Self-aligning floating wind turbine has deep water potential

The SelfAligner floating offshore wind turbine is designed for use in deep water Source: COG

HyStOH Within the framework of the joint HyStOH project, a self-aligning wind turbine has been developed. The concept, consisting of a simple, cost-effective, lightweight installation with low environmental impact, was optimised at the Hamburg University of Technology (TUHH) by extensive numerical simulations and model tank tests. The project is funded by Germany's Federal Ministry of Economic Affairs and Energy. In the following article, project partners Jens Cruse, Cruse Offshore GmbH; Moustafa Abdel-Maksoud and Alexander Düster, TUHH; Andreas Bockstedte, DNV GL; Gerrit Haake, Jörss – Blunck – Ordemann GmbH; and Sönke Siegfriedsen, aerodyn engineering GmbH, present the concept.

For offshore wind energy production in regions of deep water, Hamburg-based Cruse Offshore GmbH (COG) has designed and constructed an innovative floating system, the SelfAligner floating offshore wind turbine (FOWT). The structure of the facility is a self-aligning, semi-submersible platform that follows the wind direction automatically. The foundation is moored at a single point and uses a turret buoy to rotate freely around its anchor point. A downwind rotor and an airfoil-shaped tower induce self-aligning turning moments to follow changes of wind direction.

Construction, installation, and maintenance of fixed foundations are particularly expensive in deep waters. Therefore, to get round this challenge, the use of floating wind turbines is a suitable option, with floating foundations anchored to the seabed. The HyStOH, (hydrodynamic and structural-mechanical optimisation of a semi-submersible for offshore wind turbines) collaborative project has resulted in the design of an efficient, robust, and cost-effective facility suitable for mass production.

The concept

The foundation is attached at a single point and turns freely around a turret buoy anchored to the seabed (Figure 2). A downwind rotor and a profiled tower induce aerodynamic forces that create self-aligning torque, allowing for a passive-

