De-risking of monopile support structures for the Dudgeon Offshore Wind Farm

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The Dudgeon Offshore Wind Farm Project, located in the North Sea 32 km off the Norfolk coast of England, proposed the use of large turbines (6 MW) in relatively deep water compared to existing wind farms (20 m) and potentially harsh conditions with shallow water waves, requiring larger monopile support structures than have hitherto been used. As a part of its assessment of the feasibility of monopile support structures for such conditions, MARINTEK carried out a study for Statoil/Statkraft on the loads and load responses that could lead to structural fatigue or damage, including potential ringing and springing responses.

Due to the large diameter of the structure and its natural periods, first-order hydrodynamic load modelling may not adequately capture the action effects on the structure. The purpose of this study was to clarify whether the large-diameter monopile is exposed to non-linear hydrodynamic loads of importance for the feasibility of the selected maximum monopile diameter, and to reveal any design requirements not yet established as state-of-the-art methods for the industry. The importance of non-linear hydrodynamics, however, must be viewed against the structural responses in an integrated approach, taking both aerodynamic turbine loads and hydrodynamic foundation loads into account.

Research methodology

Major uncertainties related to estimating the integrity and fatigue life of large-diameter monopile wind turbines include

1. The effect of shallow water on the hydrodynamic loading
2. The validity of conventional hydrodynamic load models that are applicable to slender structures.

The approach is illustrated in Figure 2, and can be described as follows: (A) to use higher-order wave kinematics (2nd-order) as input to the hydrodynamic load models, (B) to employ CFD analyses to confirm that the undisturbed 2nd-order wave kinematics combined with Morison’s equation are appropriate for the water depth and diameter in question, (C) to use the CFD results to validate the Cm...
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parameters used in the Morison equation and (D) to use small-scale model tests as a final validation of the CFD results and shallow-water wave kinematics. The resulting (validated) hydrodynamic loads were then applied to an FE model of the complete wind turbine and support structure, including the aerodynamic loads on the wind turbine, nonlinear effects of the wind turbine control system, and nonlinear soil stiffness. Structural responses and stress ranges were determined by time-domain dynamic analyses in SIMA for a range of wind speeds, turbulence intensities, Hs and Tp. The aerodynamic loads were modelled using blade-element momentum theory, including dynamic inflow and dynamic stall, while the generator torque and blade pitch angles were calculated using a user-defined wind turbine control system. The fatigue life was estimated using rain-flow counting, and extreme stresses were estimated for both operational and storm conditions.

Selected results and discussion

Comparisons of base shear in both regular waves and during one steep irregular wave condition event are presented in Figures 5 and 6. CFD was run only for selected regular wave conditions. The agreement between experiments (diamond shaped markers) and CFD (red circles) in Figure 5 is rather good in general. This applies to both 1st and 2nd harmonics of the base shear. The Morison model predicts both harmonics quite well, except that it over-predicts the 2nd harmonic for the steepest wave, which had a wave height to wave length ratio of 1/20. Since the load model uses 2nd order wave kinematics up to the 2nd order undisturbed free surface, there are also 3rd and 4th harmonic contributions to the load, although these are not complete. The trends and agreement are similar for the 3rd and 4th harmonics (not shown), which is promising, since these load components are important for ringing. The loads are inertia-dominated. The mass coefficient Cm was adjusted according to the 1st harmonic in the CFD calculations, ranging from 1.6 to 2. Viscous flow separation leads to lower values than 2 in the long and steep waves. The 2nd-order and higher harmonic loads are consequences of this choice of Cm.

In the irregular wave event in Figure 6, the experimentally obtained free surface and base shear are compared to simulation results. A Cm value based on the significant wave height was chosen. The measured, calibrated wave was used

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Remotely Piloted Aircraft Systems (RPAS) are being brought into use for inspection of wind turbines. RPAS are divided into two main groups, fixed-wing and rotary-wing. Fixed-wing RPAS are mainly used for surveillance purposes, while rotary wing RPAS are most suitable for inspection due to their ability to hover.

