Research Centre for Offshore Wind Technology

Background

The EU 2020 target implies a massive installation of offshore wind. A ballpark estimate is investments of NOK 1000 billions for installation of 50 GW offshore wind in European seas. The development is ongoing, but in an early stage. Only about 1 GW of offshore wind has so far been installed in Europe, and all relatively close to shore using what can be called on-shore wind technology.

The potential for wind farms at deeper water is huge provided that costs can be reduced to a competitive level. This requires development of offshore technology, and within this field Norwegian industry and research units are in the forefront. Examples are jacket design by Owec Tower for the Beatrice wind farm, manufacturing of tripods by Aker Solutions, and the floating concepts HyWind, SWAY and WindSea (see Fig. 1). Considerable research efforts are needed to support this development. The establishment of a research centre on offshore wind technology as proposed here is essential to keep up this development.

Deep-sea offshore wind farms are expected to be large, say 1000 MW and located +50 km from shore. The environmental conditions differ here considerably from standard onshore conditions and new different design specifications have to be taken into account. This gives a basis for development of novel wind turbine concepts optimized for operation at rough off-shore conditions. The distant offshore location and size of installations further calls for development of new systems for maintenance, grid connection and system integration.

The research partners behind this initiative to establish a Research Centre on Offshore Wind Technology (Centre) are in the international forefront on critical issues, e.g. offshore technology and grid integration. The Centre will expand ongoing research activities[1], use existing labs (e.g. ocean basin) and apply results from planned full-scale field tests (HyWind, etc.).

Fig. 1: Floating concepts, from left: HyWind, SWAY and WindSea.

[1] Examples are "Development of Norwegian wind power technology" 2001-2005, "Strategic wind power programme" 2003-2007 and "Deep sea offshore wind turbine technology" 2007-2009 (www.sintef.no/wind).

Research tasks

The Centre will combine wind technology know-how with offshore and energy industry experience to enhance development of offshore wind farms. The overall objective is to advance Norwegian development and value-creation within this field, and pin-point solutions that contribute to the development of cost-effective offshore wind farms. The main ambitions are:

- Develop the Centre into a world class leading research community on offshore wind technology and support Norwegian industry to be in the international forefront.
- Establish a recruitment and educational programme that provides the industry with highly qualified personnel at Master and PhD level.
- Assist in developing new industry, products and services on offshore wind by targeted research and by being a point of contact for first validation of new concepts and linking to public development programmes.
- Provide a scientific basis for offshore wind test and demonstration projects and working closely with these for maximizing benefits and quality in implementation.
- Be a one-stop centre of knowledge on offshore wind for industry partners and public bodies.

The Centre comprises interdisciplinary tasks that are required for successful development of offshore wind farms. Emphasis is on “deep-sea” (+30 m) including bottom-fixed turbines and floaters. The research is carried out in six work packages (WPs):

- WP 1: Development of <u>integrated numerical design tools</u> for novel offshore wind energy concepts. The goal is establishment of a set of proven tools for integrated design of deep-sea wind turbines, hereunder characterization and interaction of wind, wave and current.
- WP 2: Investigation of new <u>energy conversion systems</u> for offshore wind turbines. The goal is to contribute to the development of efficient, low weight and robust blade and generator technology for offshore wind turbines.
- WP 3: Identification and assessment of <u>novel substructures</u> (bottom-fixed and floaters) for offshore wind turbines. The goal is to pin-point cost-effective solutions for deep-sea wind turbines.
- WP 4: Assessment of <u>grid connection and system integration</u> of large offshore wind farms. The goal is to develop technical and market based solutions for cost-effective grid connection and system integration of offshore wind farms.
- WP 5: Development of <u>operation and maintenance</u> (O&M) strategies and technologies. The goal is to develop a scientific foundation for implementation of cost-effective O&M strategies and technologies for offshore wind farms.
- WP 6: Assessment of <u>novel concepts</u> for offshore wind turbines by numerical tools and physical experiments, hereunder developing control systems and combining results from WP2 and WP3. Assessment is by numerical tools (WP1) and by utilizing “in-house” labs and results from full scale field tests (e.g. HyWind).

The WPs are closely interlinked (Fig. 2) with a joint aim to provide new knowledge, tools and technologies as basis for industrial development of cost-effective offshore wind farms at deep sea. The research will mainly be of pre-competitive nature including a strong PhD and post doc programme. In total more than 70 publications in peer reviewed journals are expected. Dissemination of results will further be through international conference papers, continuation and development of the established yearly wind R&D seminar in Trondheim, work-shops for industry and public bodies, newsletters and web.

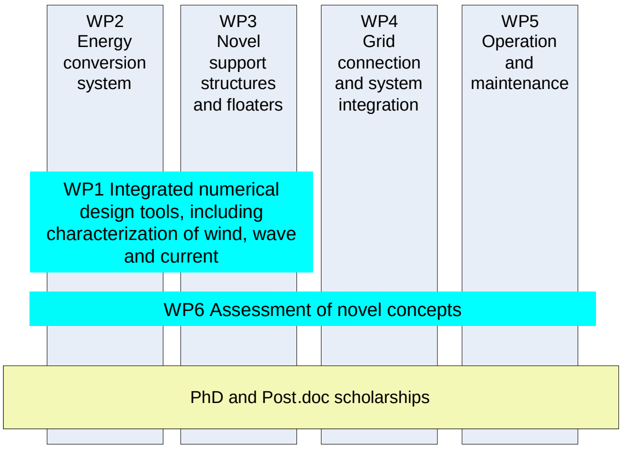

Fig. 2: Interplay between work packages.

Establishment of the Centre is timely since the international development is at its very beginning and Norwegian offshore and energy industries have a competitive advantage utilizing the many years of experience from the offshore oil and gas activities. New projects are envisaged to spur from the Centre. They could, among others, include multi-financed targeted research projects (Research Council of Norway, EU) and industry development, demonstration and commercialisation projects.

Studies on offshore wind resources and interaction with society and environment are not included in the work programme. This is because of budget limitations and prioritizing a strong technology focus. However, other centres/projects are expected to put significant efforts on these topics[2,3], and links to these and relevant stakeholders will be established as part of the management of the Centre, and through targeted seminars/workshops.

WP 1: Integrated numerical design tools

Objective

The objective is establishment of a set of proven tools for integrated design of deep-sea wind turbines, hereunder characterization and interaction of wind, wave and current.

State of the art

Numerical tools exist for design of wind turbines and substructures separately, but these must be combined, allowing for integrated design of deep-sea wind turbines. This is required both for bottom-fixed structures and floaters for accurate determination of the motions and stresses generated by the combined effects of the hydro- and aerodynamic loads. Load mitigation can be achieved by turbine control (individual pitching, smart blades), hence analysis tools must include interface for such control algorithms. In short, accurate tools must model the multi-physics of wind, waves, rotor aerodynamics, structural dynamics, hydrodynamics and control systems.

State-of-the-art tools for design of wind turbines are Fast, Bladed, Flex5 and Hawc2. These can be applied for deep-sea bottom-fixed turbines by replacing the simple structural model of the tower with a more general model and by including the hydrodynamic loading. Methods and tools for cost-optimised design of floating and fixed support structures are well established within the offshore oil

[2] The Norwegian offshore wind potential has been reported by Enova, 2007, see www.enova.no. More detailed mapping is expected by the EU project NORSEWIND, www.norsewind.eu (2008-2012).

