Themeninfo **I**/2012

A compact guide to energy research

BINE
Information Service

RAVE – Research on the offshore test field

Basic research and stress tests

A service from FIZ Karlsruhe

Straight to the point

High, far, deep and rough – this is how the RAVE research initiative itself describes the typical challenges faced by offshore wind energy. During the next few years, a dozen large-scale wind farms are being installed far off the coast of Germany in the North and Baltic seas. These are already earmarked to make up more than one third of the installed wind energy output by 2020. The sea-based wind farms will therefore make a considerable contribution to generating 35% of electricity from renewable energies by 2020, as envisaged by Germany's energy policy. That is roughly twice that produced in 2011. Since Germany's near-shore maritime areas are almost entirely protected as nature conservation areas, only areas in the exclusive economic zone (EEZ) can be considered for offshore wind energy, i.e. beyond the 12-mile zone. This means that, in comparison with our European neighbours, these wind farms will be situated further away from the coast and at greater depths.

Even if onshore wind energy has by no means exploited all the existing possibilities (e.g. repowering), the offshore wind sector offers new and interesting prospects for generating electricity. Here the wind speeds are greater than on land throughout the year and there is less turbulence. At sea it is also not necessary to limit the height of the wind turbines. On the other hand, however, there are greater investment and operating costs. The maintenance and repair of the wind turbines are also considerably more complex than on land.

The offshore sector therefore represents a considerable challenge in terms of the technology. The turbines have to be specially adapted in order to withstand the severe storms and squalls, the interaction between wind and wave energy, and the salty atmosphere. In addition, the wind farms have to be compatible with the marine ecosystem. For this reason, technological, marine and ecological aspects have been researched for more than ten years in order to determine the necessary long-term data for the technology and to protect nature. For example, Germany operates three automatic research platforms in the middle of the North and Baltic seas for this purpose: FINO 1 – 3. The next stage was taken in April 2010 when the German offshore test field "alpha ventus" commenced operation with 12 wind turbines. In 2011, 267 million kWh of wind power were produced there. As part of the applied research, operationally relevant research projects are in particular conducted here under the aforementioned RAVE name. The following brochure provides an overview of the preliminary findings from the research initiative.

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Fig. 1 *The alpha ventus wind farm. The two rows of three wind turbines at the front of the photo are Areva wind turbines while the ones behind are REpower wind turbines. The FINO 1 research platform can just be seen in the distance to the rear. The lower right image shows the neighbouring transformer station with a helicopter pad. Photo: AREVA Wind / Jan Oelker*

Stress tests in the middle of the ocean

Many people will be familiar with the use of the term RAVE in music, where it describes techno dance events. In the context of offshore wind energy, RAVE stands for "research at alpha ventus", a major research initiative that is investigating the use of wind energy in the "raving" oceans. With more than 40 project partners, it is supporting the construction and operation of the alpha ventus offshore test field. It is aimed at providing fundamental knowledge to optimise offshore wind energy.

The alpha ventus test field, which is located 45 kilometres north of Borkum at a depth of 30 metres, began operation in April 2010. It contains twelve 5-MW wind turbines that are arranged in an approximately 800 x 800-metre grid. Half of the turbines come from the REpowercompany and use a jacket structure, while the other half come from Areva Wind and use a tripod structure (Fig. 1). The developer and operator of the test field is Deutsche Offshore-Testfeld und Infrastruktur GmbH & Co. KG (DOTI), a consortium comprising the three energy supply companies EWE, E.ON and Vattenfall. Four of the wind turbines are equipped with numerous sensors in order to determine the external forces acting on the structures and to record as much operating data as possible. In particular, it is intended to incorporate the operating data and experience gained into the "Monitoring of offshore wind energy utilization" project (Offshore WMEP). Other international operators of offshore wind farms have also offered to participate in the OWMEP project as long as the confidentiality of the operating data is maintained. All participants have been assured that the data will be protected.

The 12 wind turbines are linked via inter-array cabling with a transformer station, which is installed on a platform within the test field. Here the electricity is converted into 110-kV current and fed to the mainland via a 60 km-long three-phase connection. Alpha ventus is located in the immediate vicinity of the FINO 1 research platform.

Around 40 research institutes, companies and authorities are working in 34 individual projects as part of the RAVE research initiative. Page 15 shows the structure of the initiative. Central components in the concept include the project coordination, which is being conducted by the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) in conjunction with the RAVE steering committee, and the central measurement service, which is being supervised by the Federal Maritime and Hydrographic Agency (BSH).

The areas being focussed on as part of RAVE are:

- Operation, measurement technology and coordination
- Foundation and support structures
- Wind turbine technology and monitoring
- Grid integration
- Currents and turbulences in the wind farm
- Accompanying ecological research
- Safety and social acceptance

This BINE-Themeninfo brochure presents three main research areas in detail. The first section is concerned with improvements to the wind turbines, rotor blades and foundation structures. Themes covered here include the ongoing investigations into the wind turbine technology and possibilities for lowering costs, reducing weight and optimising the maintenance intervals. The following section then focuses on the comprehensive accompanying research. Oceanographic and geological investigations are presented here that include research into scouring. This section is rounded off with a look at accompanying ecological research based on the StUK standard assessment concept. The third section examines how the large volumes of wind power generated offshore can be integrated into the electricity grid and how the supply and demand can be better aligned. In particular, it takes a look at the requirements for wind power made by the grid service providers in conjunction with wind farm cluster management and wind output forecasts.