Rotary-wing RPAS are either single-rotor (helicopter) or multi-rotor units with four (quad), six (hexa) or eight (octo) rotors. Gyroscopes and accelerometers enable multirotor RPAS to fly in a very stable fashion. A separate platform for mounting sensors can be further stabilized and isolated from vibrations.

Until now the RPAS industry has provided surveillance and inspection services based on sensors for visual inspection. These include photo and video cameras on gyro-stabilised platforms. Some companies have thermography capabilities for inspection of power transmission lines and pylons.

Inspections of wind-power turbine blades are based on both external visual inspection and close-up inspection using thermography and acoustic technology to identify structural integrity faults beneath the blade surface.

To make the case for blade inspections using RPAS as sensor platforms, we must at least equal existing inspection regimes in terms of quality and cost. There is also a need to find out if RPAS are capable of performing a complete inspection of a blade, including the integrity of the structure. This will require R&D on potential sensors and on how they can be adopted for use with a RPAS.

Important questions in this respect concern the capabilities of inspection technologies. What are the important types of flaw that need to be covered, and what are the most suitable detection technologies? What are the detectable sizes of different types of flaws? Do particular detection technologies suffer from important limitations? Are there compatibility issues between detection technologies and the RPAS?

Typical flaws and damages that need to be covered includes variations in skin thickness, debondings (including kissing bonds), presence or absence of adhesive, delaminations, dry regions, snowflaking, porosities, in- and out-of-plane waves, composite fibre fractures, and surface damage such as erosion, cracks, lightning strikes, etc.

MARINTEK has joined up with SINTEF Energy and SINTEF ICT to propose a research project on this topic. The project will address the challenge via three main activities:

- Guidance and control of the RPAS, focusing on user-friendly control interfaces and the ability of non-experts to fly the RPAS. The study will also include aspects of autonomous flight capabilities, for example, that the RPAS should be able to navigate and perform inspections without user interference.

- Sensors for blade inspection, with emphasis on technologies that would permit non-intrusive inspections of structural integrity and sub-surface damages

- Cost-benefit analysis of remote inspections using RPAS as sensor platform, looking at scenarios in which the RPAS is remotely controlled and where it performs some or all of its tasks in autonomous mode.
The installation phase of offshore wind turbines needs to be carefully planned. Different concepts are proposed, depending on the nature of the site and the foundation of the turbine units. MARINTEK’s role in a number of projects was to assess the feasibility of alternative installation operations by means of numerical simulations and model tests.

Installation of bottom-fixed offshore wind turbines

Jack-up vessels for installation of monopiles

Most offshore wind turbines have been installed by jack-up platforms or vessels in order to eliminate problems caused by crane vessel motion and thus minimise installation time. One weather-sensitive assembly task is the lift-off of turbine tower sections and other components from transportation barges or supply ships. One study, which involved dynamic analysis using SIMA, aimed to establish requirements for the soft lift-off functionality of the crane, with the aim of minimising peaks in tension at lift-off. Various winch control principles were studied. The study concluded that the dynamic amplification factor obtainable at lift-off in significant wave height, Hs = 2.5 metres was lower than acceptable 1.35. For comparison; the limiting Hs for lift-off of the heaviest modules without this crane control would be less than one metre.

Installation vessels with mooring system or DP

Large vessels have been suggested for installation of various types of foundations. These have the advantage that installation preparation takes less time than when jack-up vessels are employed. Due to the wave-induced motion of the vessel, installation of monopile foundations requires a gripper arm to hold the unit vertically during penetration into the soil. A number of studies identified the requirements for the gripper arm. Both a dynamically positioned and a conventionally moored ship were studied. A simple (4-line) mooring system tends to give larger drift motions of the vessel, and thus requires stricter requirements for the gripper arm than a mooring system with 8 or 12 lines. Levelling jacket or tripod foundations does not require accurate vertical alignment during touch-down, and a gripper arm is thus not required. One concept studied by MARINTEK involved stacking several jacket foundations on deck, for skidding to where they could be reached by two cranes. The study focused on control of the lift through the air, and lowering to the seabed. Motion in air needs to be controlled by guide-rails mounted above the deck, and auxiliary wires from the jacket legs to controllable winches. The objective of the study was to identify feasible tugger wire configurations (i.e. winch positions) and winch characteristics (tension level, tension control).