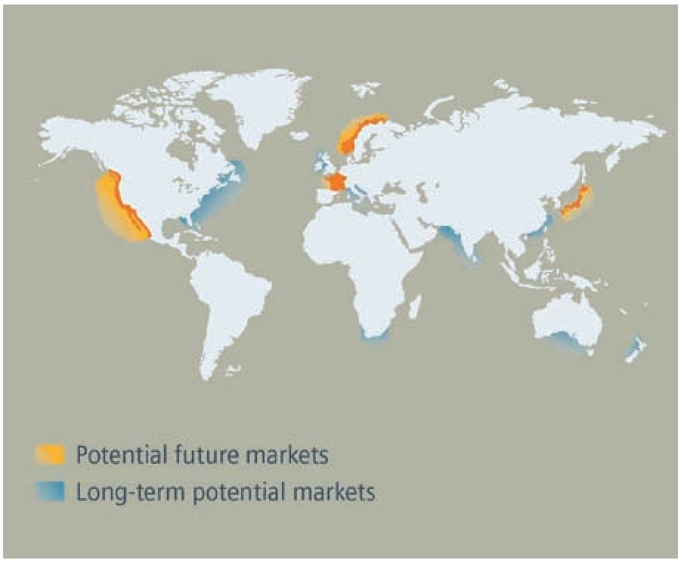

Figure 1: Potential markets for floating wind turbines Source: Siemens

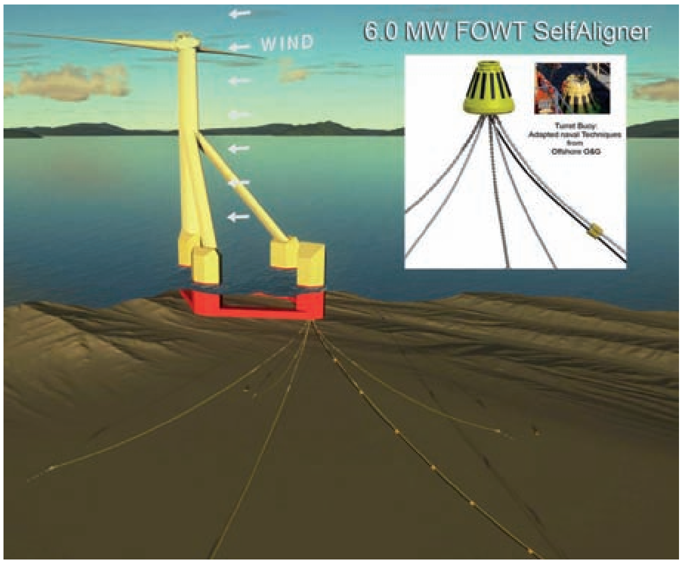

Figure 2: Design of the SelfAligner FOWT Source: COG

guided alignment of the entire floating installation.

The dynamic behaviour of the floating foundation was investigated and optimised in cooperation with the following consortium partners: Institute for Fluid Dynamics and Ship Theory, Institute for Ship Structural Design and Analysis, Hamburg University of Technology (TUHH), DNV GL, aerodyn engineering GmbH, and Jörss-Blunck-Ordemann GmbH.

The foundation of the offshore wind turbine is very stable, despite its reduced complexity. It is stabilised by approximately 5,000 tonnes of ballast water – even in harsh weather and wave conditions, the accelerations at the hub height of 100m are low and do not affect operation. The steel construction of the ›

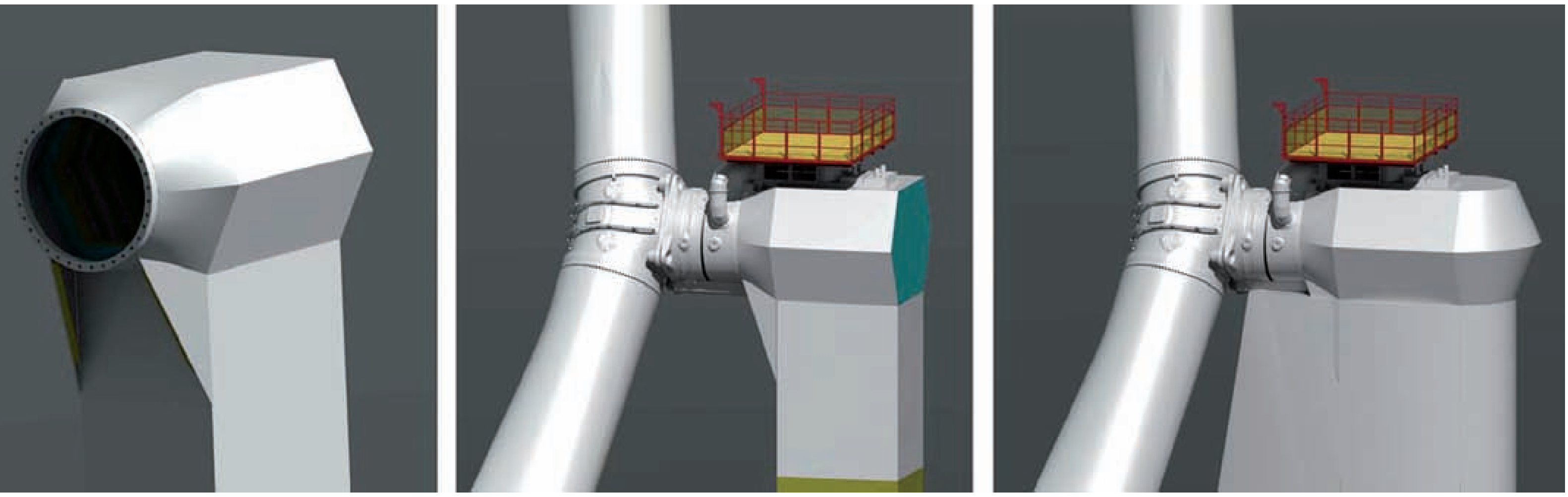

Figure 3: Tower head design, with and without aerodynamic cladding made of fibreglass Source: COG

floating foundation is based on lightweight shipbuilding methods and can easily be produced on automated production lines in existing shipyards.