Fig. 2 *A floating crane transports a tripod structure for an Areva Wind turbine into the construction field. Photo: AREVA Multibrid / Offshore foundation / Jan Oelker*

Wind turbine technology and components

It is considerably more complex and therefore much more expensive to erect wind turbines at high sea than it is onshore. It is additionally only possible to gain access to the turbines for maintenance and repair work when there are calm seas. Together with the technical reliability of the wind turbines, these factors have a decisive impact on the overall economic feasibility of wind farms.

Wind turbines designed for offshore use must feature high availability, low downtimes, considerable efficiency and long service lives, whereby the turbine weight, reliability and the optimisation of the maintenance intervals are factors that have a particular impact on the economic feasibility.

The ‘offshore wind turbine’ system

In regards to the rotor blades, the main focus is on improving the aerodynamic efficiency and reducing the manufacturing costs. Rotor blades for use at sea must be very durable and be easily accessible for maintenance purposes. In contrast to rotor blades for onshore use, however, they do not necessarily have to be optimised to reduce noise emissions. The wind turbines used in alpha ventus have rotor diameters of 116 and 126 metres, and, at their rated rotational speed, achieve blade tip speeds of 288 km/h and 324 km/h respectively. Despite their lightweight structure and the use of composite fibre material, the rotor blades can weigh up to 19 tonnes. They are continually exposed to dirt and salt particles in the ocean air, which poses high demands on their coating.

The manufacturers have adopted different ways to connect the rotor to the generator. In addition to directly coupling the hub to the generator (“direct-drive”), there are versions where one or more gear stages convert the mechanical output with a high moment and low rotational speed into a smaller moment with a higher rotational speed. The two types of wind turbines installed at alpha ventus both use gear systems, whereby the one-step planetary gear installed in the M5000 from Areva Wind GmbH transfers the moment with a single-ratio transmission to the medium-speed synchronous generator. This integrated drive and generator system enables the forces and moments of the rotor to be transferred over short distances within the tower.

With the second type of wind turbine installed at alpha ventus, the 5M from REpower, a distributed drive train was implemented in which the hub is connected to the gear system via a double-supported rotor shaft. Although this system requires a larger construction space and uses a multi-stage gear transmission, it also has a lower weight in regards to the generator. If the gears need to be replaced, the rotor and the shaft do not have to be removed but can remain on the machine bed while the gearbox is dismantled.

For mechanically and electrically converting the energy, the manufacturers rely not just on the relatively cost-efficient, doubly fed asynchronous generators that have also proved themselves on a large scale onshore but also on synchronous generators. The advantage of synchronous generators is that they can easily provide reactive power, which is beneficial for integrating the generated wind power into the grid. If generators with permanently magnetic energisation are used instead of separately excited synchronous generators, this saves on weight and reduces the tower head mass (total weight of the nacelle rotor system).

Foundation structures and tower head mass

The tower head mass has a considerable impact on the cost of offshore wind turbines. The forces and moments acting on wind turbines during operation and at standstill

Fig. 3 *Erection of a REpower wind turbine*
Photo: DOTI 2009

result from the wind and wave loads and have to be absorbed with solid support structures. The support structures are connected to the seabed and extend above the water surface. If the tower head mass can be kept small, this means that the respective tower and support structure do not have to be that strong, and hence are more cost-effective. The support structures make up around one third of the investment costs for offshore wind turbines.

The environmental conditions were the decisive parameters when designing the turbine components and support structures at alpha ventus. These include the higher average wind speeds at sea, a water depth of approximately 30 metres and corresponding wave conditions. Welded lattice structures, such as jackets and tripods, provide suitable foundations at this depth. At alpha ventus, the REpower wind turbines are mounted on jackets as foundation structures. Jackets have rectangular shapes and are also utilised with other maritime technologies, such as gas and oil platforms. The FINO 1 research platform and the wind farm's transformer station are also constructed on jacket foundations.

The six wind turbines from Areva Wind have been anchored to the seabed using tripods as the foundation structure. Here pipes create a three-sided pyramid (tetrahedron) that supports a central pipe in the middle. In order to fix the support structures to the seabed, both the jackets and tripods are anchored to the seabed using 35 to 45 metre-long piles. Once the support structures have been placed in position, the individual tower segments are mounted above the water surface. The nacelle is then mounted and the rotor star connected. With 90 and 92 metres, the hub heights of the installed wind turbines are less than the prototypes constructed on land. The foundations have a decisive impact on the safety of the overall wind turbine system. For example, extreme deformations caused by excessive surface loads or changes in the stiffness of the building ground can influence the operation of wind turbines or even cause the entire structures to fail.