Offshore turbine unit assembled on shore and installed by specialized vessel

The challenges involved in assembling the rotor and nacelle of a wind-turbine on field by means of offshore lifting operations can be avoided if the assembly is mounted entirely onshore. The challenge then centres on performing the towing and the installation safely. We performed a study of such a concept with a bottom-fixed wind turbine. During transport out to the field, the deballasted wind turbine is laid on two barges attached to each other at the bow. During installation, the barges are moored to the seabed and the turbine is ballasted and lowered. Stabilizing wires from the barge to the foundation ensure the pitch and roll stability of the installation. The main focus was the hydrodynamic interaction between the barges and the lower part of the turbine foundation.

Simulations of the installation using MARINTEK’s software SIMA included the barge, its anchor system, the wind turbine, the stabilising wires, the strand jacks (used to lower the wind turbine), the changing mass of the turbine foundation due to ballasting procedure, and the hydrodynamic coupling between the foundation and the barge. The simulation results were in good agreement with the results of model tests also performed at MARINTEK.
GBF concept (www.gbf.eu.com)

The joint venture Gifford BMT Freyssinet (GBF) has proposed a concept in which the entire turbine unit is assembled on shore, loaded onto a specialised transportation and installation vessel and installed on the sea bed. The vessel can be ballasted to float at a wide range of drafts, from 6.25 metres at the quayside to 45 metres at the installation site. Motions of the vessel carrying the turbine unit were simulated at all drafts. Key parameters calculated, including nacelle accelerations during all phases of transportation and the potential impact energy after the unit, had been released from the vessel on the sea bed. The simulation showed that all open-sea transport and the installation could be performed with acceptable regularity.

Floating OWT (Hywind) assembly, transport and maintenance access

Upending

The bottom section of a floating OWT is towed at a heeling angle from the fabrication yard to a sheltered location for further assembly.

The question was raised as to whether the tower would undergo uncontrolled, fast upending at some point during ballasting. The simulation showed that if the ballast water was filled from the lower end, the upending would be kept under control. It also concluded that if the ballast water was supplied near the top, water that was initially prevented from flowing to the lower end by ring stiffeners could move fast as a cascade as the heeling angle passed a certain level and result in temporary loss of control.

Assembly

The assembly operation in sheltered water was studied for two crane vessel alternatives. Five assembly steps were simulated for each alternative; lifting of three tower sections, nacelle and rotor with blades. The objective of the study was to estimate the weather window (limiting sea state) for the operation. Irregular winds and waves were modelled. The operational criteria were the relative motions in the radial and axial directions at the connection point between each of the suspended units and the floating tower base. Due to the large lifting height, the crane boom and the topping lines were modelled, with the boom hinged to the vessel. For each of the lifts, different materials and winch characteristics were studied for the pendulum control wires.

Tow to field

Preliminary studies suggested that the Wind Turbine Generator (WTG) could start an undesired sway, and even worse, roll motion when passing a certain threshold speed during the tow operation. Excessive motions need to be avoided since the nacelle has a low permissible acceleration. MARINTEK therefore performed model tests of the towing operation from the assembly site to the final production site. The objective of the model tests was to determine the threshold speed at which the assembled vertical Hywind WTG would start the vortex induced rolling motion. Two towing draughts were tested; 61 and 76 m.

The tests revealed that at a draught of 61 meters the unit was stable with transverse nacelle acceleration below 1 m/s up to a towing speed of 1.4 m/s, while a stable tow was registered up to 1.6 m/s at a draught of 76 m.

