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

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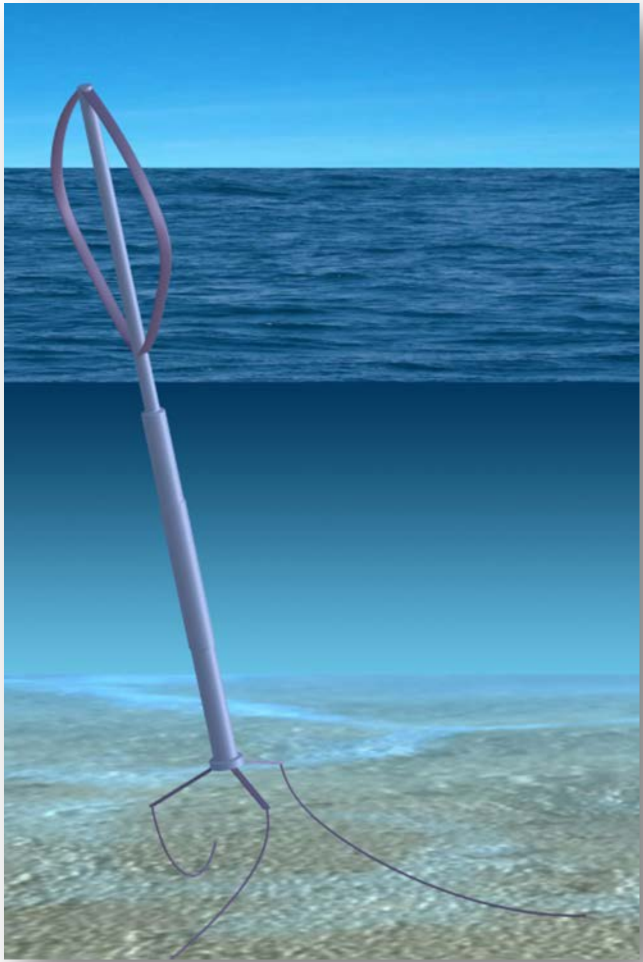


DeepWind

- 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

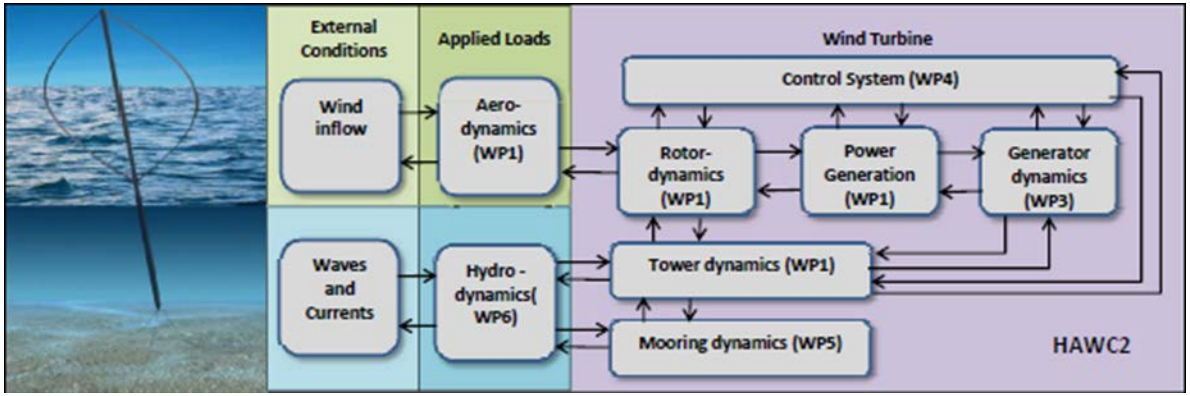
Vita L, Zhale F, Paulsen US Pedersen TF, Madsen HA, Rasmussen F. *Novel Concept For Floating Offshore Wind Turbines: Concept Description And Investigation Of Lift, Drag And Friction Acting On The Rotating Foundation* in Proceedings of the ASME 2010 29th International Conference on Ocean, Offshore and Arctic Engineering, June 6 Shanghai 2010 **OMAE2010-20357**

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* Risø 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

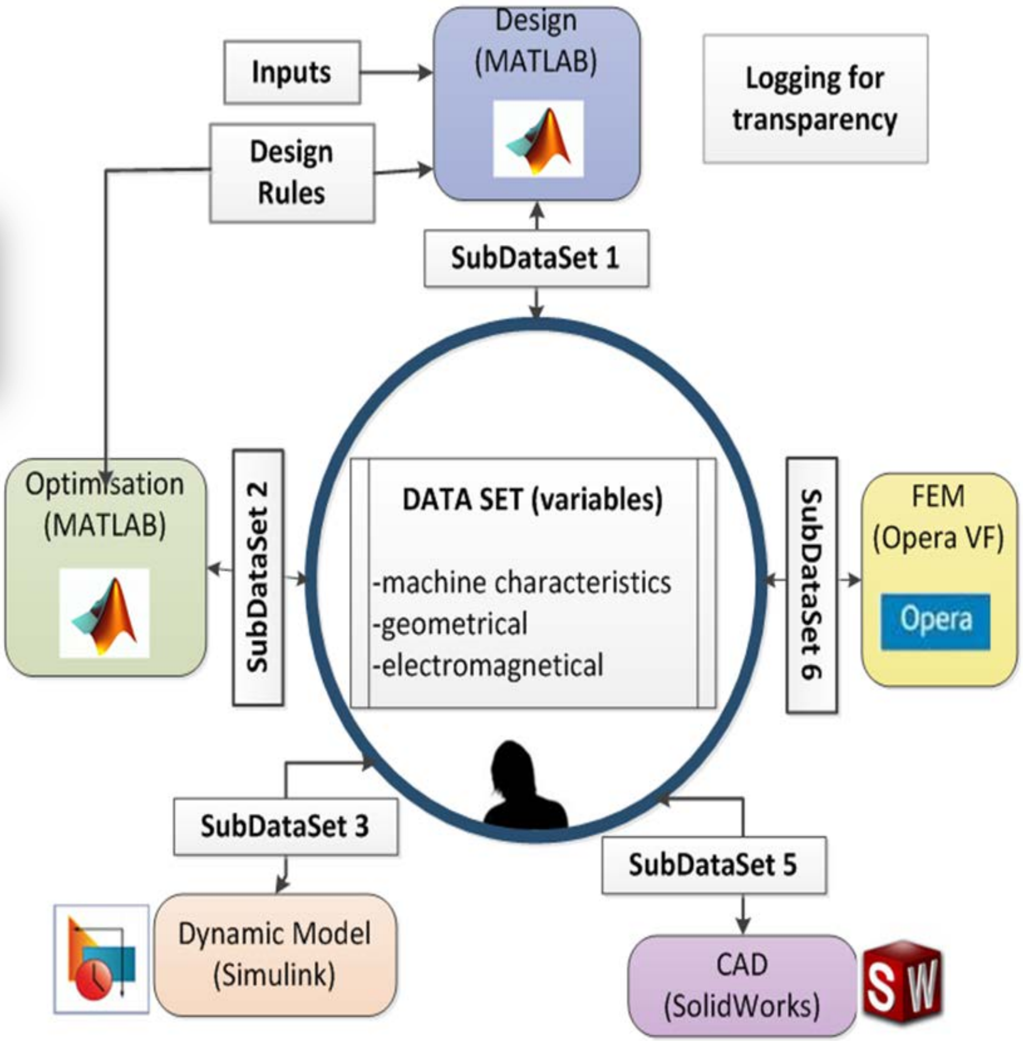


Design suites(2)

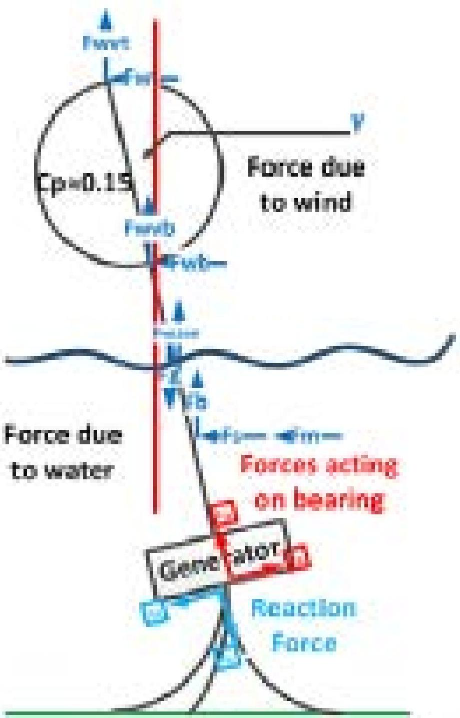
- Generator design tool
- CAD design tool