The SelfAligner FOWT should prove easy to install in waters of typical continental shelf depths. The ready-to-use turbines, assembled in dock or alongside a pier, can easily be towed to their positions and, in a simple process, can be connected to the turret buoy mooring without the need for a special installation vessel. For large repairs, shutdowns or upgrades, the units can be towed back to the coast. Maintenance manoeuvres are easier and require less sophisticated equipment. This also increases the safety of the staff.

Construction noise, a problem for some marine creatures, is limited. Provided that the seabed comprises suitable material, the suction anchor system is easy to install and remove. It covers a relatively small area and can be removed, leaving almost no residue.

Criteria for the selection of the wind turbine were low weight and trouble-free operation. The Super Compact Drive (SCD) turbines, developed by aerodyn engineering GmbH, fulfill these requirements. SCD technology is a fully integrated concept for lightweight drives and wind energy converters, reducing the mass of the tower and its foundations. As an industrial partner in the HyStOH project, aerodyn has taken over the development and integration of the wind energy turbines into the tower structure. Thus, the experience in turbine design could be combined with a new floating foundation technology for a competitive market option.

Based on the turbine load rating, initial load limits were determined for the tower head connection. The study included parameters such as rotor orientation, turbine power, number of blades, rotor diameter, hub height, and type class. In addition, the necessary mass data for the rotor-nacelle assembly (RNA) was determined and used for the structural pre-planning of the tower and foundations. The calculated aerodynamic load and more detailed turbine data were used to verify the high-fidelity modeling of other project partners.

The design of the RNA was carried out by aerodyn, based on the derived loads in a fully coupled simulation environment considering aeroelasticity, hydrodynamics, structural behaviour, and wind turbine control. The results went into the design process for the tower nacelle interface, gearbox, generator, rotor hub, and rotor blade design. Finally, a concept for the powertrain arrangement and the rotor blades was derived taking into account the float-specific regulatory

