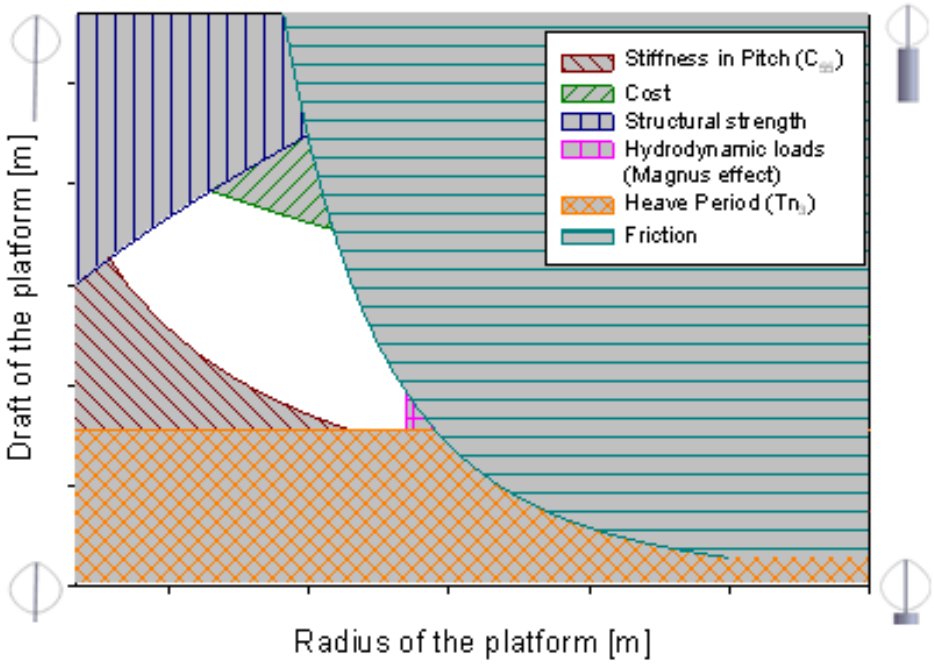


DeepWind
1 st BaseLine 5 MW Design Floater



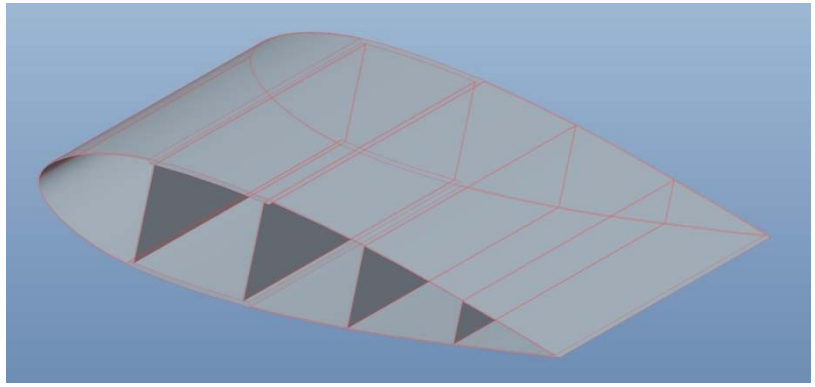


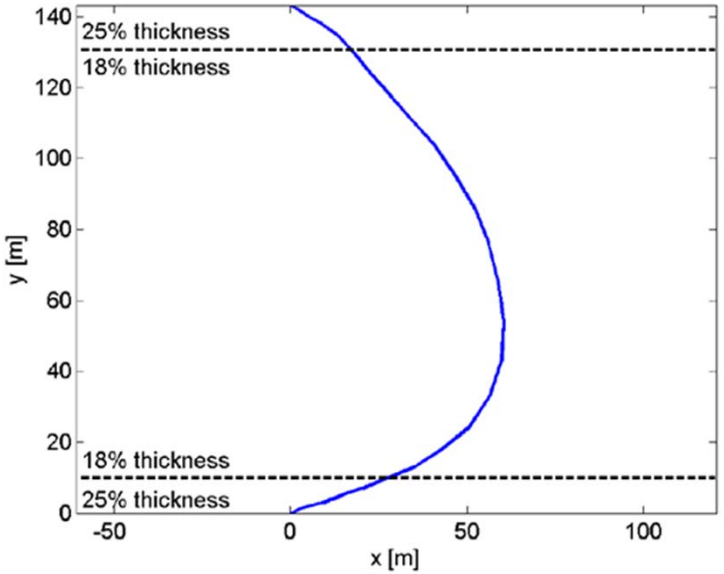
- Design space limitations

Hywind site:
~5000 tons mass
~ 35/60 sec natural periods in yaw/surge

DeepWind
BaseLine 5 MW Design Blades

- Blade length 200 m
- Blade chord 5 m constant over length
- Blades pulltruded, sectionized GRP
- NACA 0018 and NACA 0025 profiles