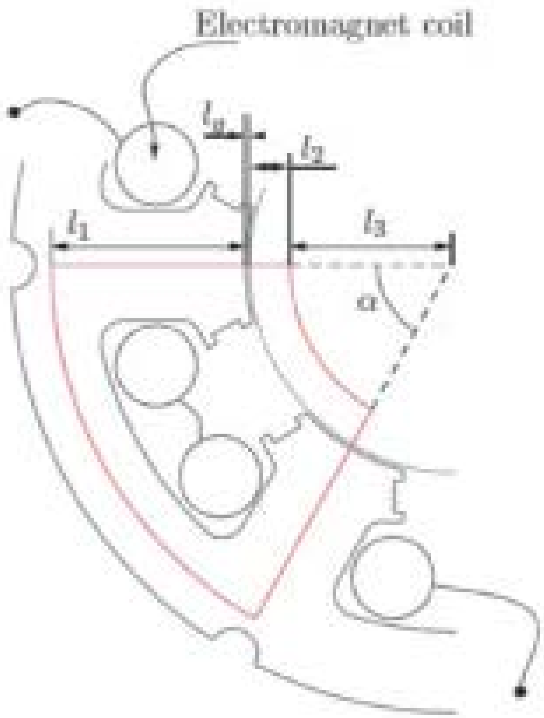
Leban K, Ritchie E, Argeseanu A .Design Tool for Large Direct Drive Generators: *14th International Conference on Optimization of Electrical and Electronic Equipment - OPTIM 2014* -SUBMITTED

✓ Optimization
✓ Simulation
✓ Visualization

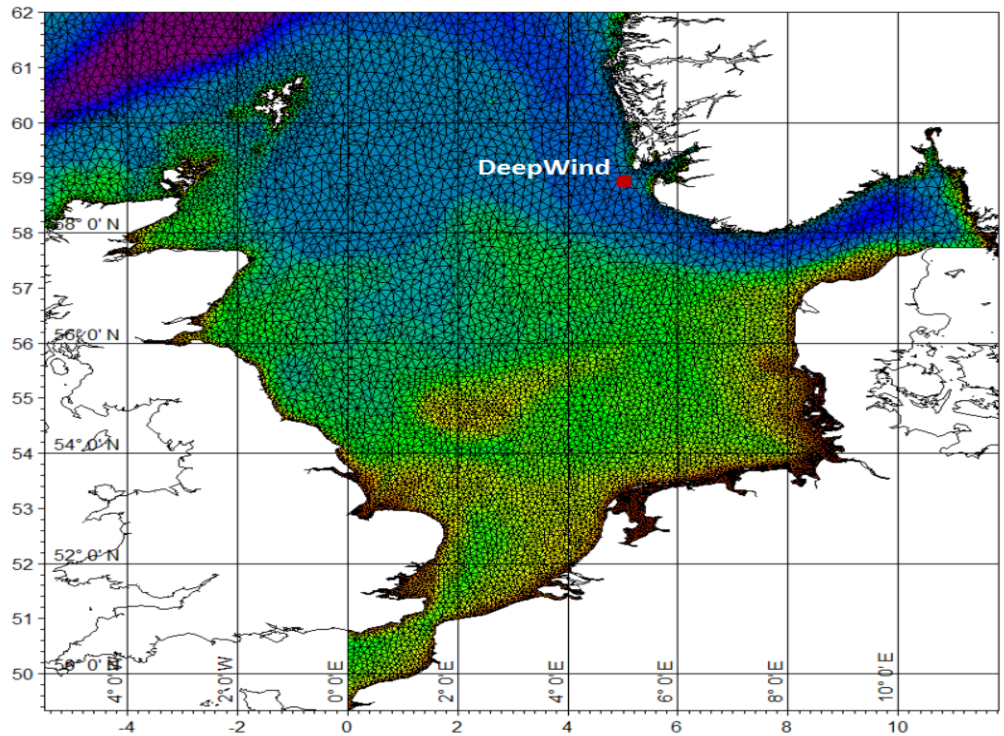


Bearing design-test rig





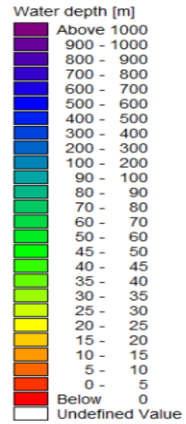
Preconditions-Site(Karmøy, No)



Latitude: 59° 8'44.88"N,

Longitude: 5° 1'25.66"E

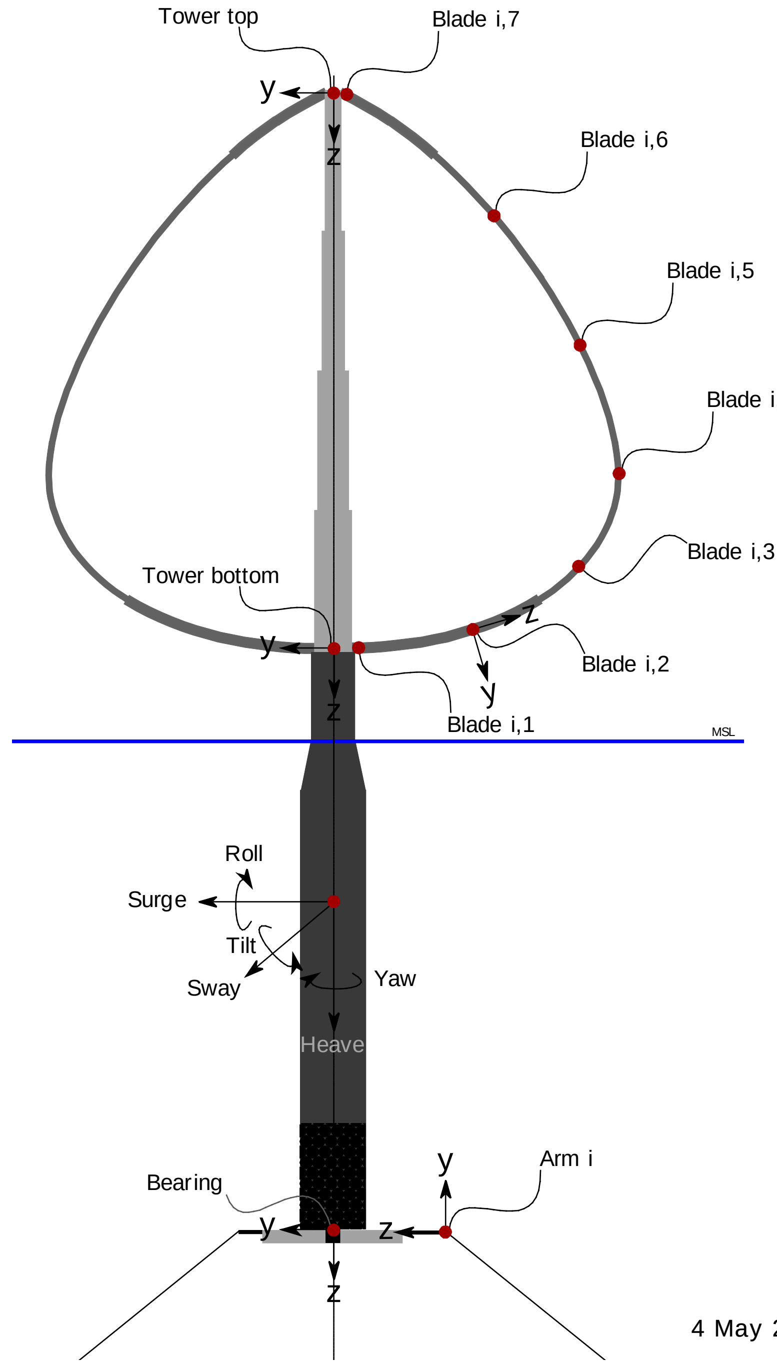
DHI's Hindcast model



Velocity of the water currents at the surface	[m/s]	0, [0.35,0.7]
Maximum significant wave height H_s	[m]	14
Maximum peak wave period T_P	[s]	16
Wind speed (limit wind speed of the design)	[m/s]	<25

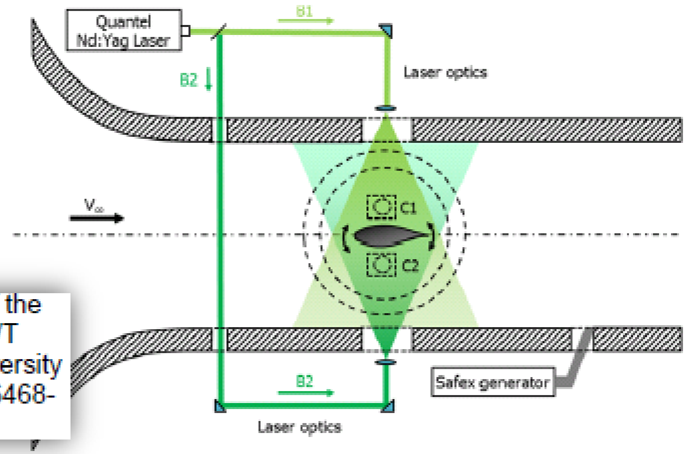
Sketch of the concept

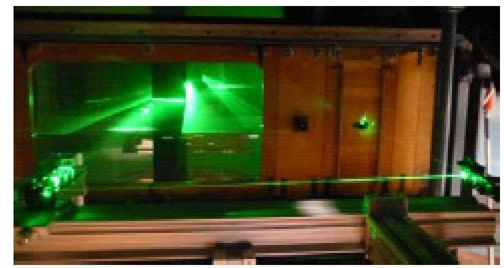
- Modified rotor shape
  - |ε|<5000E-6 m/m
  - Sectionized NACA 0018,0025 profiles
  - Light rotor with pultruded blades
- Simple conical support tower
- Floater design implemented
- Generator at end of rotating spar