Maintenance and cooling

All of the main components in the offshore wind turbines are designed with large maintenance intervals in mind in

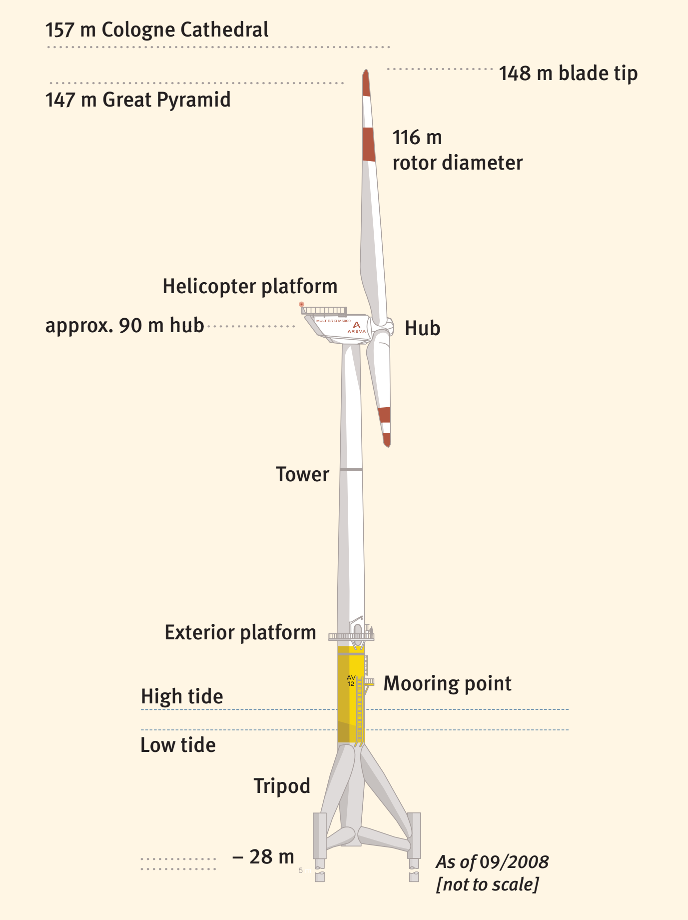

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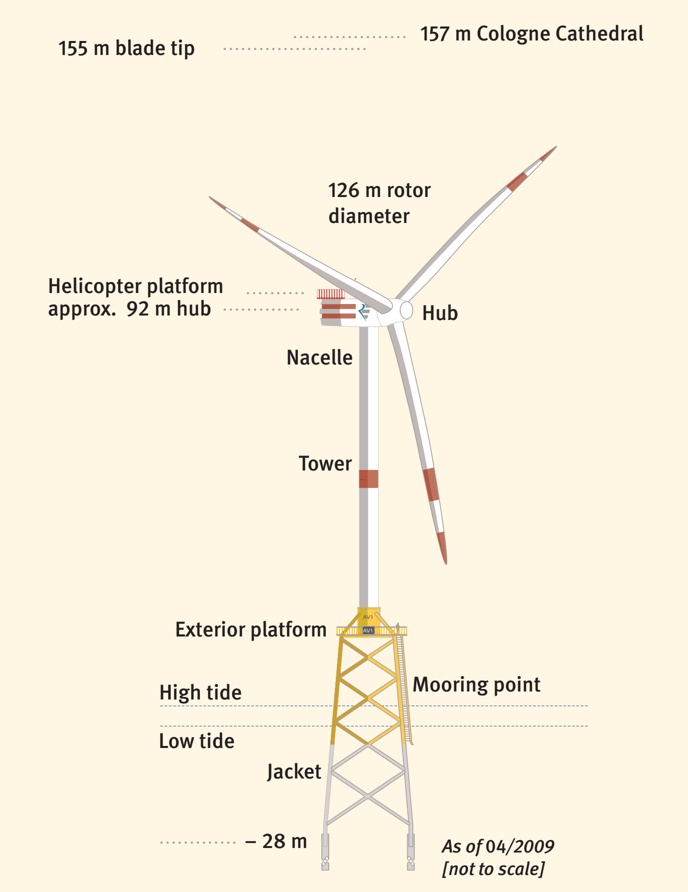
Fig. 4 *The AREVA Wind M5000*
Source: DOTI 2009



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[not to scale]

Fig. 5 *The REpower 5M*
Source: DOTI 2009

Fig. 6 *The large THIALF offshore work platform lifts a jacket foundation into position.*
Photo: DOTI 2009

Fig. 7 *Raising the rotor blade star*
Photo: DOTI 2009

order that there are also sufficient reserves during poor weather conditions. Both turbine types have helicopter abseil platforms in order to improve the accessibility of the turbines for installation and maintenance work.

In addition to the special structural design of individual components, the wind turbines also have another feature that is specific to their offshore use. Air-air or liquid-air heat exchangers are used for cooling the generators and drive systems in order to encapsulate them from the external environment and thus ensure that they cannot be corroded by salty sea air. An air processing system is even used to generate excess pressure in the tower and the nacelle. This measure is also intended to prevent penetration by corrosive and salty ambient air. All external metallic surfaces are protected with a special multiple coating to protect against corrosion.

Further research requirements

As part of the RAVE research projects, researchers from institutes and industry are working on solutions for specifically optimising the system technology and components for turbines. Two of the twelve wind turbines are equipped with numerous sensors for conducting load, output and grid measurements. Two other wind turbines, which are located downstream in the main wind direction, are also equipped with measurement sensors to a lesser extent.

Fig. 8 *Tugboats tow all the components to alpha ventus.*
Photo: DOTI 2009

High-resolution SCADA data (Supervisory Control And Data Acquisition) are recorded for all twelve wind turbines. The FINO 1 research platform is located close to the test field. Its data, the data from all the measurement sensors and the SCADA data from the test field are stored in a central database and are available to research partners.

