Outcomes of the DeepWind conceptual design

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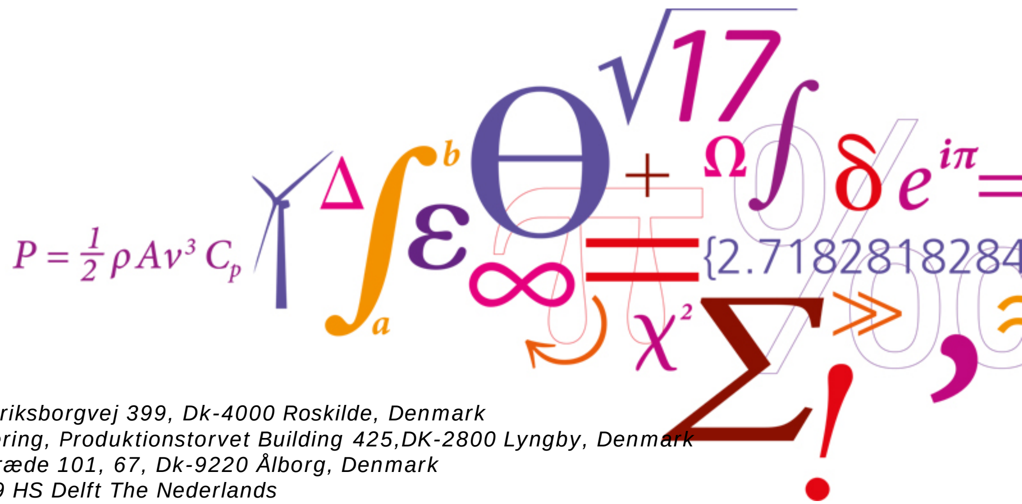

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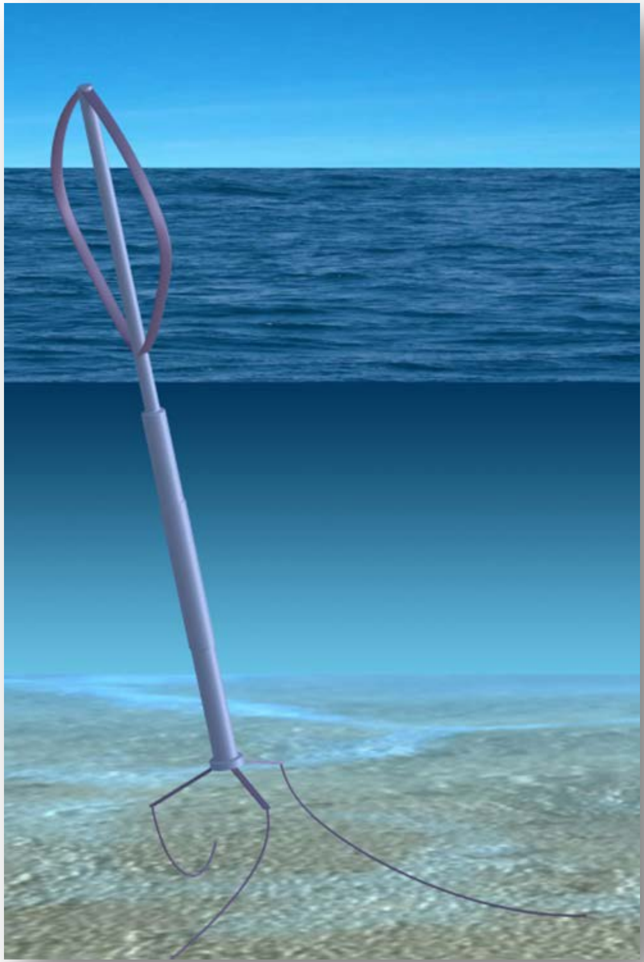


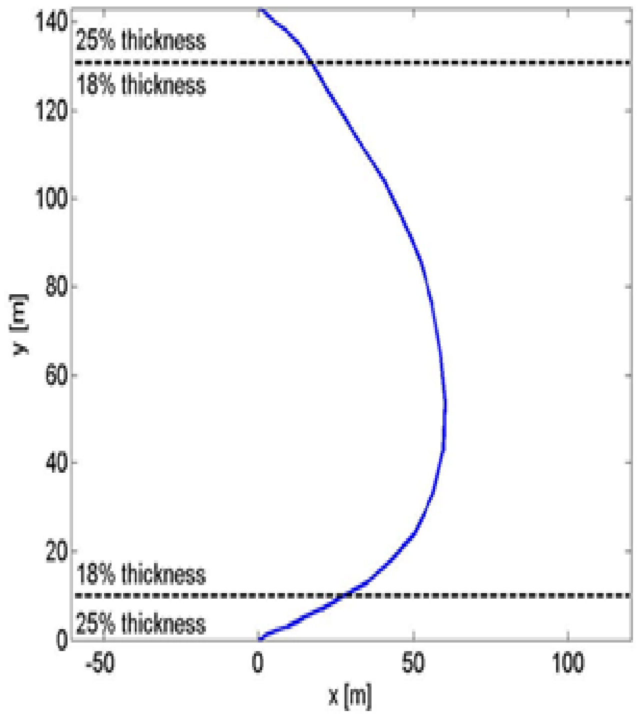
DeepWind Concept
FP7 project (2010-2014)