[3] Centre for Sustainable Energy Studies and Centre for Environmental Design of Renewable Energy are planned to start in 2009, though pending on funding from the Research Council of Norway.

and gas sector. Example state-of-the-art tools for floating platforms are WAMIT[4], SIMO and RIFLEX[5]. These have been interfaced with wind turbine models for simulation of floating wind turbines, however convergence and stability problems were experienced[6,7]. Improved coupled tools are being developed as part of ongoing research, e.g. KMB-project[8], IEA Wind Task 23[9] and UpWind[10], but in an early stage. More accurate simulation of the aerodynamic response of turbine blades requires CFD tools[11,12], and design methods should be developed analogous to tools for oil and gas platforms[13,14,15,16]. The combined effects of wind, waves and current are important, and work is needed to determine the micro-scale characteristics and coupling between these as input for numerical design tools.

Research tasks

Accurate numerical tools are a key for efficient development of new technology. Such tools exist for land-based and shallow water wind turbines, but must be developed for deep-sea wind turbines (Task 1.1). Deep-sea wind turbines are subject to a combination of wind, wave and current forces that must be accounted for in numerical tools, thus characterization of these are given attention (Task 1.2).

Task 1.1 Code development

The goal of this task is to develop a set of proven tools for integrated design of deep-sea wind turbines by accounting for wind and sea environment, hydrodynamic and aerodynamic loads, structure dynamics and elasticity, generator behaviour and automated control systems. Emphasis is on floating turbines including various designs for up- or downwind rotor, mechanical and hydraulic transmission, gearbox, generator, tower and support structure, floater and anchoring. Time domain as well as frequency domain approaches will be addressed.

The research will focus on features not yet covered in existing software, especially relating to moored, floating wind turbine concepts. The novel features will as far as possible be integrated in existing, robust and internationally leading software.

---

[4] WAMIT is an advanced set of tools for analyzing wave interactions with offshore platforms and other structures or vessels, www.wamit.com.

[5] SIMO is a time domain simulation program for study of motions and station keeping of multibody systems. RIFLEX is an efficient program system for hydrodynamic and structural analysis of slender marine structures. Detailed descriptions are available at www.marintek.no (click on "software and tools").

[6] J. M. Jonkman and M. L. Buhl, Jr., 2007, "Development and Verification of a Fully Coupled Simulator for Offshore Wind Turbines ", Conference Paper NREL/CP-500-40979 for 45th AIAA Aerospace Sciences Meeting January 2007

[7] Skaare, B., et. al. (2007) Integrated Dynamic Analysis of Floating Offshore Wind Turbines. Proceedings of 2007 European Wind Energy Conference and Exhibition (EWEC), Milan, Italy, May 7-10.

[8] KMB project "Deep-sea offshore wind turbine technology", 2007-2009, www.sintef.no/wind.

[9] IEA Wind Task 23: Offshore wind technology, www.ieawind.org.

[10] UpWind, EU FP6, www.upwind.eu.

[11] Breton, S.-P., Coton, F.N., Moe, G., "A Study on rotational effects and different stall delay models using a prescribed wake vortex scheme and NREL phase VI experiment data", Wind Energy, 11(2008): no. 5, 459-482

[12] N.N. Sørensen 2008, "CFD methods for wind turbine aerodynamics", In 21st Nordic Seminar on Computational Mechanics, Eds: T. Kvamsdal, K. M. Mathisen and Bjørnar Pettersen, page 39-42, CIMNE, Barcelona.

[13] Fylling, I and Kleiven, G "Simultaneous Optimisation of Mooring and Riser Systems for Floating Production Vessels", Proc. OMAE2000 conference, 2000.

[14] Ormberg, H., Lie, H., Stansberg, C. T., (2005) "Coupled Analysis of Offshore Floating Systems", Ch 10 in Numerical Models in Fluid Structure Interaction, ISBN 1-8312-837—6,WIT Press, Boston 2005.

[15] Fu, S.X., Moan, T., Chen, X.J. and Cui, W.C. "Hydroelastic analysis of flexible floating interconnected structures". J. Ocean Engineering, 2007, Vol. 34, pp. 1516-1531.

[16] Taghipour, R., Perez, T. and Moan, T. "Hybrid frequency-time domain models for dynamic response analysis of marine structures". Ocean Engineering, 2008, Vol. 35, No. 7, pp. 685-705.

The task will draw upon new knowledge and numerical sub-models being developed in WP2 (energy conversion), WP3 (substructures) and WP6 (control), and combine these into a set of fully integrated design tools.

The total suite of tools will span a wide range of applications. This includes user-friendly and fast tools for conceptual studies and preliminary design, tools for real time automatic control applications and state-of-the art computational tools enabling detailed and highly accurate analysis to validate particular features.

The latter applications will also include state of the art aerodynamic modelling of wind turbines by use of 3D Navier-Stokes solver, parallel processing, advanced grids and advanced turbulence models[17]. Parameterised geometric models will be established, that combined with a isogeometric analysis concept will enable very accurate and efficient prototype testing and design optimization.

Code validation will be carried out using published results, experiments (WP6) and results from prototypes or demonstrators, hereunder the HyWind test expected to start by fall 2009.

Task 1.2 Wind, waves and ocean current

The goal of this task is to gain an improved understanding of micro-scale wind, wave and ocean current as input for numerical design tools of deep-sea wind turbines. This will be done by analysis of measurements and modelling.

Reliable offshore wind measurements are available from Denmark and Germany (FINO 1, 2 and 3 platforms). In the Norwegian offshore waters no wind energy measurement program has yet been conducted, but some wind information is available for selected sectors with marine characteristics from Frøya, Sør Trøndelag, through the NTNU wind program (Gjerstad et al., 1995[18], Heggem, 1997[19]). The meteorological observations from oil rigs in the North Sea and the Norwegian Sea are of limited use for offshore wind energy analysis since the data often are significantly affected by the oil rig itself. New measurements are expected from the HyWind test[20], and through dedicated measurement programmes employing a floating platform[21]. In addition, to ensure availability of high quality offshore measurements, funds are requested (separate application enclosed) to procure, install and operate one dedicated wind, wave and current measurement facility. The measurements will be used to characterize the micro-scale wind, wave and ocean current conditions at selected locations in Norwegian offshore seas. Attention will be given to the coupling of ocean waves and swells to the turbulence pattern and the wind profile of the marine boundary layer.

After the wind has passed a wind turbine, turbulence develops downstream and wake losses become an important constraint to the energy production for the wind turbines downstream. Internal wake

[17] Y. Bazilevs and T. J. R. Hughes 2008, “NURBS-based isogeometric analysis for the computation of flows about rotating components”. *Computational Mechanics*, In press.

[18] Gjerstad J, Aasen SE, Andersson HI, Brevik I og Løvseth J, 1995 An Analysis of Low-Frequency Maritime Atmospheric Turbulence, J. Atm. Sci. 52, 2663-2669

[19] Heggem T, 1997 Measurements of coastal wind and temperature. Sensor evaluation, data quality, and wind structures, Dr. Sci. thesis, Dept. of Physics, NTNU, Trondheim, Norway

[20] StatoilHydro will install a 2.3 MW prototype of a floating turbine outside Karmøy by fall 2009. As part of this test there will be measurements of wind, wave and ocean current.

[21] The platform measures wind, wave and ocean current. Numerical methods are applied for compensation of platform motions. The wind measurements are by a LIDAR system. Project in planning by Fugro OCEANOR, Leosphere, StatoilHydro and NTNU to be started in 2009.

losses may be as large as 10-20% in offshore wind farms (Barthelmie et al, 2004)[22]. Large offshore wind farms may generate increased turbulence and reduced average winds several tenth's of km downstream (Rethore et al, 2007)[23]. Thus calculations of the wake losses are also important for neighbouring wind farms. Different wake modelling techniques are given in Barthelmie et al. (2004), and Frandsen at al. (2006)[24]. These, together with assessment of offshore measurements, will be used as basis for developing models to characterize wind, wave and ocean current characteristics inside and downstream of a wind farm.