The dynamic tow line tension was studied using numerical analysis with SIMA. The towline initially specified consisted of:

1. 100 m length of 76 mm tow wire
2. 30 m length of 100 mm tow chain
3. A ‘crows-foot’ of two 50 m lengths of 100 mm chain connected to the tow chain and to two fairleads on Hywind.

This towline is short and has high elastic stiffness. It was found that wave-induced surge motions of the tug would lead to unacceptably high tension under summer storm conditions, unless the mean tension could be kept well below 200 kN, which can be done by allowing the tow to drift with the wind and current.

A more robust towline was suggested. This would involve inserting a segment of elastic hawser or using a longer tow wire. Tow wire lengths up to 1100 m were analysed. Assuming utilization of half the break strength of the tow wire, a significant wave height up to 8 m may be acceptable at a wind speed of 25 m/s and a speed through the water of 1 m/s. In order to operate in 12 m Hs waves in strong winds, the mean towline tension would have to be reduced by allowing the

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Determining cost-optimal vessel fleet for maintenance operations at offshore wind farms

Electricity generation by offshore wind farms has created a new and rapidly developing industry that currently has a great need for decision-support tools and systems. Such tools are important as a means of making offshore wind farms a profitable energy source for the future, by helping the industry to identify cost-effective solutions to reduce the cost of energy from wind farms.

A joint industry project, FAROFF (FAR OFFshore operation and maintenance vessel concept development and optimisation) was established in 2012 to develop both new vessel concepts with improved operability and decision-support tools/models that extend the existing state of the art in this area. FAROFF was financially supported by the Research Council of Norway and by contributions from the project participants.

As a part of the project, MARINTEK has developed a decision-support system (DSS) that determines cost-optimal vessel fleets for maintenance operations at offshore wind farms. Vessel characteristics, fleet composition and the necessary infrastructure such as vessel and maintenance bases, turbine access and offshore platforms/mother vessels can be evaluated from both an operator’s and a vessel developer’s perspective. The DSS can be used both at an early phase of planning to provide decision support regarding the vessel fleet that should be acquired, and at regular intervals during the life-cycle of the wind farm to make cost-effective adjustments to the fleet.

The DSS takes into consideration any number of classes of vessel, including helicopters, and identifies the most cost-efficient mix of these vessels for purchase and/or charter. The objective function used by the DSS to evaluate the different options for the maintenance vessel fleet minimizes the sum of capital and operating costs of the vessels and bases, as well as downtime costs incurred while failures resulting in non-operating turbines are being repaired.

Our optimization-based DSS represents a new approach compared with existing simulation-based DSSs for logistics for offshore wind farms. Optimal or near-optimal solutions are determined directly from the DSS. This means that the user is not dependent on a domain expert to input a potential solution to be evaluated in the search for a near-optimal solution.

To decide when a given class of vessel can operate, the DSS uses the weather limitations of the classes in conjunction with weather data from the location of the wind farm. Methodologies for numerical analysis of docking operations by an active motion-compensated access device and a simple fender have been developed to determine the vessels’ weather limitations. The proposed frequency-domain approach to the analysis of docking operations using a fender is new, and is extremely efficient in comparison with time-domain simulation.

The methodologies developed for the numerical analysis of the docking operations have been applied to two vessel/access concepts. The calculated limiting significant wave heights at different wave peak periods and wave headings provide a basis on which short-term operational decisions can be made. The calculation of long-term docking operability provides technical data in the comparison and selection of different vessel/access concepts for any given wind farm. These methodologies can be used in docking operability assessments for a variety of vessels that employ active motion-compensated devices or fenders as access systems to the offshore wind turbines.

More technical details for the vessel fleet optimization model and the numerical analysis of the docking operations can be found in references [1] and [2].

Experimental modelling of wind loads on offshore wind turbines in wave tanks

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When offshore wind turbines are being tested in an ocean basin, both the wave and wind loads that act on the structure need to be represented accurately. In representing wind loads, a simple downscaling of the blade geometry would lead to much lower Reynolds numbers and very poor aerodynamic properties.

