ENERGY

Floating Wind R&D at DNV GL

An international industry perspective

COWIT 2018 – Sacramento, CA

Jarett Goldsmith

13 March 2018

DNV GL is a global classification, certification, technical assurance and advisory company

OUR PURPOSE

TO SAFEGUARD LIFE, PROPERTY AND THE ENVIRONMENT

Global reach – local competence

150 years	**400** offices	**100** countries	**~13,000** employees

Organized to maximise customer value

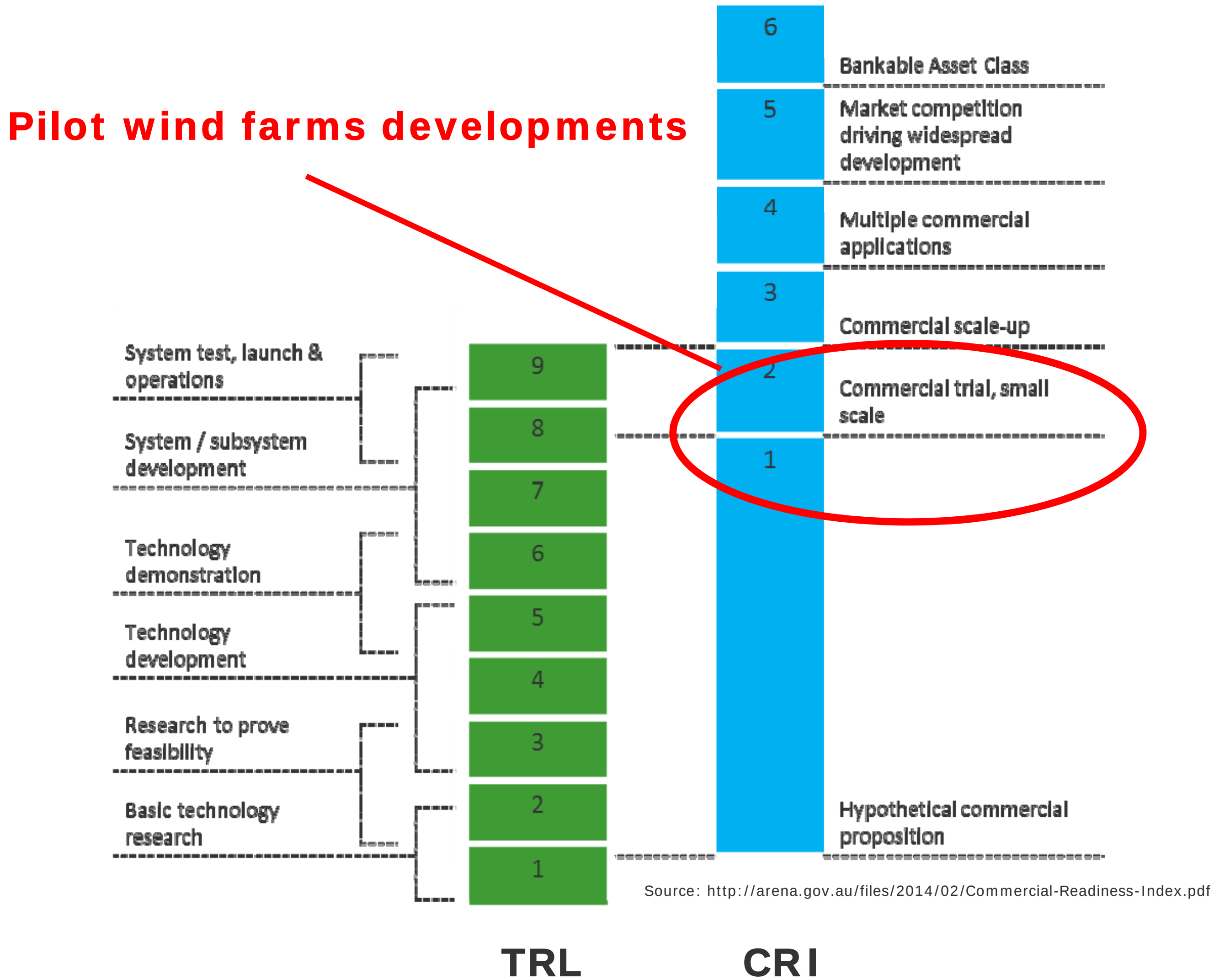
DNV GL’s offshore wind experience

- First offshore wind work under taken in 1989
- Involvement in 90% of major operating offshore wind projects worldwide
- Project Certification of 70% of operating projects

- Pre-development and project development support, certification, contracting/owner’s engineering, financing support, construction and marine operations, asset management

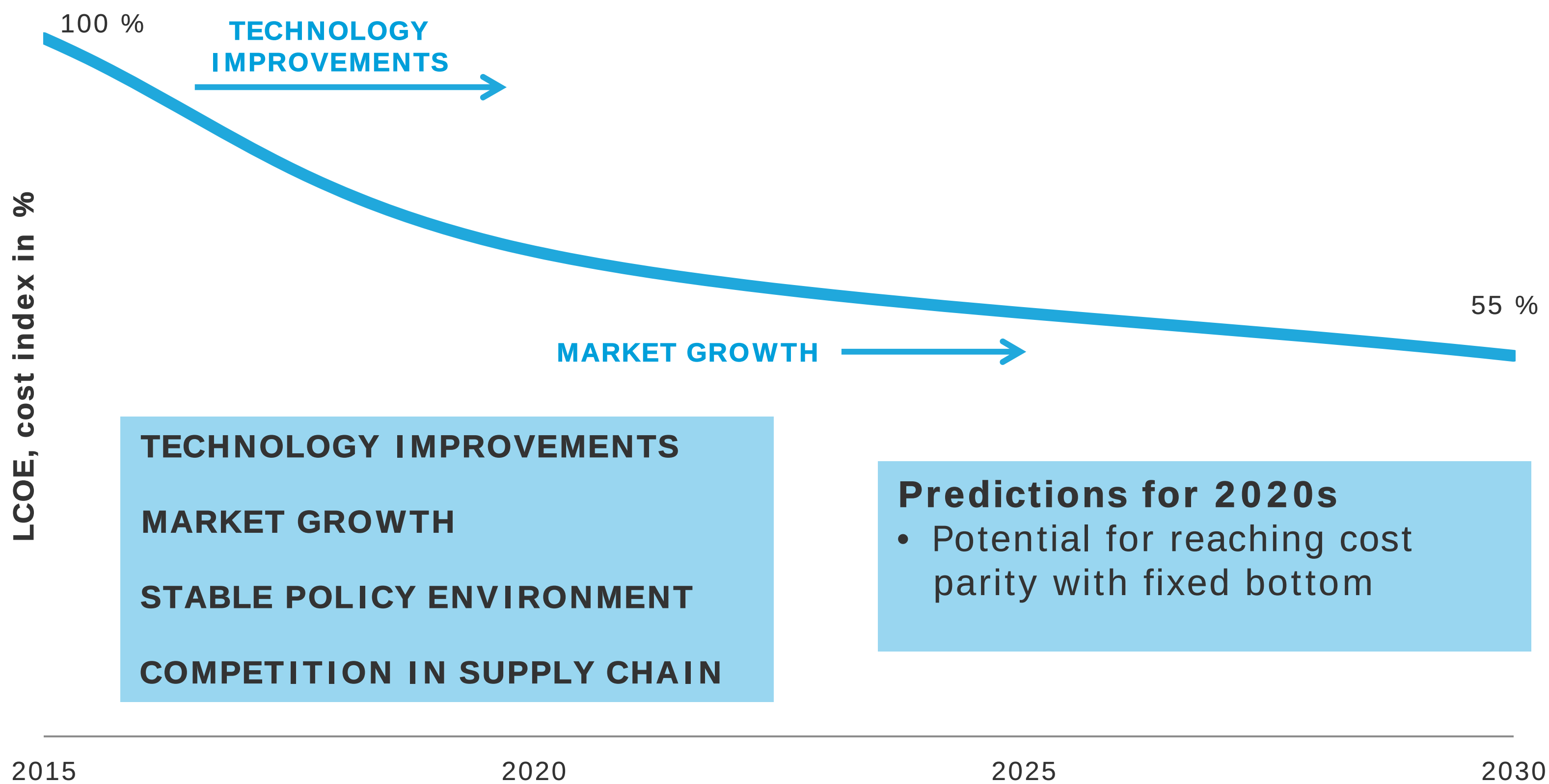
- 480 assignments covering 69,000 MW of advisory services completed, including,
  - Technical Due Diligence performed: 86 assignments
  - Offshore energy assessments: 8,000 MW
  - Project management services: 20 project

