Foundations and Support Structures

THE CHALLENGE

In Europe the total capacity of installed offshore wind power is expected to increase from today's approximately 1 GW up to 20 – 40 GW in 2020 (see Figure 1). Today, only a small number of offshore wind farms with very few of them as large as the 160 MW plant with 80 turbines at Horns Rev have been installed or are currently under construction. The proposed exploitation of the enormous offshore wind potential will be technically and economically feasible only with much larger wind farms at more exposed sites.

Valuable experience regarding different aspects of offshore wind farm design such as installation, marine environment and component design is available from previous projects. Most of the offshore projects currently under way use mono-pile or gravity-based support structures designed for shallow water locations up to 20 m water depth only. Future sites in European waters will require deep-water foundation concepts though. Beside the challenges these site conditions pose, offshore wind farms of the future will have a typical installed capacity of 400 MW and will be equipped with turbines in the 5MW class and possibly larger, involving new installation and maintenance strategies.

Therefore, the primary objective of work package (WP) 4 Offshore Foundations and Support Structures is to develop innovative, cost-efficient wind turbine support structures to enable the large-scale implementation of offshore wind farms across the EU, from sheltered Baltic sites to deep-water Atlantic and Mediterranean locations, as well as in other emerging markets worldwide. The WP will achieve this by seeking solutions which integrate the designs of the foundation, support structure and turbine machinery in order to optimise the structure as a whole. Particular emphasis will be placed on large wind turbines, deep-water solutions and designs insensitive to site conditions, allowing cost-reduction through series production.

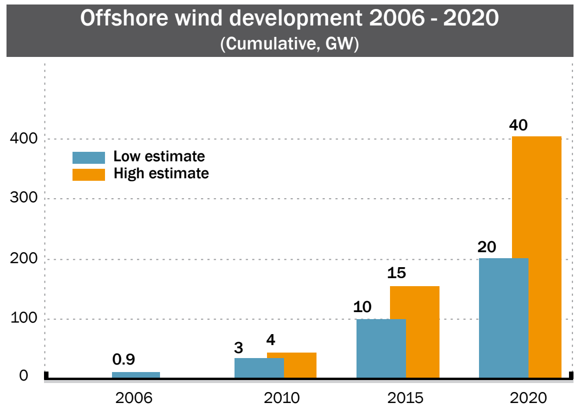
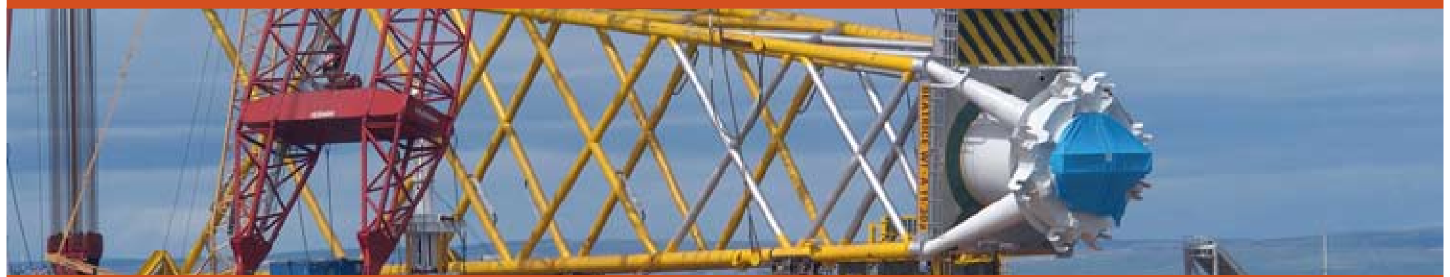


Figure 1: Offshore wind development up to 2020 [EWEA].

UpWind

SIXTH FRAMEWORK PROGRAMME



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THE RESEARCH ACTIVITIES

While innovative solutions for the rotor nacelle assembly will result from the other WP's, the emphasis of this WP lies on the support structure and the interaction of the design of the support structure and the rotor nacelle assembly. The research activities are divided into three areas, as shown in the table below.

The objectives of Task 4.1 are mitigation of dynamic support structure loading and compensation of the inherent variability of site conditions within a large wind farm. The integration of support structure and turbine designs and the use of smart turbine control are expected to achieve this. The task will mainly focus on the development of control algorithms, where different methods ranging from operational control to dynamic control will be further evaluated in order to select the most promising approaches for development. Simultaneously, a reduction of the site sensitivity of structures (e.g. different conditions with respect to water depth, soil, wind and waves) will be attempted by employing the control system, structural tuning and the selection of particular structural concepts.