One approach is to use specially designed airfoils that are intended to replicate the full-scale aerodynamic loads. However, taking this approach, only the thrust can be replicated fairly, while the non-thrust components of the aerodynamic loads (torque, pitch and yaw moments, as well as sway and heave forces) are not scaled correctly, if indeed they are considered at all in the model. Another issue is the difference between wind-field quality in wave tanks and in wind tunnels.

The research performed within NOWITECH included model tests of a novel braceless semi-submersible concept, referred to as 5-MW-CSC (see Figure 1). Prior to the experiments, a numerical analysis of this structure was performed using the MARINTEK simulation tools SIMO and RIFLEX, coupled with the AeroDyn module from NREL. The analysis focused on the consequences of partial aerodynamic loading (i.e. neglecting non-thrust aerodynamic loads) for the responses of interest: motions, mooring line tension and internal structural loads. The general conclusion was that certain non-thrust aerodynamic loads were of importance for the behaviour of this particular structure, and that these should be included in the experimental modeling.

In collaboration with NTNU, we designed an experimental setup that enables all the aerodynamic loads on the wind turbine to be simulated. Several actuators and load transfer mechanisms are controlled in real time by the results of a numerical simulation using AeroDyn. Figure 2 shows the results of pitch-decay tests for various wind velocities, illustrating how aerodynamic damping, present via the coupled AeroDyn calculations, influences the experimental results in real time.

This approach is expected to greatly improve the level of accuracy of model tests for offshore wind turbines, which will contribute to the design of safer, better optimised structures.

The authors would like to acknowledge the key role played by NTNU PhD student Valentin Chabaud in the course of this work.

Figure 1. The 5-MW-CSC substructure model at scale 1:30. A square frame is used to connect the actuators to the turbine.

Figure 2. Decay in pitch of the 5-MW-CSC wind turbine, without wind, and with a constant wind velocity of 8m/s and 20m/s. For the latter, the aerodynamic loading is reduced by the turbine controller prescribing a pitch angle of 17.5 degrees to the blades.
Full-scale testing of offshore power cables

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MARINTEK’s Marine Structures Laboratory operates a number of rigs for full-scale dynamic testing of flexible risers, umbilicals, and power cables. The test rigs were designed to apply loads typically experienced by flexible risers and cables as key components in floating production systems; cyclic bending, tension, internal pressure and temperature.

In recent years, the issues related to compressive loads have attracted more attention and concern in the cable industry. To respond to this challenge, in 2014 MARINTEK built a full-scale test rig for dynamic testing of umbilicals and power cables subjected to combined bending and compressive loads.

MARINTEK has been performing full-scale qualification and fatigue testing of flexible risers and umbilicals since 1997. Interest in full-scale testing of power cables for offshore applications has increased significantly lately, and several full-scale tests of dynamic power cables have been carried out by the Marine Structures Laboratory. The experience gained during full-scale qualification testing has been used to build a new rig for full-scale compression testing of power cables and umbilicals.

**Full-scale qualification testing**

Dynamic power cables are installed between a floating structure (platform, FPSO, floating wind turbine) and the seabed. The cables are exposed to significant loads from waves, current and platform-induced motions. The objective of a full-scale test is to verify the structural integrity of the cable, including the end-fitting and bend stiffener, under simulated operational conditions. The test programme is designed to simulate the loading and accumulated fatigue damage that the cable is expected to experience during its operational lifetime.

The test programme is developed on the basis of global finite element analyses including the seabed, cable, water, floater, current, waves etc. The global analysis will estimate the motions of the floater (platform, FPSO, wind turbine) and the attached cable under a range of weather conditions for operational and accidental situations. Important results are time series of tension and curvature along the length of the cable. The results are used as input to a local analysis of the cable that calculates stresses in local components. The stress results are used in a fatigue analysis in which the fatigue life of the cable is estimated. To verify the fatigue calculations, and confirm if the cable will survive the service life loads, a full-scale test is required.