Airfoil development

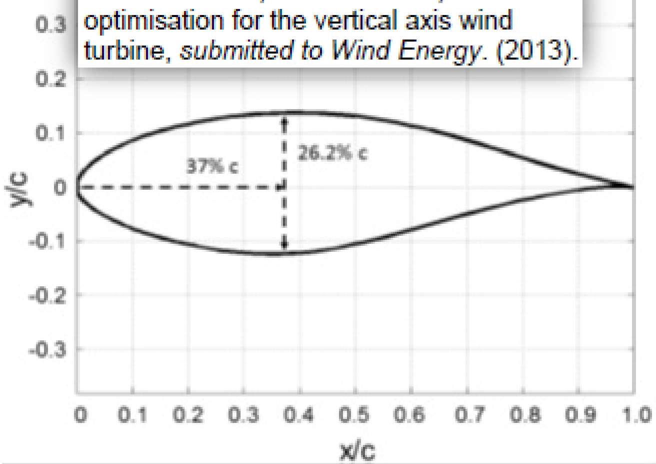
LTT WT TUDelft

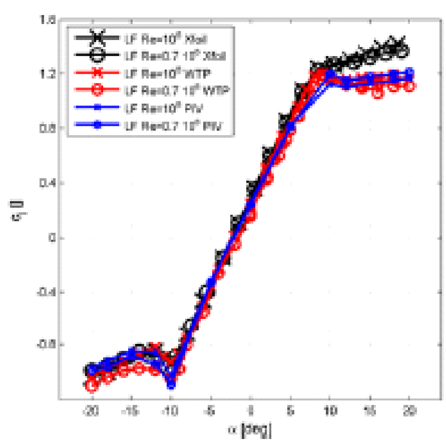


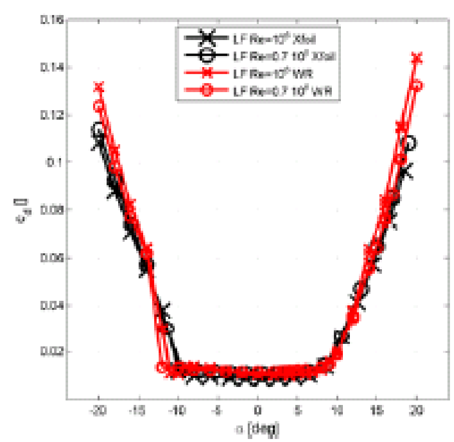


Simao Ferreira, C. The near wake of the VAWT: 2D and 3D views of the VAWT aerodynamics. PhD thesis,Delft University of Technology. ISBN/EAN:978-90-76468-14-3. (2009).

Simão Ferreira, C. and Geurts, B. Aerofoil optimisation for the vertical axis wind turbine, *submitted to Wind Energy*. (2013).

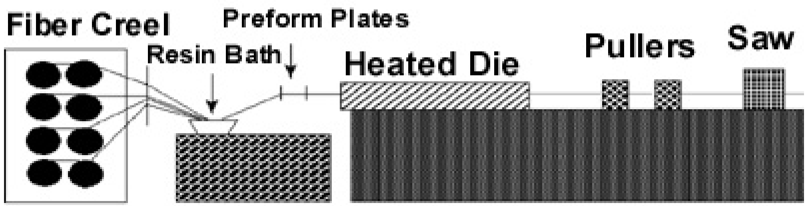






Blade Design

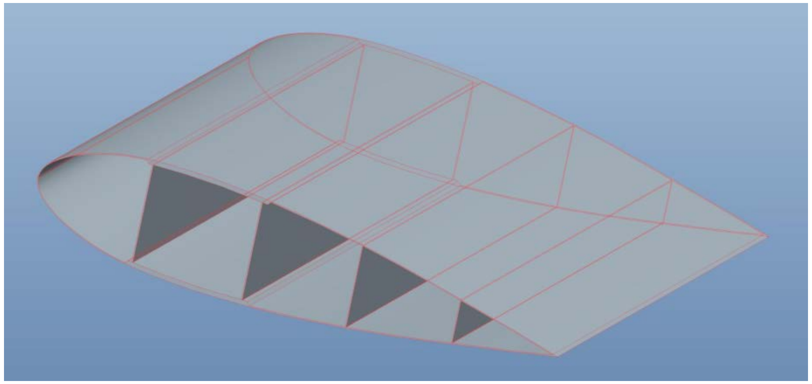
Pultrusion:



Constant chord over length

Low manufacturing cost +

Structural strength for thin profiles -



5 MW blade section, 1st baseline

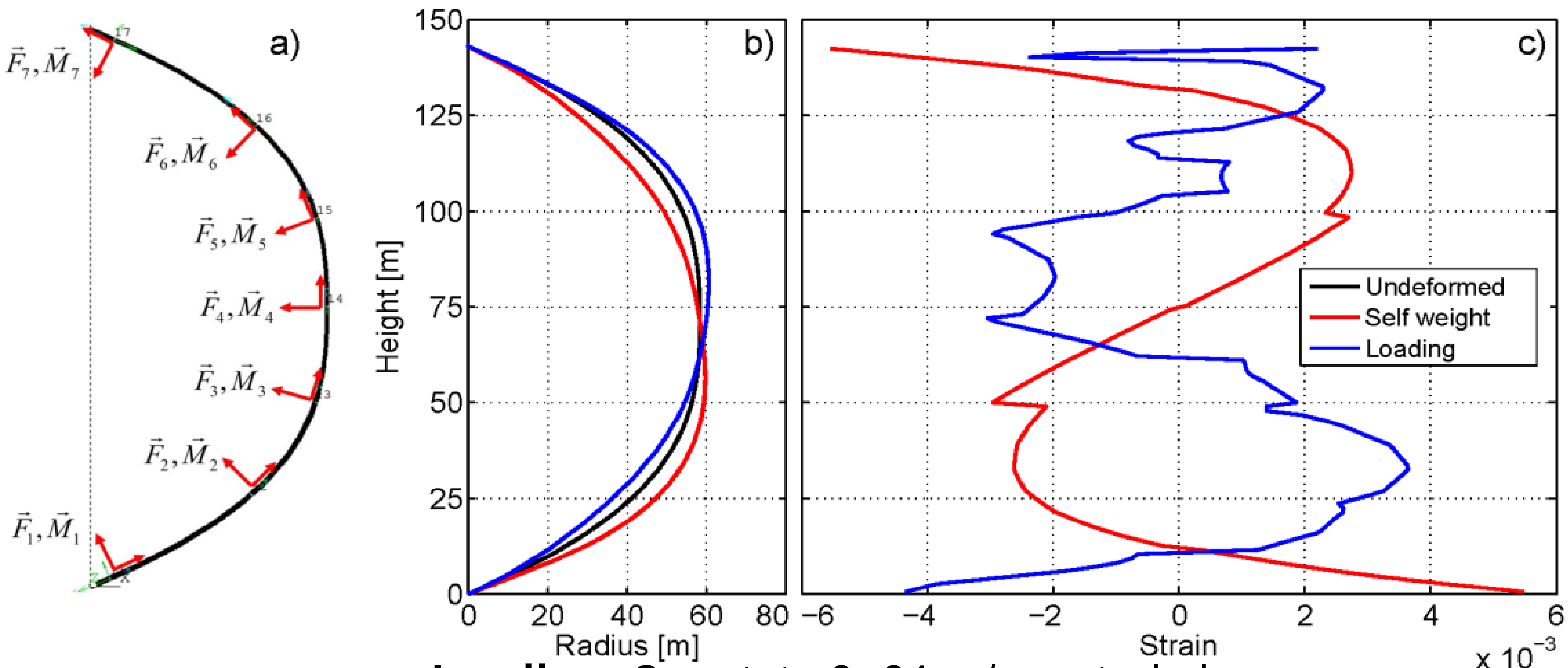
Rotor shape:

.:. 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

Blade shape optimization

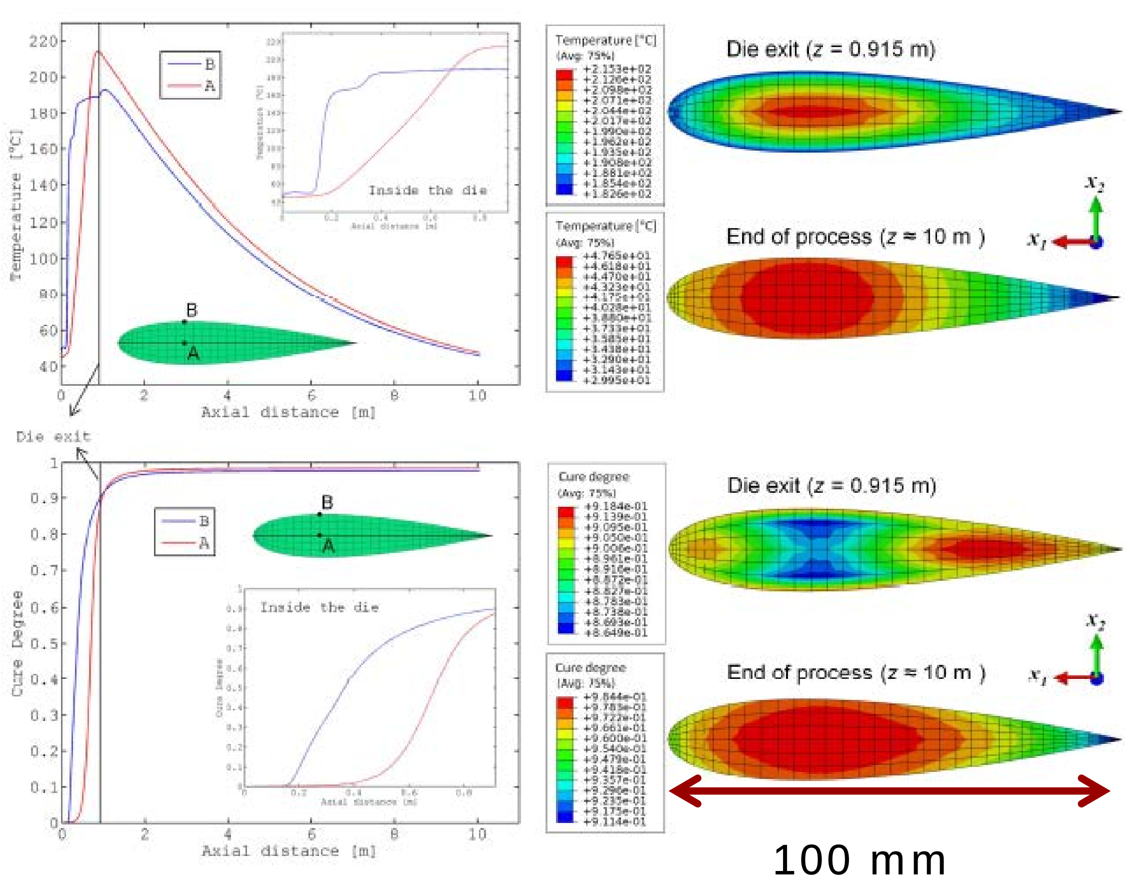


Loading: Sea state 3, 24 m/s no turbulence

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

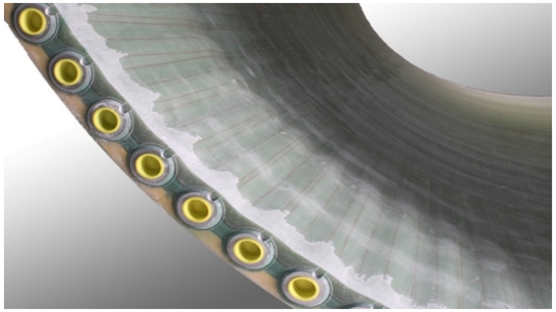
- DeepWind-from idea to 5 MW concept Energy Procedia (2014)

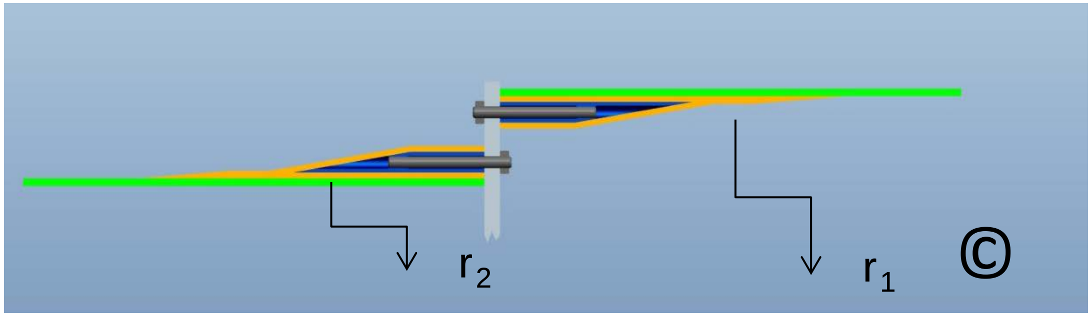
Pultrusion manufacturing



- Baran I, Tutum CC, Hattel JH. The internal stress evaluation of the pultruded blades for a Darrieus wind turbine. Key Eng. Mat. 2013; 554-557: 2127-2137

Industrial joints solution



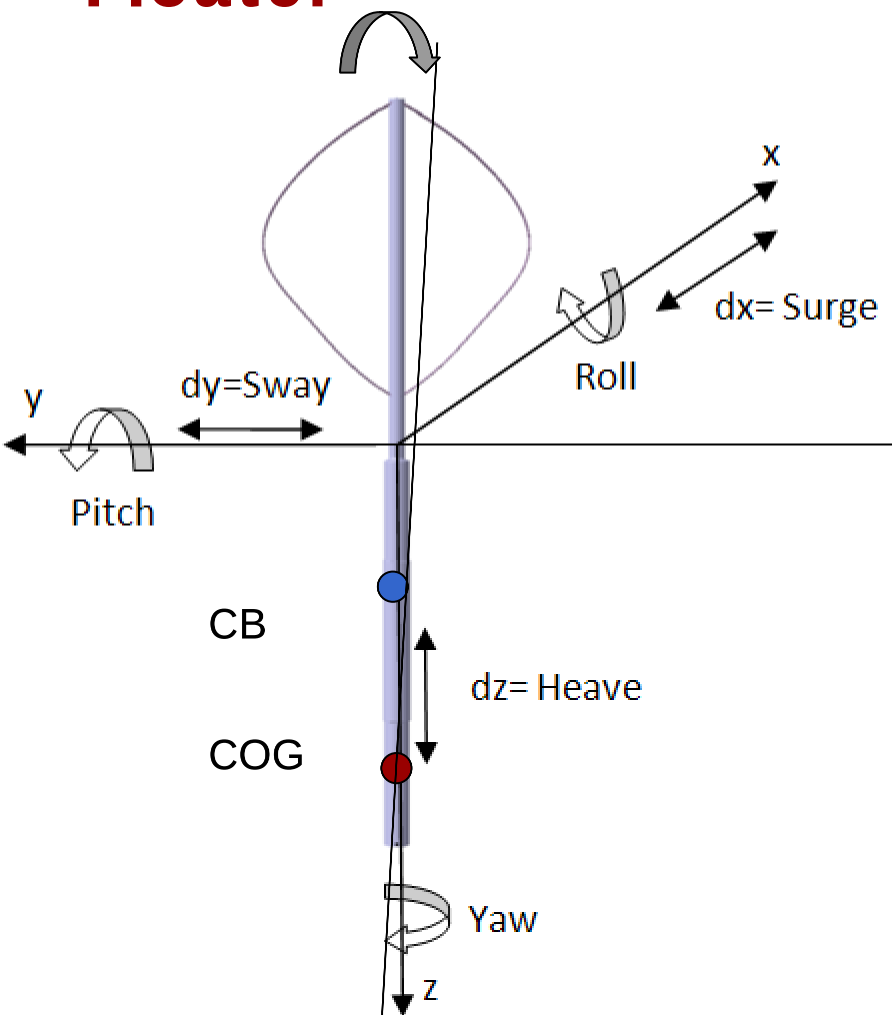


Courtesy of SSP Technology A/S

Slim profile-------Joint------Thick profile

- Investigation of potential extreme load reduction for a two-bladed upwind turbine with partial pitch," Taeseong Kim, Torben J Larsen, and Anders Yde, Wind Energy, submitted 2013.

