Floating wind turbines: the future of wind energy?

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Outline

- Trends in (offshore) wind energy
- Concepts of floating wind turbines
- Some challenges
- Research in the field at LR
Trends in (offshore) wind energy
Scale-up success

- 171 m Ø
- 126 m Ø
- 33 m Ø
- A380 Airbus

Year: 89, 91, 93, 95, 97, 99, 01, 03, 05, 07, 09, 11, 13, 15

Power: 0.3, 0.5, 1.3, 1.6, 2, 4.5, 5, 7.5, 8 MW
How big is 8MW?
How big is 8MW?

Samsung S7.0-171 83.5 m blade length
Cumulative wind power installations in Europe (GW)

Wind in power – 2015 European Statistics, EWEA report (Feb. 2016)
Cumulative wind power installations offshore in Europe (MW)

The European offshore wind industry - key trends and statistics 2015, EWEA report (Feb. 2016)
Types of foundations

Newly installed foundations in Europe in 2015

- 97% monopiles (385 structures)
- 3% jackets (12 structures)

In 2015, there were 3,313 foundations installed offshore in Europe

Monopile: www.londonarray.com (May, 2016)
Limitations of current technology

Most seas are deeper than 50 metres

Existing commercial foundations are not economically viable in deep seas

Concepts of floating wind turbines
Main types of foundation

- **Tension leg platform**: Stability, Moorings, Assembly, Dry dock, Installation, Towing to site, Depth (50-150 m)
- **Semi-submersible**: Buoyancy, Moorings, Dry dock, Towing to site, Depth (50-150 m)
- **Spar buoy**: Ballast, On/off-shore, Towing or not, Depth (100m - ?)
Recent developments

2008 – Blue H (80kW)

http://www.bluehengineering.com/historical-development.html
Recent developments

2009 – Hywind (2.3MW)

Upcoming – Hywind Scotland Pilot Park (30MW)

Photo: Trude Refsahl/Statoil

www.statoil.com/HywindScotland
Recent developments

2011 – WindFloat (2MW)  
Upcoming – WindFloat Atlantic (25MW)  

Recent developments

2011-2016 – Fukushima Forward project (2MW, 5MW, 7MW)

http://www.fukushima-forward.jp
And much more...
And much more…

State of development of selected floating turbine concepts

- Mitsui (JP)
- Mitsubishi (JP)
- Ideol (FR)
- Gusto (NL)
- HiPR Wind (EU)
- Diwet (FR)
- Hywind (NO)
- Toda (JP)
- Japan Marine (JP)
- Sway (NO)
- Nautica AFT (US)
- Sea Twirl (SW)
- Gicon (GE)
- Blue H (GE)
- Pelastar (US)
- Iberdrola Etorlai (SP)
- Mitsui (JP)

Source: Main(e) International Consulting, LLC
Combining wind and wave energy

http://www.floatingpowerplant.com
Floating airborne wind energy

http://www.skysails.info/english/power
Some challenges
Some challenges

• **Turbine**
  – Rotor-wake interactions
  – Control systems
• **Support structure**
  – Conservatism in the design (not cost effective)
  – Relation between size of turbine rating
• **Mooring lines**
  – Dynamic behaviour of moorings, esp. in shallow water
  – Anchors and soil conditions
• **Electrical infrastructure**
  – Dynamic power cables
• **Operation and maintenance**
  – Harsh environmental conditions
• **Design standards**
  – Lack of experience leads to conservative designs
  – Modelling of the system dynamics

Technologically feasible but needs to be cheaper!
Numerical modelling

Accuracy

CFD & FEM
Detailed design

Aero-servo-hydro-elastic coupling
Design validation

Reduced modeling
Pre-design

Cost
Research at LR
High-fidelity modelling of FSI

Unstructured mesh fluid/ocean model (finite elements)

A highly multi-scale example: astronomically forced M2 tide in the North Atlantic coupled to the North and Baltic Seas. A high resolution mesh is required to resolve the channels connecting the Baltic and North Seas but a much coarser mesh is acceptable in the North Atlantic. More than two orders of magnitude difference between coarsest and finest resolutions.

http://fluidityproject.github.io
High-fidelity modelling of FSI

1. Solve the equations of motion of the fluids on the fluid-dynamics mesh
2. Transfer the fluid forces
3. Solve the equations of motion of the solids on the solid-dynamics mesh
4. Transfer the solid position and forces

ACTION = REACTION

Mesh adaptivity to refine the solid concentration field

Fluid-dynamics mesh across the entire domain

Solid-dynamics mesh across the solid structure
Applications

• Wind/tidal turbine modelling through actuator disks

• Dynamics of a floating monopile

• Aerodynamics of kite wings

• Wave-structure interactions
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• Wave-structure interactions
Wave-structure interactions

• Regular waves of steepness \( ak = 0.01 \)
  where \( gk \tanh(kh) = (2\pi T)^2 \) and \( T = 1 \)

• Intermediate water depth: \( h/\lambda_0 = 0.45 \) \( (\lambda_0 = 2\pi g/\omega^2) \)

• Inviscid flow

Reference: linear wave theory (MacCamy & Fuchs, 1954)
Wave-structure interactions

- Theoretical solution
- Defined-body approach
- Immersed-body approach
Wave-structure interactions

- Irregular waves
- Amplitudes of the focused wave ($k_p$ is the Jonswap peak)
  
  \[ A_{\text{sum}} k_p = 0.018 \quad A_{\text{sum}} k_p = 0.09 \]

- The amplitude is maximum at: \( x_f = 10h \) and \( t_f = 7.5T \)

Reference: second-order calculation (Sharma & Dean, 1981)
Wave-structure interactions

Second-order solution

\[ A_{\text{sum}} k_p = 0.018 \]

\[ A_{\text{sum}} k_p = 0.09 \]
Wave-structure interactions

\[ A_{\text{sum}k_0} = 0.018 \]

\[ A_{\text{sum}k_0} = 0.09 \]
Wave-structure interaction
Upcoming works

• CFD modelling of the TetraSpar concept (Stiesdal, 2016), with Deltares and NTNU

• Re-design of blades for model-scale testing, with MARIN

• Build synergies at TU Delft and internationally on floating wind energy
The future of wind energy?

**LEVELISED COST OF ELECTRICITY (LCOE) OF MAJOR POWER GENERATION TECHNOLOGIES IN EUROPE**

- Hard coal: ~60 €/MWh
- Natural gas: ~100 €/MWh
- Nuclear: ~150 €/MWh
- Onshore wind: ~100 €/MWh
- Offshore wind: ~150 €/MWh
- Rooftop PV: ~75 €/MWh

Subsidies and costs of EU energy, Ecofys (Nov. 2014)
The future of wind energy?

Cost comparison for a wind farm of 800 MW installed capacity

* Electrical infrastructure installation cost per MW for floating is based on demo park scale and are therefore not directly comparable to bottom fixed.
Thank you for your attention