Floating wind has just started to move into the CRI scale



Floating wind commercialization likely to intially be driven by technology improvements – Large role for R&D efforts to support

Estimated LCOE reduction 2015 – 2030



TECHNOLOGY IMPROVEMENTS

MARKET GROWTH

STABLE POLICY ENVIRONMENT

COMPETITION IN SUPPLY CHAIN

Predictions for 2020s

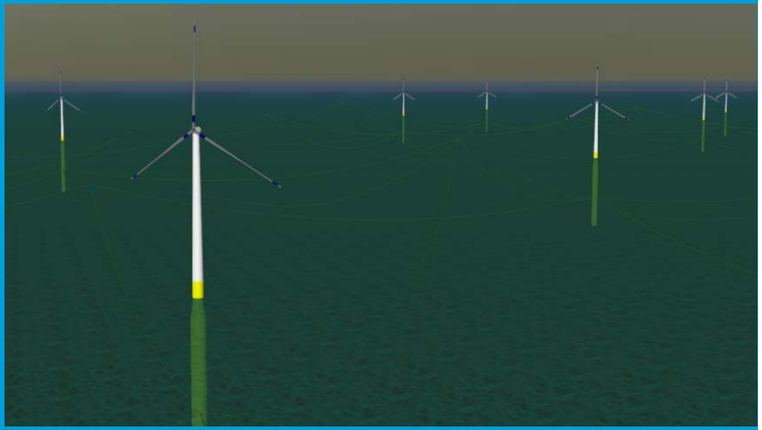
- Potential for reaching cost parity with fixed bottom

Note LCOE is not the single indicator of competitiveness for floating wind.

E.g. important to account for different market frameworks, time and location of production

Feasibility of shared moorings

- Market review
- Anchor reduction efficiency calculation
- Mooring pattern that achieves > 30% efficiency
- Coupled analysis for survival conditions – intact & redundancy
- Mooring integrity review using HazID and BowTie
- Installation, inspection and maintenance planning

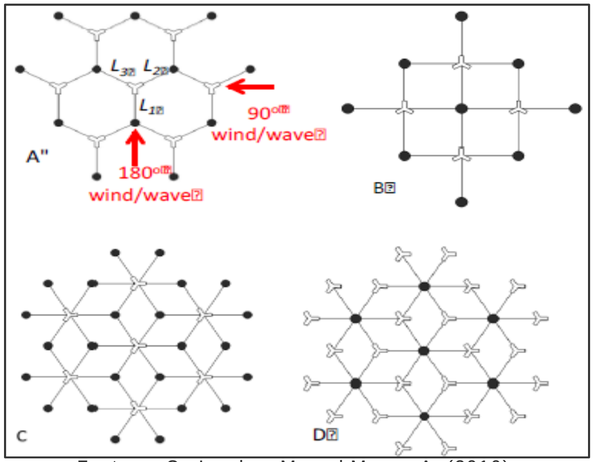


Existing literature suggests:
Cost reduction potential of overall system ~5%, ref Ebbesen 2016
Potential to reduce anchor numbers by a factor of 3, ref. Fontana 2016

Three areas identified and prioritised for further development:

1. Anchors which retain structural integrity and stability when loaded in various directions. An EU project is now underway to fully understand shared anchor performance.
2. Advanced modeling tools to accurately represent behaviour of multiple fully integrated FOWTs including improved understanding of wake effects.
3. Streamlined installation, maintenance and failure response procedures which limit operational disruption to other units.

Contact alex.argyros@dnvgl.com

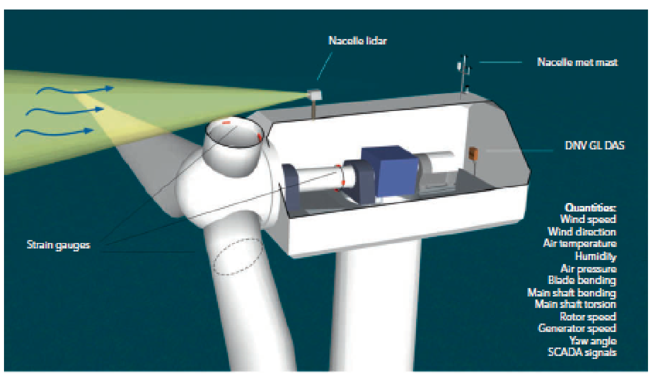


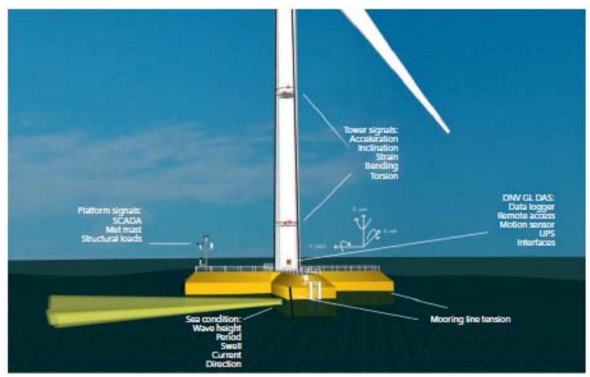
Fontana, C., Landon, M. and Myers, A. (2016).