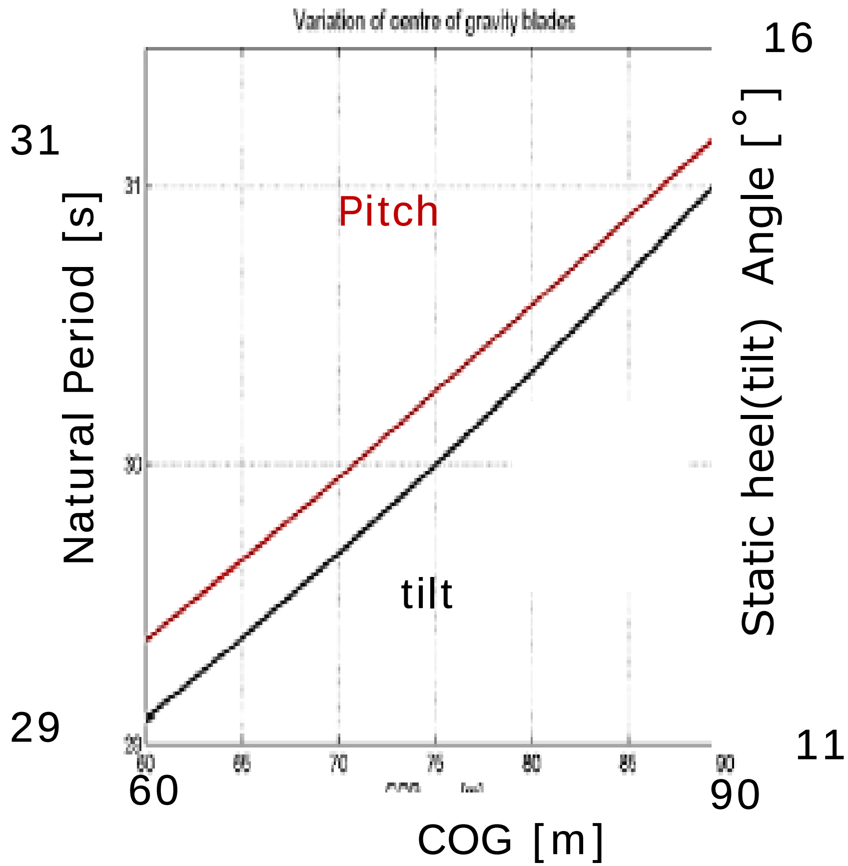
Floater

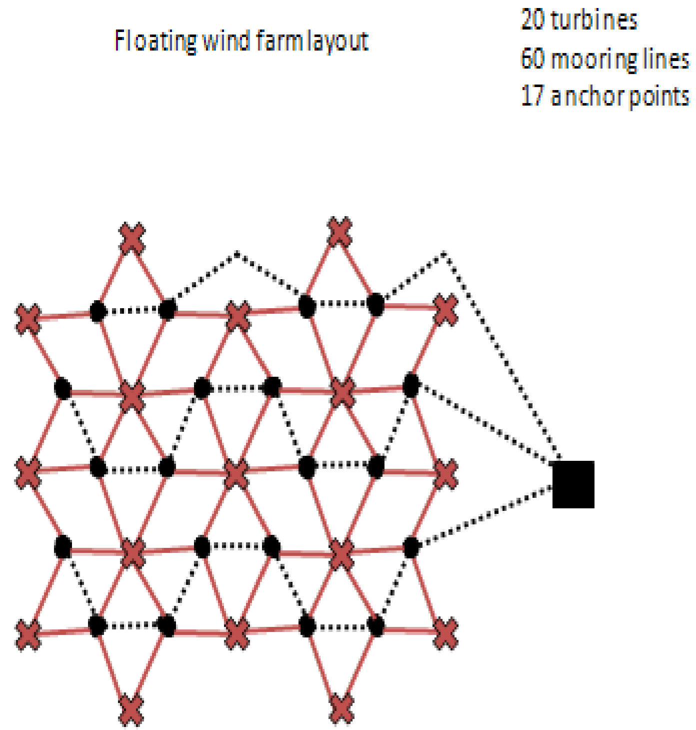


- Gravity stability: vertical distance between COG and BC
- If Rotation around COG and weak Pitch-Surge coupling : .:. $T_{n5} = 2Pi \sqrt{(I_{55}+a_{55}/k_{55})}$

- Avoid resonance
  - ❑ Tn> wave periods with significant energy contents
  - ❑ (I55 + a55) increase or decreasing k55

Floater

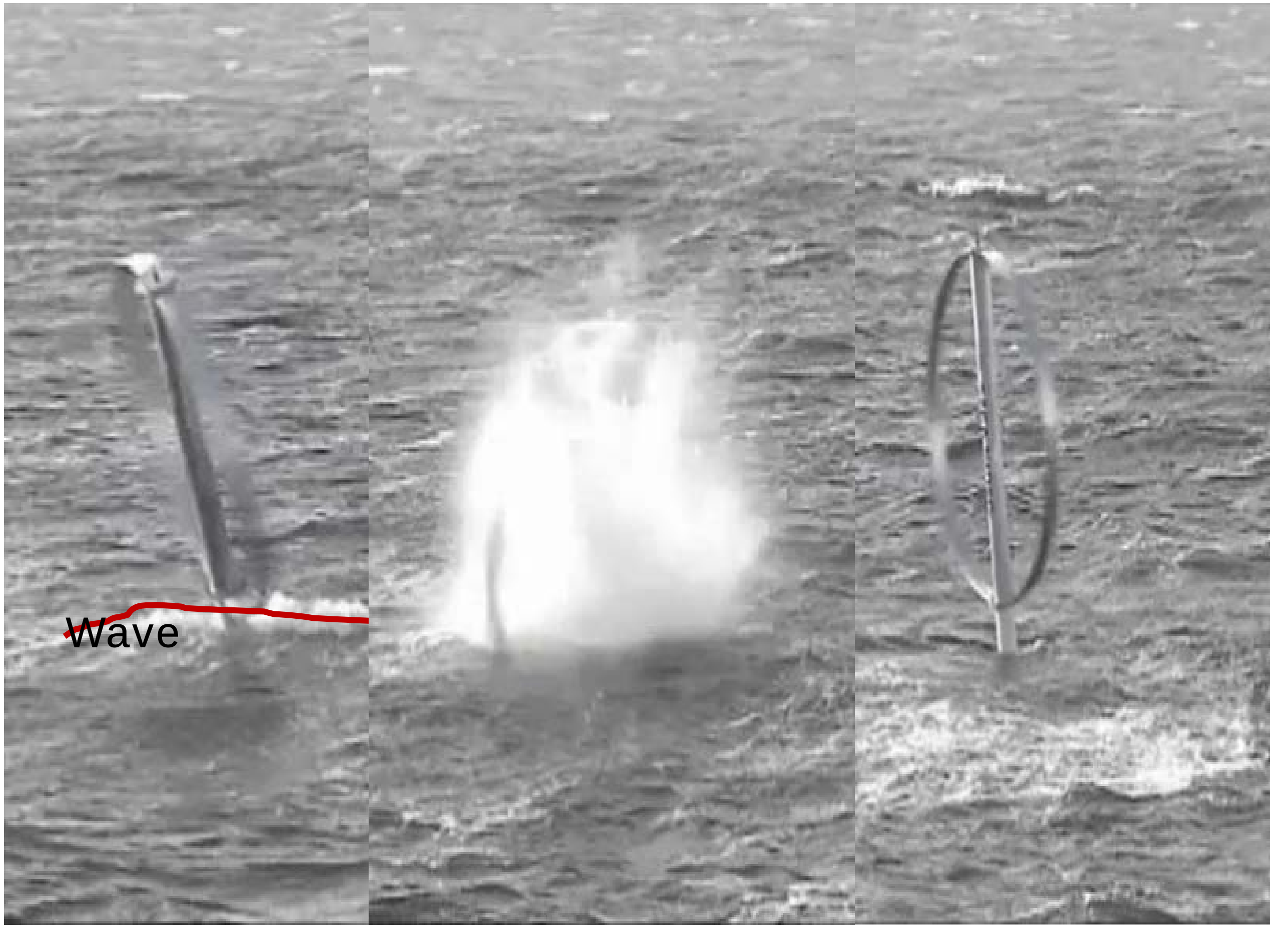

Variation of centre of gravity blades
16
31
Pitch
Natural Period [s]
Static heel(tilt) Angle [°]
30
tilt
29
11
60
65
70
75
80
85
90
COG [m]