Both the turbine manufacturers and the certification bodies are considerably interested in comparing the loads that actually occur on the wind turbines in the test field with theoretical design assumptions. The calculation of loads on offshore wind turbines by means of aero-elastic and hydrodynamic simulations of the overall system has previously met with difficulties that require the development of new calculation models and software tools. This particularly applies to separate support structures such as tripods and jackets. Based on fictitious wind turbines, such models are being compared theoretically and further developed as part of the “Offshore Code Comparison Collaboration Continuation (OC4)” project within the International Energy Agency’s (IEA) Wind Annex 30 scheme and as part of the “Offshore Support Structures” work package within the EU’s UpWind project. Prior to alpha ventus, no measurements had been conducted on a high-sea wind farm that could have been used to validate these new program components. Therefore, there is a considerable need to compare the loads simulated using the to some extent newly developed computer programs with the actual measurement data acquired from the offshore wind turbines.
This comparison also takes the various foundation concepts into account in order to display any differences.

This integrated modelling and validation of entire wind turbines in an environment with wind and waves enables the global loads to be determined and thus makes it possible to optimise components. In future, more detailed models, for example using finite element or multibody simulations, will enable the components to be investigated in even greater detail. The multibody simulations depict both the structural and dynamic loads in the closest detail, including, for example, the tooth root bending stresses in a gear wheel during operation. This new knowledge enables the turbine components and support structures to be further developed in terms of their function and weight, and the entire design process chain to be optimised. In regards to the foundations, various criteria are

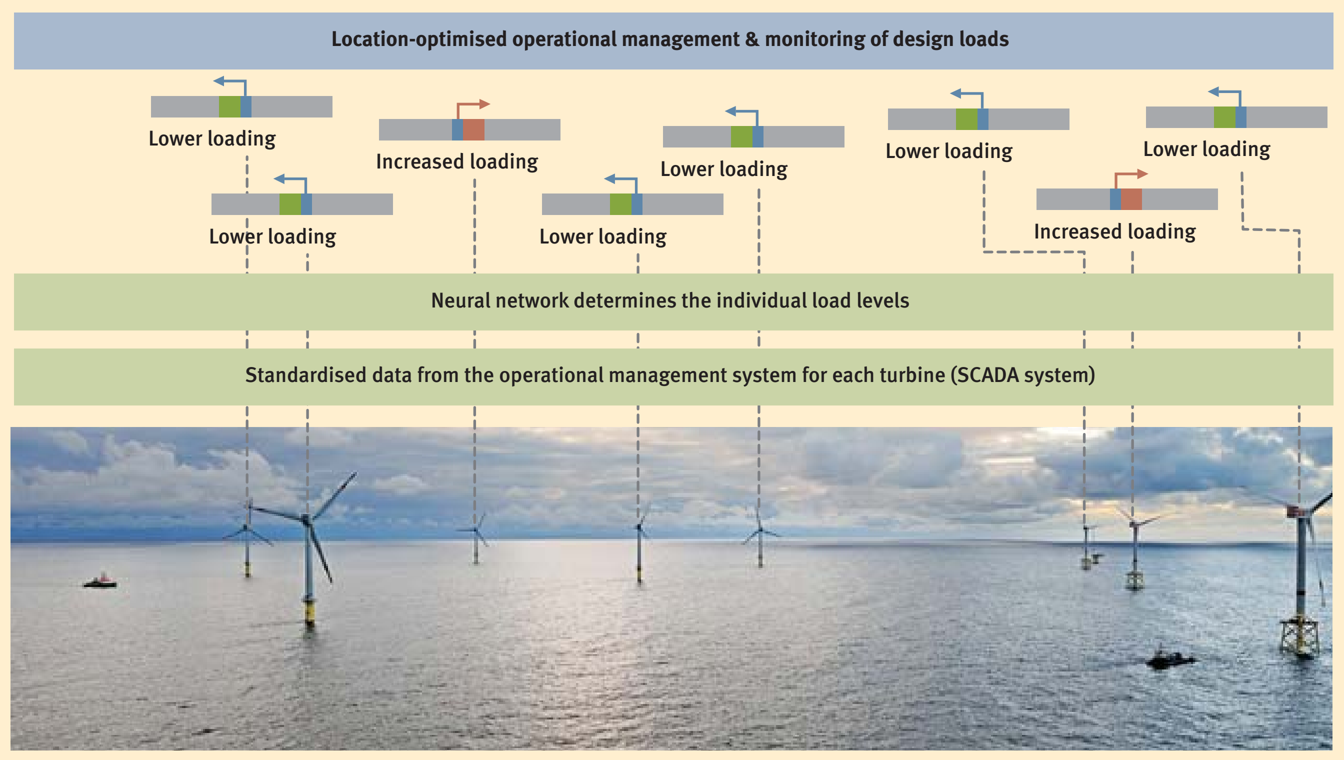


Fig. 9 *Location-optimised operational management and monitoring of design loads [example data]*
Source: SWE, University of Stuttgart

drawn up in order to be able to choose corresponding foundation systems for different turbine sizes and configurations as well as locations. For this purpose, new measurement models and calculation methods are being developed for every system. The models are validated by comparing them with the forces and moments actually measured during the installation and operation of research turbines, whereby the foundation piles are equipped with sensors to measure expansions in the components.