DNV GL measurement services

Reliable measurement services for new technologies

- Conceptual design of monitoring system
- Installation of Instruments
- Commissioning of Monitoring
- Remote-Control LoFOT-Monitoring
- Transfer of recorded values into physical units
- Transfer of data into fixed coordinate system
- Reporting
- LofoT-Add-On: customer specific adaption of monitoring system





Developing innovative tools to support advisory services that advance floating wind…

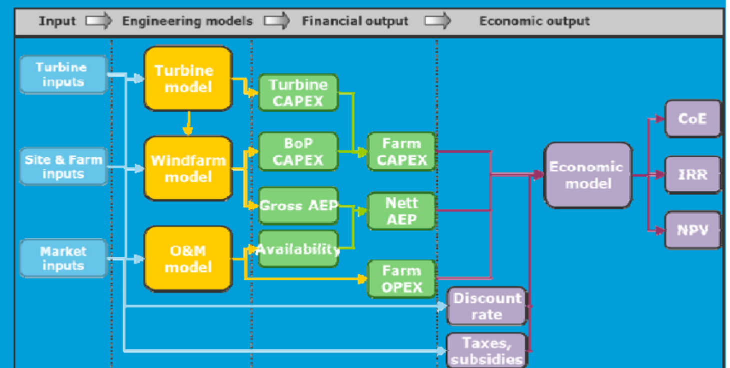
Strategic Decision Support

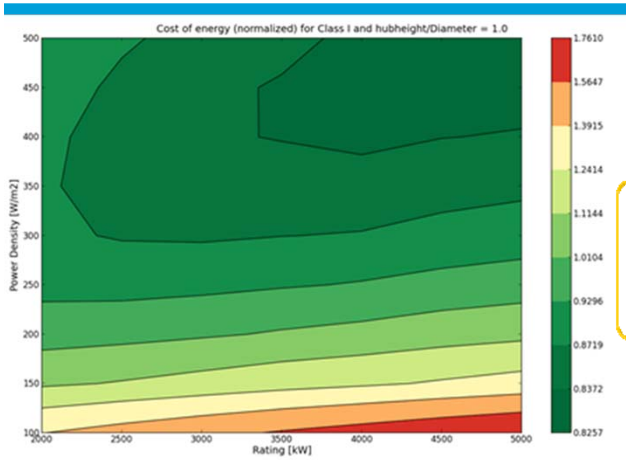
Turbine Architect

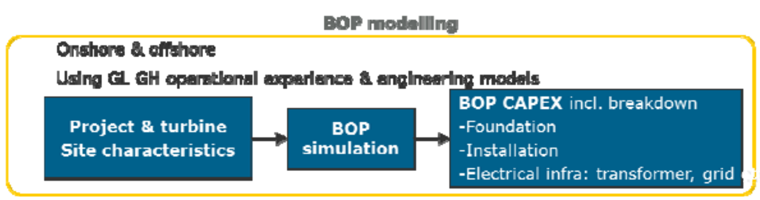
Turbine cost modeling through optimization and experience

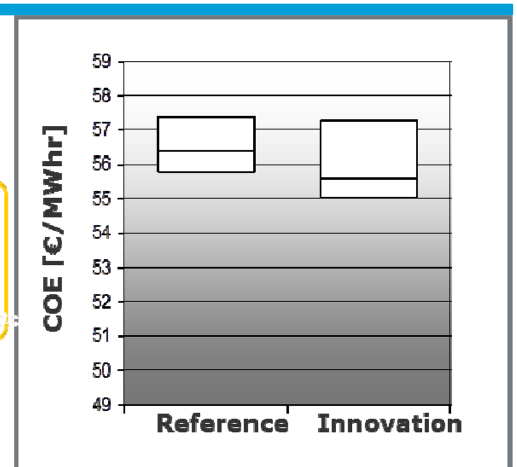
- Cost of energy predictions
- Structural loads database
- Structural & mechanical design optimisers based on loads
- Balance of plant model

- Strategic pre-design to target competitive concepts
- Quantify economics of innovation in technology
- Benchmarking against reference systems









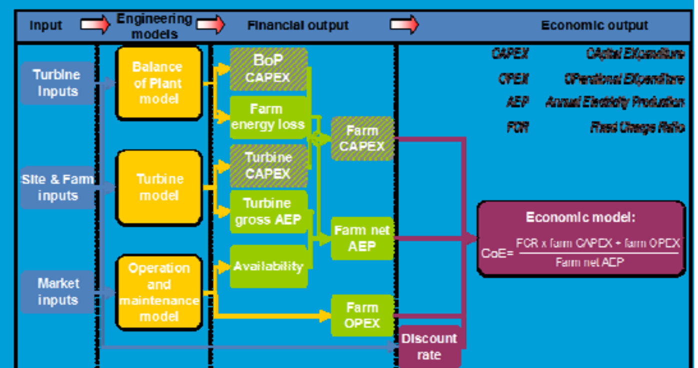
DNV·GL

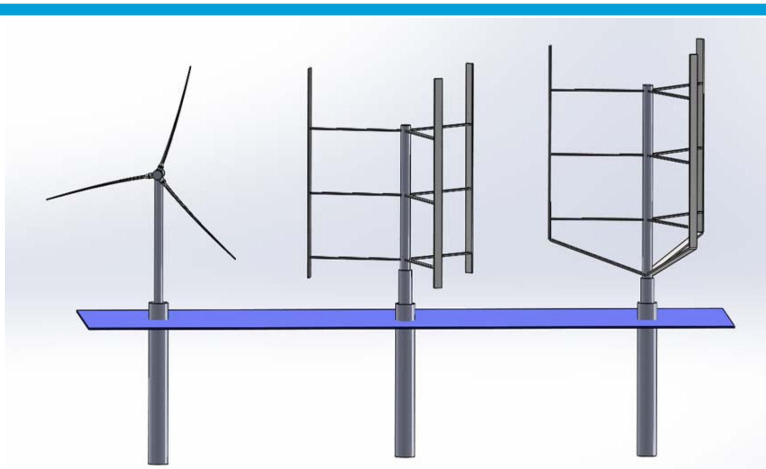
Floater Cost Modeling

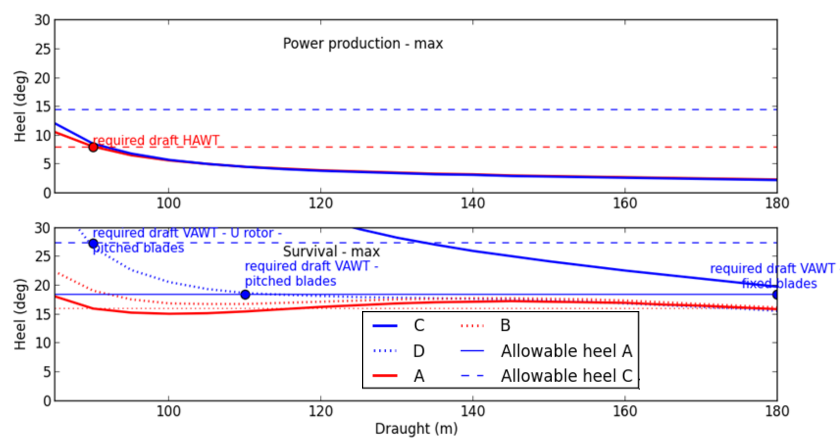
Predicting costs for a diverse range of floating designs

- Cost assessment for primary/secondary steel, ballast, anchor and mooring lines
- Draft optimized by tool based on allowable heel angles

- DNV GL Turbine.Architect used to predict costs using, amongst others:
  - Database of loading
  - Structural design optimizers
  - Calculated RAOs





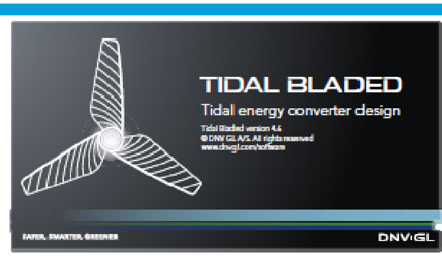


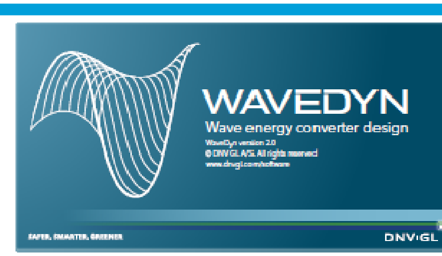
DNV·GL

Design and Planning Tools

Diverse suite of tools for machine design and site planning

- Validated software for the simulation of wind turbines, tidal stream turbines and wave energy converters
  - PerAWaT
  - OC3/OC4/OC5
- Site planning tools to analyse and optimize farm layouts
- Vast experience in wave energy, pushing modeling capabilities of floating wind