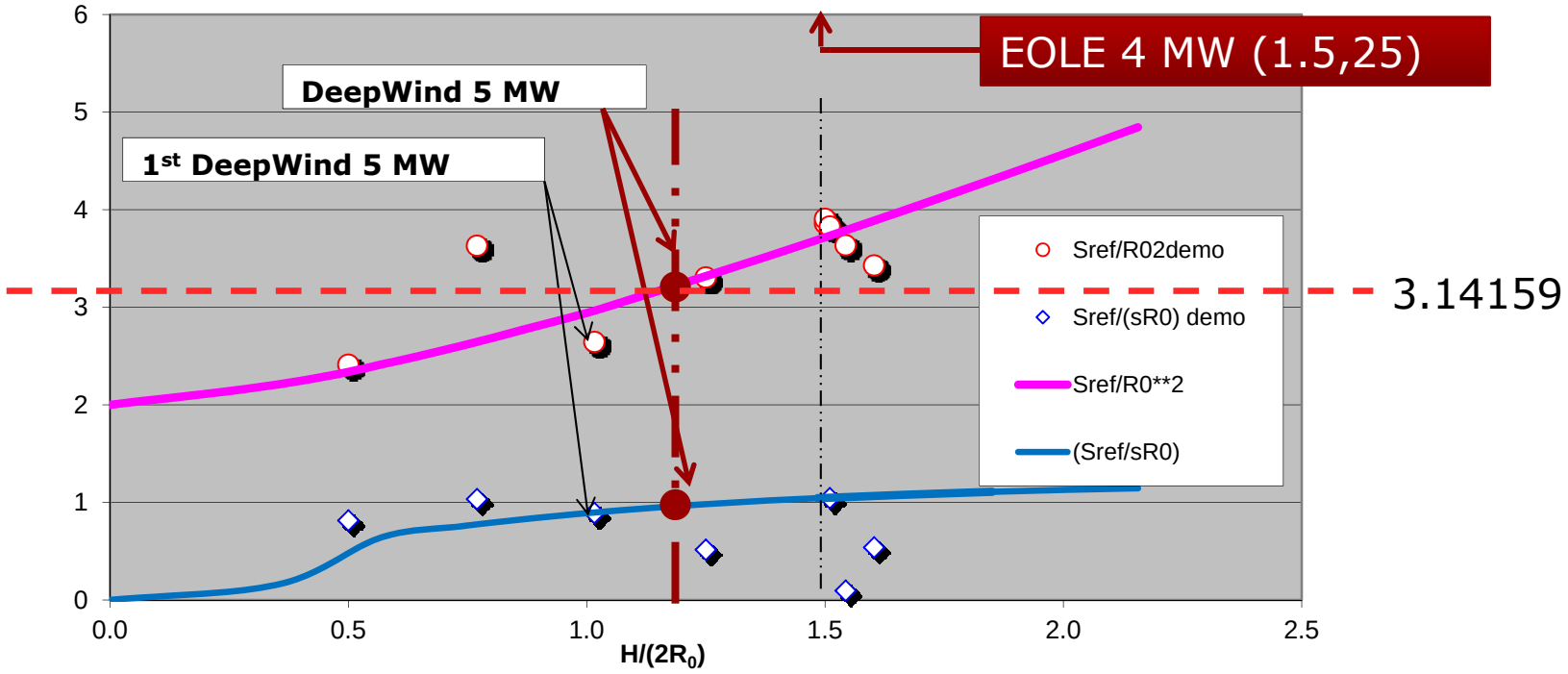




DeepWind
5 MW Design Rotor

Geometry

Rotor radius (R_0)	**[m]**	**60.5**
$H/(2R_0)$	**[-]**	**1.18**
Solidity ($\sigma = Nc/R_0$)	**[-]**	**0.165**
Swept Area (S_{ref})	**[m²]**	**11996**

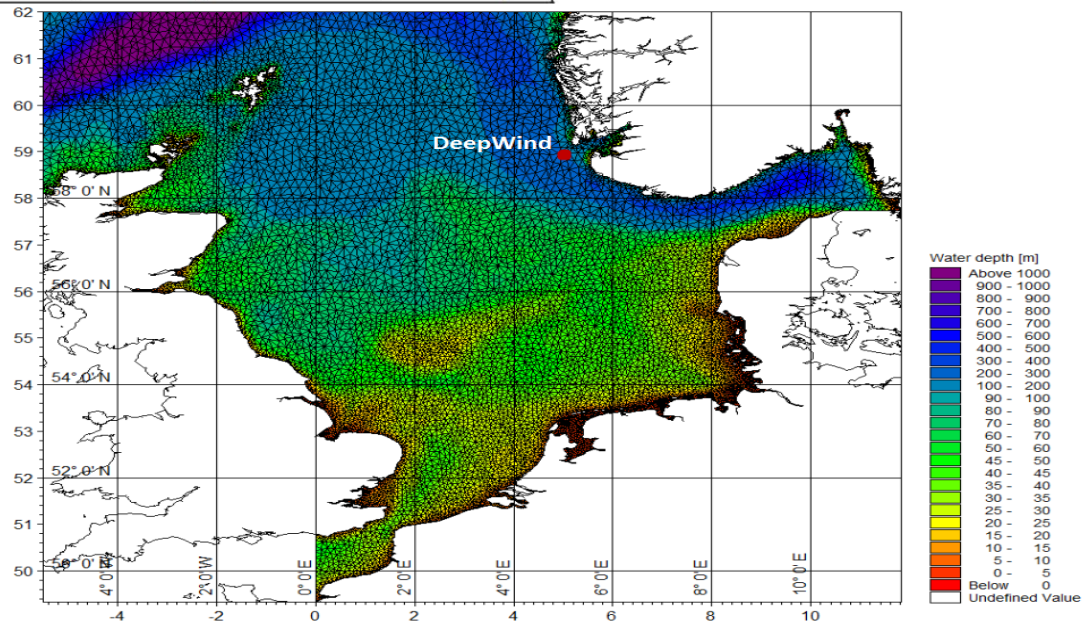


DeepWind
Load cases

- Deterministic flow with Power law wind shear
- Airy waves
- Sea current 0-0.7 m/s