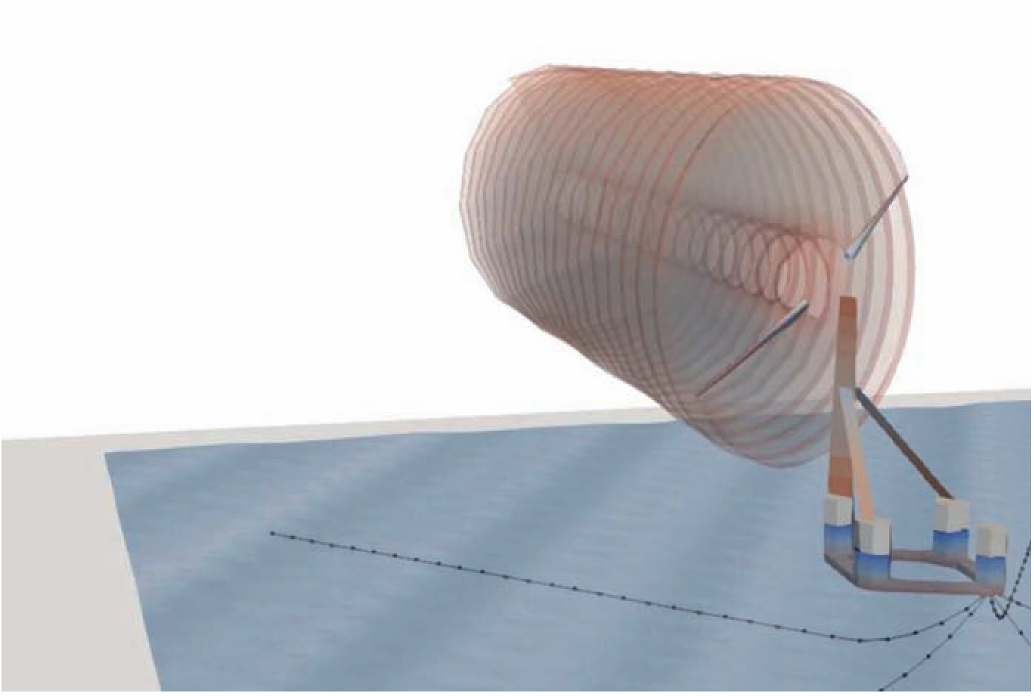

Figure 4: panMARE simulation Source: TUHH

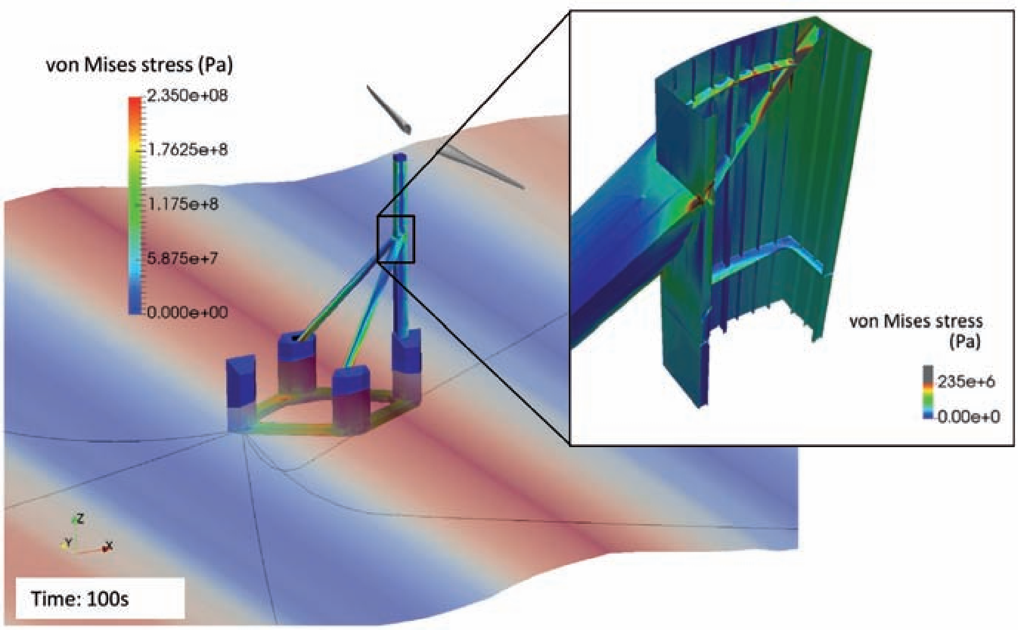

Figure 5: Simulation of FSI and stress analysis with detailed FE model

Source: TUHH

requirements to enable a fully functioning wind turbine on the floating foundation. The design takes into account site-specific environmental impact, including operational burdens and survival conditions.

Hydrodynamic behaviour

Accurate prediction of the motion behaviour of a floating wind turbine is a critical issue in the design and development of a self-aligning system because many factors must be considered. The ability to self-align depends not only on the momentary forces of the sea and the current but also on the aerodynamic loads, which are mainly caused by the tower and the turbine rotor. In addition, the tension of the anchor lines that hold the system in place contributes significantly to the forces acting on the floating structure.

Furthermore, extra forces are induced by wind turbine operation due to different dynamic effects. Small roll and pitch motions of the platform create large gantry and rotor motion amplitudes in the longitudinal (along the axis of rotation) and transverse directions. The movement along the longitudinal direction causes a complex interaction between the rotor and its wake. The movement in the transverse direction induces a gyroscopic moment. Reliable simulation of the platform movement requires the consideration of all acting forces and moments.

During the design process, all the above-mentioned loads were included in the time domain. The applied numerical simulation method for the calculation of the aero- and hydrodynamic behaviour required accurate calculation of the forces of the rotor at oblique flow. The transient hydrodynamic loads strongly depend on the wetted surface of the platform at any time. Therefore, the relative position between the actual waterline of the platform and the wave height must be constantly updated. In particular, the resistance of self-aligning floating wind turbines must be calculated with great accuracy, since it has a strong influence on the movement of the platform.