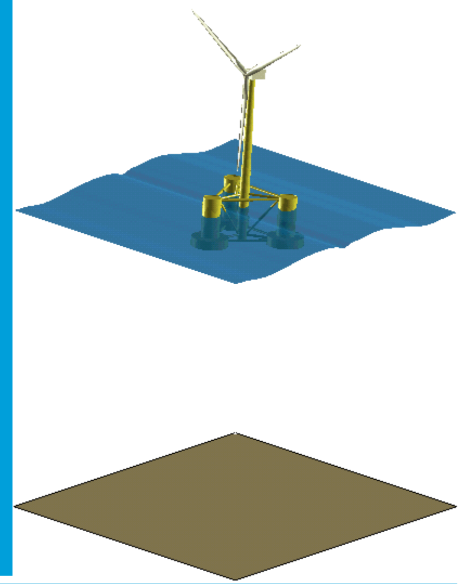


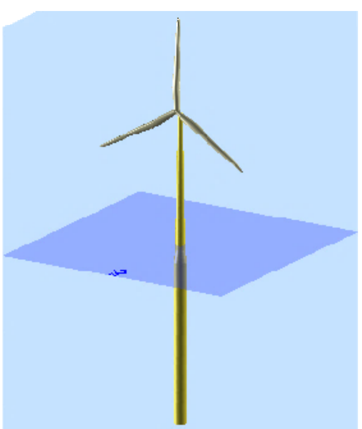
Numerical Modeling

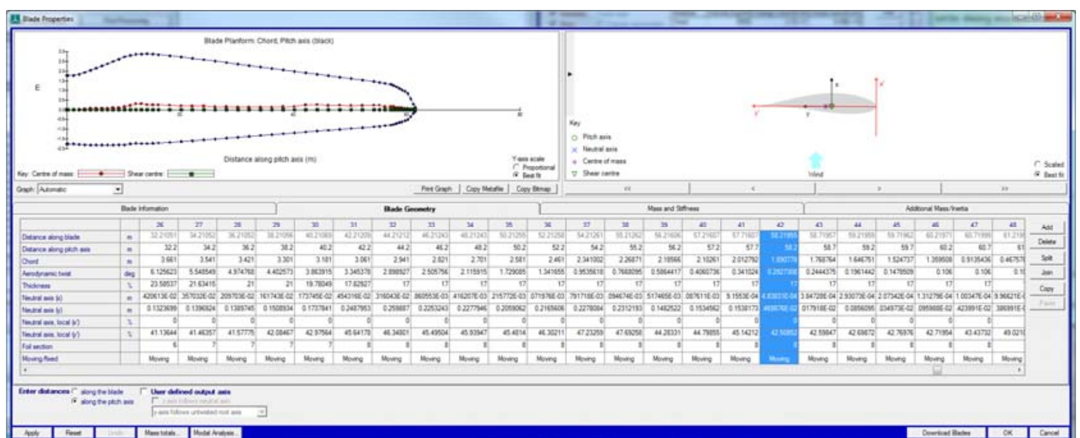
Bladed

Numerical modeling of floating systems

- Established, industry standard wind turbine modelling tool
- Fully coupled performance and loading calculations
- Morison's (2011) and Boundary Element (2014) Method Hydrodynamics
- Flexible multibody structural engine
- Quasi-static mooring line representation







DNV GL concept design support
Bladed used in real floating wind projects

MAIN OPERATING DEMONSTRATORS

In operation since	Demonstrator
2009	Hywind demo – 1st spar buoy
2011	WindFloat demo – 1st semi-sub (now decommissioned)
2012	Kabashima/Goto Spar – 1st concrete/steel
2013	VolturnUS – 1st concrete semi-sub
2013	Fukushima Compact Semi 2MW
2015	Fukushima V shaped semi sub 7MW
2016	Fukushima Advanced spar 5MW







SOME PROJECTS UNDER DEVELOPMENT/CONSTRUCTION

Demonstrator / pilot farm	Turbine	Platform	Country
Floatgen	Vestas	Ideol	France
Hywind Scotland	Siemens	Statoil	Scotland
Windfloat Atlantic	Vestas	Principle Power	Portugal
Eolmed (Gruissan)	Senvion	Ideol	France
Groix Atlantic	GE	DCNS	France
Provence Grand Large	Siemens	SBM	France
Eoliennes Flotantes Golf du Lion	GE	Principle Power	France
NEDO demonstrator 1	?	Ideol	Japan
NEDO demonstrator 2	?	Ideol	Japan
Kincardine wind farm	?	?	Scotland

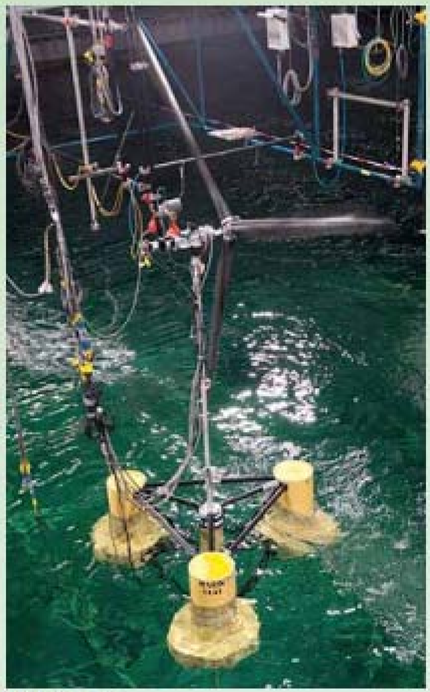
Bladed was or will be used in a significant number of these projects

DNV GL have performed **>20 different floating wind projects** in the last 10 years using **Bladed** for different turbine OEMs and platform designers

OC5 – Phase 2, Semisubmersible

OC5 = Offshore Code Comparison Collaboration, Continued, with Correlation

- Extension of the code-code comparison with measured data.
  - NREL 5MW, performances measured at 1:50
  - Floater: DeepCwind 2011
- Wind , Wave , Wind+Wave cases
- New features used in Bladed:
  - Dynamic mooring lines
  - 2nd order forces
- Finished beginning 2017

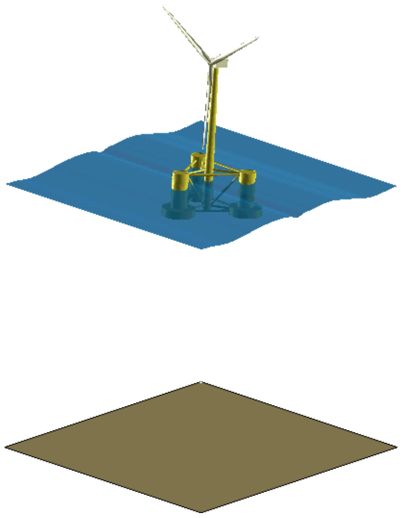


(b) Phase II:
Semi—Tank Testing
Jan 2015–May 2016

Bladed Hardware Test Module (Bladed HTM)