	H_s [m]	T_s [s]	Current [m/s]
Sea state 0	0	0	0
Sea state 1	4	9	0.35 for $V_0 < 14$ m/s, 0.7 for $V_0 > 14$ m/s
Sea state 2	9	13.2	0.35 for $V_0 < 14$ m/s, 0.7 for $V_0 > 14$ m/s
Sea state 3	14	16	0.35 for $V_0 < 14$ m/s, 0.7 for $V_0 > 14$ m/s

- Water depth 200 m
- Site along Norwegian coast
- Met-ocean data, hindcast©DHI and WF



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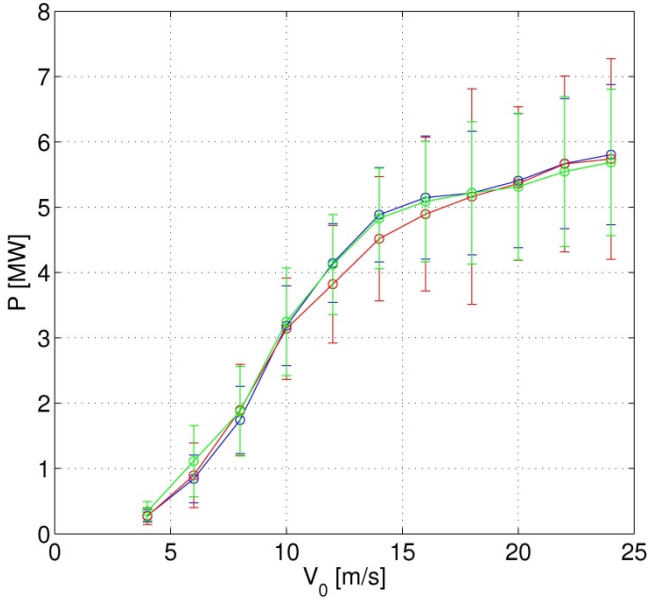
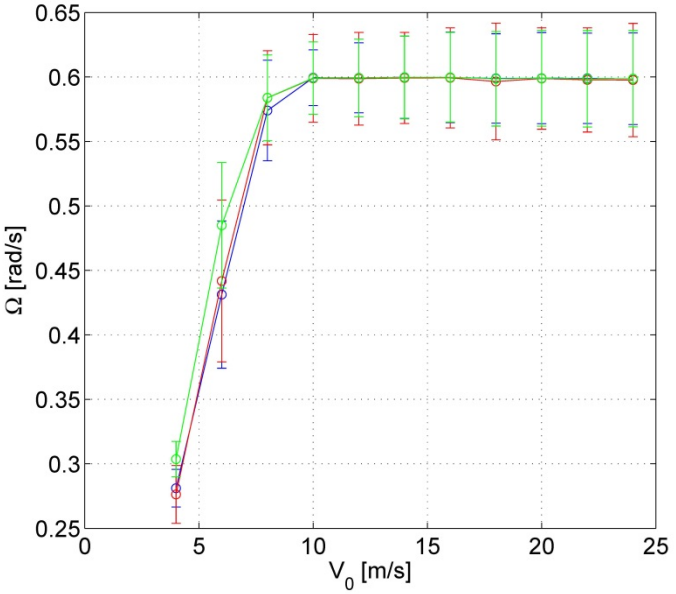
DeepWind
BaseLine 5 MW Design Performance

Performance

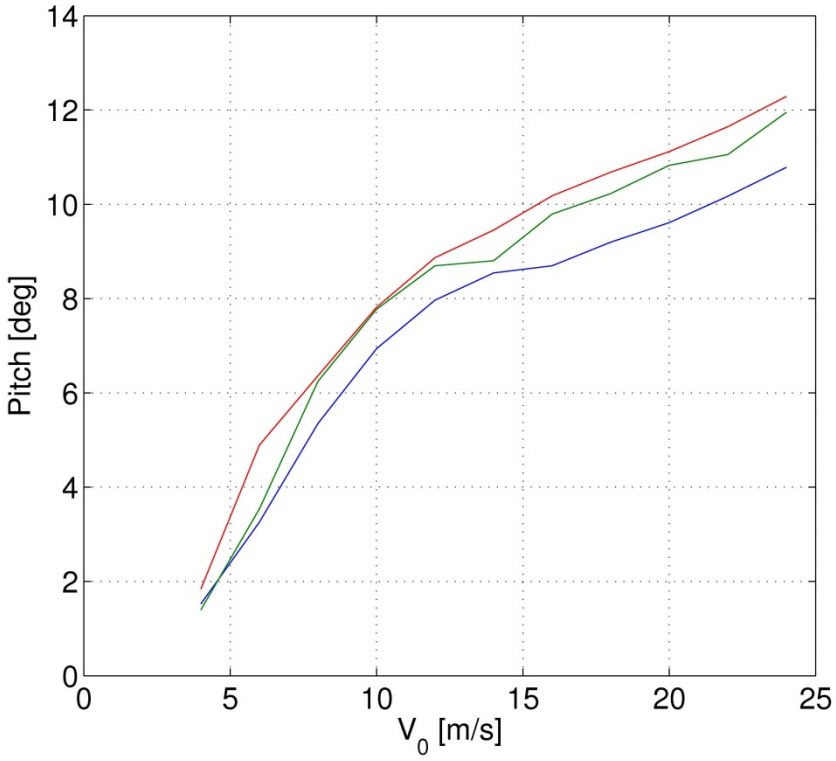
Rated power	**[kW]**	**5000***
Rated rotational speed	**[rpm]**	**5.73***
Rated wind speed	**[m/s]**	**14**
Cut in wind speed	**[m/s]**	**5**
Cut out wind speed	**[m/s]**	**25**