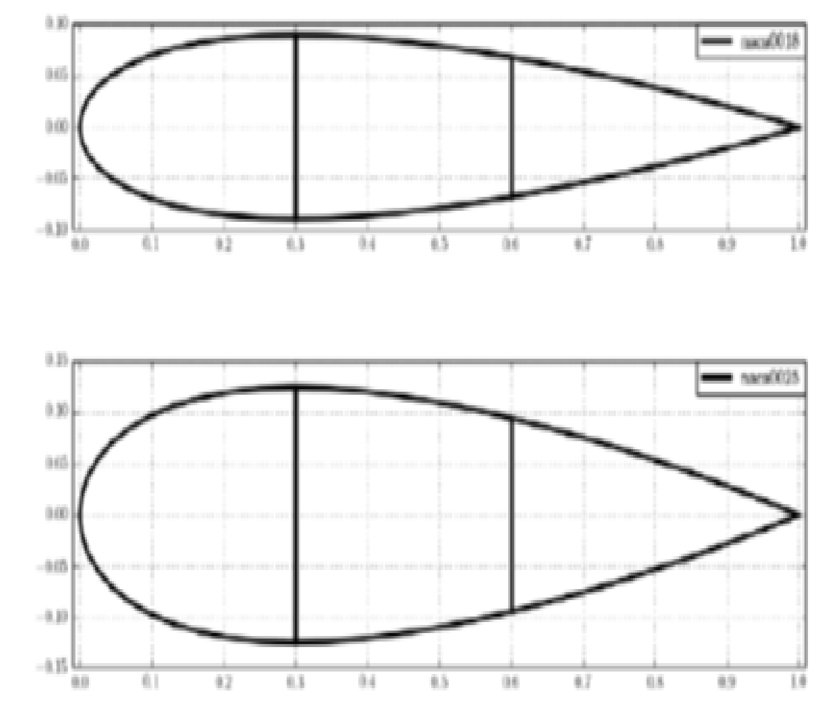
- A radical new design- aiming for better COE and a more reliable wind turbine
  - Few components-less failures at less cost
  - Pultrusion-less failures; cost approximately 30% of conventional blade
  - Operation not influenced by wind direction
  - New airfoil profiles available for better efficiency
  - 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

- Paulsen et al. The 5 MW Deepwind Floating Offshore Vertical Wind Turbine Concept Design - Status And Perspective Proceedings of EWEA 2014,Barcelona
- Paulsen et al. DeepWind-from idea to 5 MW concept Energia Procedia Vol. 53, 16-Sept. 2014, pp 22-33
- Verelst D, Madsen HA., Borg M, Paulsen US, Svendsen HG, Berthelsen PA. (2015) Integrated simulation challenges with the DeepWind floating vertical axis wind turbine concept. To be submitted in Energy Procedia 2015

Rotor

Modified Troposkien shape; analyses with NACA 0018/25 airfoils

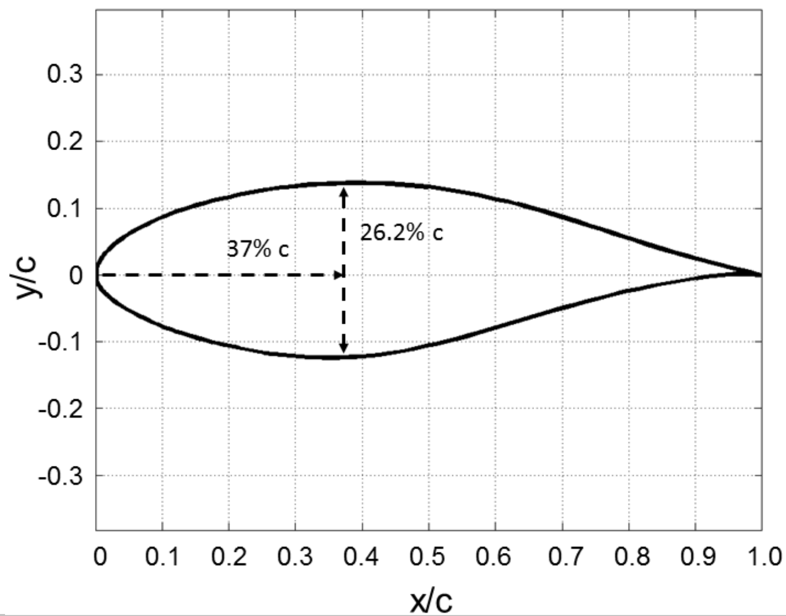


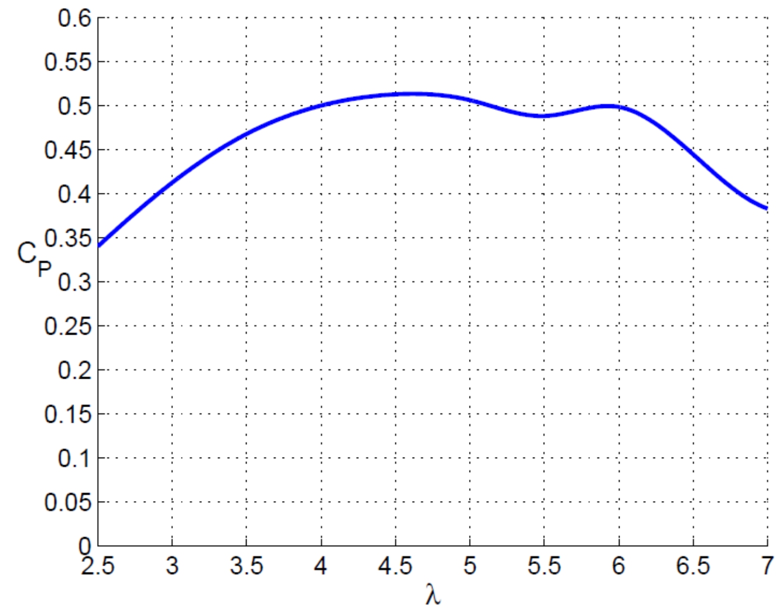


- Paulsen et al. DeepWind-from idea to 5 MW concept Energia Procedia Vol. 53, 16-Sept. 2014, pp 22-33

Advances
Rotor

C_P aerodynamic simulation with DU12W262 for a Reynolds number of 1×10^7 with free transition on 2-bladed 5 MW DW rotor(without stall)