- Transforms the Bladed design simulation to a real-time hardware-in-the-loop simulation
- Use the same turbine model developed in turbine design and load calculations
- Customise the Bladed simulation to model complex behaviour
- Flexibly connect turbine hardware to the simulation
- Versatile set of input/output modules easily added to the simulation
- Test scripting system to manipulate the simulated environment and evaluate pass/fail results

Bladed can be used for validation of floating wind turbine tests, including hardware-in-the-loop testing



Bladed HTM for floating wind testing

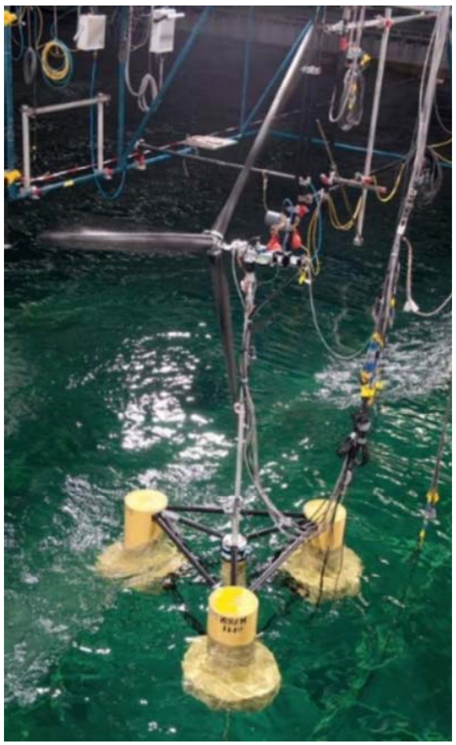
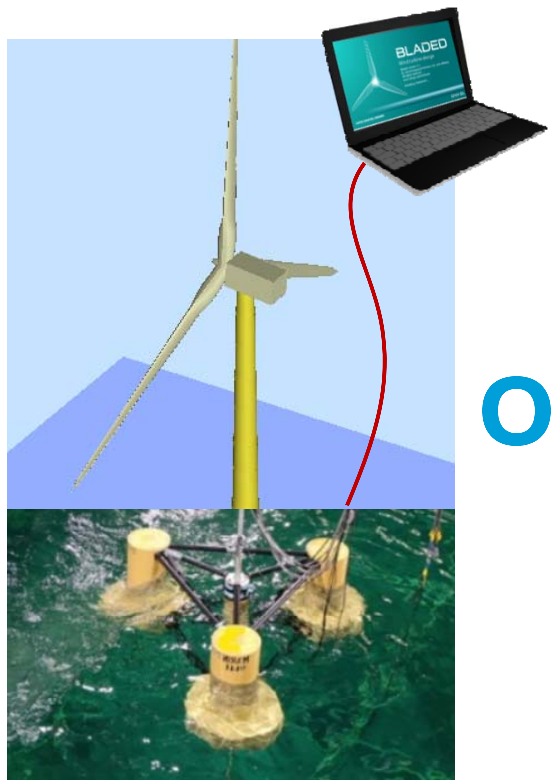


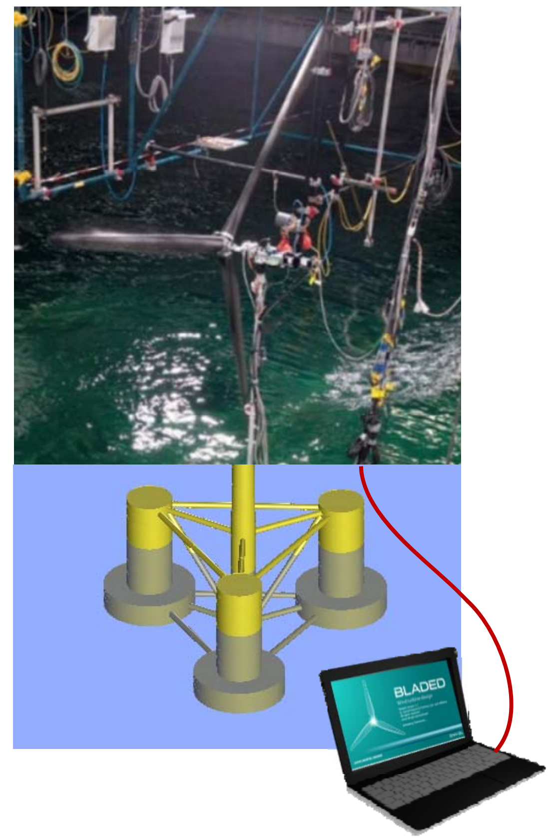
Photo provided by Andrew Goupee, University of Maine

Replace **turbine** with servo-motor running in real time in Bladed HTM



OR

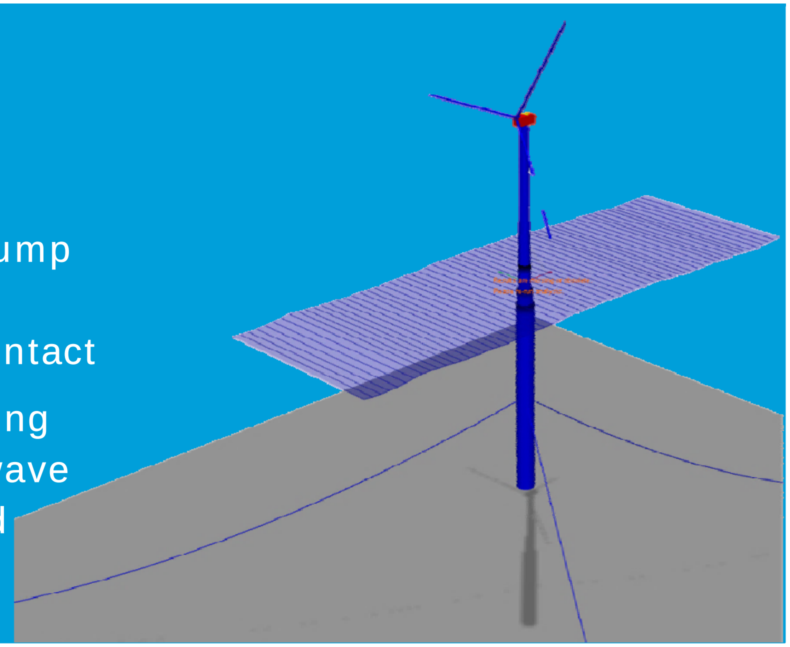
Replace **platform** with servo-motor running in real time in Bladed HTM