WP 2: Energy conversion systems

Objective

The objective is to contribute to the development of efficient, low weight and robust blade and generator technology for offshore wind turbines.

State of the art

The energy conversion system of the offshore wind turbines being installed today are basically as for onshore wind turbines. The expectation is that significant life-cycle cost reductions can be achieved by developing an energy conversion system specifically for offshore conditions. In this, requirements to aesthetics and acoustic noise can be relaxed, while specific attention should be given to weight and reliability. Low weight is desirable, while this must not compromise reliability.

The most common energy conversion system for wind turbines includes a slow rotating three-bladed horizontal axis up-wind rotor connected a gearbox driving a high speed generator. Typical sizes are 2-5 MW with rotor diameters up to 126 m. New rotors being developed resembles the same basic characteristics (HAWT), but increasing in size and with improved blades. New blade profiles, materials, pitch and rotor-speed control, and smart blade technology[25] are topics of on-going research. Alternative rotor concepts have been suggested, e.g. vertical axis, but none have gained any market share.

An alternative with growing market share to the common gearbox and high-speed generator concept are the direct-drive generator concept[26]. This is advantageous by avoiding use of a gearbox that may fail, but is today significantly heavier than the gearbox concept. Other concepts are on the market[27], and more are being developed[28]. The many new gear and generator concepts being developed by the industry clearly indicates lack of consensus on a winner, and need for more knowledge on the field.

---

[22] Barthelmie, R., Larsen, G., Pryor, S., Jørgensen, H., Bergstrøm, H., Schlez, W., Rados, K., Lange, B., Vølund, P., Neckelmann, S., Mogensen, S., Schepers, G., Hegberg, T., Folkerts, L. and Magnusson, M. 2004. ENDOW (Efficient Development of Offshore Wind Farms): Modelling Wake and Boundary Layer Interactions. Wind Energ., 7,, 225-245.

[23] Rethore, P-E., Bechmann, A., Sørensen, N N., Frandsen, S., Mann, J., Jørgensen, H E., Rathmann, O. and Larsen S E. 2007. A CFD-model of the wake of an offshore wind farm: using a prescribed wake inflow. Journal of Physics: The science of making torque from wind. Conference Series 75, 012047.

[24] Frandsen, S., Barthelmie, R., Pryor, S., Rathmann, O., Larsen, S., Højstrup, J. and Thøgersen, M. 2006. Analytical Modelling of Wind Speed Deficit in Large Offshore Wind Farms. Wind Energ., 9, 39-53.

[25] IEA Topical Expert Meeting (2008) The application of smart structures for large wind turbine rotor blades.

[26] Enercon has been pioneering the concept of a direct drive generator. They employ a multi-pole wound synchronous generator. ScanWind also applies a direct drive generator, but permanent magnet. Siemens and other large manufacturers are now developing similar direct-drive concepts.

[27] Multibrid 5 MW and WinWinD 3 MW use a single stage gear and medium speed permanent magnet synchronous generator. Clipper 2.5 MW applies a novel gear with four high speed shafts each driving a permanent magnet synchronous generator. DeWind 2 MW comes with a two-stage gearbox in combination with a hydrodynamic coupling and a conventional synchronous generator directly connected to the grid.

[28] Examples of new concepts being developed in Norway are SmartGenerator (novel PM machine with ironless stator), ChapDrive (hydraulic transmission) and AngleWind (new type of eccentric gearbox).

Even more than for bottom supported turbines, weight reduction becomes desirable especially for the rotor and components in the nacelle of floating turbines. For instance, today glass fiber blades[29] may have to be replaced by carbon fiber[30,31], nano-composite materials[32] with high ultimate and fatigue strength, or even multifunctional coatings[33]. The development of self-healing polymeric materials in which damage triggers an autonomic healing response is an emerging area of research that could significantly extend the working life and safety of components for rotor blades[34].

Research tasks

This work package focus on critical components of the energy conversion system which comprise the rotor, mechanical/hydraulic transfer and generator. Emphasis is on the rotor blades (Task 2.1) and generator (Task 2.2).

Task 2.1 Rotor blades

Rotor blades for future offshore wind turbines may be 80 meters or longer (for a 10 MW wind turbine) and will be subject to highly varying structural loads. This puts tremendous demands on the materials used, and notably the application of new materials will be explored. Alternative aerodynamic and structural designs will be investigated for up-wind and down-wind operation, hereunder high-RPM operation. Rotor aerodynamic research will focus on smart blade technology using active flow control (like flaps, spoilers or turbulence generators) on tailor-made blade sections as an alternative to conventional blade pitch control. Activities will merge know-how from wind turbine and aerospace research[35]. The potential of smart technologies for power and thrust control is especially interesting for floating wind turbine concepts. Key elements to be considered in validating alternative blade designs are aerodynamic efficiency, defect and damage tolerance, fatigue performance, condition monitoring, adhesive/mechanical joints, buckling, weight and cost.

Focus will also be on developing new material systems. Using competence on nanosized capsules technology (see also complementary activities in WP3), self-healing matrix materials will be developed. Use of embedded sensors or fibre-optical systems, in conjunction with advanced damage characterization algorithms, is expected to become an important technology in extending the life and reducing life cycle costs of new generations of blades. Numerical and experimental tools for understanding and predicting the material response on multi-axial cyclic loading will be developed. Models for quantitative prediction of damage development, de-lamination of composite plies and crack growth are necessary in order to develop and qualify new material solutions and to ensure the structural integrity and lifetime predictability of materials, components and systems.

Novel coatings containing multifunctional nanosized particles for turbine blades will also be assessed with regards to texture for improving the aerodynamic properties, wear properties and/or reduce salt/ice deposition.

---

[29] P. Brønsted et al., “Wind rotor blade materials technology”, European Sustainable Energy Review, issue 2, 2008, pp. 36-41

[30] K. J. Jackson et al., “Innovative design approaches for article large wind turbine blades”, Wind Energy, v8, i2, 2005, p141-171.

[31] P. S. Veers et al., “Trends in the design, manufacture and evaluation of wind turbine blades” Wind Energy, v6, i3, 2003, pp. 245-259.

[32] R. Stokke, “Utilization of nano-technology in composite materials”, SINTEF A6334, 2008 (in Norwegian)

[33] H. Schröder, “Nanotechnology for Wind Energy”, Nanotech Northern Europe Conference, 2008.

[34] D. Y. Wu et al. “Self-healing polymeric materials: A review of recent developments”, Progress in Polymer Science (Oxford), v 33, n 5, May 2008, p 479-522

[35] E. Stanewsky, Adaptive wing and flow control technology, Progress in Aerospace Sciences, Vol. 37, Issue 7, Pages 583-667, Elsevier Sciences Ltd., 2001.

Research will be by desktop studies (analytic/numerical modelling) and model-scale experiments. Planned experiments include test of coating characteristics with regards to salt/ice repellence. A wind tunnel test of a small scale blade-section with smart-blade features, including novel materials for improved strength/weight ratio and coating for improved aerodynamic performance are planned as part of WP6. Test of full scale blades are expected to be done in close cooperation with the industry in separate projects being developed by the Centre.