Continual condition monitoring

Offshore wind turbines require greater monitoring during their operation, since their accessibility is hampered at sea and the maintenance and production downtime costs are considerable. In order to identify faults at an early point and optimise the maintenance work, systems for monitoring the condition have been developed. These continually monitor all components (for example, the gears and generator) and notify the control centre in good time should any faults occur. The combination of condition monitoring techniques with intelligent monitoring of the load and output behaviour provides promising prospects for the future. The additional load monitoring can also improve the economic viability. This concerns, for example, the optimisation of the turbine operation in terms of the expected remaining service life of the components and the prevention of excess mechanical loads. The loads are monitored during operation before any initial damage is actually caused, which can be identified by means of the condition monitoring. Such continual load monitoring has not been previously used for wind turbines since considerable research is still required into the long-term stability of the corresponding sensors and their calibration. Instead of using new sensors, an approach has been developed in which the loads can be monitored using standardly recorded measurement signals and neural networks.

The research work conducted by the manufacturers is initially concerned with optimising individual system components, for example transformers, converters, gears and cooling systems. In addition, new blade connection concepts and aerodynamic profiles are being developed for the rotor blades. In terms of the operational management, research work is being conducted into disconnecting turbines in severe winds and new control possibilities. Here the highly promising predictive control system should be mentioned, with whose help a laser-based LIDAR system records the wind field in front of the wind turbines and integrates this advance information into the control system. The aim is to lower the loads for the same or higher yields. In order to ensure the availability and monitoring of wind turbines remote from the coast, work is also being done to improve the SCADA systems.

The previous results from the RAVE research initiative have enabled new equipment and methods for installing wind turbines to be researched for future offshore projects and installation methods to be (further) developed. Further substantial results for optimising the turbine technologies are expected for the future.

Fig. 10 *Schematic depiction showing the recording of multibeam echo soundings made by the BSH's WEGA measurement, wreak search and research ship*
Source: BSH

Researching the basics

The offshore sector places considerable demands on turbine and foundation structures. In order to be able to provide reliable long-term data for designing and planning purposes, north German research institutes have developed a concept for basic research and measurement sensor technology as part of RAVE. The areas focussed on include oceanography, meteorology, geology, structural dynamics and ecology.

The alpha ventus wind test field is situated in an area of the North Sea that is typical for offshore projects in the German Bight. The wind turbines have been constructed on foundation structures that, depending on the depth of water, can be up to 45 metres deep and are anchored to the seabed at a depth of up to 30 metres. Wind turbines at sea are subject to much greater loads than on land. That particularly applies to sites with water depths of 30 metres and more. Important research aspects can therefore be investigated here. These include the external operating conditions, structural dynamics, foundations for the wind turbines and, in particular, the grid integration. The main loads on wind turbines are caused by environmental parameters such as the sea state, wind, sea wash, weathering, corrosion and scouring (see page 10). The North Sea has very strong tidal currents. The Federal Maritime and Hydrographic Agency (BSH) has developed a concept for the measurement sensor technology in conjunction with its project partners, the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), the German Wind Energy Institute (DEWI) and Germanischer Lloyd – Garrad Hassan (GL). For this purpose, four of the wind turbines constructed at alpha ventus from both manufacturers have been equipped with several hundred measurement sensors.

Measurements are currently being conducted on the mechanical stresses and loads (vibration, expansion, torsion), electrical characteristic data and operational noises. In addition, oceanographic and geological studies are also being conducted in the test field that investigate the interaction between offshore wind farms and the maritime environment. Temperature sensors have been mounted at various depths in the water that provide information on stratification and temperature changes in the test field. Numerous echo sounders on the foundations supply information on the scouring behaviour and dynamics. Radar level measurements and cameras on the platforms record sea state data. In addition, the data for the ocean currents are being measured with three current meters (ADCP, Acoustic Doppler Current Profilers) and a wave rider buoy to determine the significant wave heights, wave periods and direction. The ADCPs determine the speed and directional distribution of the water columns above and provide additional sea state data. These measurements are particularly important for logistically planning the cost-intensive shipping and work operations at the wind farm, since personnel are not allowed to access the wind turbines if the waves are too high.

More than 1,200 different measurement sensors have been installed in total on the wind turbines, foundation structures for the turbines, transformer station and seabed. The BSH is coordinating the measurement tasks and is also conducting its own hydrographical and geological investigations as part of the research. The data is transferred daily from the measurement computers to the BSH where it is collected. There it is analysed and transferred to the central research archive, which can be accessed by the RAVE scientists.

Since 2003, DEWI GmbH has been collecting the world's most comprehensive wind measurements in the offshore sector at the FINO1 platform (see page 11) near the test field. It is also conducting measurements on the AREVA Wind turbines.

GL Industrial Services GmbH is responsible for the entire logistics for the RAVE measurement service project. GL Garrad Hassan GmbH is responsible for measurements on

In practice

LIDAR – Measuring the wind with laser beams

Using laser beams, LIDAR technology (Light Detection And Ranging) is used for conducting range and speed measurements and for remote sensing atmospheric parameters. In the wind energy sector, it is usually used to measure the wind direction and wind speed from the ground. This eliminates the need to make complex measurements with a meteorological mast.

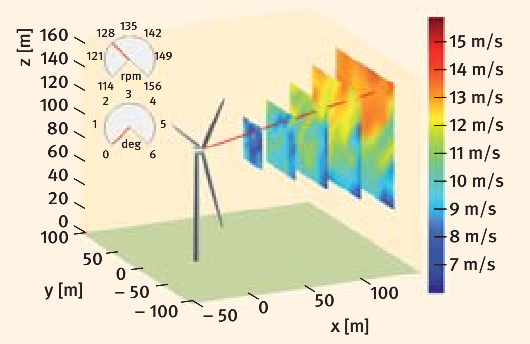
Researchers from Stuttgart have modified a LIDAR device so that it can make horizontal measurements from a wind turbine nacelle. Using a specially developed scanner, the laser scans arbitrary points across the entire wind field in front of the wind turbine, which enables the three-dimensional wind field to be reconstructed.