To meet the requirements, the simulation method panMARE was further developed at the Institute of Fluid Dynamics and Ship Theory of the TUHH and used as part of the project to simulate the comprehensive load of turbine and platform. This method is used to calculate the three-dimensional aero- and hydrodynamic flow field. The calculated rotor flow includes the trailing surfaces of the rotor blades and their interaction with the rotor, taking into account the rolling and pitching movement of the plant.

The simulation enables calculation of the current wetted surface of the structure. In addition, the method allows the inclusion of external forces such as hull resistance. The project partners have developed a dynamic anchoring model capable of detecting the tensile forces at the anchorage, depending on the movement of the structure and the characteristics of the sea. When calculating the movements of a floating installation such as this, the coupled aero- and hydrodynamic forces, as well as the anchor forces, are treated synchronously [1].

In particular, panMARE is useful for predicting movement under extreme load conditions and analysing self-alignment properties [2] [3]. The passive alignment of the platform and rotor can be simulated for different wind, flow, or shaft angles. Likewise, dynamic conditions with changing wind or flow directions or speeds can be simulated. A verification study was then performed by comparing simulation results with established numerical methods [4]. For the examined load cases, a good compatibility was obtained. In addition, wind tunnel and wave tank trials were conducted to validate the aerodynamic and hydrodynamic models.

Numerical simulation of the fluid-structure interaction

Floating wind turbines experience significant stress in rough seas. To ensure their structural integrity and evaluate their performance, it is important to consider fluid-structure interaction (FSI). In this way, the influence of the aero- and hydrodynamic fluid forces on the movement behaviour of the structure and also on the deformations and stresses of the individual components must be determined. Extensive FSI simulations using detailed finite element (FE) models of the SelfAligner FOWT were carried out at the Institute for Ship Structural Design and Analysis (Figure 5).

To simulate the FSI, a software called comana (5) was developed, enabling a partitioned approach to coupled multi-field problems. Due to their separate treatment, the variables could be assessed independently, enabling a flexible approach and more comprehensive FSI analysis. In this project, the simulation method panMARE (Institute of Fluid Dynamics and Ship Theory) was coupled with the FE method-based ANSYS (ANSYS Academic Research Mechanical) [6]. Precise stress analysis was an essential part of the project and the strategy that was adopted enabled ›