Task 2.2 Generators

New concepts for low weight, integrated and reliable generators for large wind turbines will be developed. The combination of novel direct driven generators and new foundations for the blades can result in a breakthrough for huge wind turbines.

Both gearless (direct driven) electric generators and novel concepts for transmissions used for high power offshore wind applications are to be investigated. Key activities are as follows a) Shaft/bearing/nacelle structural concepts b) Rotor hub designs (integrated designs/new composite materials) c) Magnetic design of generator rotor (Permanent Magnet vs. Super Conductive Rotors) d) Low weight ironless stators based on new materials with a maintenance free cooling systems e) alternative transmission with low cost generator at sea level. Important elements to be considered are reliability, maintainability, weight, efficiency and cost.

A key activity is to develop analysis models for coupled problems which include structural analysis with focus on new materials, vibrations, magnetic forces and thermal stresses. Work will mainly be by theoretical modelling, possibly supported by laboratory verifications of components. Field testing of scaled designs are expected to be done in a continued close cooperation with industry in separate projects being developed in collaboration with the Centre.

WP 3: Novel support structures and floaters

Objective

The objective is to develop novel, cost-effective support structures and floaters for deep-sea wind turbines.

State of the art

The potential for large wind farms at deep-sea is huge provided that costs can be reduced to a competitive level. This requires development of novel support structures and floaters. The jacket and tripods currently being demonstrated (Beatrice/OWEC Tower and Alpha Ventus/Aker) form a good starting point, but must be further developed to ease installation and reduce costs. Floaters are the only viable option at sea-depths above 100 m, and can possibly be applied also at smaller depths. Much based on the extensive knowledge about floating platforms for the oil and gas sector[13-16,36], the Norwegian industry has already embarked on developing floating concepts such as HyWind, SWAY and WindSea. International interest is apparent by activities of IEA and EU-projects, Siemens participation as supplier of the wind turbine in the HyWind test, Vestas patent on an alternative floater[37] and the demonstration of the BlueH concept[38]. Further developments are needed to achieve commercial products. In this, combining wind turbine and offshore oil and gas technology may be a key to success. The challenges associated with the future developments of

[36] Moan, T. "Floating Production Systems for Oil and Gas in Harsh Environments", 4th Keppel Offshore & Marine Lecture, 2006, National University of Singapore.

[37] Vestas patent WO/2004/061302. Wind turbine with floating foundation comprising at least three submerged buoyancy bodies, http://www.wipo.int/pctdb/en/wo.jsp?wo=2004061302.

[38] BlueH launched the installation of a small two-bladed wind turbine on a submerged deepwater platform off the coast of Italy in December 2007, http://www.bluehgroup.com/.

support structures are partly to accommodate turbines with larger capacity (larger rotor blades), establish more efficient installation procedures and accomplish designs that limit expensive offshore maintenance by implementing design criteria that imply high reliability and robustness. Moreover, corrosion and other degradation phenomena will require more attention in the design and operation of offshore than for land-based turbines. Application of novel types coatings with good abrasion resistance and durability is therefore of significant interest.

Research tasks

This work package comprises research on the structural design of bottom-fixed support structures (Task 3.1) and floaters (Task 3.2), and the protection of these by coatings (Task 3.3).

Task 3.1 Bottom-fixed support structures

The goal of this task is to identify and assess novel bottom-fixed support structures for wind turbines at intermediate water depths (30-70 m). A truss type tower will save tower weight and eliminate the need for a transition link to an upper tubular tower[39]. Also it could be used with a downwind rotor, permitting a more flexible rotor that cones away from the tower and thus introduces centrifugal forces that counteracts the thrust generated root flap bending moment. Foundation technology (depending on bottom conditions), transport and installation are further subjects for investigation. In particular systems that allows for doing a complete installation in-shore, and then floated to site would be preferable. In this, the application of alternative structures and materials will be studied.

The research is basically conducted by analytical and numerical studies. Field testing of new designs are expected to be done in close cooperation with the industry in separate projects being developed by the Centre.

Task 3.2 Floating support structures

Floating wind turbines are mainly suited for water depths of 100 m and more, but can possibly be of interest also for smaller water depths based on lightweight turbines and novel floater designs. The mooring system, which is an important cost element in floating systems, and electric cable arrangements shall preferably allow for easy connection and disconnection in case the wind turbine needs to be towed to shore for maintenance and repair. The interaction between wave- and wind-induced motions makes the design of such systems a particular challenge. Design and inspection criteria as inferred from the oil and gas industry[40] and the unique features of wind turbine support structures, response analysis, suitability for mass production and ease of installation in view of minimum life cycle costs, are key topics to be addressed in this task. Also, the use of alternative materials to steel and concrete for the floater will be considered.

The research is basically carried out by analytical and numerical studies, but also through scaled tests of novel structures in the MARINTEK Ocean Basin as a part of WP6. Field testing of new designs are expected to be done in close cooperation with the industry in separate projects being developed by the Centre.

Task 3.3 New coatings

The work in this task focus on the development of new coating systems (see also complementary activities in WP2) and laboratory test methods to characterize relevant coatings. A main issue is coatings that protect components against corrosion and wear in a 20 years perspective rather than

[39] Haiyan Long; Geir Moe, "Truss Type Towers in Offshore Wind Turbines", EOW2007, Germany

[40] Moan, T."Fatigue reliability of marine structures – from the Alexander Kielland accident to life cycle assessment of safety", ISOPE keynote lecture, San Francisco, 2006. J ISOPE, 2007;17(1):1–21.

the current 10 years state-of-the-art. Polymer coatings based on nanosized capsules[41] and particles[42], and self lubricated coatings are a possible option in this connection. The work will include the development of methods to repair damaged coating on-site (WP5).

Test method shall reflect the harsh offshore conditions in order to assure the reliability of the proposed materials. Thus, new tribology tests in corrosive media will be developed to reproduce the required conditions.

The research activity will be a combination of analytical work, numerical simulations and laboratory testing.

WP 4: Grid connection and system integration

Objective

The objective is to develop technical and market based solutions for cost effective grid connection and system integration of offshore wind farms.

State-of-the-art

With increasing penetration of wind energy in many countries wind farms are treated more and more as conventional power plants regarding their controllability and operational reliability. As a consequence transmission system operators (TSOs) have established firm requirements for grid connection of wind farms (grid codes). Topics related to transmission grid developments and electricity markets are high on the research agenda and are being treated in several European and international projects by TSOs and the wind energy community[43]. There are, however, a number of topics and additional challenges related to large scale offshore wind power that need further research.

At offshore locations there is no existing grid, and the present technology for grid connection and power transmission may not be suitable for deep sea offshore applications. This requires development of new solutions for electricity conversion, transformer stations and the topology and layout of internal wind farm grids as well as offshore transmission networks. The choice of technology will also have impacts on the control and operation of offshore wind farms. The project team at NTNU and SINTEF ER will contribute to this developments with a broad range of modelling tools[44] and experimental facilities through the Renewable Energy Systems Laboratory[45].