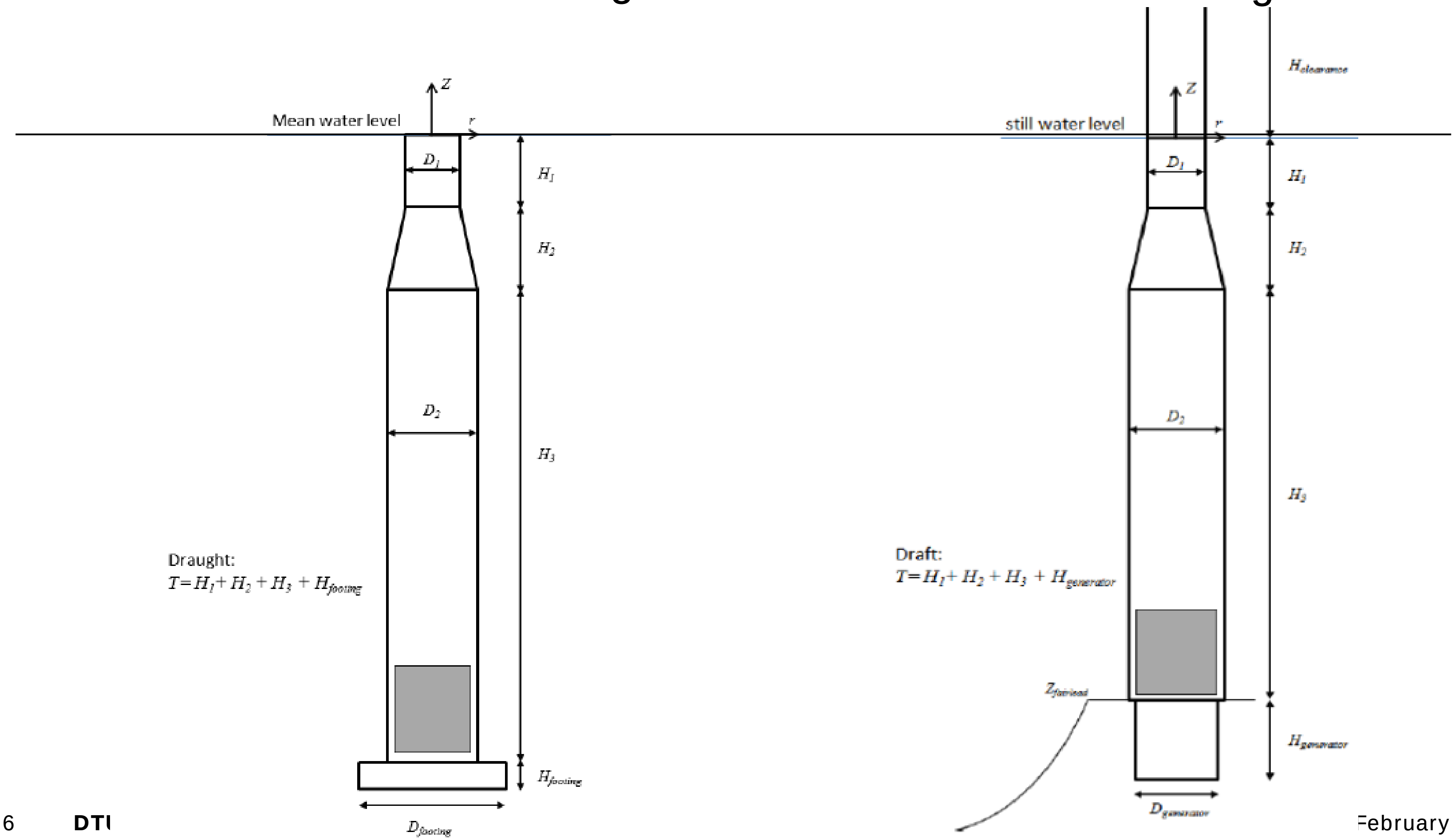
- Ragni D, Simão Ferreira CJ, Correale G. (2014) Experimental investigation of an optimized airfoil for vertical axis wind turbines. Journal of Wind Energy, DOI: 10.1002/we.1780
- Simão Ferreira CJ, Geurs, B. (2014) Aerofoil optimization for vertical-axis wind turbines Wind Energy, DOI: 10.1002/we.1762