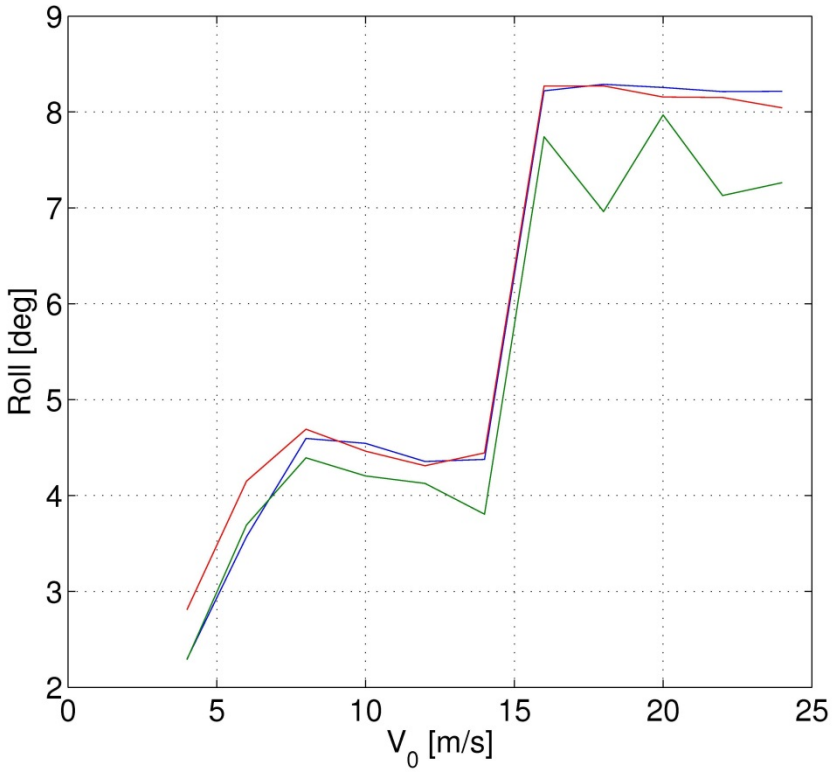


Floater performance at Sea states: 0.35 -0.7 m/s Current

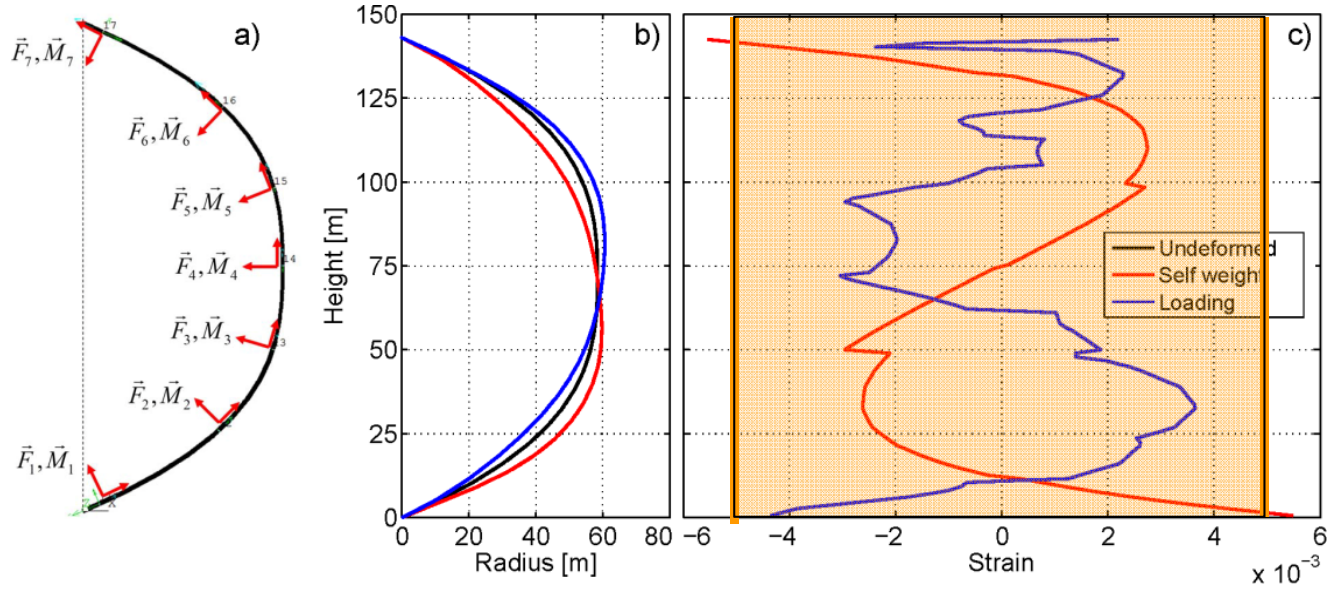
- Pitch



- Roll
  - ➢ Magnus forces change with current



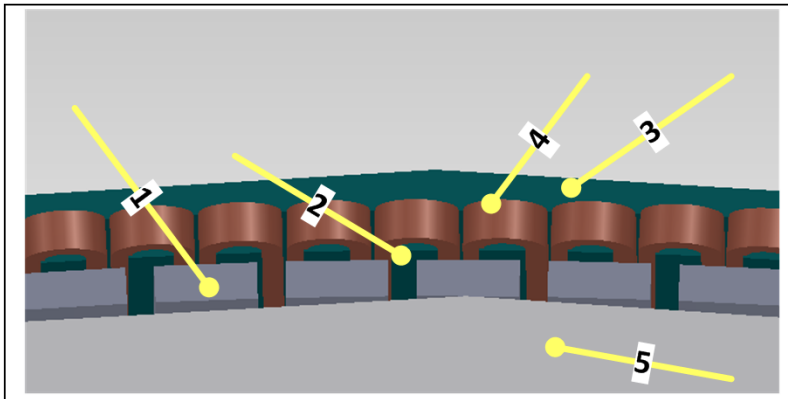
Constant blade chord with different profile thickness