The full-scale test program is designed to ensure that the structural component most susceptible to fatigue will experience cumulative damage in the test equal to or greater than that expected in the field in the course of its service life. The test programme is divided into a number of load cases, each of which represents a different weather condition. The load cases have a different bending angle amplitude, tension, frequency and number of cycles. The development of the dynamic load programme is usually based on the principles outlined in API Recommended Practice 17B.

A typical dynamic power cable is expected to experience more than 100 million waves during its lifetime, but a full-scale test usually includes only 2 million cycles in order to simulate the predicted cumulative damage within a reasonable timeframe. Hence, the test program includes only medium- to high-wave sea-states. The accumulated damage from small-wave sea-states is taken into account by running more cycles for the sea-states included in the load programme. The number of cycles within each load case is adjusted to give both the correct total cumulative damage in the test and the correct distribution of damage caused by the various sea-states.

The load program defines the number of cycles, curvature range and tension for each load case. In the dynamic test
rig, bending angle and tension are applied to the cable. To estimate the bending angle required to achieve the correct curvature in the dynamic test rig, an analysis of the test sample as installed in the rig is required (Figure 3). The analysis provides the relationship between the angle applied in the rig and the resulting cable curvature.

The following parameters are usually of most interest during the full-scale tests:

- Number of cycles
- Tension load
- Piston movement in the tension actuator
- Bending angle
- Bending moment
- Cable temperatures

The tension load and bending angle are important because they define the primary applied loads. The tension actuator position is also of interest, as any failure in the tensile armour wires will result in a reduction in axial stiffness and produce a slight elongation of the cable, which can be detected by the measured tension actuator position.

After testing, the cable is inspected for any wear, damages or abnormalities before it is dissected and its components are carefully inspected.

**Compression and bending testing**

Umbilicals and power cables are usually installed at low tension and may be subjected to compressive loads during both installation and operation, typically as a consequence of vessel heave and current loads. This may lead to local buckling of components and potentially to overall torsion instabilities. API Specification 17E (and ISO-13628-5) does not provide specific guidance with respect to acceptable levels of compression, nor does it discuss how buckling develops and possible consequences. Common industry practice has been not to accept compression at all. Qualifying products to allow some compression will increase their range of use and significantly increase the weather window for installation. Better understanding of the behaviour of a cable in compression, as well as a determination of acceptable levels of compression are requested by the industry.

The Joint Industry Project on Stress and Fatigue Analysis of Umbilicals and Power Cables - Phase III, includes development of analytical methods, numerical studies and full-scale testing of umbilical and power cables subjected to compressive loads.

The process of buckling of tensile armour wires and umbilical components may be divided into two general categories:

- Radial buckling or bird-caging, often seen as armour “lifting”. This phenomenon may lead to dislocation of armour wires and a weakening of the cross-sectional strength of the cable. Tensile armour wires and cable components are often supported by anti-buckling tape to avoid radial buckling.
- Transverse buckling. If the anti-buckling tape or outer sheath is strong enough to prevent radial buckling, the tensile armour wires may move laterally.

The combination of compression and bending is assumed to reduce the compressive capacity of the umbilical or power cable. It is therefore important to take both into account simultaneously, during both testing and analysis.

A sketch of the new rig built for full-scale testing of power cables of umbilicals subjected to compressive loads is shown in Figure 4. Special methods were utilized in the rig design to achieve:

- Close to constant curvature along the length of the test specimen at any given point in time
- Constant compression level during each cycle
- Dynamic cycling
- One component in tension, all other components in compression. Total tension/compression close to zero, which will avoid global buckling effects during testing

Cyclic bending is important because it may trigger lateral armour-buckling over time in the cable during compression. Several computer-controlled hydraulic actuators were installed to ensure accurate loading during all cycles.

The rig was completed in 2014 (Figure 5). Two power cables have been successfully tested, and a third cable will be tested shortly.