Precise knowledge of approaching wind fields enables, for example, anticipatory changes to be made to the turbine control systems, whereby the rotor can be optimally oriented in relation to the wind direction and the pitch angle of the rotor blades can be adjusted in accordance with the wind conditions. The wind turbine recognises if a gust comes and can react correspondingly. If both the fatigue and extreme loads can be reduced during the 20-year service lives of wind turbines, this will enable the wind turbines to be made lighter and the energy yields to be increased.

In future, it is intended to use horizontal LIDAR measurements for certifying wind turbines in regard to the power curve and load measurements both on land and at sea (including floating wind turbines). The horizontal wind field measurements provide spatially neutral information about the entire rotor area.

Fig. 11 *LIDAR scanner mounted on a nacelle*
Photo: SWE, University of Stuttgart

Fig. 12 *Wind field measurements using LIDAR scanners*
Source: SWE, University of Stuttgart



En passant

Fig. 13 *A rotor blade model being tested*
Photo: BMU

Lightweight structures – Automation – Superconductors

The total weight and, in particular, the tower head mass are important factors in determining the economic feasibility of wind turbines. An increased use of lightweight components could help to reduce costs.

The aeronautic and automotive sectors are also focussing on the use of lightweight materials such as glass-fibre-reinforced (GFRP) or carbon-fibre-reinforced (CFRP) plastics. However, the opportunities for generating synergy effects through the cross-sector collaboration have not yet been grasped by the wind industry. The wings of airplanes and the rotor blades of wind turbines show several fundamental similarities, although – when the respective largest airplanes and turbines are compared – wings have to be able to withstand greater forces whereas rotor blades are longer. Aircraft manufacturers have many years of experience in the deployment of difficult-to-process CFRP for components and parts, the use of sensors to measure loads and the automation of manufacturing processes.

Components with high-temperature superconductors – a technology that is currently entering the market with the first pilot applications for use in power plants, electricity grids and engines – could also open up new opportunities for large wind turbines. If the existing generators using permanent magnets were replaced with superconducting coils, this would enable the same output to be achieved with a generator that is half the size and with less weight. This would also reduce the consumption of rare earth elements. However, the cost and the more complex production have until now hindered the large-scale market introduction of superconducting technologies.

Fig. 14 *Rotor blade production*
Photo: Nordex 2007

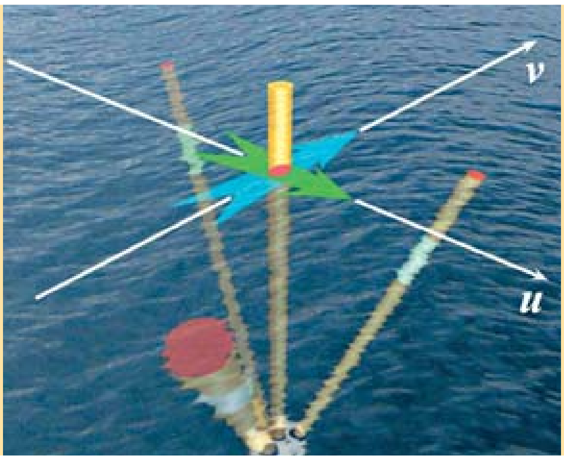


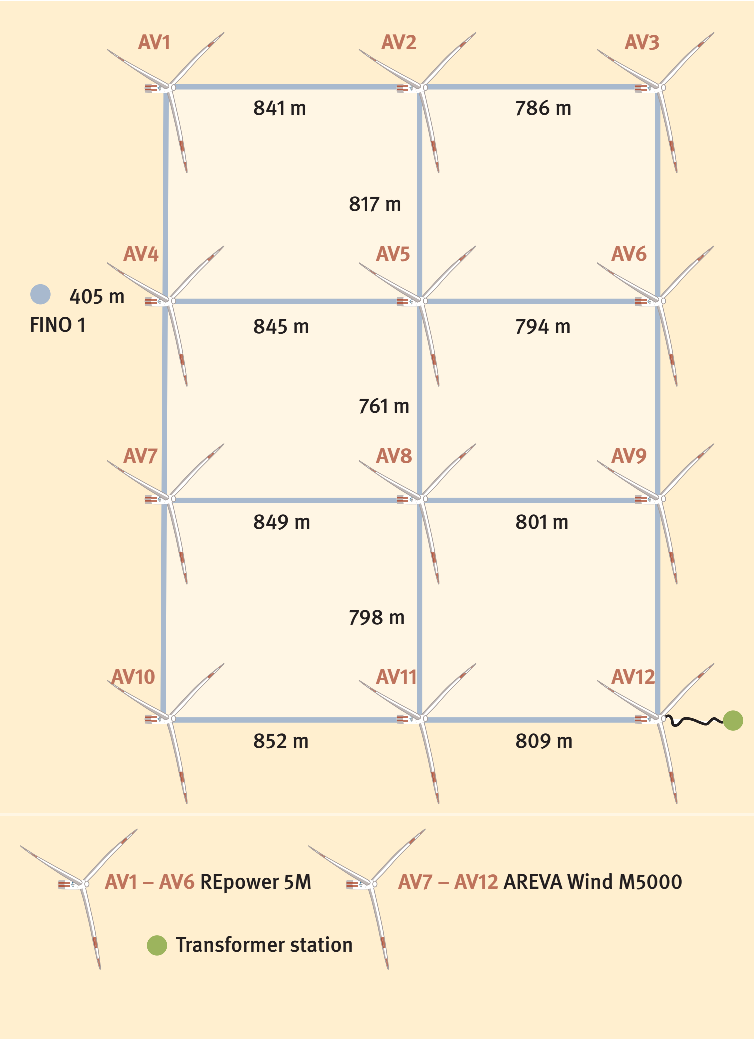
Fig. 15 *Schematic design of an ADCP current meter*
Source: Nortek