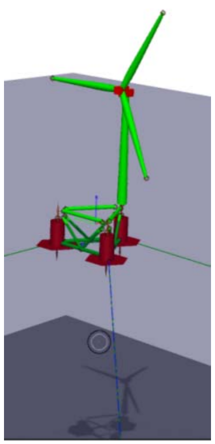


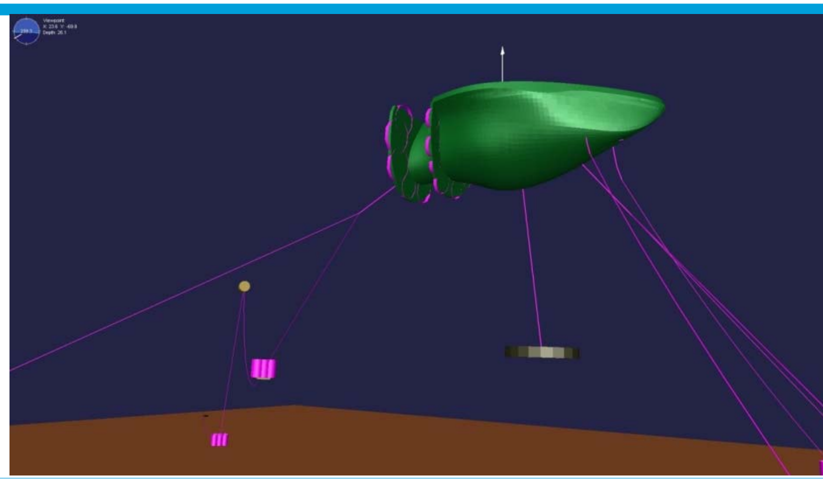
Dynamic Modeling

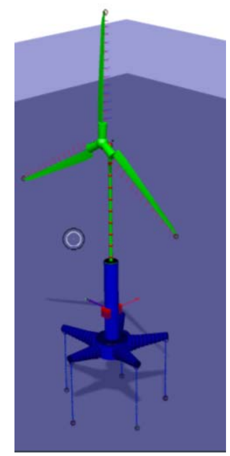
Analysis of mooring systems using SIMA

- Software is state-of-the-art for oil and gas platform modelling
- Spar, semi-submersible and tension leg types
- Hydrodynamics through Morison or BEM forces
- Mooring lines with clump weights and buoys, including sea floor contact
- Vast experience coming from floating wind, wave energy converter and oil and gas industries





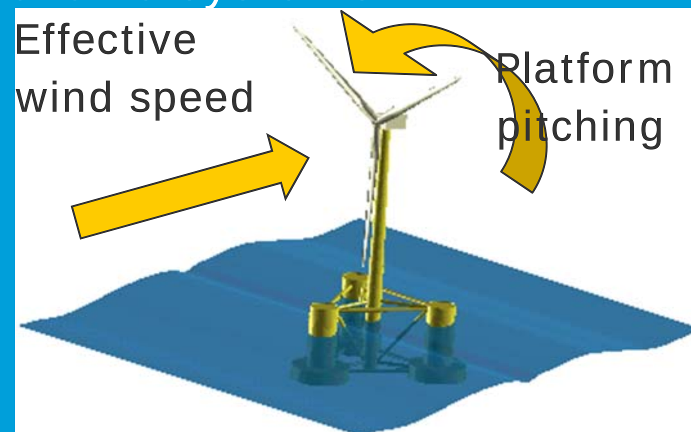


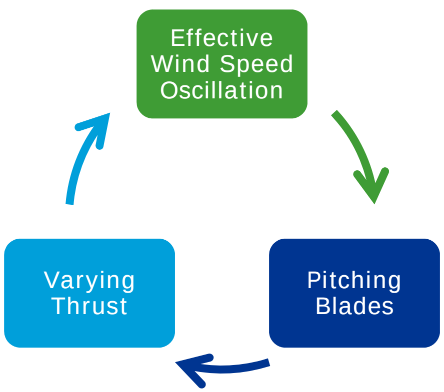


Control Algorithm Design

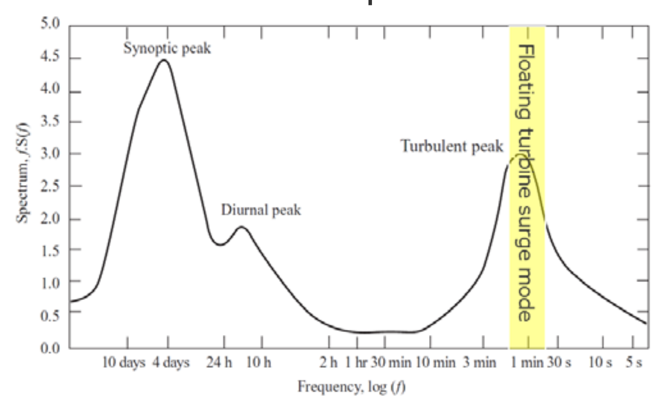
Designing control systems for floating wind turbine systems

- Platform pitch motion adds low frequency oscillation to effective wind speed
- Standard rotor speed control above rated uses blade pitch action, which varies the rotor thrust
- Appropriate control design can result in platform stability
- Very active in research and commercial projects involving floating wind turbines





- Wind turbulence is active at platform motion frequencies



Turbine Engineering Support (TES) Track Record in Floating Wind

Blue H Technologies load calculations and market analysis

- Feasibility studies behind the Blue H Technologies tension leg prototype
- Installed off the southern coast of Italy
- Modeling work, load calculations and integration of a conventional controller into the coupled model of the concept in 2009/2010
- Market analysis and cost comparisons

Turbine Engineering Support (TES) Track Record in Floating Wind

SWAY Support

- Support over various years between 2009 and 2012
- Full scale load calculations
- Unique control design, implementation and commissioning
- 1/7th scale prototype modeling and training
- 1/7th scale floater has been operated and tested in Norwegian waters

Turbine Engineering Support (TES) Track Record in Floating Wind

MHI 7MW coupled modeling

- Advanced floating platform modeling work in the early stages of floating wind development in 2012 and 2013
- Cutting edge work to bring together a coupled model of the MHI-designed system
- Largest floating wind turbine to date installed by MHI on their V-shaped floater in 2015

BLADED
Wind turbine design

Turbine Engineering Support (TES) Track Record in Floating Wind

Principle Power WindFloat platform modeling, verification and validation

- Modeled a future development of the WindFloat concept in coupled loads analysis software Bladed
- In position to support turbine OEMs interested in installing their turbines on this world-leading foundation
- Been proven through carrying out verification of Bladed against Principle Power's coupled design tool, with great agreement seen, and validation of both tools against tank test results

BLADED
Wind turbine design

Turbine Engineering Support (TES) Track Record in Floating Wind

Hitachi collaboration

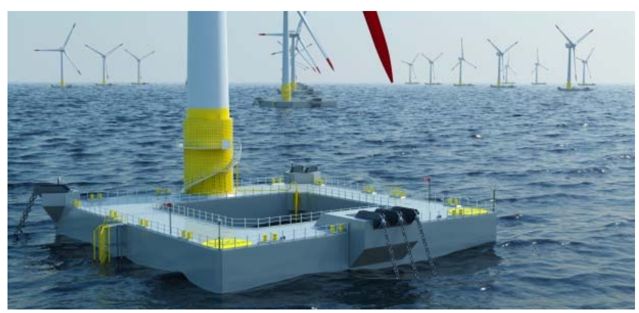
- 2016 DNV GL worked alongside Hitachi (OEM with the most full scale turbines installed on floating platforms at the time)
- The Hitachi 5MW turbine was modelled atop a semi-submersible floating concept
- Full floating offshore load calculations and tuning of the turbine controller to suit the floating environment
- Provided to Hitachi for them to assess the design of the turbine under such conditions