5000 μm/m limit

- Blade weight from ~ 157 Ton to ~ 45 Ton per blade
- 5000 μm/m limit: complex strain distribution but in control
- Less bending moments and tension during operation
- Potential for less costly pulltruded blades

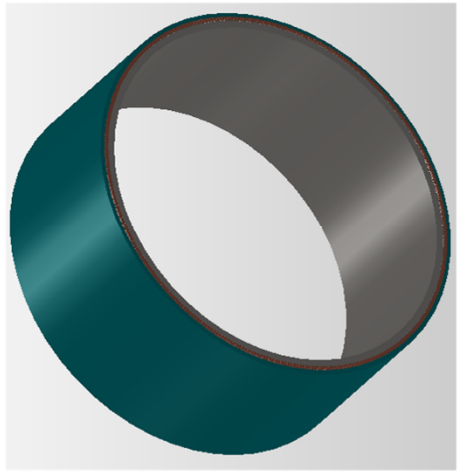
DeepWind
Generator



Sample segment of the generator produced by the Design Tool.

Legend:

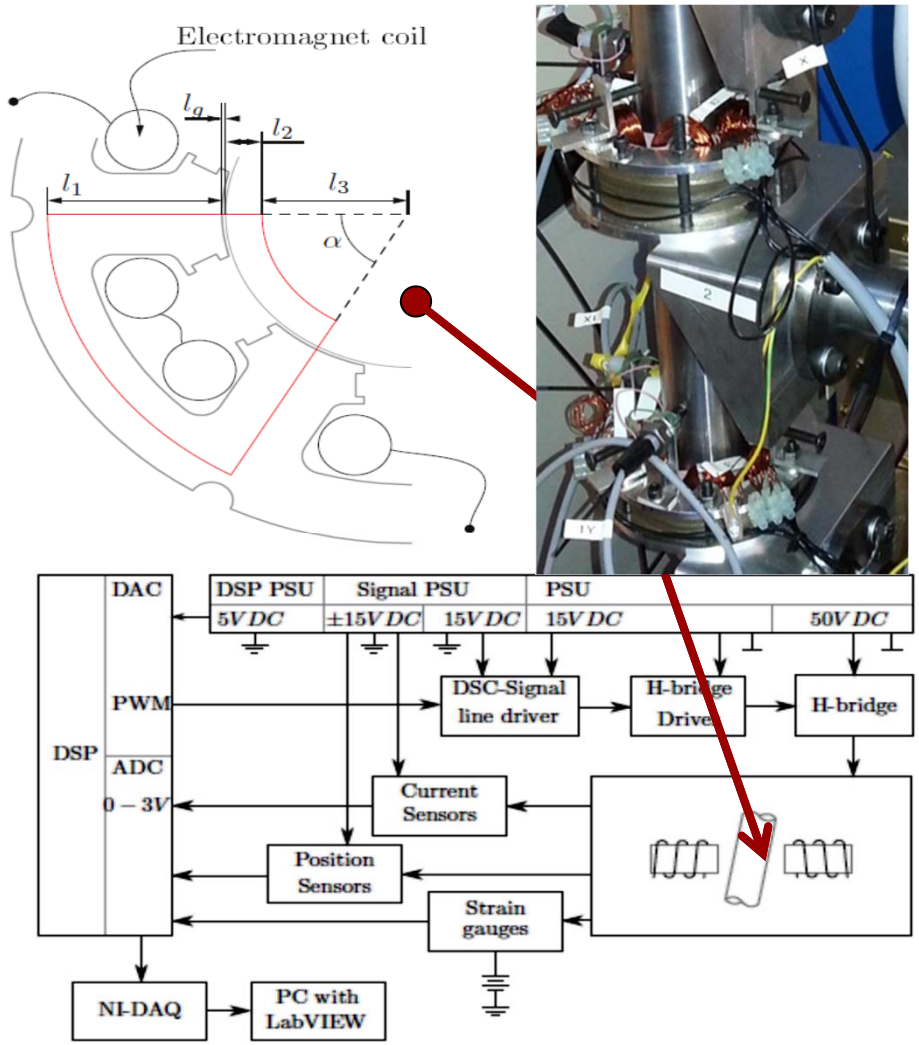
1) Permanent magnet
2) Stator tooth
3) Stator back iron
4) Winding coil
5) Rotor back iron


3D sketch of the active parts of the 6 MW DeepWind Generator.