Fig. 16 *Female research diver on the FINO 1 platform*
Photo: BMU – Edelhoff

REpower turbines as well as for grid measurements on both the alpha ventus transformer platform and the Hagermarsch transformer station.

Flensburg University of Applied Sciences has investigated the operating noises emitted from the wind farm with hydrophones anchored to the ground and is also conducting research into the underwater sounds emitted by the wind turbines.

Fig. 17 *Site plan for alpha ventus*



Accompanying geological research

The geological investigation programme is focussing on the interactions between the foundation elements and the seabed. In particular this relates to the development of scouring around the foundation piles and the resulting shifting of sediment in the wind farm.

Scouring occurs when structures such as the foundations for wind farms are inserted in a flowing medium. The flow patterns change in the immediate area around these structures, which leads to increased erosion of the seabed. This creates hollows around the structures, which is known as scouring. The depth and extent of the scouring can have an impact on the stability of wind turbines. To record the local scouring depths near the wind turbine foundations and their dynamics, a series of echo sounders were fixed to the foundation structures of the AV4 (jacket structure) and AV7 (tripod structure) research turbines. The echo sounders record the scouring depths and their dynamics with temporally high-resolution measurements.

Regular, comprehensive hydro-acoustic measurements with multibeam echo sounders, side-scan sonars and high-resolution sediment echo sounders enable the impact of changes in the sediment dynamics to be assessed in terms of the structure and properties of the upper layers of the seabed. Regular pressure soundings with dynamic penetrometers and geo-technical laboratory tests provide information on changes in the compactness of the surface sediments.

The accompanying geological research therewith intends to check the forecasts from the environmental impact assessment (EIA), which were produced as part of the approval process. In this respect, the investigation concept has a greater scope than the measurements made by the wind farm operators as part of the operational monitoring.

Scouring investigations

Using 19 stationary echo sounders, which have been installed on the foundation structure of the AV7 research

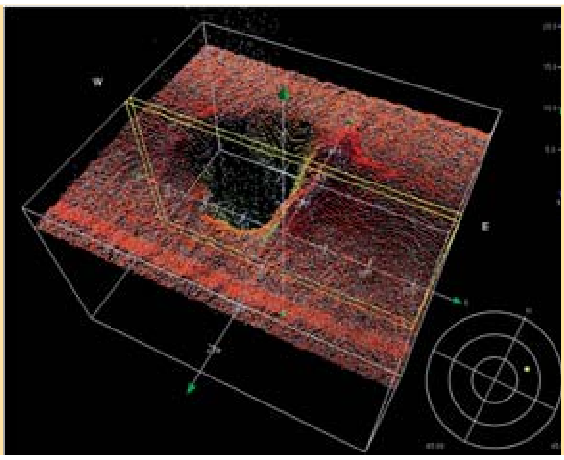


Fig. 18 *3D depiction of the multibeam echo soundings of the scouring on the AV7 from October 2010. View from the south-eastern direction into the scouring. Source: BSH*

turbines, the scouring depths are continually measured around the pile foundations and beneath the central segment. Each echo sounder currently records the depth values at roughly 20-minute intervals. Although these temporally high-resolution recordings provide an excellent insight into the dynamics of the scouring formation, the stationary echo sounders only enable selective recording of the scouring depths. In order to gain information about the spatial extent of the scouring, a multibeam echo sounder makes comprehensive measurements twice a year around the AV7 research turbine. The continual recordings made by the stationary echo sounders show that, from the point when the recordings began at the end of August 2009 to around the middle of January 2010, maximum scouring depths of between 5 and 5.5 metres very rapidly developed beneath the central segment. In October 2010, this central scouring extended to between 6 and 6.5 metres (Fig. 23, 24).

The multibeam echo soundings made on the AV7 research turbine in October 2010 confirm the scouring depths depicted in Fig 23. A comparison of the multibeam echo soundings from October 2010 with the data from previous trips shows that the initially separate areas of local scouring around the foundation piles for the tripod have increasingly grown together over time with the scouring beneath the central tower segment (central scouring). In the 3D depiction of the multibeam echo soundings from October 2010 (Fig. 18), the individual areas of scouring can hardly be distinguished from one another. A global scouring area is beginning to develop that encompasses the central scouring beneath the tower segment and the local scouring around the foundation piles.

The investigation results show that the effects of the wind turbines on the sediment dynamics and thus the scouring behaviour and the sediment properties have up to now been limited to the area beneath the wind turbines. According to current knowledge, the stability of the wind turbines is therefore ensured.