Cost effective integration of large offshore wind farms will only be a reality if there exists a well functioning market for power trade. With the anticipated size and location of wind farms, e.g. in the North Sea, this market has to be seen in a European perspective. In this context Norwegian hydro power has also an important position with its ability to provide balancing services that will be increasingly important in the future European power system. A new type of planning tools integrating power market and network analysis is needed for market design and development of offshore grids as well as reinforcements of existing networks. Existing simulation tools and

[41] C. Simon, “Smart Coatings Based on Nanosized Capsules”, Eur. Coatings J. Vol. 2 (2007) p. 32-37.
[42] C. Simon and F. Männle, “*High Performance Coatings based on Hybrid-Organic-Inorganic Polymers, Paint and Coatings Industry*”, 21(10), (2005) pp. 104-110.
[43] For example EU Intelligent Energy Europe projects “EWIS” and “TradeWind”, and working groups within IEA and Utility Wind Interst Group (UWIG) in North America.
[44] Sørensen, Norheim, Meibom, Uhlen:, ”Simulations of wind power integration with complementary power system planning tools”, Electric Power Systems Research Journal, Vol. 78, 2008.
[45] Renewable energy System laboratory. See www.sintef.no/energylab

optimisation methods developed at NTNU and SINTEF ER for transmission system planning and power market analysis[46] represent a good starting point for this work.

Offshore grid and offshore wind developments also create new possibilities that need to be studied, e.g. using offshore wind farms for supplying electricity to offshore oil and gas installations.

Research tasks
Three main research tasks are planned where studies will be carried out using numerical tools (existing or to be developed as required), supported by measurements and laboratory experiments.

Task 4.1 Internal electrical infrastructure for offshore wind farms
The aim of this task is to contribute to better design of the electrical infrastructure of offshore wind farms, leading to significant cost reductions and improvements in operational reliability. The research activities include development of concepts and optimal layouts of internal wind farm grids and functional design of converters and offshore transformer stations (redundancy, configuration, dimensioning and protection). Focus is on system aspects and possibilities of using new technologies, hereunder development of numerical simulation models of offshore wind farms and electrical infrastructure for assessment of power system operation and grid stability. Development of components (connectors, cables, etc) as such will be by other projects[47], but coordinated with the Centre.

Task 4.2 Grid connection and control
This task deals with offshore wind farms in a system perspective, with main emphasis on grid connection, operation and control. The aim is to assess and develop cost effective controls and grid solutions for offshore wind farms, and to analyse new technologies and possibilities for overall improvements in power system monitoring and control. The main research activities include:
- Analyses and design of alternative solutions for grid connection depending on the size and location of the offshore wind farm, e.g. concept of connection (to shore by single line, multi-terminal solutions and connection to oil and gas installations), choice of AC versus DC, choice of voltage levels, etc. An important goal is to develop methods and tools to make a network design suitable for expansion.
- Analysis and design of wind farm controls taking into account power system security issues, system operation technologies and operator requirements (grid codes).

Topics of research include grid topology design, power flow and stability analysis, hereunder participation in a new CIGRE Working Group on modelling and performance analysis of long HVAC sub-sea cables.

Task 4.3 Market integration and system operation
Offshore wind energy will only be a reality if there is a sufficient demand and a willingness to pay for the electricity. This will require access to and integration with the European power markets. The aim of this task is to assess the impact of offshore wind on the power system (taking proper account for trans-national power markets and regulatory aspects) in order to identify what are the main barriers in terms of grid constraints and market limitations to full exploitation of the offshore wind potential. The main research activities are:
- Analyses of the European power systems' operation, focusing on the impacts of offshore wind on power flows and market prices. The studies will take into account variations in wind power

[46] Doorman, G., Botterud, A.: "Analysis of Generation Investment Under Different Market Designs", IEEE Trans. Power Systems, Volume 23, Issue 3, Aug. 2008.
[47] Applications are sent to the Research Council of Norway for development of connectors, breakers, transformers and power electronics related to offshore wind power ("KMB"-projects to be started January 2009).

production and geographical distribution of the wind farms in analysing implications on network and market operation.
- Assessment of market solutions for efficient operation of power systems with large amounts of renewable generation, including studies on how to ensure optimized use of existing hydropower with storage for cost effective balance management.
- Investigations of an offshore super-grid for connecting offshore wind farms, oil-rigs and transmission to shore. The focus will be on the European dimension and benefits of international balancing and levelling of wind power variations.

Studies will be coordinated and build on recent and on-going IEA[48] and EU projects[49]. The ultimate goal is to prepare a road-map for offshore grid topology and market solutions for cost-effective integration of offshore wind in Europe.

WP 5: Operation and maintenance

Objective

The objective is to develop a scientific foundation for implementation of cost-effective operation and maintenance (O&M) concepts and strategies for offshore wind farms.

State of the art

Offshore wind farms are exposed to harsher environmental conditions than onshore wind farms. Accessibility for inspection and maintenance is more restricted resulting in higher O&M costs and more limited accessibility for human interventions.

O&M strategies, which maximise the energy yield from turbines while minimising O&M costs, are essential for the commercialisation of offshore wind power[50]. Advanced condition and risk based strategies and technologies will be necessary to face this challenge, as well as assessment of O&M aspects during initial design of wind turbines and wind farms to avoid unnecessary costs during the operational phase.

Operation and maintenance of wind power plants has been addressed in a number of EU-funded projects. The OffshoreM&R[51] project concluded that a technical condition based strategy should be established in the future. One of the conclusions of the CONMOW[52] project was that presently, insufficient knowledge is available to make prognoses on how failures will develop. The UpWind[53] project has published a report on condition monitoring that focuses on the measuring methods and physical principles rather than sensor types and systems.

Design requirements for human intervention in routine maintenance operations have made it necessary to focus on access technology for adverse weather conditions. The access systems must be capable of transferring people and equipment safely to the turbine, and for some operations this will require specially designed solutions that may increase operating costs[54].

---

[48] IEA Wind Task 25: Design and Operation of Power Systems with Large Amounts of Wind Power.
[49] The participation in the EU IEE project "TradeWind" (2006 – 2008) represents an important basis regarding the development of power system and market simulation tools and the availability of wind and power system data. Participation in the EU IEE project "WINDSPEED", contract no. IEE-07-759, can also be considered part of this Task.
[50] European Technology Platform for Wind Energy (TPWind), http://www.windplatform.eu/
[51] OffshoreM&R (2006) Final Report – Advanced maintenance and repair for offshore wind farms using fault prediction and condition monitoring techniques – OffshoreM&R.
[52] Wiggelinkhuizen, E., Verbruggen, T., Braam, H., Rademakers, L., Xiang, J., Watson, S. & Giebel, G. (2007) CONMOW: Condition Monitoring for Offshore Wind Farms. EWEC 2007. Milan, Italy.
[53] UpWind "State of the Art Report - Condition Monitoring for Wind Turbines", www.upwind.eu.
[54] G.J.W. van Bussel, W.A.A.M. Bierbooms, " Analysis of different means of transport in the operation and maintenance strategy for the reference DOWEC offshore wind farm", OWEMES April 10-12, 2003, Italy

The optimal size of an offshore wind farm will be significantly larger than onshore both with respect to the size of the wind turbines and number of units, resulting in increased logistical challenges. To obtain maximum availability, the O&M strategy needs to consider basic issues such as crew size, repair time, weather windows and spare parts in combination with the logistics infrastructure comprising supply vessels, helicopters and inventory depots.

The "Center for Integrated Operations" (IO Center)[55] is carrying out research to promote accelerated production, increased oil recovery, reduced operating costs and enhanced safety and environmental standards. Among the topics addressed and of relevance for offshore wind is O&M, including remote surveillance, control and operation. O&M strategies for offshore wind can not be directly adapted from the offshore oil and gas industry, but need to be further developed into a low cost scenario for being able to cope with competitive concepts. Nevertheless, considerable knowledge is available from the research in the IO Center which can be adapted to the needs of offshore wind farms.

Research tasks
The research in this WP will be carried out on cost-effective maintenance strategies (Task 5.1), surveillance and condition monitoring concepts (Task 5.2), and access and logistics technologies (Task 5.3).