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

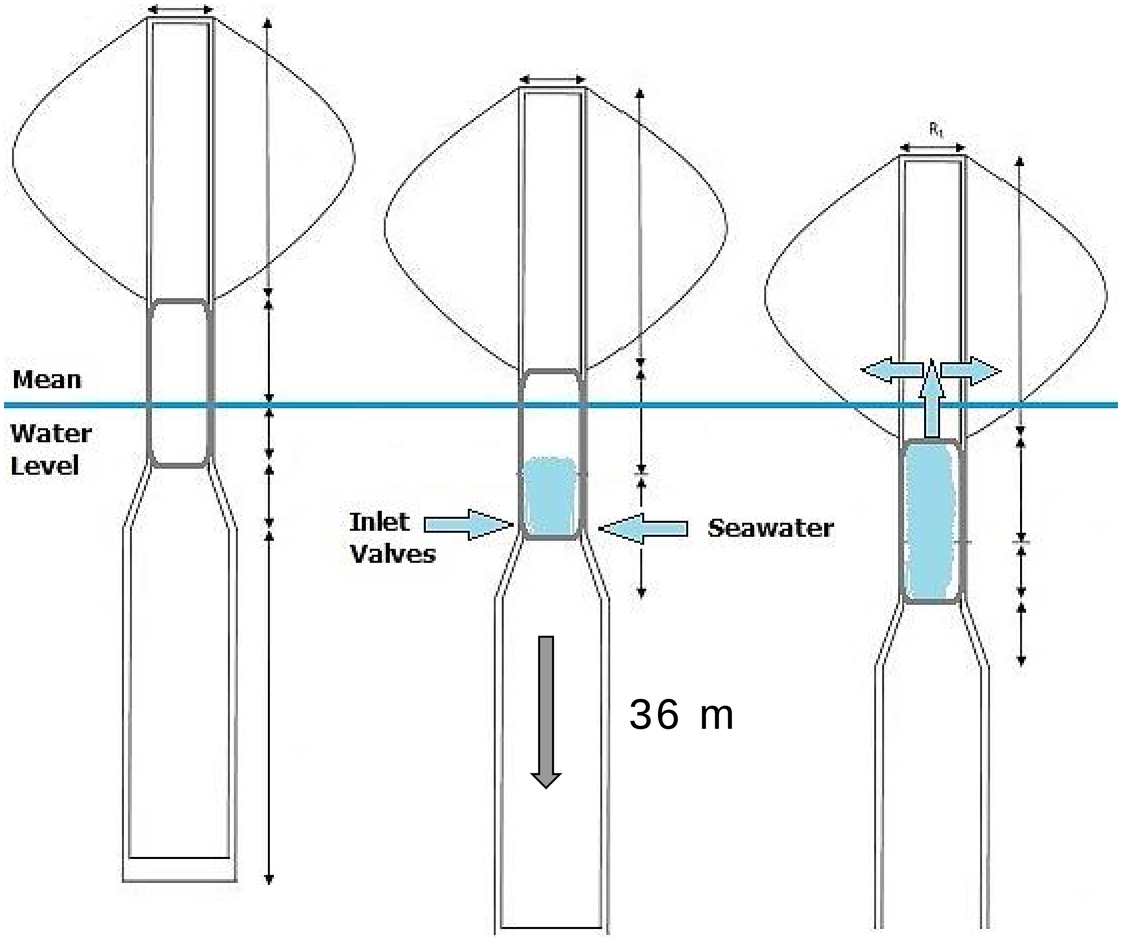
Huge Rotor Inertia

Slow rpm 0.6 rad/s

Max sinking depth to avoid mooring line twisting is 65 m

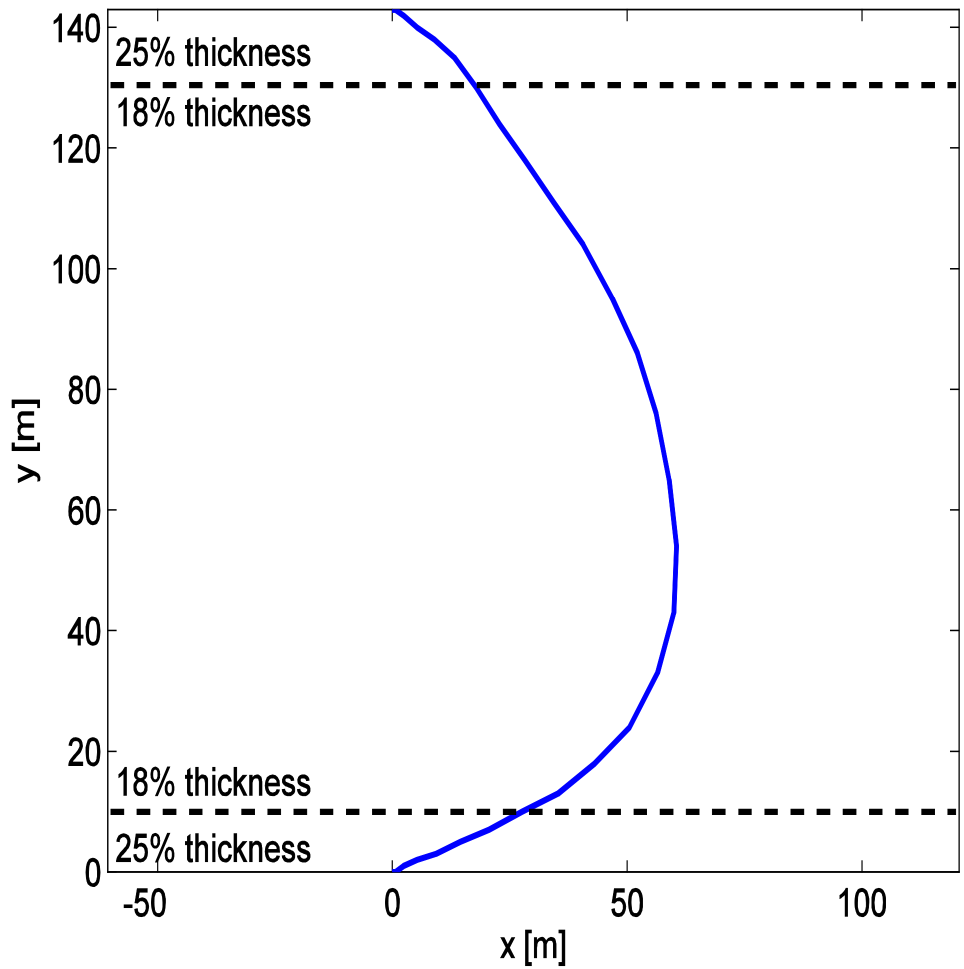
≈ 50 deg twist

.:. 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

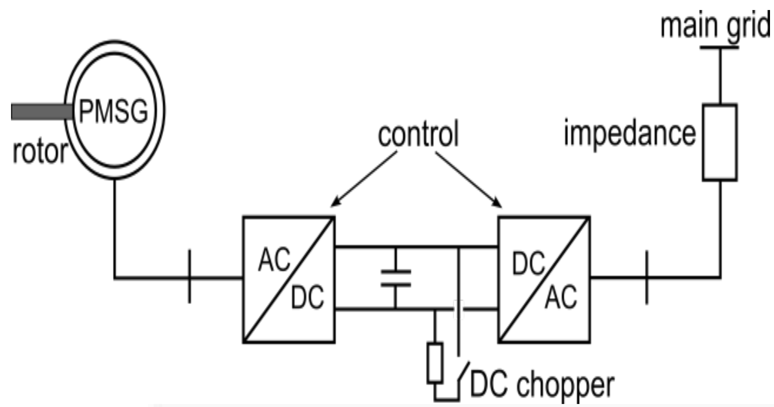
Direct Drive

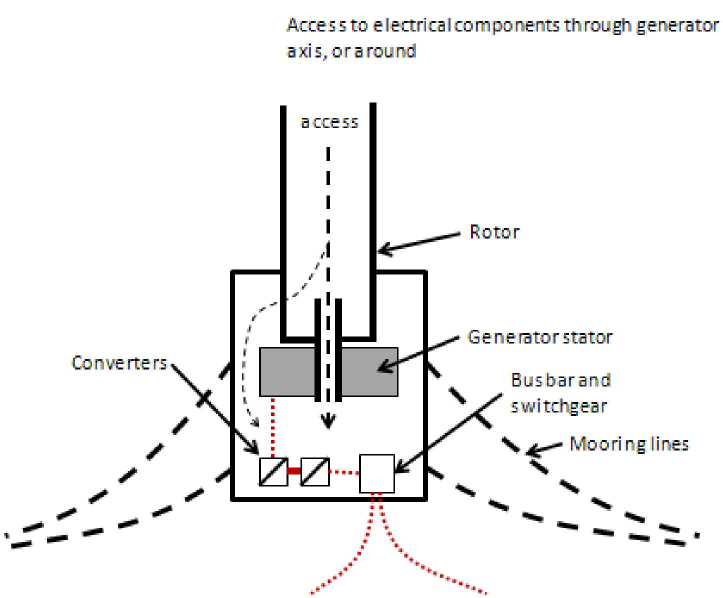
Permanent Magnet

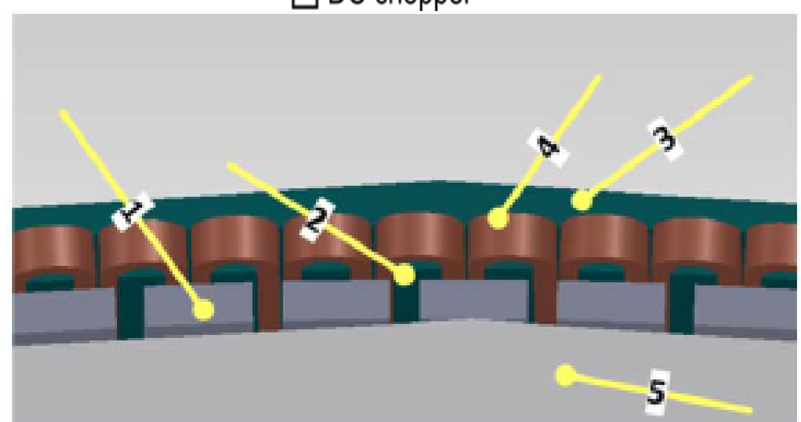
Radial Flux

Height x Dia ≈3m x 6m

Weight (core material) ≈ 90 T





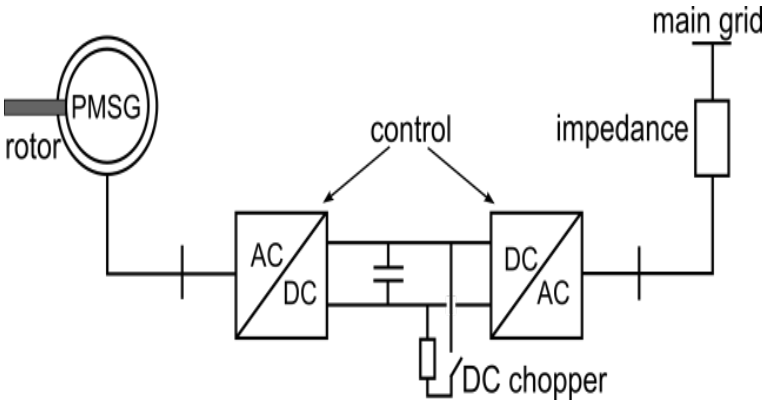


Legend: [1]Permanent magnet [2]Stator tooth [3]Stator back iron [4]Winding coil [5]Rotor back iron