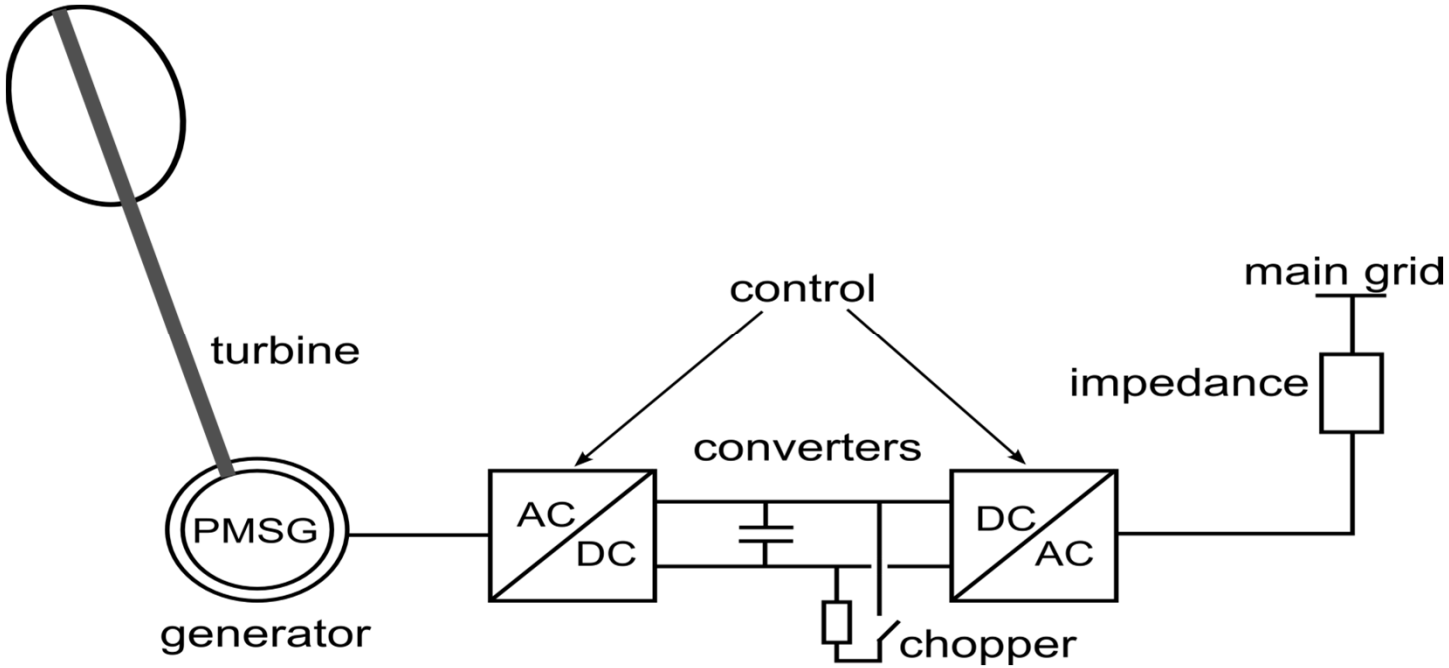
Dimension	Value [mm]
Outside Diameter	5811
Inside diameter	5346
Length O/A	2648

DeepWind
Magnetic Bearing

- A controlled magnetic bearing was chosen for study in a test rig
- necessary to control the forces generated by the bearing(relationship between the magnetic force and the distance is in unstable equilibrium
- DSP based control system is proposed, using appropriate sensors and a controlled power supply for each direction unstable equilibrium



DeepWind
Baseline 5 MW Electrical system



General diagram of the power transfer system.

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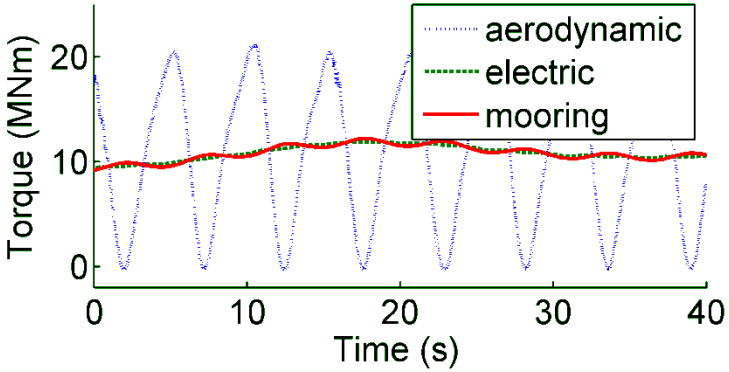
Special control challenges with Deepwind



2p damping with notch filter and PI controller

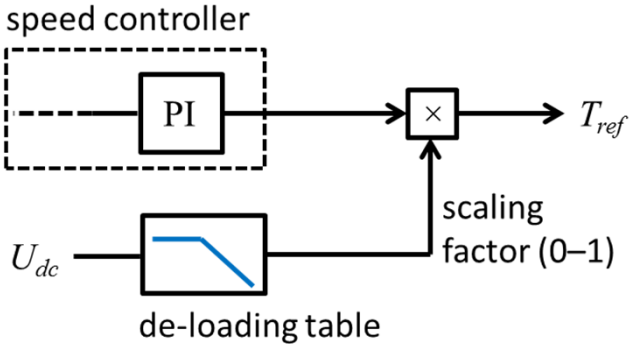
- All active turbine control via generator torque (no pitch control)
- Large 2p variations in aerodynamic torque
- Stator is not fixed,

generator speed = rotor – stator

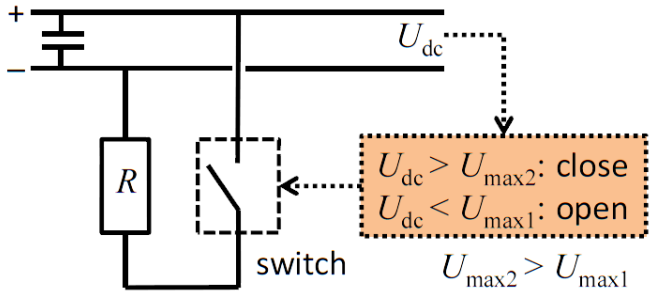
DeepWind
Fault ride-though capability

- Crucial for grid code compliance
- Illustrates interesting coupling between controls, turbine and mooring dynamics