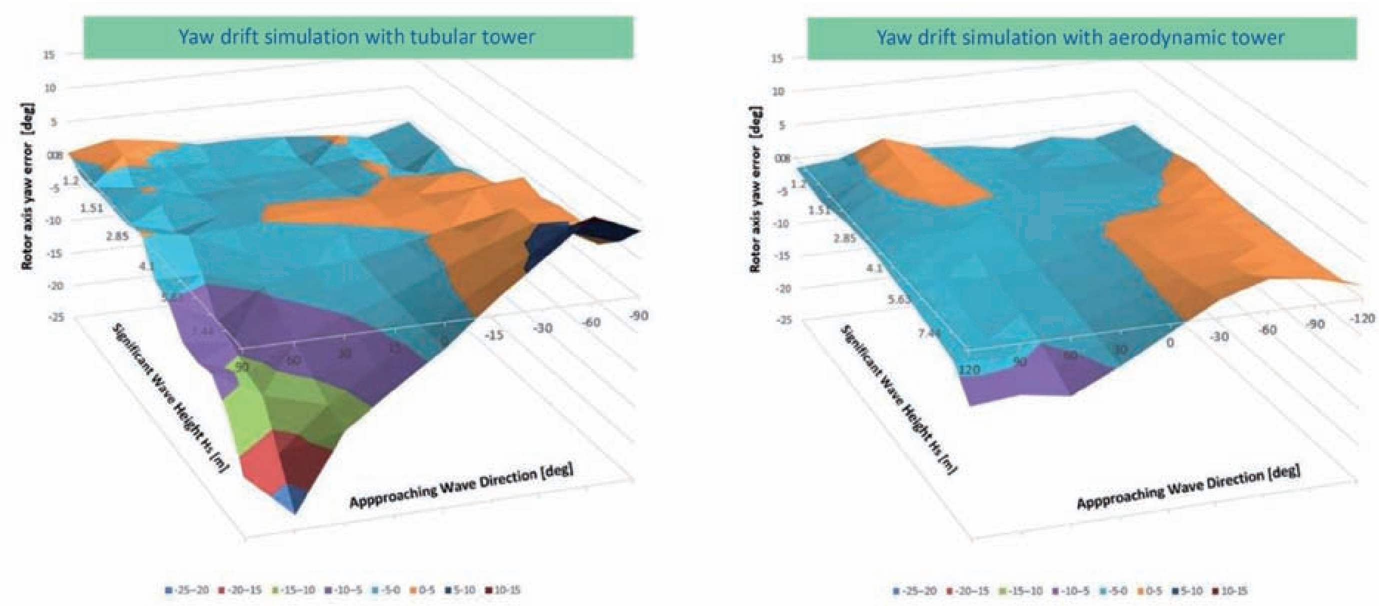

Figure 6: Yaw drift dependent on wind-wave offset with round (left) and profiled tower (right) Source: DNV GL

detailed and comprehensive structural assessment of the SelfAligner turbine structure.

Definition of the design principles and the load simulation model

The aerodynamic design of the SelfAligner FOWT and a special anchorage enhance the passive self-alignment of the platform in the current wind direction and make the active yaw system of conventional wind turbines superfluous [7] – see Figure 6. The development of this innovative floating wind energy concept was part of the project, which gained Renewables Certification (RC) from DNV GL. The classification society contributed to the design F document, which includes the technical boundary conditions such as general environmental conditions, design methods, safety, testing and validation procedures, as well as the codes and standards for future concept development and prototype certification.

The project partners were provided with the definitions of design load cases for the floating structure. With the simulation program Bladed, load calculations were carried out using a fully dynamically coupled, integrated simulation model [8]. This model covers the entire turbine, the tower, the float, and the anchorage while interacting with turbulent wind and stochastic sea conditions, and incorporating non-linear turbine control. DNV GL supported the project partners in the structural calculation and in the design of the anchoring system.

Constructive design of the SelfAligner FOWT

The idea of using shipbuilding principles is to reduce the steel weight and manufacturing cost of the support structure, making the most of automation in the manufacturing process. In addition, the design of the structure should generate forces to align the rotor.

Based on the aerodynamic requirements for self-alignment, the tower is located on the leeward floater, which is connected to the middle floats by two struts. The pivot and anchor point is always on the windward side to maximise the lever arm of self-aligning forces. Tower and struts are designed to optimise the aerodynamic behaviour as symmetrically profiled cross-sections. For the construction, only a stiffened box girder is used, while the leading and trailing edges are made of lightweight construction material such as fibreglass, with no additional support required.

The structural design of the SelfAligner FOWT for manufacturing in standard shipbuilding processes poses a new challenge. The extreme and fatigue loads on a wind turbine during power genera-