Results-Electrical system

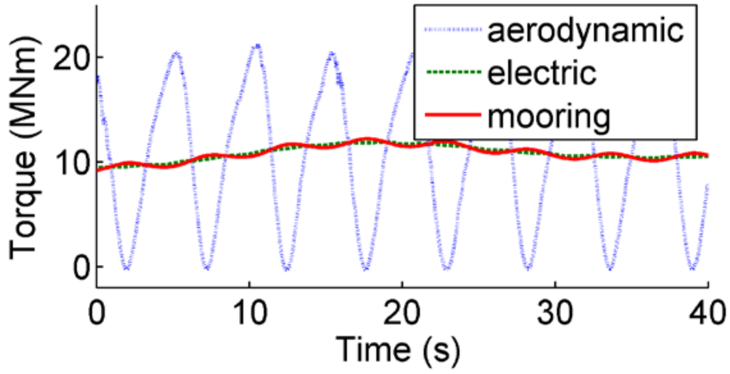
Grid integration

4 quadrant inverter

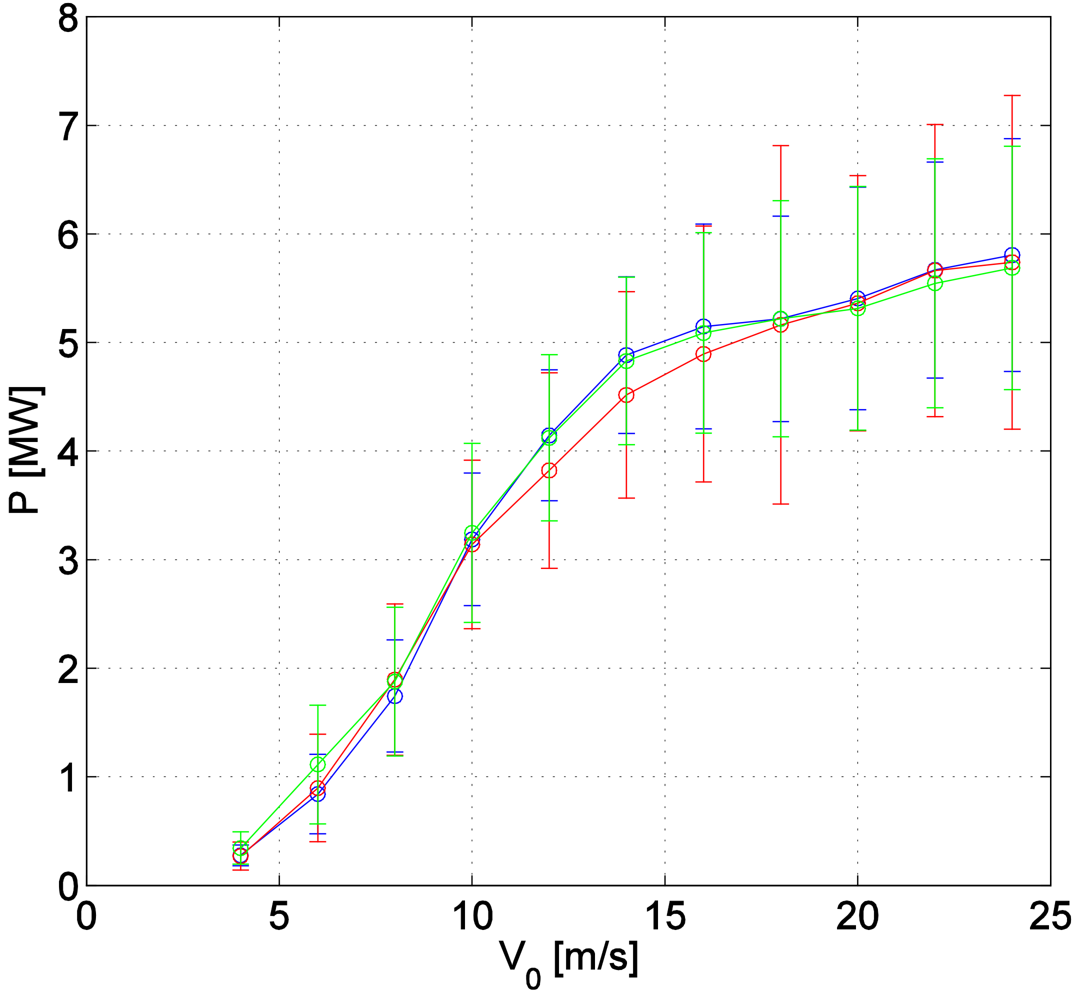


All active turbine control via generator torque

2p damping with notch filter and PI controller

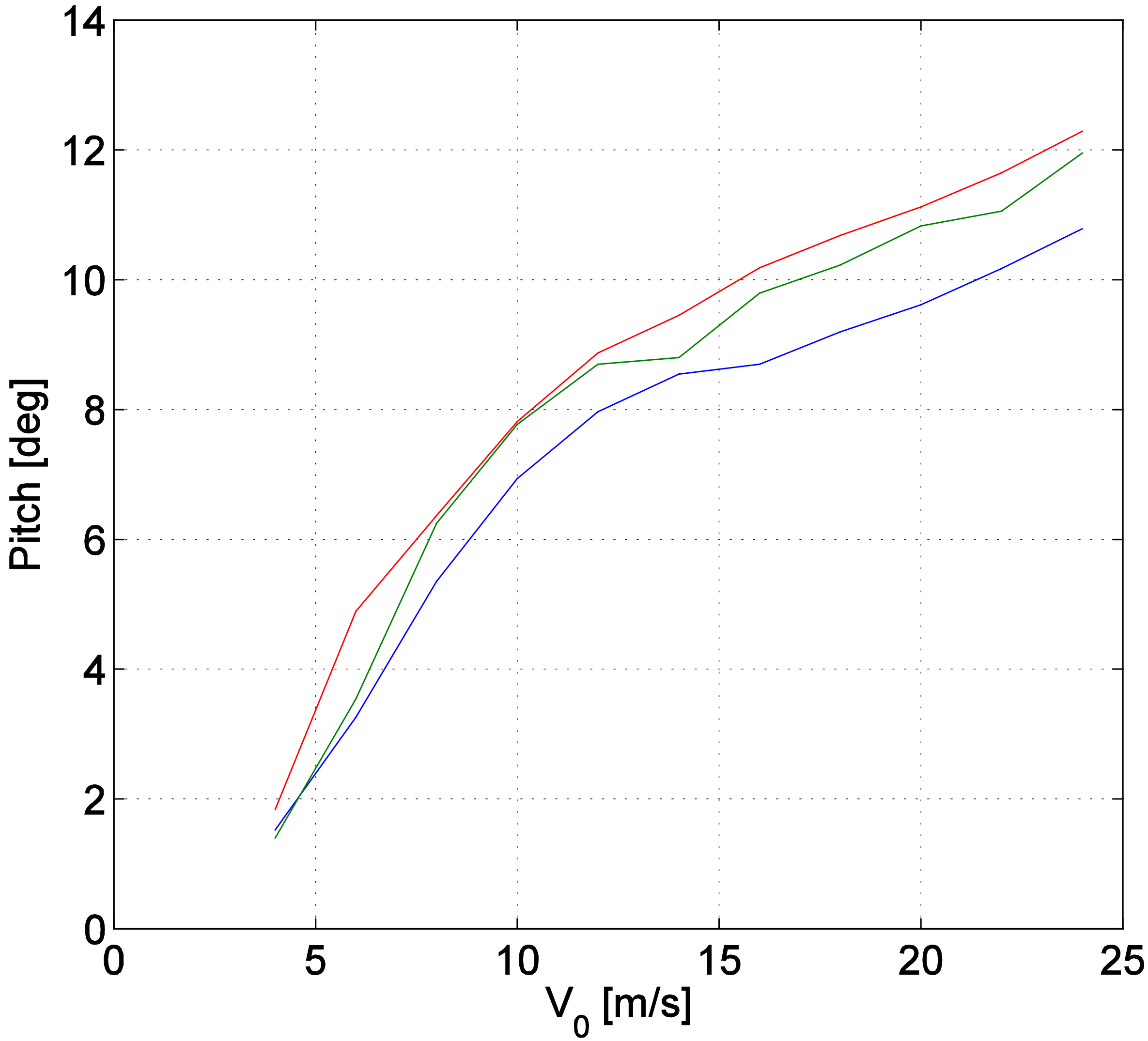


Results-power curve



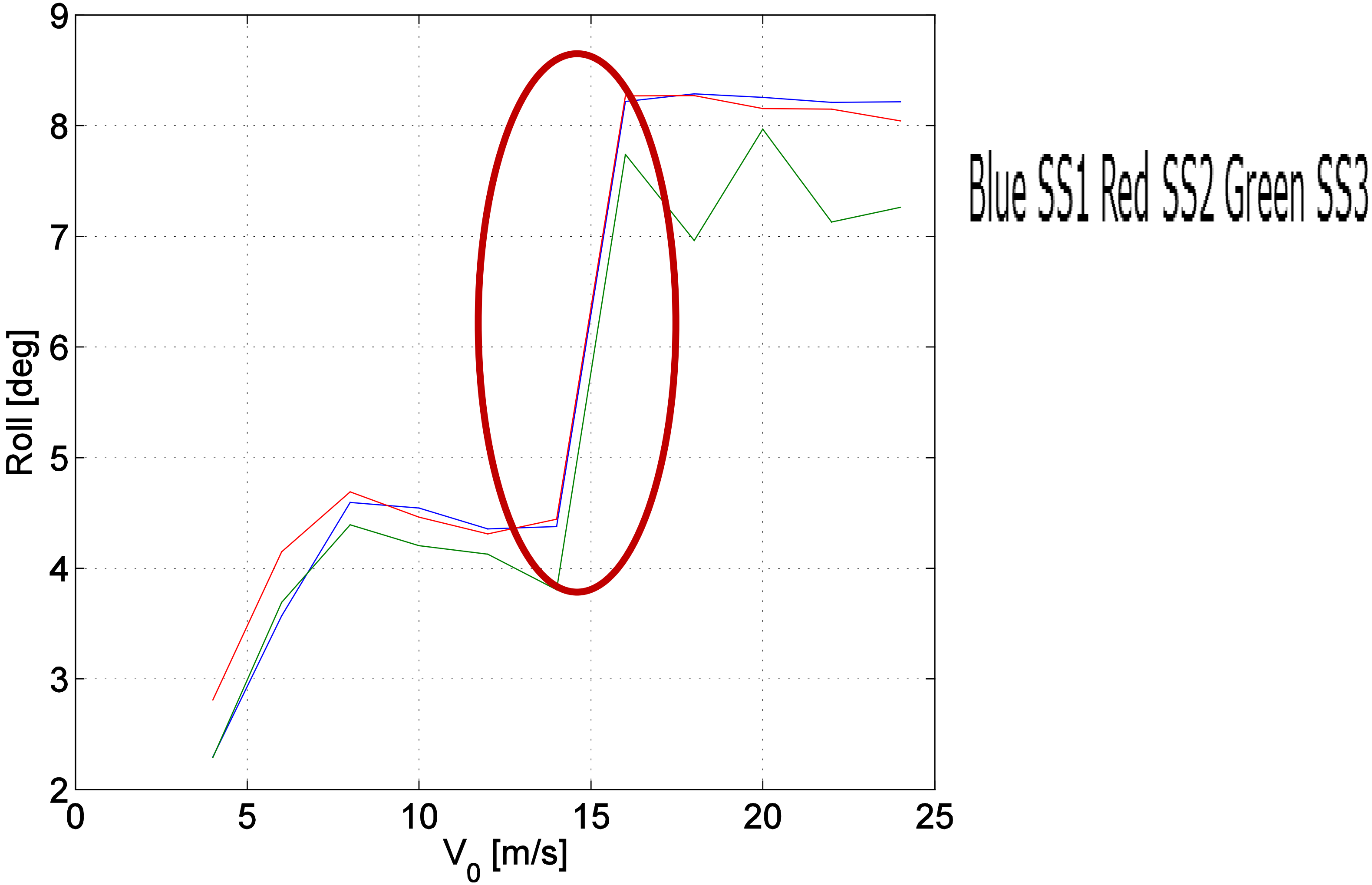
Blue SS1 Red SS2 Green SS3

Results-pitch

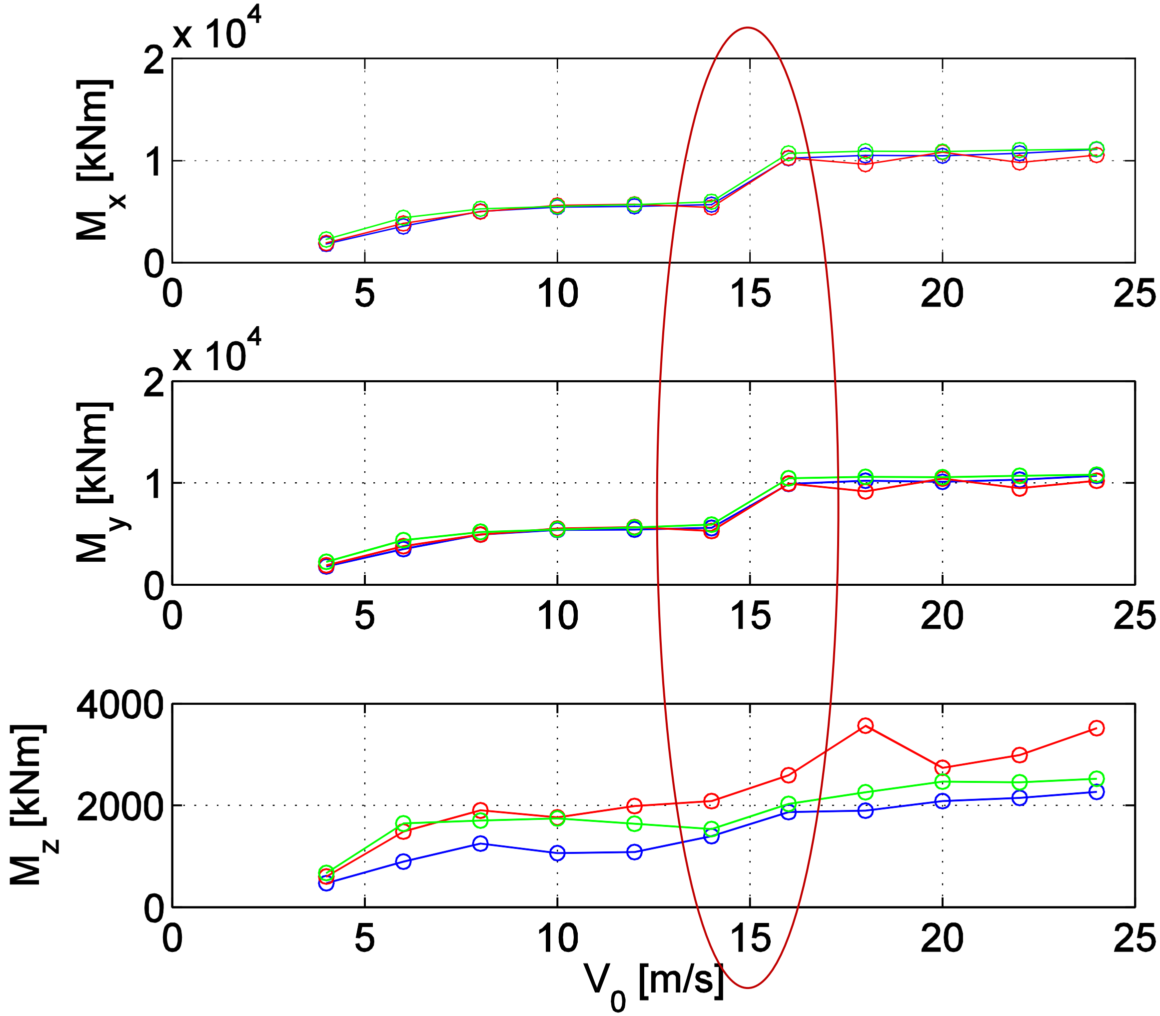


Blue SS1 Red SS2 Green SS3

Results-roll



Results-moments



Conclusions

- Demonstration of a 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 CD_0 and good C_P 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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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).

Thank You for Attention

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