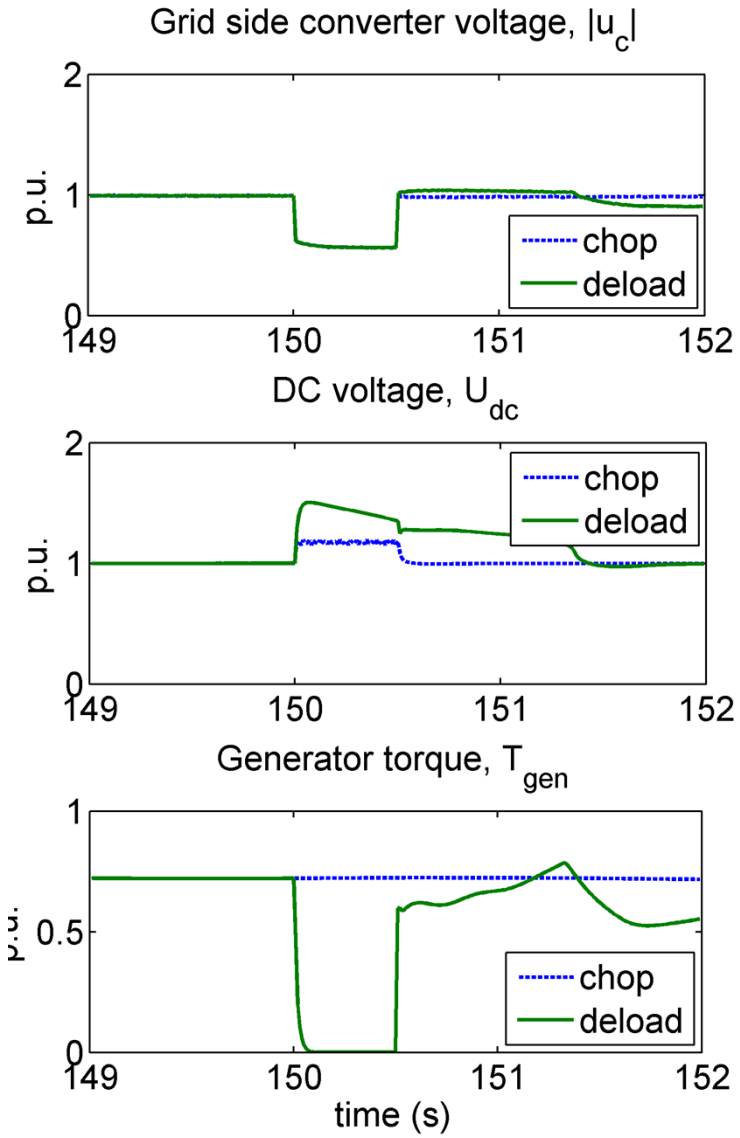
ALT 1: De-loading system
Absorb excess energy in rotation of the turbine by reducing generator torque



ALT 2: DC chopper system
Dump excess energy via switched resistor in DC link



DeepWind
Simulations – fault ride-through



500 ms voltage dip in the grid, propagated to converter terminals

Resulting DC link voltage increase needs to be limited, to avoid damage and allow ride-through

Chopper ✓ OK

De-loading × Not working very well

Generator torque unaffected with chopper system, drastically reduced with de-loading system

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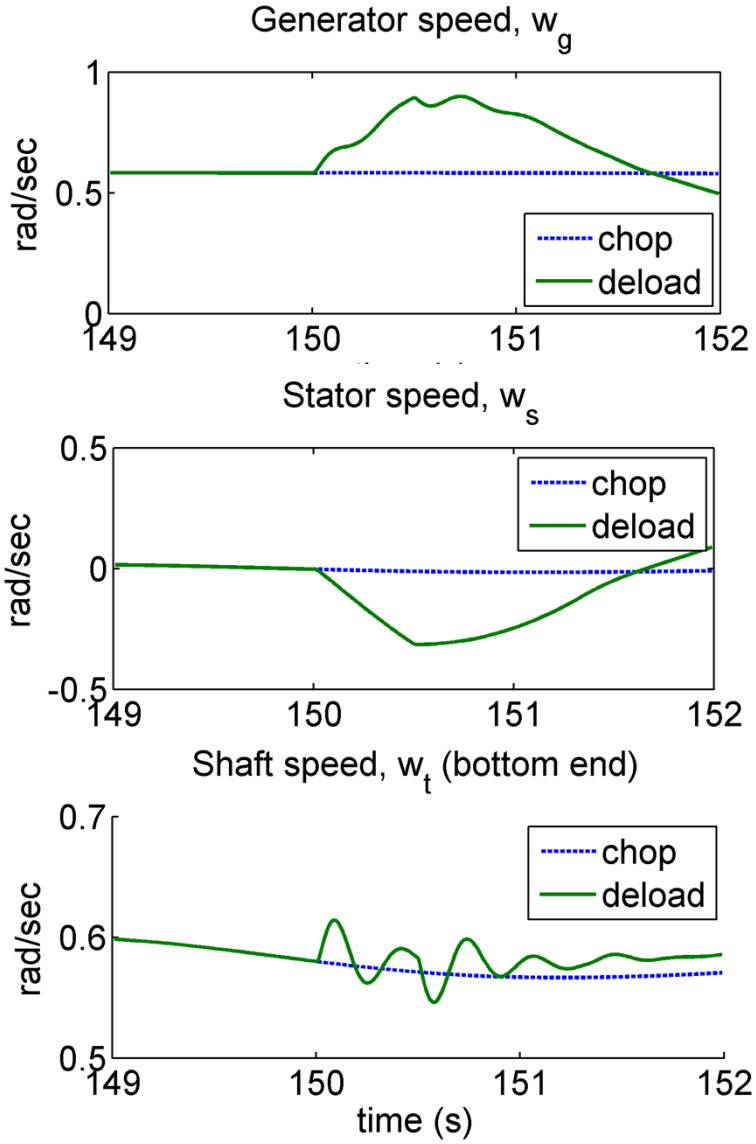
Turbine response to grid fault