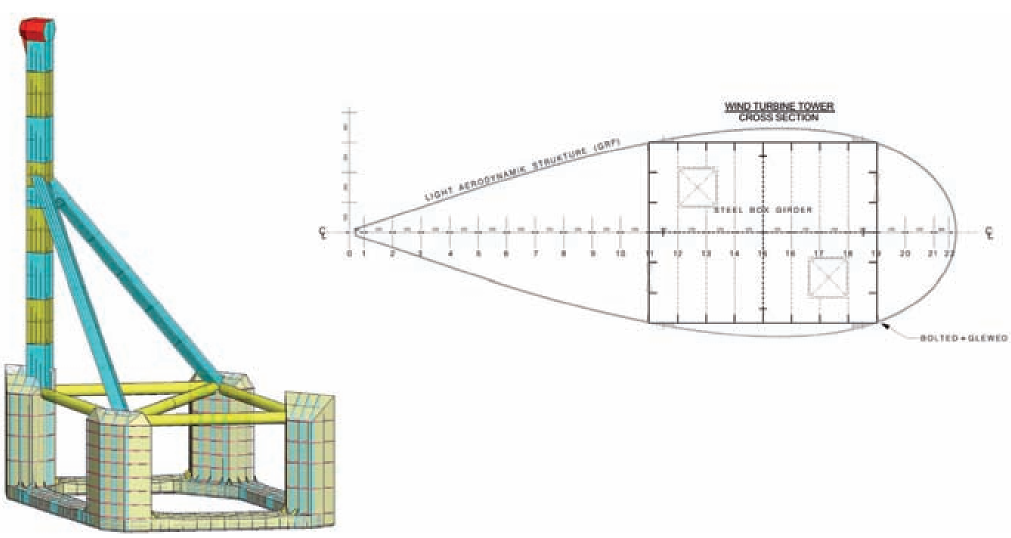

Figure 7: Optimised design: structure (left), the cross-section of the tower (right) Source: COG

tion are significantly different from those imposed on a ship. The design and manufacture of the wind turbine support structure differ from traditional shipbuilding methods and therefore compromises are necessary in terms of material thickness and manufacturing processes. Due to the limited permissible wall thickness of the mast and the struts, the stability of the structure must be carefully analysed. Stiffening elements of different sizes in the longitudinal and horizontal directions were therefore optimised in terms of number and dimensions to reduce the weight of the structure. The result is shown in Figure 7.

Regarding the material fatigue test, there are several standard details for connection points of T- and HP-profiles known in the shipbuilding industry. Details of the components relevant to the fatigue check can lead to a reduction of the stress concentration factors (SCF) by a factor of three or more by design adaptation. In particular, the connections of the tower and the struts to the floats, in which the forces are transmitted to the float, must be carefully designed. To cover all relevant aspects of the aerodynamics, the wave motion, and the anchor system, loads were analysed in a fully coupled model.

Logistics concept

To account for the requirements and experience in the investigation of assembly logistics, interviews were conducted with all project partners at the Fraunhofer Center for Maritime Logistics and Services CML. The results of the interviews and further research were evaluated and included in a logistics concept.

Conclusion

The HyStOH project has succeeded in developing the self-aligning wind energy plant, SelfAligner FOWT. For the calculation of the motion behaviour of the plant, a simulation model was created which can show the coupled aero- and hydrodynamic impact combined with the anchoring forces. Based on the simulation results, the geometry of the plant was optimised and analysed for strength using FSI. It resulted in a relatively light structure compared with other floating wind turbines. It is robust because of its simple construction. For the demanding offshore use in windy regions, such a system is more suitable than one with active yaw steering. Commercial exploitation in the foreseeable future, therefore, is likely.

Acknowledgments

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Next-generation floating offshore wind turbine foundation

Illustration of the new floater design

NEW DESIGN | Tractebel Overdick has developed a new floating wind foundation concept for 15+ MW wind turbines with a "hydrogen ready" option. The floater design is said to have been optimised to reduce the overall costs of the floating foundation, through all major fabrication, installation, and operational aspects. It provides sufficient deck and sheltered areas to install modularised "add-on packages". Hydrogen production modules and exporting equipment can easily be added and compartments of the floater can be used as buffering tanks, the German-Malaysian company said. Alternative modules such as hydrogen field supply and bunkering or high-voltage export modules may further be considered to make the future floating offshore wind farm more versatile.

Offshore hydrogen production

The company has also designed an updated large-scale offshore hydrogen production platform. It is based on a previously developed 400-MW hydrogen production platform. The main focus of the new version was to increase the overall capacity up to 800 MW. The hydrogen platform can now be extended by specific modules which are increasing flexibility and improving overall performance. The add-on modules comprise a high-voltage export module, enabling the export of electricity in parallel with hydrogen, an interconnection module to operate the hydrogen platform in a cluster of offshore high voltage substations, and an offshore hydrogen bunkering module, allowing the direct supply of hydrogen to the assets operating in the field.

Illustration of the hydrogen production platform

Source for both illustrations: Tractebel Overdick