In Task 4.2, the goal is to develop support structure concepts for water depths beyond 30m through innovative bottom-mounted, very soft or floating concepts. In this task, current design practice and experience will be merged with the new techniques from Task 4.1 and applied to concept development for deeper water. The planned method is based on a preliminary review of design and installation methods, and a study of the range and applicability of different foundation and support structure types, e.g. monopile (soft-stiff or soft-soft), tripod or lattice type with soft-stiff characteristics, and very soft compliant structures as well as floating structures.

Finally, Task 4.3 aims to enhance integrated design tools for the design of large numbers of structures at deep-water sites, and to actively support the development of dedicated international standards which specify best practice for the design of offshore wind farms (e.g. site-specific design, aerodynamic and hydrodynamic impact, low-risk structures, floating concepts). The development of innovative concepts in Tasks 4.1 and 4.2 requires enhancement of the capabilities of existing design tools and methods with respect to the description of turbine, support structures and site characteristics as well as the rapid processing of many similar designs.

fatigue loads and event-triggered dynamic loads (see Figure 2).

On the design level / base, an objective is to design the support structure with smaller water piercing members in order to reduce inertia-dominated fatigue waves. A further reduction of hydrodynamic sensitivity can be achieved by combining relatively stiff foundations and substructures with relatively soft tower designs. This will result in small deflections in the submerged part and associated low overall excitations.

Beside changes in the design characteristics, new approaches for operating

WP 4 "Offshore Foundations and Support Structures"		
TASK 4.1 Integration of support structure and wind turbine design	TASK 4.2 Support structure concepts for deep water sites	TASK 4.3 Enhancement of design methods and standards
Develop and enhance the integrated design process for offshore wind turbines	Design innovative bottom-mounted support structures (e.g. truss-type)	Design tools and methods for bottom-mounted support structures
Control concepts for mitigating aerodynamic and hydrodynamic loading	Analysis of very soft structures (monopile- or braced-type)	Design tools and methods for floating support structures
Compensation of site and structural variability	Design floating structures	Support of the IEC-61400-3 offshore standard

Table 1: Contents of WP4 "Offshore Foundations and Support Structures".

RESULTS AND EXPECTATIONS

The major goal of this WP is to enable large-scale implementation of offshore wind farms. This aim can be reached mainly through cost-effective design solutions – both on the turbine and the support structure side. In Task 4.1, the first studies focused on the mitigation of aerodynamic and hydrodynamic loads on the total offshore wind turbine system. Load mitigation can be tackled at four different levels, i.e. at the design base, operational control, dynamic control of offshore wind turbines might result in lower total loading. Certain loading situations such as varying site conditions or failure/emergency cases might be solved with the aid of advanced operational control strategies. These strategies could imply new control devices like tower feedback or a tower mass damper, but also changing the operational definitions of the turbine model.

As already addressed while discussing operational control, new dynamic control systems are expected to be the main

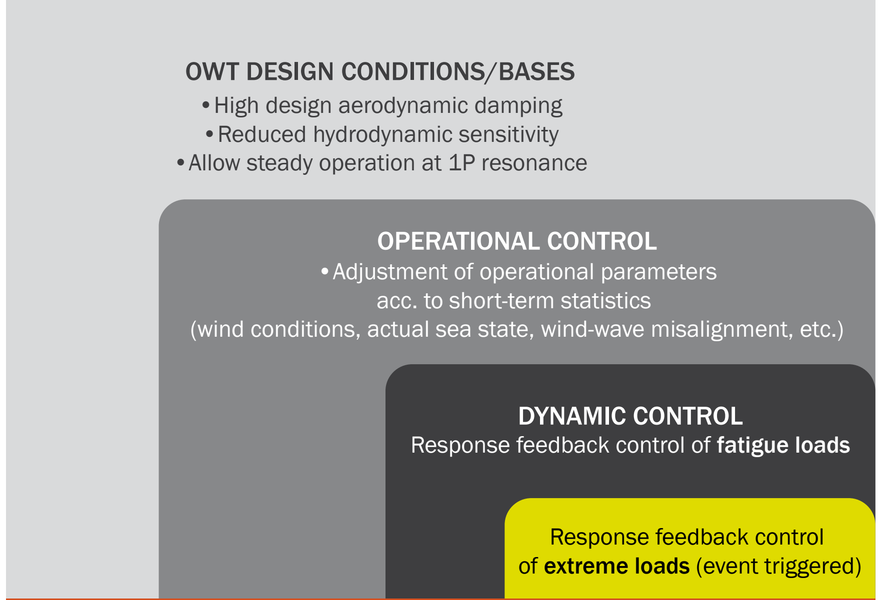

Figure 2: Levels of load reduction concepts.

solution for mitigation loads on the offshore turbine. Indeed, different studies have shown that relatively small pitching actions can generate quite effective damping of the fore-aft tower top loading.