Advances

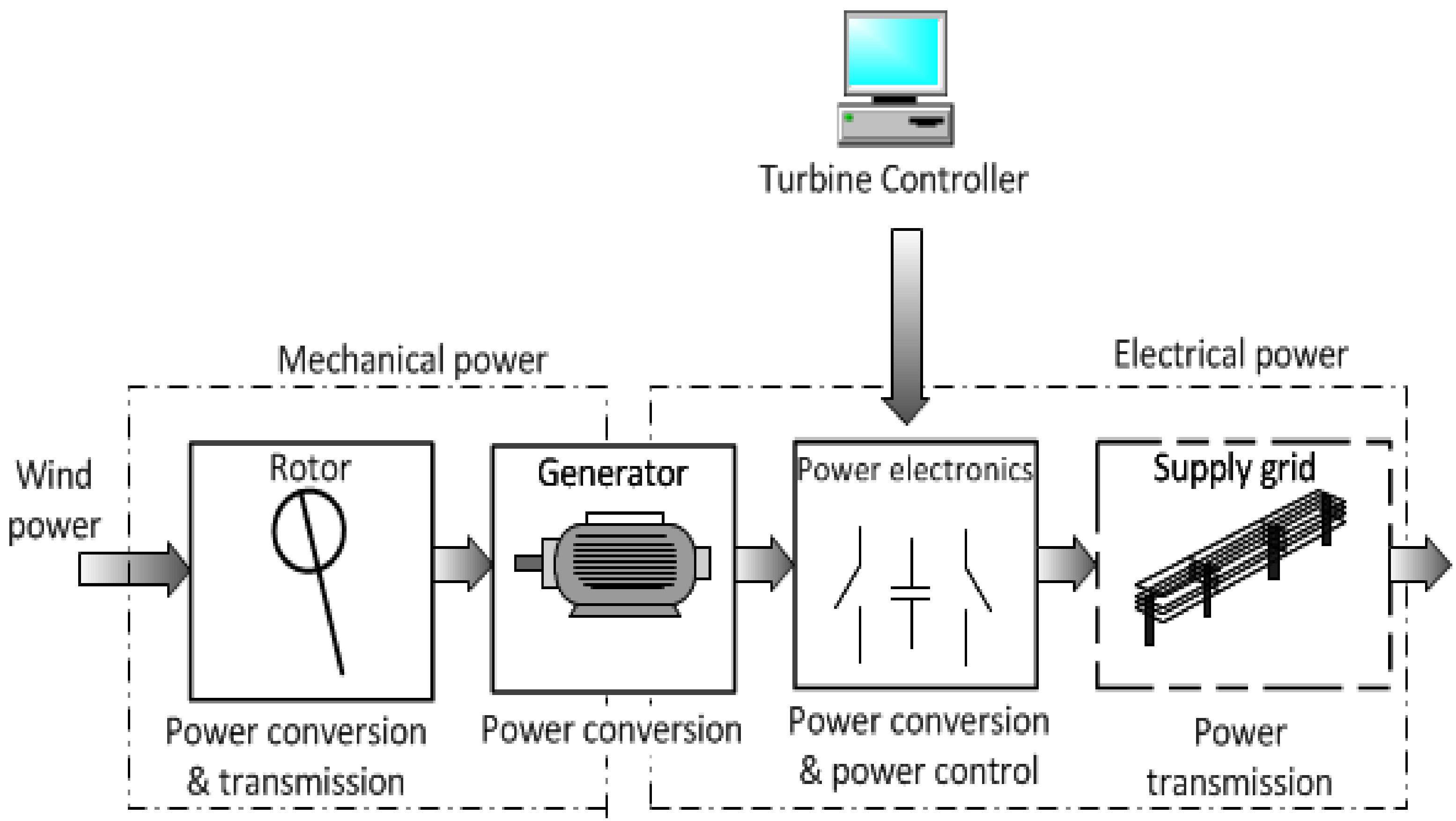
Floater

- Draught 108 m, redundancy with 6 mooring lines

1st floater design | 2nd floater design



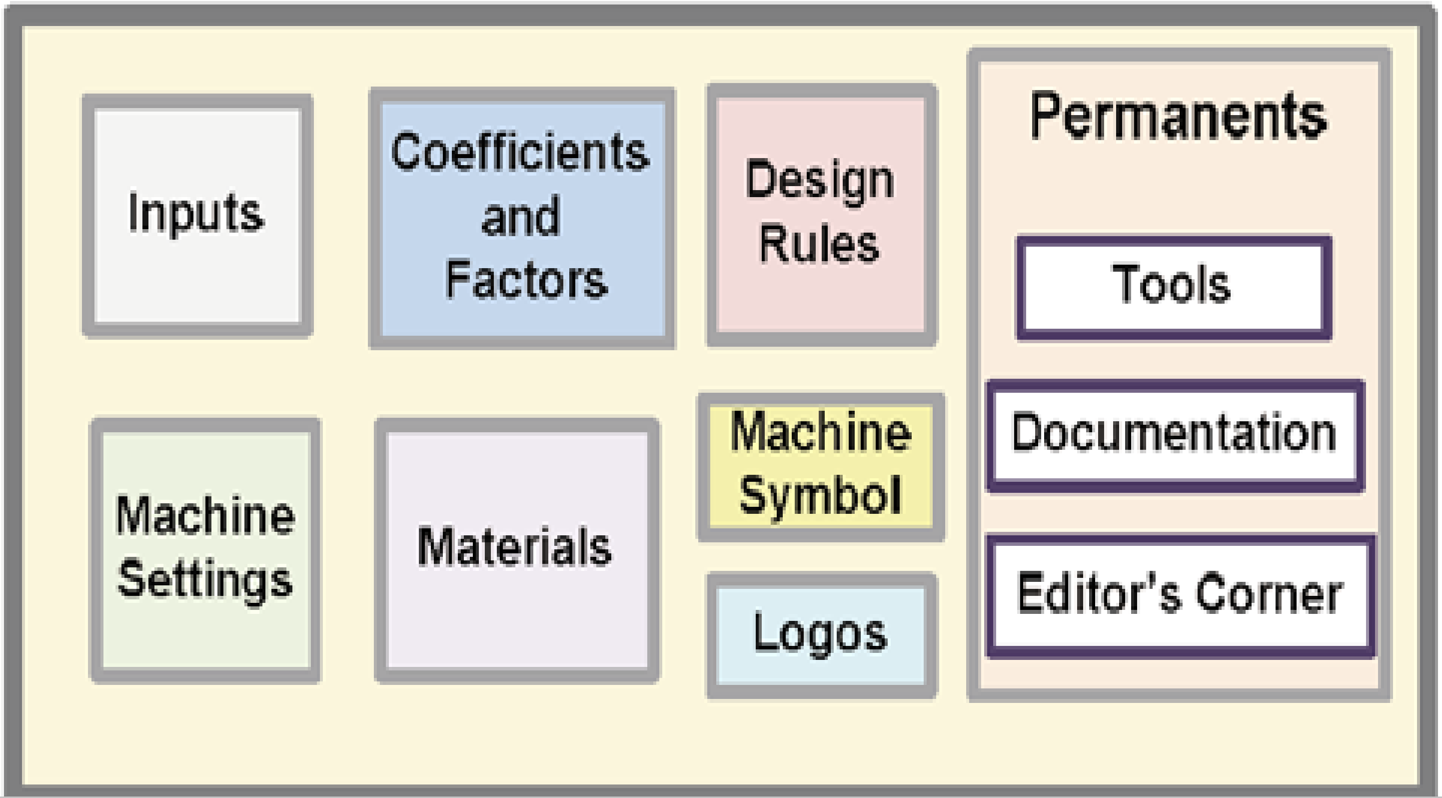
Advances
Power transmission



Advances

Power transmission

- Map of NESSIE design tool GUI

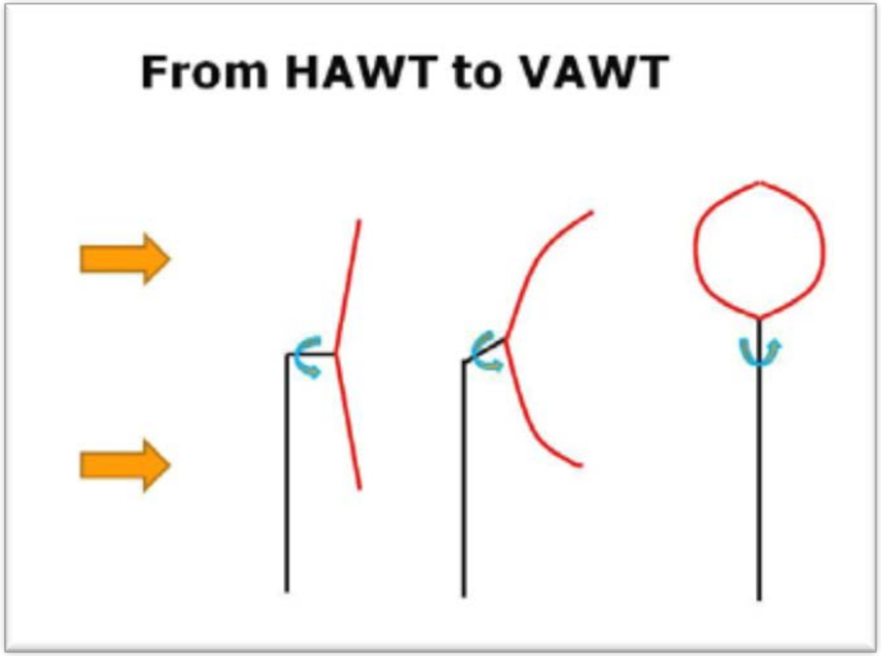


❑ Leban KM. (2014) Design Tool for Direct Drive Wind Turbine Generators: Proposed solutions for direct drive Darrieus generators 20MW. Department of Energy Technology, Aalborg University. 183 p. Research › Ph.D. thesis

Advances

Deepwind Simulations

1) code development and validation including different type of measurement campaigns on model rotors