Task 5.1 Maintenance strategies
A reliability-availability-maintainability-safety (RAMS) approach will be used to develop the maintenance strategies on component and system level. Methods will be developed focusing availability in a life cycle cost perspective. A generic framework for establishing O&M strategies for offshore wind farms will further be developed. Damaged coatings in offshore structures need to be replaced in harsh conditions (low temperature, high humidity, etc), resulting in a need for new maintenance/replacement techniques to fulfil the requirements given by the coatings/materials developed in WP2.

Task 5.2 Surveillance and condition monitoring
A major part of the O&M concept for offshore wind turbines will be comprehensive monitoring and surveillance facilities[56]. Condition monitoring methods and tools for predictive maintenance strategies will be adapted and developed, seeking to integrate condition monitoring and predictive component degradation models into the control system.
A key issue will be the specification of which parameters to monitor, location of sensors, measurement intervals, etc. Knowledge about material- and component degradation mechanisms and failure modes is vital in that sense.

Task 5.3 Access and logistics technologies
Logistics operations related to large offshore wind farms under rough weather conditions is a challenging issue. Effective access systems for safe personnel entry on offshore structures will be analysed. Various solutions for towing of floaters for repair inshore versus on-site repair will be evaluated concerning feasibility, safety and costs. Development of safe and efficient concepts and techniques for installation, hook-up, commissioning, intervention and replacement logistics, including marine operations, are crucial research topics for development of competitive offshore wind farms. Methods for optimization of necessary support infrastructure from a system point of view will be developed.

---

[55] Center for Integrated Operations in the Petroleum Industry, http://www.ntnu.no/iocenter
[56] MARINTEK Technical Condition Index Methodology

WP 6: Assessment of alternative design concepts

Objective
The objective is to develop and assess novel concepts of deep-sea wind turbines by numerical tools and physical experiments, hereunder developing control systems and combining results from WP2 and WP3. Assessment is by numerical tools (WP1) and by utilizing "in-house" labs and results from full scale field tests (e.g. HyWind).

State of the art
Offshore wind turbines of today are close to identical with on-shore wind turbines. This is clearly not representing a design optimized for offshore conditions, and new improved concepts and technologies for offshore wind turbines should be developed. Better concepts are expected through combining wind and offshore oil and gas experience. Since maintenance and repair are more expensive for offshore facilities, robust and reliable technology is of paramount importance. Conceptual design studies, exploring the interaction between the energy conversion, support structure and control system, should be carried out in order to minimize the life cycle costs. In this, applying smart control systems for load mitigation and structural stabilization is expected to be a key for cost reductions. Such integrated design studies requires development of new methods and software (WP1), and must be validated against scaled laboratory tests and full scale field tests. Such tests are also required to demonstrate the technology, especially full scale field tests are crucial for proving operation and bringing deep sea offshore wind closer to commercialization.

Research tasks
This work package includes development of control systems for load mitigation and minimization of motions (Task 6.1), overall concept assessment (Task 6.2), experiments and demonstrations (Task 6.3).

Task 6.1 Development of control systems
The development and use of control systems is expected to contribute significantly to reducing the life-cycle cost of energy from offshore wind farms. The main aim of this task is to develop new control schemes for load mitigation and minimization of unwanted swings and motions. This is considered critical for large offshore wind turbines, and especially for floaters. Topics of study are adaptive control, application of advanced sensors (including sensing of incoming wind over the rotor area, e.g. by Lidar mounted in nacelle for proactive wind turbine control), independent blade pitch control and generator torque control, stabilization of floating structure and active damping of loads and swings in blades, drive-train and tower. Schemes for increased energy gain may also be investigated expecting a possible gain in annual production of up to 5 %. Control issues related to improving power plant capabilities of offshore wind farms will for the most be dealt with within WP4.

Task 6.2 Assessment of alternative design concepts
This task will make overall assessment of novel wind turbine design solutions. The task will make sure to bind the more component focused works together. This includes identifying alternative system designs and exploring how system performance can be improved by systematically studying the influence of components in the energy conversion and support structure. The assessment will be made by use of numerical tools, possibly supported by physical experiments (Task 6.3). Examples of studies to be conducted are a) the impact of wind turbine top-weight on floater or jacket performance, b) up-wind versus down-wind turbines, and c) floating wind turbines in shallow or

moderate water depths[57]. Studies may require development/adaptation of numerical tools that will be conducted as part on WP1.

Task 6.3 Experiments and demonstration

The aim of this task is to carry out, link and develop experiments and demonstration as a means to support the development of novel offshore wind farm technology. Planned activities include:

- Executing experiments and demonstration utilizing "in-house" lab and test facilities.
- Establishing links to external test/facilities for cooperation (HyWind test, SWAY test, etc), e.g. using measurement data for validating numerical models.
- Preparing tasks for developing such test and demo facilities.
- Making first assessment of ideas for new products etc submitted by Centre partners or external parties and soliciting sources for public funding and further development.

The activities will be carried out based on needs identified by the Centre and in close cooperation with industry partners.

PhD and post doc programme

The PhD and post doc studies will be carried out as an integrated part of the work packages. Table 1 shows the 15 PhD / post doc studies planned to start during the 3 first years of the Centre. In total 25 PhD or Post Doc studies are planned as part of the Centre.

Table 1: PhD / post doc studies planned to start during the 3 first years of the Centre.

#	WP	Subject	Supervisor
1	1	Quantitative analysis of the aerodynamic performance of the wind turbine rotor by use of Navier-Stokes CFD	Trond Kvamsdal
2	1	Evaluation of the dimensional dynamic forces on large floating wind turbines	Ole Gunnar Dahlhaug
3	2	Lift control of wind turbine rotor blades by use of smart material devices manipulating the aerodynamic rotor properties.	Per-Åge Krogstad, Andreas Echtemeyer
4	2	Influence of material and process parameters on fatigue of wind turbine blades in a marine environment.	Andreas Echtemeyer
5	2	Novel generator concepts for low weight nacelles. Integrated design of generator and mechanical structure for a maintenance free system.	Robert Nilssen
6	3	Bottom-fixed support structure for wind turbine in 50 m water depth	Geir Moe
7	3	Life cycle criteria and optimization of floating structures and mooring system	Torgeir Moan
8	4	System stability and control of wind farms to fulfil grid connection requirements (grid codes)	Tore Undeland
9	4	Balance management with large scale offshore wind integration	Gerard Doorman
10	4	Development of market models incorporating offshore wind farms and offshore grids.	Olav Fosso
11	5	Maintenance optimisation of wind farms from design to operation (models, methods, framework).	Jørn Vatn
12	5	Development of material degradation models to optimise the inspection and monitoring program.	Roy Johnsen
13	6	Comparative study of floating concepts	Torgeir Moan
14	6	Assessment of benefits of downwind rotors due to weight savings using new and thinner airfoils and improved directional stability of turbine	Per-Åge Krogstad, Geir Moe
15	6	New control schemes for load mitigation and stabilization of floating wind turbines	Tor Inge Fossen, Kjetil Uhlen

[57] Henderson, A.R., Bulder, B., Huijsmans, R., Peeringa, J., Pierik, J., Snijders, E., Van Hees, M., Wijnants, G.H. & Wolf, M.J. (2003) Feasibility Study of Floating Windfarms in Shallow Offshore Sites. Wind Engineering; Vol. 27, No. 5, pp. 405-418.