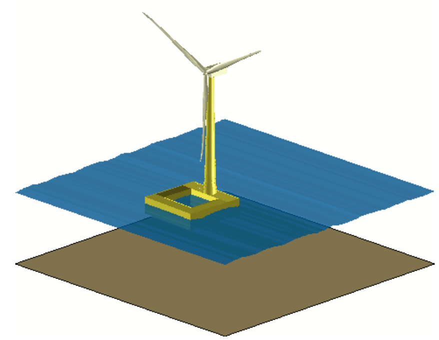
BLADED
Wind turbine design

Turbine Engineering Support (TES) Track Record in Floating Wind

Ideol long term collaboration

- Working alongside Ideol since 2014 - French floating platform designer with innovative barge type platform design
- Modeled several turbines on top of Ideol platforms, either as feasibility studies or for real ocean demonstrators both in Europe and Asia.
  - Several turbine OEMs (confidential), with turbines ranging from 2 to 5 MW.
- Typically includes initial modeling of the whole turbine, platform and mooring system in Bladed with successful verification of Bladed's floating capabilities against other hydrodynamic codes.
- Full floating load calculations and control re-design for the turbines





DNV GL experience in French floating wind projects

Client	Project	Description	Year
Confidential	Technical review of floating wind project	Extensive review of technical aspects and cost for proposed floating windfarm	2014
Confidential	Technical review of floating wind project	Extensive review of technical aspects and cost for proposed floating windfarm	2015
Confidential	Technical Due Diligence of three floating wind project on the French pilot Farm	Extensive review of technology, permitting, grid connection, contractual, energy production assessment, installation, planning and cost aspects for 3 proposed floating windfarm	2016
Confidential	Energy production Assessment	Energy production assessment for an allocated pilot farm in the Mediterranean Sea	2016

DNV GL Renewable Certification - Floating wind

Certification services

- **Certification description** and procedures
  - **DNVGL-SE-0073; 'Project certification of wind farms according to IEC 61400-22'**
  - IEC 61400-22; 'IEC System for Conformity Testing and Certification of Wind Turbines'
  - Local national legation

- Design **Requirements**
  - **DNV-OS-J103; 'Design of Floating Wind Turbine Structures' or GL IV-2 "Guideline for offshore wind turbines"**
  - DNV-OS-J101; 'Design of Offshore Wind Turbine Structures'
  - IEC 61400-3 ; 'Design requirements for offshore wind turbines'

  - *Under development - IEC 61400-3-2 : 'Design requirements for Floating offshore wind turbines'*

Developments to support industry standardization

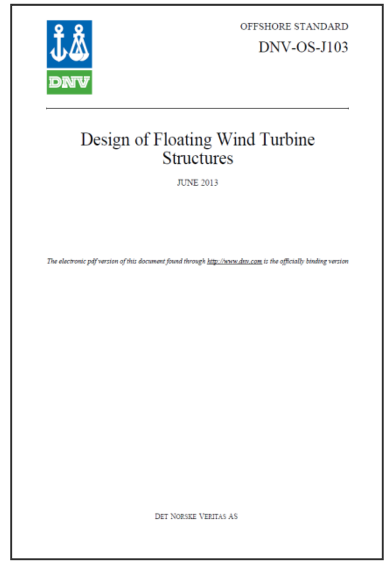
1. JIP: "Coupled dynamic analysis of floating wind turbines“ –
   - The aim of this JIP is to gain a deeper understanding of the coupled dynamic analysis of floating wind turbines and develop recommendations to effectively guide designers and engineers

2. DNV GL is part of the European Horizon2020-funded programme LIFES50+, led by Norway’s MARINTEK
   - upscale four floating wind turbine concepts to 10MW.

3. Development of Floating wind standard
   - Compile best industry practice and into an industry accepted standard

DNV-OS-J103 to be revised to become DNVGL-ST-0119

- DNV-OS-J103 published 2013
- Being revised during 2016 – 2017 to become a DNV GL standard
- Work performed internally in DNV GL, but with input from industry
- Reflect industry experience since the first issue
- Consideration of new international standards e.g. IEC TS 61400-3-2
- Harmonize with new and revised DNV GL standards
- DNVGL-St-0119 to be published during spring 2018


OFFSHORE STANDARD
DNV-OS-J103

Design of Floating Wind Turbine Structures

JUNE 2013

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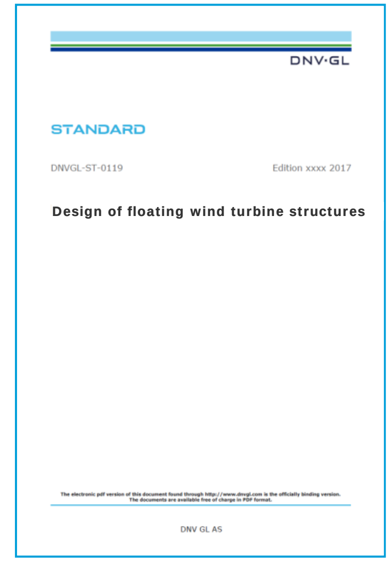