Figure 3. Analysis of cable and bend stiffener in the rig.

Figure 4. Design of rig for full-scale testing of power cables and umbilicals subjected to combined compression and bending loads.

The sample is instrumented to detect any instabilities related to compressive loads. Sudden negative elongation, torsion and developments over time are all of interest.

The rig was completed in 2014 (Figure 5). Two power cables have been successfully tested, and a third cable will be tested shortly.
DTOcean EU project: Optimal design tools for ocean energy arrays

MARINTEK is a partner in the project DTOcean (Optimal Design Tools for Ocean Energy Arrays), which is a European collaborative project funded by the European Commission under the 7th Framework Programme, (http://www.dtpcean.eu/). DTOcean is led by the University of Edinburgh and has 18 partners from several European countries.

The objectives of DTOcean are:

• To develop a full suite of whole-system software design tools for the design, development and installation of wave and tidal energy converter arrays in a cost effective, timely and environmentally appropriate manner.

• To perform strategic identification of enabling technologies that can reduce deployment costs and improve the performance of energy arrays.

• To provide the wave and tidal energy sector, and its stakeholders, with well validated guidelines for accelerating decisions by means of reducing risks and uncertainties.

DTOcean comprises four content-orientated Work Packages (WP3-6) guided by two defining work packages (WP1-2) which underpin a range of array sizes and hydrodynamic layouts. The outputs of, feedback from and interactions among these packages culminate in Work Package 7, in which the design tools are actually developed. All in all, these define the operational science and technology effort and are supported by a work package for dissemination and exploitation (WP8). The list of work packages thus comprises: Scenarios, Array Layout, Electrical System Architecture, Moorings & Foundations, Lifecycle Logistics, System Control & Operation, Design Tool Development & Operation, Knowledge Management, Dissemination & Exploitation.

The marine renewable energy (MRE) sector is progressing from single devices to device arrays. Current mooring/foundation technologies used in MRE are based on offshore petroleum industry practice. Before MRE arrays can be commercialised, a number of issues will have to be addressed. These include the hydrodynamic array layout, electrical infrastructure, operations, maintenance, control, moorings, foundations, installation and logistics. The DTOcean project aims to accelerating the industrial development of ocean energy power generation knowledge, and providing design tools for deploying the first generation of wave and tidal-energy converter arrays. Figure 1 shows schematic layouts of possible mooring and foundation for MRE devices. The assessment of a mooring or foundation system needs to incorporate several key aspects, including reliability, economics and environmental impact. MRE mooring and foundation assessment comprises several steps, as illustrated in Figure 2. The trans-

Figure 1. Schematic of possible mooring and foundation arrangements for a single MRE device.

Figure 2. Steps in mooring and foundation assessment; Considerations specific to moorings (dark green) and foundations (light green) are shown. Note: the abbreviation ‘CC’ refers to Consequence Criteria.
DeepWind – Future Deep Sea Wind Turbine Technologies – is a four-year EU-funded FP7 research project that was launched in 2010 and has recently come to an end. The objective of this project was to explore the technologies needed for the development of a new and simple floating offshore concept with a vertical axis rotor mounted on a rotating floating support structure. The project consortium includes 13 international partners from the EU and USA led by DTU Wind in Denmark. MARINTEK was in lead of WP5 – Mooring, floater and torque absorption systems.

The DeepWind project was motivated by the idea that technical improvement in offshore wind energy is necessary, calling for dedicated technology development rather than relying on existing land-based solutions. The concept is based on a spar type floater with an innovative 5 MW vertical axis wind turbine with a Darrieus-type rotor design. The power is generated by a generator located at the bottom of the structure, which is held in position by the mooring system. Traditional vertical axis wind turbines (VAWT) require large bearings due to the large reaction forces from the rotor axis. The DeepWind concept differs from other VAWT concepts in that the entire structure rotates. The submerged rotating substructure utilises the water as a roller bearing to reduce the dynamic effect of the bending moment on the turbine, thus eliminating the need for large mechanical bearings.