2) contribution to turbine design of 1kW demonstrator, 5MW Deepwind final design and initial simulations on a 20MW turbine



- ❑ Structural core based on a multibody formulation
- ❑Joints modeled by geometric constraints

Use for VAWT´

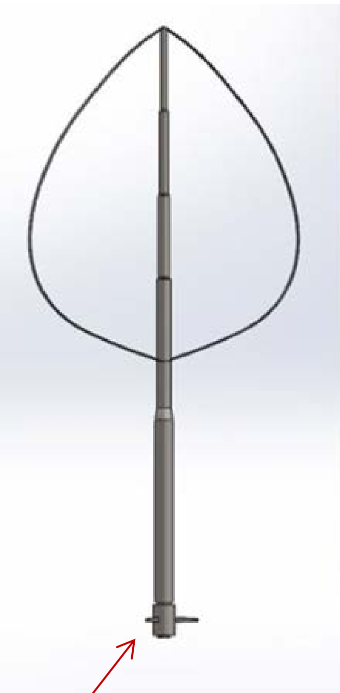
- ➢ **Arbitrary geometry** √
- ➢ **Hydrodynamic loads** √
- ➢ **Wave loads** √
- ➢ **Mooring lines** √
- ➢ **Turbulent inflow model** √
- ➢ **Aerodynamic blade loads** √
- ➢ **Dynamic stall** √

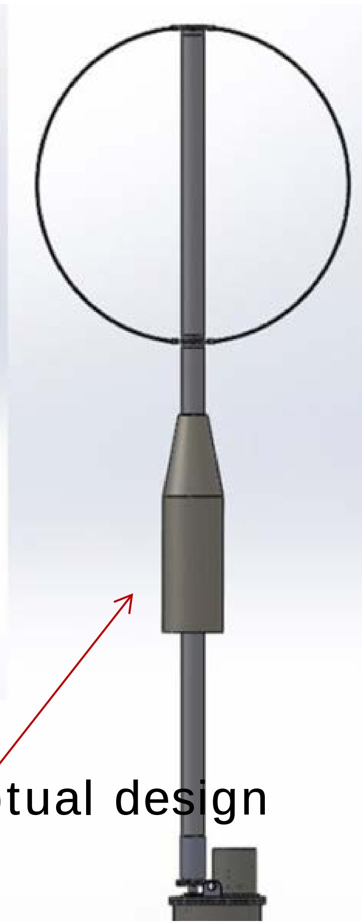
- ➢ **BEM induction model** √
- ➢ **Magnus forces on floater** √

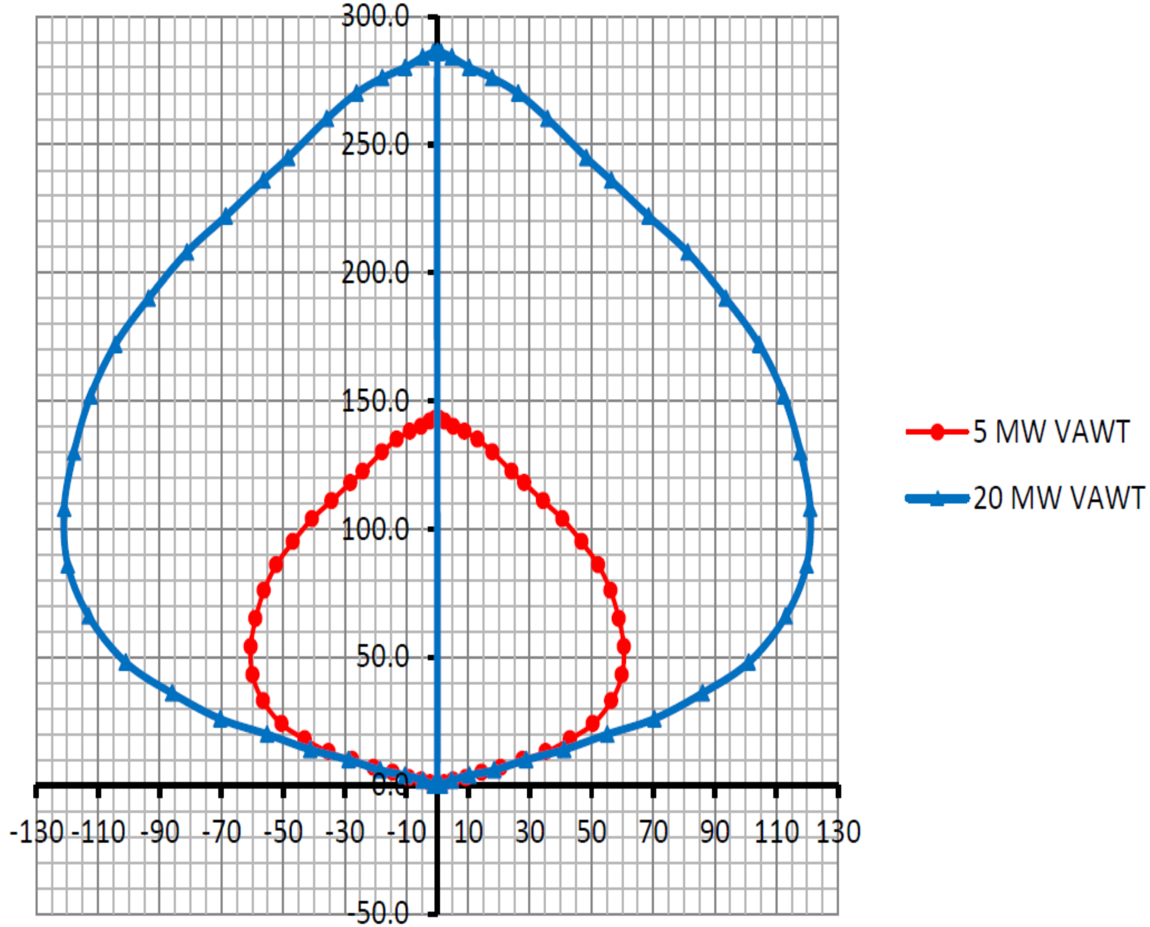
❑ Verelst D, Madsen HA, Kragh KA, Belloni F (2014) Detailed Load Analysis of the baseline 5MW DeepWind Concept. DTU Wind Energy E-0057