Therefore, a further preliminary study of a tower feedback control device was performed and showed promising results. This device will be further developed for offshore purposes, since especially wave excitation dominates the vibrations of the system in deep-water locations.

The first step in Task 4.2 was to evaluate different support structure types with the aid of an evaluation matrix. The matrix was used to identify critical aspects for the choice of support structure concepts for various conditions – e.g. varying water depths or soil conditions. A further objective of the analysis was to gain insight in the problems involved in designing support structures for offshore wind turbines in deeper waters. After this step a review of different installation methods for various existing bottom-founded support structure types was performed. Following these pre-studies, a cost model for support structures was developed, which will be a main decision driver for later design solutions and developments, especially in Task 4.1.

A first preliminary design is being made for a support structure solution, whereas different solutions will be compared in the end of the project. An UpWind reference support structure design for a given deep-water offshore site will be presented by the end of the project.

In the third Task 4.3, a review of various models for irregular, non-linear waves suitable for design purposes was performed in order to assess their relevance for future offshore wind farms. In addition, support was given to the finalisation of

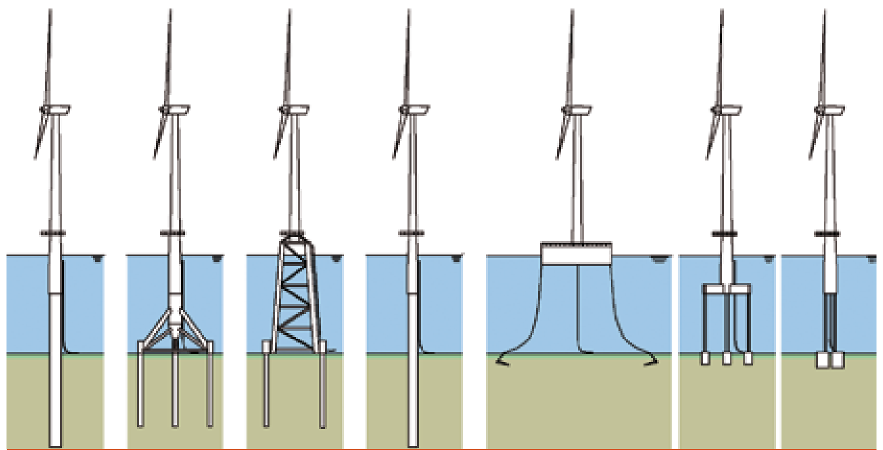

Figure 3: Different support structure concepts. From left to right: monopile, tripod, jacket, compliant, barge floater, tension leg platform and spar floater structure.

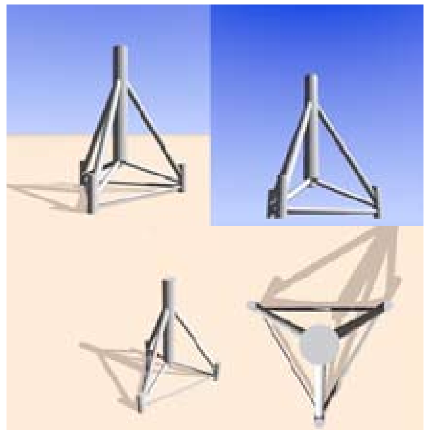

Figure 4: Tripod structural model for test simulations.

the draft of a new international standard for offshore wind turbines IEC 61400-3 ed.1. In parallel a new design tool for integrated simulations of offshore wind turbines with advanced deep-water support structures was developed. In the support structure part, a finite element based code with hydrodynamic loading capabilities is employed for the dynamic modelling of arbitrary space frame structures. As common for finite element codes, structures are defined on the basis of many discrete elements by definitions of their node connectivity, properties and types. The rotor nacelle assembly with all required aeroelastic, electro-mechanical and control features is modelled with relatively few model degrees of freedom with the FLEX5 simulation code, a tool used throughout the wind industry. A well-defined interface between both codes allows fully-integrated aero-elastic simulations without major invasive changes in the source code and algorithms of the subsystems codes. The new software capabilities are demonstrated by the analysis of a typical tripod support structure (see Figure 4).

The verification of the design tool for bottom-mounted support structures is ongoing, but first results in comparison to the industry standard wind turbine simulation code Bladed are promising. After a successful verification of the present tool, the next step will be the analysis of other arbitrary structures such as jackets.