The DeepWind project has largely been based on previous knowledge and developments in vertical axis wind turbine technology combined with offshore technology. The results reflect this new combination of distinct technologies, and primarily provide answers as to whether the proposed technology has potential to move large wind turbine systems based on the proposed concept into the development phase. More specifically, the project work packages have resulted in a range of proof-of-principle tests and the development of a toolbox of design modules that support the overall key question.

MARINTEK’s role in the DeepWind project has been to identify a feasible floating support structure and cost-optimized mooring system configuration. Essential differences between vertical axis- and horizontal axis turbines (HAWT) are the difference in magnitude of the torque, which is inversely proportional to the rotor speed, and that the torque of the HAWT is balanced by gravity forces, while the much larger torque of the VAWT must be balanced by the mooring system. MARINTEK’s task was accomplished using the optimisation tool WINDOPT [1] – a program for conceptual optimization of a spar-type floater and mooring system for offshore wind turbines. In this case, the spar floater and mooring system have been optimised with respect to design requirements and the external loads imposed by winds and waves.

Further upscaling from a 5 MW concept to 20 MW turbines is currently under consideration, and a new research proposal to the EU Horizon 2020 programme is in preparation. More information about the DeepWind project can be found on the project website www.deepwind.eu.

Bibliography


The DeepWind project

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ferability of existing approaches to offshore structure design is questionable for MRE devices, and more relevant guidance that takes the particular requirements of MRE arrays into account is required. For example, hydrodynamic interactions between the devices could result in loads being applied to the array mooring or foundation systems that are different from those that impact an individual device. The next deliverables of DTOcean will cover these aspects in more detail.

DTOcean EU project ....

MARINTEK’s main contribution so far has focused on the applicability of offshore mooring and foundation technologies for MRE device arrays. MARINTEK has employed state-of-the-art in-house mooring and foundation software for analysis of the arrays of MRE devices. These software packages have long been successfully employed in the offshore petroleum sector.

Reference:

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as input to RIFLEX. The time-series was first filtered so as to extract the linear part of the time-series, then the second-order low- and high-frequency parts were reconstructed in RIFLEX, treating the filtered time series as if it were from a theoretical wave spectrum realization (Figure 6). R-1 denotes simulations with linear waves as input to the Morison load model, one integrated up to the still-water level (SWL, strictly linear wave theory) and the other up to the linear free surface (IWL). The green curve, R-2, includes 2nd-order wave kinematics up to the 2nd-order free surface. Although R-1 IWL provides better agreement than R-1 SWL in terms of maximum base shear amplitude, on high-pass filtering, the higher harmonic loads that are important for ringing are not present in the R-1 load signals, as expected, whereas they are captured quite well in the R-2 model. It is therefore feasible to suggest that the Morison load model with 2nd-order wave kinematics integrated up to the 2nd order free surface is a considerable improvement over the state-of-the-art method (R-1, IWL), although further work is needed to assess the actual ringing response.

Figure 6. Example of load comparisons from ringing type of steep, non-breaking irregular wave event.

Simulation of marine ....  
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tow to drift with the wind, in which case the water depth might be a limiting factor for allowable towline length.

Transfer of maintenance personnel
Various types of light personnel transport boats have been used to carry personnel and light equipment for inspection and maintenance of OWT. Transfer from the vessel bow to the tower can be problematic, and is not without risk of injury. Existing motion-compensation platforms tend to be too voluminous and heavy for such small vessels and a fixed gangway connection has been avoided because of the desire to back off rapidly in case of an extreme wave or another unexpected incident. One method is to maintain thrust against vertical bumpers on the tower and try to stick to the tower by friction. Dynamic simulations revealed that the limiting sea state for personnel transfer must be around one metre Hs, because at higher sea states the friction may not always be great enough to hold the bow, and the times of vertical sliding are often unpredictable.

Tow configuration with Hywind at 76 m draught.

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