Upscaling

Deepwind 1 kW-5 MW 20 MW



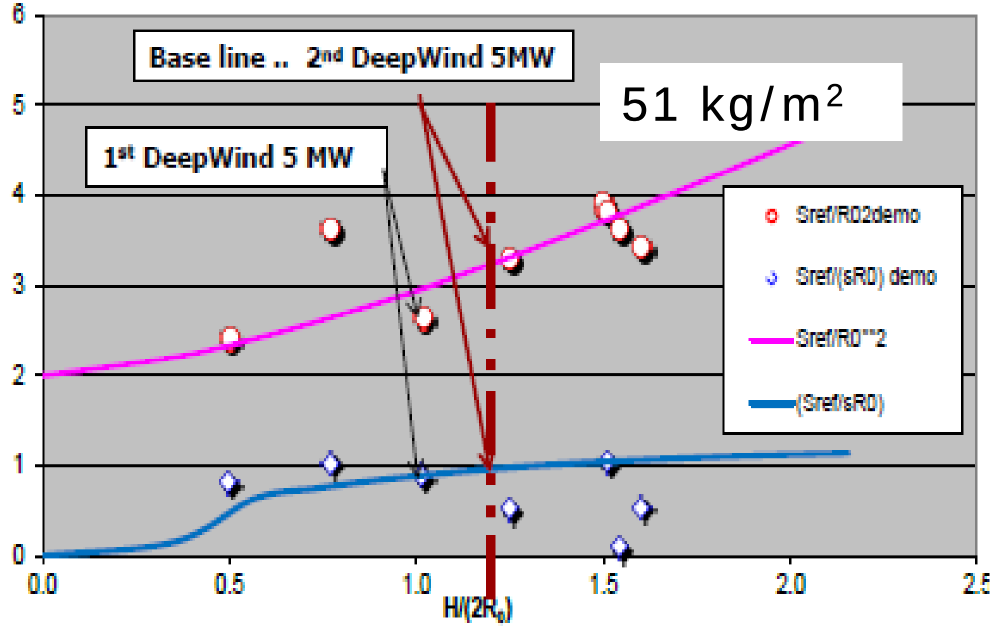




5 MW conceptual design

1 kW upscaled to 5 MW

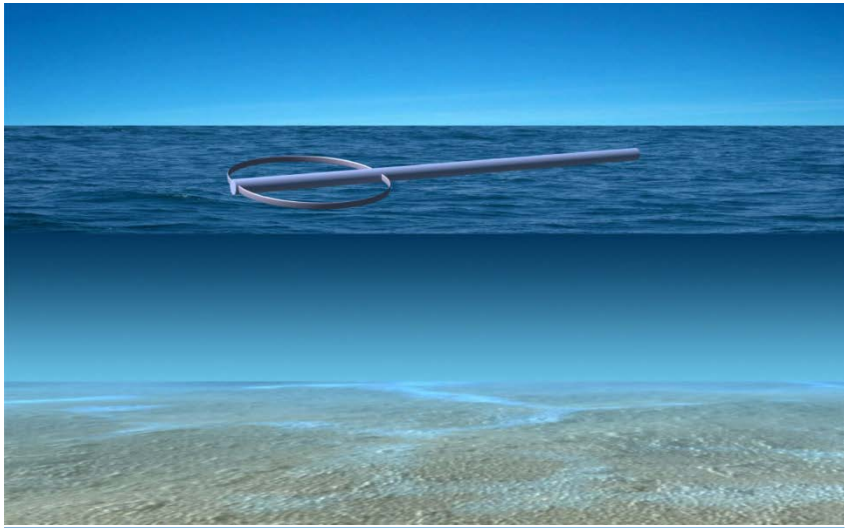
Cost of Technology
Deepwind 5 MW

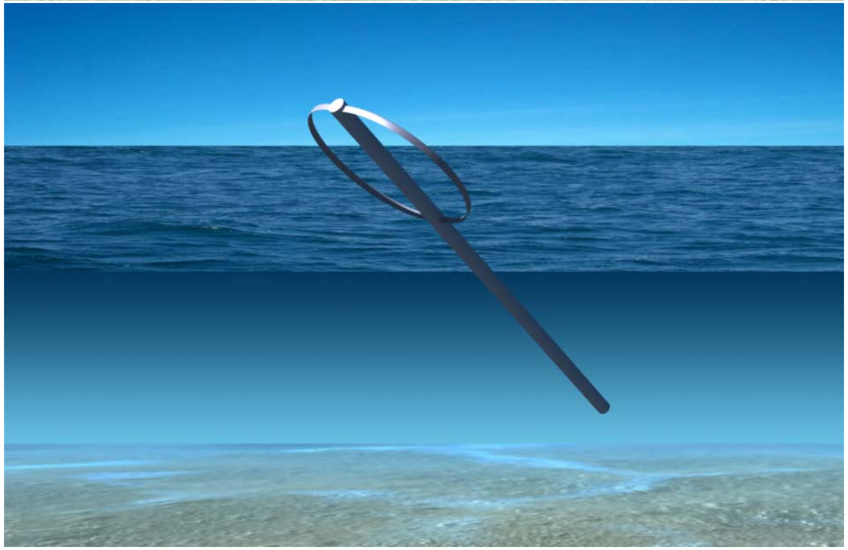


Operational and Performance Data			Geometry		
Rated power	[MW]	5	Rotor radius (R)	[m]	60.49
Rated rotational speed	[rpm]	5.95	Rotor height (H)	[m]	143
Rated wind speed	[m/s]	15	Chord (c)	[m]	5
Cut in wind speed	[m/s]	4	Solidity (σ =Nc/R)	[%]	16.53
Cut out wind speed	[m/s]	25	Swept Area	[m^2]	11996

Installation, Operation and 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.