Organization

The Centre will consist of leading R&D partners and industries:

Research partners:
SINTEF Energy Research (SINTEF ER, centre management), MARINTEK, Institute for Energy Technology (IFE), Norwegian University of Science and Technology (NTNU), SINTEF Materials and Chemistry (SINTEF MC) and SINTEF ICT
Associate (international) research partners:
Risø DTU (DK), Massachusetts Institute of Technology (MIT, USA) and National Renewable Energy Research Laboratories (NREL, USA)
Industrial (funding) partners:

- Statkraft, StatoilHydro, Vestavind, Dong Energy, Lyse, Conoco Phillips (energy companies)
- Statnett (transmission system operator)
- Umoe Mandal, Aker Solutions, SmartMotor, ScanWind, Devold AMT, SWAY, ChapDrive, Fugro Oceanor, Vestas (manufacturers)
- Veritas (classification society)

Associate partners:
Innovasjon Norge, NORWEA

The research partners have a long history of collaboration and have since the last decade worked systematically in developing wind power know-how and solutions through RCN programmes, EU projects and bilateral industry projects. SINTEF ER is in collaboration with MARINTEK, SINTEF ICT and SINTEF MC seeking internal strategic funding for an offshore wind program within the SINTEF Group. The Centre will expand ongoing research activities[1,58,59,60], using existing labs (Fig. 3) and applying results from planned full-scale field tests (HyWind, etc.).

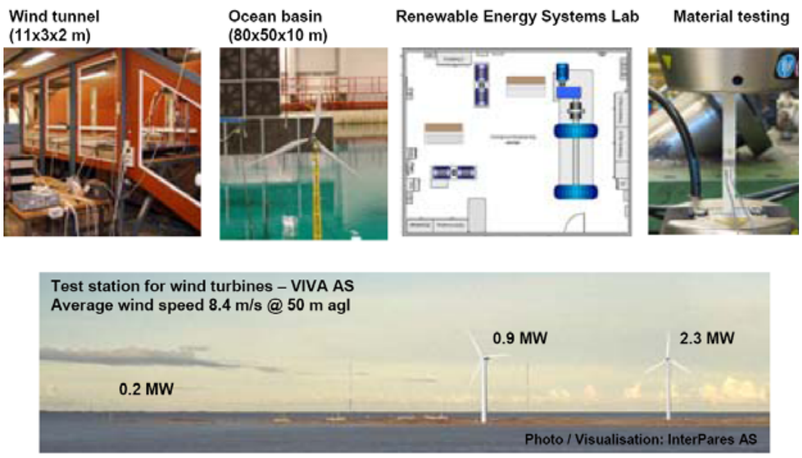

Fig. 3: Labs operated by SINTEF, NTNU and IFE.

The Centre is expected to develop by involving more research partners and industry, hereunder engaging professors in part-time positions, and pursuing opportunities to start new projects with industry, RCN and EU as partners for enhancing progress of deep-sea offshore wind technology.

[58] The Ocean Energy Research Program is a joint initiative by Statkraft, NTNU, Uppsala University and DTU. The program includes approximately 30 new scientific positions (PhDs, senior researchers and one professor) and initiatives to engage students into offshore renewable energy.
[59] NTNU-SUP: Offshore Wind Energy in Norway: Setting the Basis (186952) – phd programme - 2008-2011
[60] PhD-pool by Centre for Renewable Energy, www.sffe.no.

More industrial partners are expected to join. Initial contact has been made with Siemens Wind Power, EON, EDP and Vattenfall. Invitation of public bodies such as NVE, Enova and OED will also be considered.

The organization of the centre is shown below (Fig. 4). All partners are members of the General Assembly that gives guidance to the Executive Board (EB) and approves the annual implementation plans. The EB is responsible for the quality and progress towards the Research Council of Norway (RCN) and the financial contributors. EB will make critical decisions and resolve possible conflicts. EB comprises 10 representatives with industry majority and lead. Representatives in EB is the research partners (3), major financial contributors (3) and industry partners elected by GA (4).

The lead of the Centre Management (CM) is responsible for the day-to-day operation of the centre and reports to the EB. The CM has resources dedicated to a) recruitment and education and b) innovation and dissemination. The CM is further supported by the Scientific Committee (SC, NTNU lead) and the committee on Innovation and Commercialisation (IC, industry lead).

Work Package (WP) leaders coordinate the research tasks in the WPs and reports to the CM. Each WP consists of several Tasks. The Task leaders are responsible for preparing plans for EB approval and executing the work in accordance with budgets and deliverables defined in approved plans and within the centre contracts. Industry involvement in the individual WPs is through participating in a "core-team" consisting for each WP of the WP leader, task leaders and industry representatives with regular meetings (4 per year or more).

The industry involvement is enhanced by the IC. The IC will make sure that results from the centre are communicated to the industry partners (by seminars, newsletters, etc.), and that the possibilities for establishing new projects (including EU projects), products, services or processes with one or more partners are pursued. The IC will also link with Innovation Norway and their national network of SMEs.

The SC will be responsible for developing, in collaboration with the CM and WP leaders, a top quality PhD and post doc programme. This includes an active recruitment strategy, invitation of international capacities for giving lectures, arrangements of scientific colloquia and seminars, and exposing scholars to industry and leading international research groups.

CVs for key staff are enclosed, hereunder indication of WP leaders.

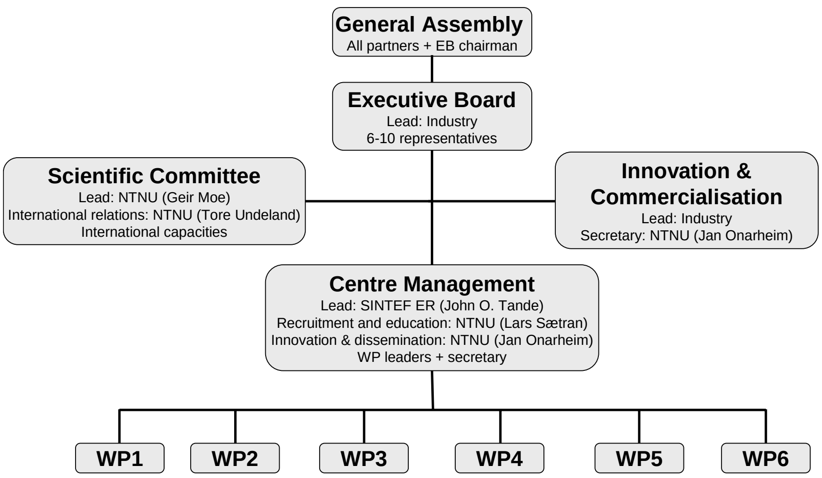

Fig. 4: Organization of the centre.

International cooperation

The research partners have a long history of international cooperation, e.g. through EU-projects, IEA[61], IEC[62] and EAWE[63]. The Centre will enhance this, hereunder international capacities (professors / researchers) are expected to join the scientific committee of the Centre (see Fig. 4). Agreements (LOIs) on close cooperation are received from Risø DTU, MIT and NREL, i.e. world-class leading on wind research. The cooperation includes a) participation in the Scientific Committee of the Centre, b) mutual short or long term visits by scientific staff for giving lectures, advising PhD students and collaboration on research, and c) PhD students staying for short or long term periods at the Centre and vice versa. More international agreements on cooperation is expected, e.g. with a German university or others.

Time Schedule

The centre is expected to run for 8 years starting early in 2009. Activities are already started through the ongoing KMB-project "Deep sea offshore wind turbine technology" constituting a good basis for a smooth start-up of the centre. Some time (6 months) is still expected for constituting the centre organization and scaling up activities. The General Assembly is expected to meet once per year, and the Executive Board twice per year. All WPs are expected to run for the full duration of the Centre, though with varying intensity as indicated by the yearly budget (Table 4). Milestones for the first 5 years of the Centre are listed below (Table 2).