Chopper system:
Turbine completely unaffected by the fault

De-loading system:
Generator torque rapidly reduced
→ Rotor (turbine) and stator (mooring system) acceleration in opposite directions
→ Severe stress on mooring system
→ Shaft vibrations in turbine

The de-loading scheme does not work with Deepwind's non-fixed stator

But interesting illustration of the coupling between turbine/generator/mooring/controls

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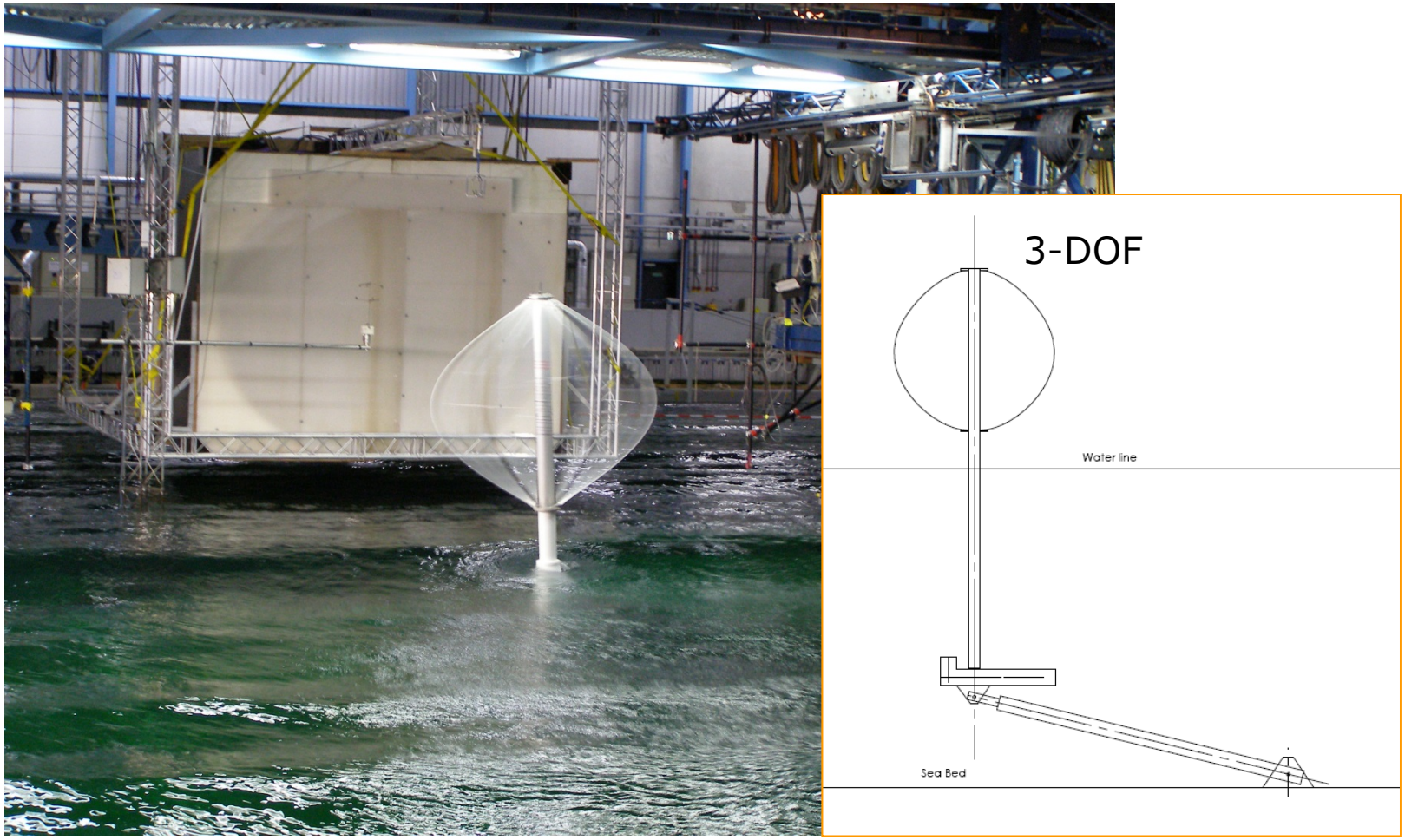
Conclusion

- Demonstration of a optimized rotor design
  - √Stall controlled wind turbine
  - √Pultruded sectionized GRF blades 2 profile sections
  - √2 Blades with~95 T total weight, ~3½x less weight than 1st baseline 5MW design
  - √Less bending moments and tension during operation
  - √Potential for less costly pulltruded blades in terms of power capture
- Use of moderate thick airfoils of laminar flow family with smaller CD_0 good C_P and favourable rigidity
- Suite available for designing deep sea underwater, new radial flux synchronous generator module
- Utilizing magnetic bearings for generator module as option
- Generator and Controller implemented in global model
- Floater optimized for most dominant variables
- Grid compliance

DeepWind
Video from Ocean lab testing



Thank You

Questions?

Thanks to the 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).

And
European Commission