DNV·GL

STANDARD

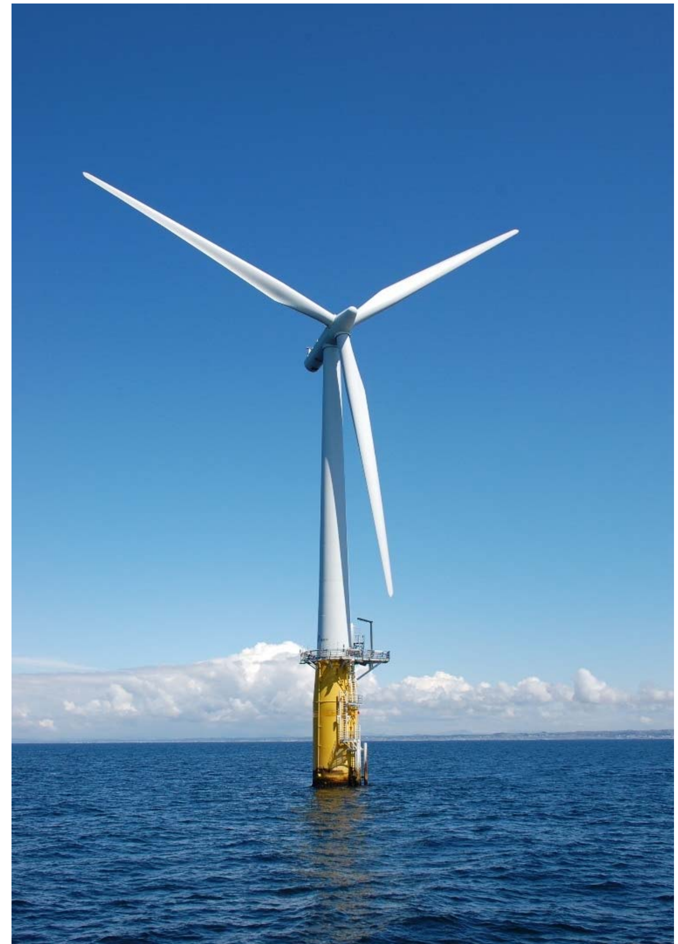
DNVGL-ST-0119 Edition xxxx 2017

Design of floating wind turbine structures

DNV GL AS

Main revisions

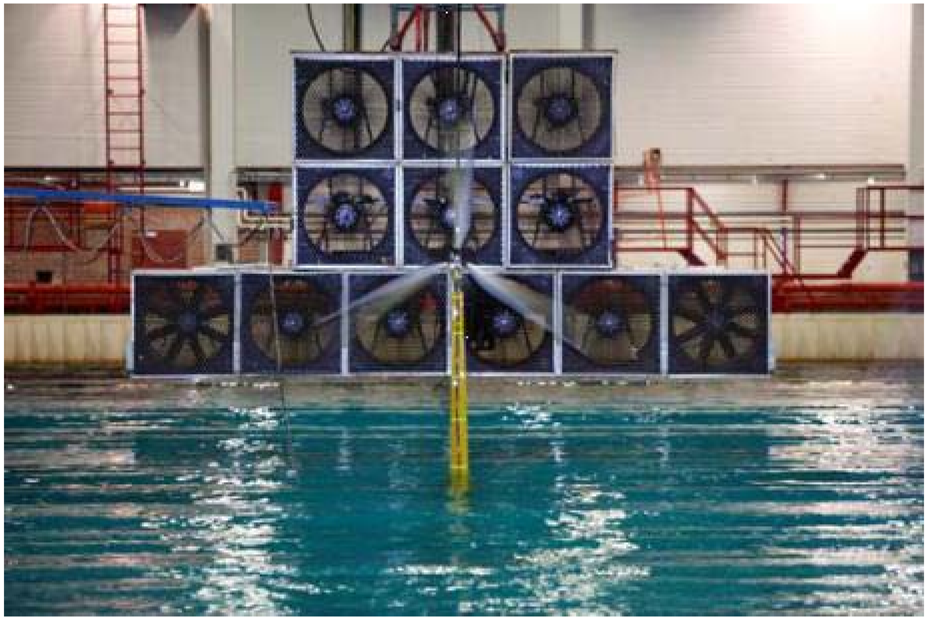
- Reference to new DNV GL standards (e.g. DNVGL-ST-0126)
- Safety class concept has been replaced with consequence class
- Formulation of floater-specific load cases
- Requirements for investigations to be performed to support the exemption from designing unmanned floaters against damage stability
- Fatigue factors for substructure on similar level as for bottom-fixed structures
- Fatigue factors for steel mooring lines and tendons
- Recommendations for shared anchor points
- Floater motion control system and its integration with the control and protection system for the turbine


Hywind
Photo: Knut Ronold DNVGL

Renewables Certification Track Record in Floating Wind

Innwind.EU, European Research

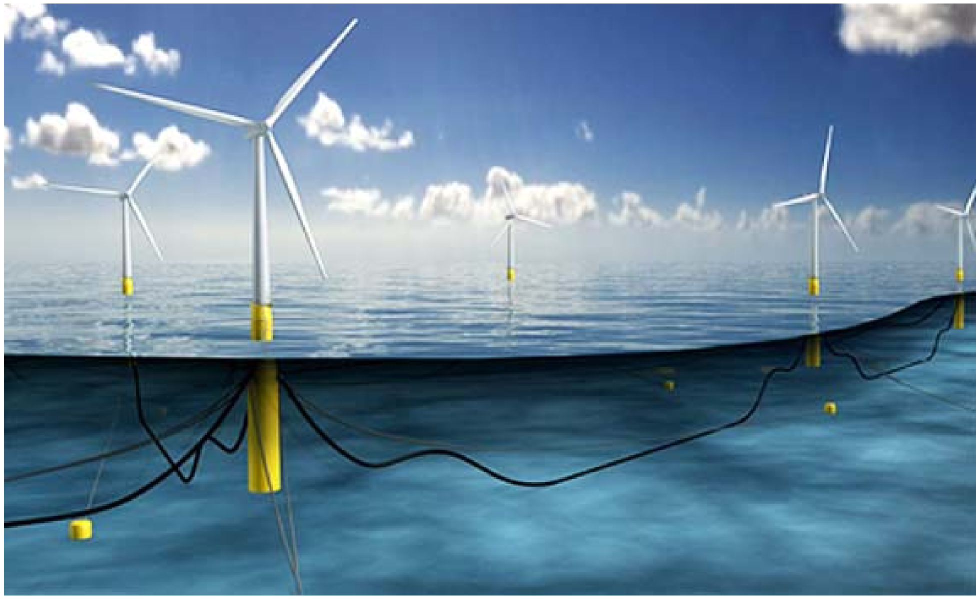
- Support in control design for floating wind turbines
- Definition of test load cases and accompanying tank tests at ECN, Nantes, and DHI Copenhagen
- Guideline development for 10 – 20MW wind turbines on fixed and floating structures 2013 - 2017



Renewables Certification Track Record in Floating Wind – Verification of the Hywind Scotland Pilot Park

Verification of design of Hywind floater system and cables according to DNV-OS-J103

- Design basis including metocean conditions
- The detailed design of the tower, substructure, mooring system, anchors and cables
- Independent load analysis of the floater system



Renewables Certification Track Record in Floating Wind

Verification of design of Pelastar TLP for a site in UK according to DNV-OS-J103

- Design basis including metocean conditions
- FEED design of the tower, substructure, mooring system and anchors
- Independent load analysis of the floater system

Renewables Certification Track Record in Floating Wind

WINFLO, France

- Assessment of design basis
- Assessment of load case table
- Stability criteria

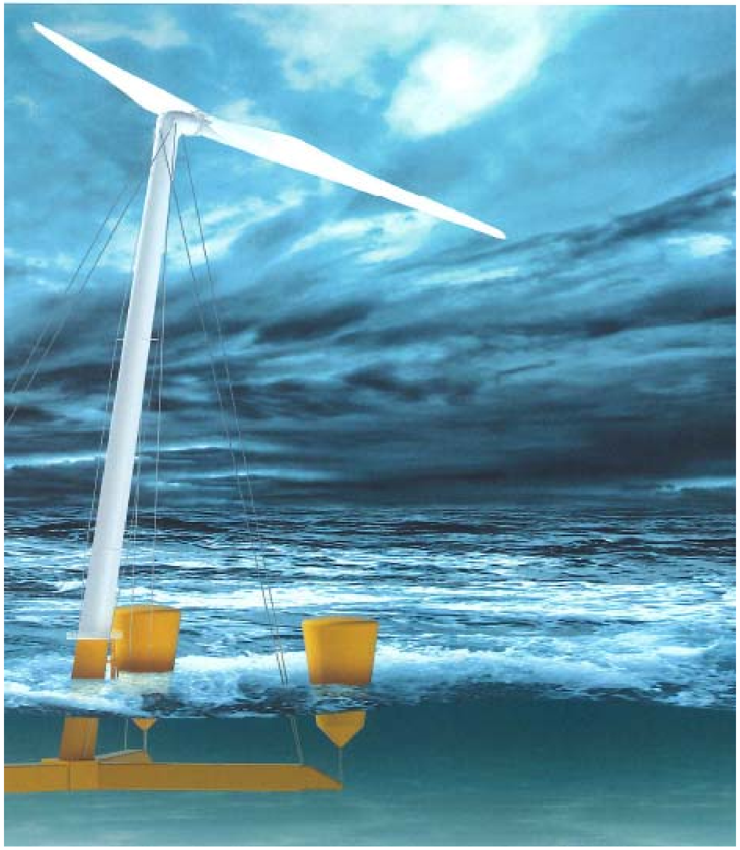
- Certification Report 2013

Renewables Certification Track Record in Floating Wind

aerodyn SCD8.0MW concept

- Design Basis Assessment according to DNV-OS-J103
- Design Basis Certification Report 2014

SCD® nezzy 8.0 MW



Renewables Certification Track Record in Floating Wind

APIA Idermar floating met mast

- Assessment of design basis
- Assessment load case definition
- Load assessment according GL Guideline 2012
- Structural verification 2013

Contact us for more info…

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SAFER, SMARTER, GREENER