Table 2: Milestones for the first 5 years of the Centre.

#	WP	Year	Description
1	0	2009	Constitution of Centre, incl. consortium agreement, detailed work plan and Executive Board
2	1	2010	Design tool for cost optimization of floating support structure and mooring system.
3	1	2010	Validation of numerical design tool against measurements from HyWind test (report)
4	1	2011	Characterization of micro-scale wind, wave and ocean current at a selected deep sea site in Norwegian offshore seas (numerical data and report)
5	2	2012	Basis for wind tunnel test of small scale blade-section with smart-blade features, including novel materials for improved strength/weight ratio and coating for improved aerodynamic performance (report)
6	2	2012	Novel lightweight direct-drive integrated generator concept (report)
7	3	2012	Design of new cost-effective bottom-fixed structure for use at 30-70 m water depths (report)
8	3	2013	Basis for scaled test of optimized floater and mooring system for use at 50-100 m water depths (report)
9	3	2014	Test of new coating in laboratory verifying lifetime protection against corrosion (numerical data and report)
10	4	2012	Numerical simulation models of offshore wind farms and electrical infrastructure for assessment of power system operation and grid stability (numerical models and report)
11	4	2014	Recommendation on technical solutions and control requirements for integration of offshore wind farms to shore and to oil and gas installations (report).
12	5	2012	Recommendations on concepts for access technology and logistics support (report)
13	5	2014	Description of novel condition monitoring system for offshore wind farms (report)
14	6	2013	Wind tunnel test of small scale blade-section with smart-blade features, including novel materials for improved strength/weight ratio and coating for improved aerodynamic performance (numerical data and report)
15	6	2012	Control scheme for load mitigation and minimization of motions of floating wind turbine (control algorithm and report)
16	6	2014	Scaled test in MARINTEK Ocean Basin of optimized floater and mooring system for use at 50-100 m water depths (numerical data and report)

[61] Present and recent participation in IEA Wind R&D activities include Annex 19 (cold climate), 20 (aerodynamics), 21 (dynamic wind farm models for power system studies, headed by SINTEF Energy), 23 (offshore), 24 (wind-hydro integration) and 25 (system operation).
[62] Participation in IEC TC88 include MT21 (power quality, convener by SINTEF Energy) and WG3 (offshore).
[63] SINTEF, IFE and NTNU are partners in the European Academy of Wind Energy (www.eawe.eu)

Budget and Finance

The budget (Table 3 and Table 4) is mainly for scientific staff (NOK 300 millions), and a minor part only for other expenses (NOK 20 millions), including cost of building blade-section and test in wind tunnel (NOK 4 millions) and building scale model of floating wind turbine and test in MARINTEK Ocean Basin (NOK 4 millions).

Funds for procurement, installation and operation of a dedicated wind, wave and current measurement facility are applied for as enclosed, and not included in the budget of the Centre presented here.

Very significant additional funds (in the order of NOK 100 millions) are required for establishing an offshore infrastructure for full scale field testing and demonstration of deep-sea wind technology (and other marine renewable sources). This is important for proving operation and bringing deep sea offshore wind closer to commercialization, and the Centre expects in cooperation with the industry to play an active role in pursuing funding for establishing such infrastructure.

Table 3: Budget in NOK millions for the 8 year period of the Centre. WP lead is indicated by shaded cells.

Activity	SUM	NTNU	IFE	SINTEF ER	MARINTEK	SINTEF MC	SINTEF ICT	Others(1)
WP1	40	16	8	0	8	0	8	
WP2	44	12	13	1	0	14	0	4
WP3	50	16	7	0	17	10	0	
WP4	48	16	0	32	0	0	0	
WP5	48	12	0	16	12	8	0	
WP6	58	20	4	8	22	0	0	4
Management	32	8	3	15	3	3	0	
SUM	320	100	35	72	62	35	8	8

1: Others are industry own finance (in-kind).

Table 4: Year by year budget per WP and partner in NOK millions.

Activity	2009	2010	2011	2012	2013	2014	2015	2016	SUM
WP1	8	8	8	8	2	2	2	2	**40**
WP2	6	6	6	6	6	6	4	4	**44**
WP3	8	6	6	6	6	6	6	6	**50**
WP4	6	6	6	6	6	6	6	6	**48**
WP5	6	6	6	6	6	6	6	6	**48**
WP6	2	4	4	4	10	10	12	12	**58**
Management	4	4	4	4	4	4	4	4	**32**
SUM	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**320**

Years shall be understood as relative to start-up date of the Centre, e.g. year 2009 means from start-up of the Centre in 2009 (likely in the fall) and 12 months ahead.

Financial support is confirmed by the enclosed LOIs. The industry part is exceeding the indicated sum. This will be used for expanding the budget above the indicated NOK 320 millions. Some LOIs are on condition that cooperation with CMR is established. These issues (budget, finance and cooperation) will be cleared in the period of constituting the Centre.

Table 5: Finance plan per annum in NOK millions.

	Cash	In-kind	SUM
Own finance (SINTEF, IFE, NTNU)	-	10	**10**
Industry	9	1	**10**
Research Council of Norway	20	-	**20**
SUM	**29**	**11**	**40**

Implications for industry / funding partners

Driven by the EU2020 target there is a strong commercial development of offshore wind farms at shallow waters. Deep sea wind farms are a subject of research and demonstration, and there is now a window of opportunity for Norwegian industry to take a strong position in Europe within this field. The Centre is in this context a strategic national tool.

Research in collaboration with industry has created value and new business. From the oil and gas industry, multiphase technology and LNG at Snøhvit are well known. The design of the Centre with industry integrated with research personnel in the WPs, will enhance dissemination and business development for the involved partners. Innovation Norway's national SME network on Ocean Energy will be exposed for the activities and results.

The possibility of gathering the actors (i.e. industry, SME, researchers) will create additional values that is not achieved in bilateral projects. The centre will facilitate the development of a Norwegian industrial cluster on offshore wind, in order to ensure increased value creation.

The research partners have a long-lasting tradition for commercial spinouts from research, e.g. Kjeller Vindteknikk, ChapDrive and SmartMotor.

The Centre will contribute to development of cost-effective deep sea wind farms being a key point for the commercial development of the involved energy companies. In the near future the vast majority of offshore wind farms will be bottom-fixed. Deep-sea wind farms based on floaters are expected to be commercial by 2020. The nature-given potential is enormous (14000 TWh/y within the Norwegian continental shelf). A realistic goal for Norwegian development is 20 TWh/y of offshore wind within 20 years. For EU ten times or more can be expected.

Statnett, as system operator, has a particular interest and need to know the implications of large scale generation from offshore wind farms. The Centre will contribute with such knowledge.

Manufacturers of equipment will get access to new knowledge, methods, procedures, tools and technology relevant for developing their business.

Veritas may apply results from the Centre as basis for developing new Standards and Recommended Practices on offshore wind.

Environmental consequences

The Centre is expected to enhance the development of offshore wind farms, and by this contributing to increasing the share of renewable generation in the power system. Assuming that this replaces generation from conventional coal fired power plants, emissions will be reduced with some 5-10 million tonnes of CO2 for every TWh of offshore wind generation. Deep sea wind farms may be used in conjunction with electrification of offshore oil and gas installations, and will by this directly contribute to reducing Norwegian emissions of green house gasses and reaching Kyoto targets.

Equal rights

The Centre will seek gender equality by encouraging women to apply for the PhD and post doc grants.