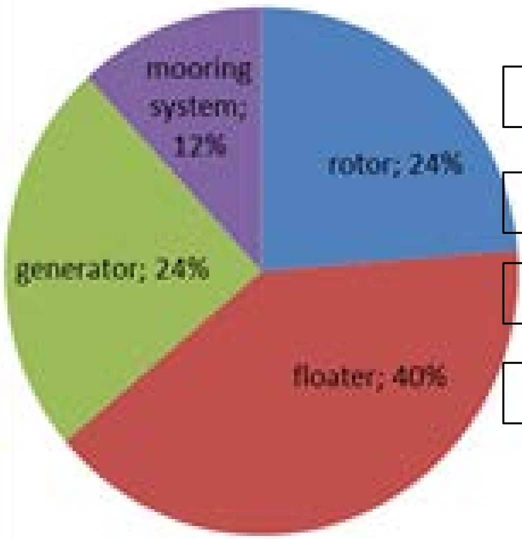


- O&M
  - ✓ Moving the counterweight in the bottom of the foundation is possible to tilt up the submerged part for service.
  - ✓ It is possible to place a lift inside the tubular structure.

Cost of Technology

Deepwind 5 MW

Left : Floater with steel material. Right: Floater made of reinforced concrete



	k€	Cost [k€]	
rotor	2123	2,123	35%
floater	3591	859	14%
generator	2173	2173	36%
mooring system	1062	862	14%
total	8,949	6017	100%

100 MW Wind Farm project economy	Energy production	MWh/year	19,953
	Net production	MWH/year	19,306
	Windfarm production 98%	MWH/year	378,399
	Wind farm hexagonal mooring*	k€	175,083
	specific cost	€/kWh*	0.46

- Myhr A, Bjerkseter C, Ågotnes A, Nygaard TA(2014) Levelised cost of energy for offshore floating wind turbines in a life cycle perspective Elsevier Renewable energy66, 714-728

Cost of Technology

Deepwind 5 MW

LEVELIZED COST OF ENERGY

$$COE = \frac{(FCR * ICC) + LRC}{AEP} + AOM$$

COE = LEVELIZED COST OF ENERGY, $/kWh	- - - - - - ->	101c€/kWh
FCR = FIXED CHARGE RATE, per year	→	10%
LRC = LEVELIZED REPLACEMENT COST, $/yr (major repairs)	→	450,000€/yr
ICC = INITIAL CAPITAL COST, $	→	9 M€
AEP = ANNUAL ENERGY PRODUCTION, kWh	→	19 GWh/yr
A0M = ANNUAL OPERATION & MAINTENANCE, $/kWh	→	30 c€/kWh

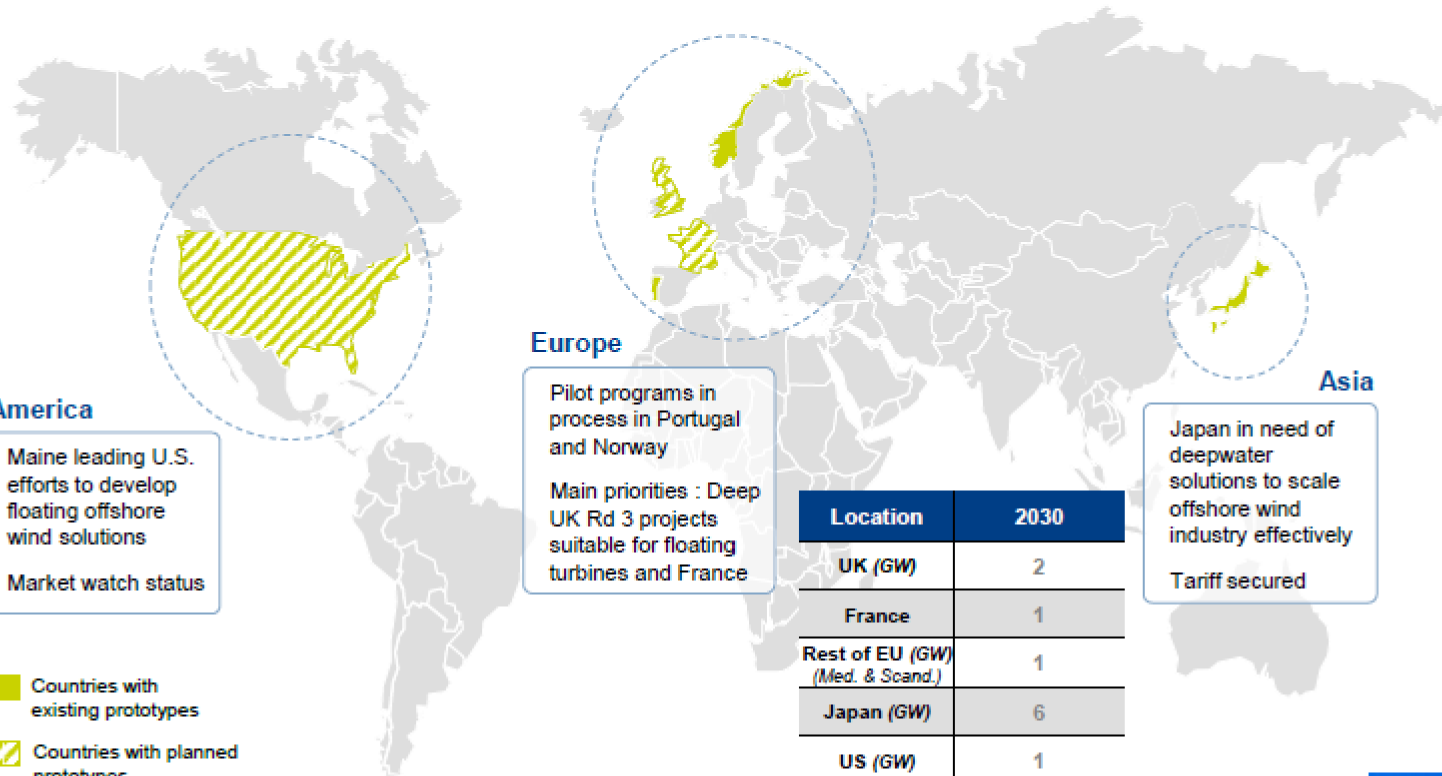
LCOE approach following:

Simplified model based on utility approach: 500MW 100-110€/MWh OPEX 30€/MWh

- 100MW: 65€/MWH, 500 MW 62€/MWh
- with high/low rates: between 59 and 75 €/MWh

- Myhr A, Bjerkseter C, Ågotnes A, Nygaard TA(2014) Levelised cost of energy for offshore floating wind turbines in a life cycle perspective Elsevier Renewable energy66(2014)714-728
- Maples B.et al.(2013)Installation, Operation, and Maintenance Strategies to Reduce the Cost of Offshore Wind EnergyNREL/TP-5000-57403

Floating market potential



America

Maine leading U.S. efforts to develop floating offshore wind solutions

Market watch status

Europe

Pilot programs in process in Portugal and Norway

Main priorities : Deep UK Rd 3 projects suitable for floating turbines and France

Asia

Japan in need of deepwater solutions to scale offshore wind industry effectively

Tariff secured

Countries with existing prototypes

Countries with planned prototypes

Location	2030
UK *(GW)*	2
France	1
Rest of EU *(GW)* *(Med. & Scand.)*	1
Japan *(GW)*	6
US *(GW)*	1
TOTAL *(GW)*	**11**

Deepwind closure meeting – Roskilde – 29/09/2014 – p.8

NENUPHAR
OFFSHORE WIND TURBINES

Conclusions

- Simulation tools are provided-they are working to details
- 5 MW Conceptual made ready
  - Challenges in rotor and yaw stability
- Cost analysis
  - Simple analysis promising but rudimentary; to be improved
  - Floater materials for cost of floater important
  - Mooring system
  - Variability of cost for resources(e.g. steel prize)
  - Wind turbine around 1800 €/kW, with new floater material 30% less
  - COE around 100€/MWh
  - OPEX mostly unknown due to unknown procedures(30€/MWh)
  - Differences in Development and consenting for industrial model
- Concept to be looked further into towards higher TRL.

Acknowledgements

The work is a result of the contributions within the DeepWind project which is supported by the European Commission, Grant 256769 FP7 Energy 2010- Future emerging technologies, and by the DeepWind beneficiaries: 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).

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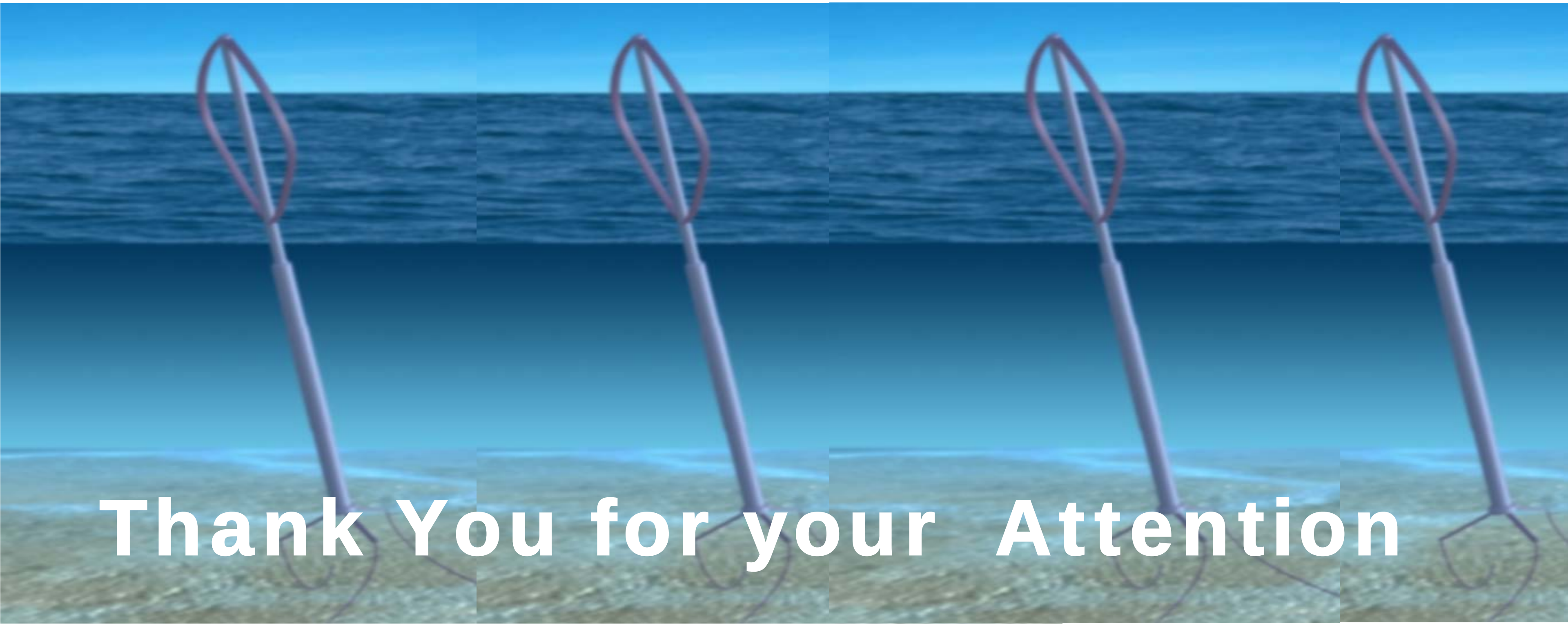
Thank You for your Attention