Accompanying ecological research

One of the German government's aims is to ensure the environmentally compatible development of offshore wind energy. Therefore a central component of the approval

In practice

The FINO research platforms

The planning, design and certification of offshore wind farms require reliable long-term data about the marine and meteorological conditions at sea. In order to collect this data and close existing gaps in knowledge, the automatic FINO 1 (2003; North Sea), FINO 2 (2007; Baltic Sea) and FINO 3 (2009; North Sea) research platforms were constructed, which are equipped with scientific measurement instruments. There is an intensive exchange of data between FINO 1 and the RAVE project.

Each platform has a wind measurement mast and measurement instruments for determining physical oceanographic parameters (e.g. pressure and temperature) and for the accompanying ecological research. The meteorological data is used to calculate the average wind speed, main wind direction and the distribution of the wind throughout the year as well as the frequency of turbulence. This meteorological data and the results of dynamic structural tests enable the loads, fatigue and service lives of the technical equipment and structure to be estimated.

Various camera and radar systems along with acoustic systems record the migration of birds and bats. The underwater structures for the platforms act like artificial reefs in the sea. The increasingly dense natural settlement of plants and animals on these components over time is therefore also being evaluated. Further research topics include warning systems for ensuring the safety of shipping, changes in the sediment, investigations of the water quality, logistics, the development of meteorological simulation models and the investigation of the platforms' structural dynamics and waves in the German Bight.

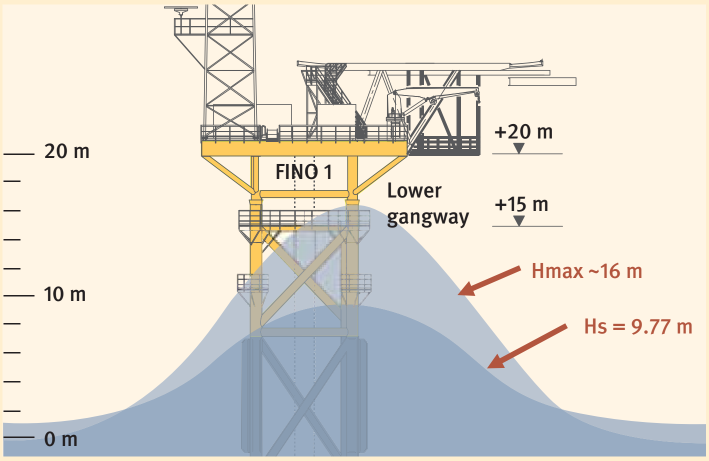


Fig. 19 *During "Cyclone Britta" in 2006, FINO 1 was struck by extreme waves and the lower gangway was slightly damaged at a height of 15 metres. Source: GL – Garrad Hassan*

Fig. 20 *Camera system for researching birds installed at a height of 51 metres on the north side of the measurement mast on FINO 2*
Photo: GL – Garrad Hassan

Fig. 21 *Porpoises also occur in the North and Baltic seas. Photo: Fjord&Baelt / F. Graner*

Fig. 22 *Red-throated Divers also live along the German coasts during the winter. Photo: H. Bäsemann*

process for offshore wind farms is the environmental impact assessment, which forecasts the extent to which the construction of wind farms will endanger the maritime environment. The investigation of benthos (organisms inhabiting the seabed), fish, resting and migratory birds as well as marine mammals is therefore stipulated in the respective wind farm permits. The requirements are described in detail in the BSH's "Standard – Investigation of the Impacts of Offshore Wind Turbines on the Marine Environment" (StUK3 for short). The concept is based on a 'before and after' comparison and thus encompasses the investigations that have been made two years prior to the construction, during the construction and three years afterwards.

The monitoring is intended to provide answers to the following questions:

- What effect does the noise intensive construction work and the operating phase have on porpoises and seals?
- Will porpoises, seals and resting birds continue to use the wind farm areas as a habitat?
- How do migratory birds react to spinning, illuminated wind turbines?
- Are there collisions or evasive movements?
- How does the habitat change for benthic organisms and fish near the foundations?

As part of the accompanying ecological research for alpha ventus, the obligatory investigations in accordance with StUK3 are being supplemented with the more detailed "StUKplus" research project. The aim is to evaluate StUK3, which is being used for the first time in an offshore wind farm, and to increase the level of knowledge about the ecological impacts of offshore wind farms.

The preliminary findings from the construction phase and the first operational year are described below.

Fig. 23 *Scouring depths recorded by the ES 18 echo sounder beneath the central segment in autumn 2010*
Source: BSH

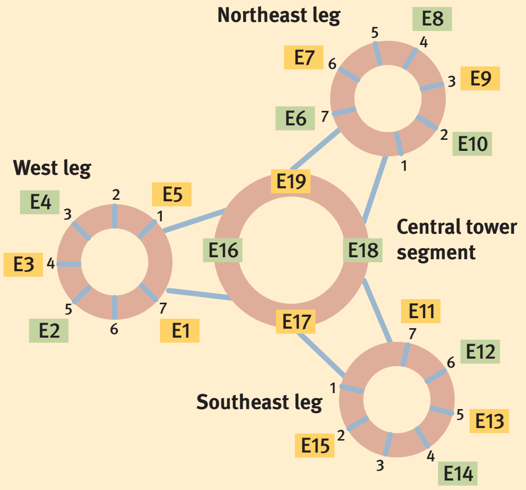


Fig. 24 *Top view of the echo sounder installed on the AV7. The coloured coding refers to the computer used for recording the echo soundings.*
Source: BSH

Fig. 25 *Marine growth on foundation. Photo: Sebastian Fuhrmann*

Fig. 26 *Porpoise near the transformer station during a break in the pile-driving. Photo: BSH*

Fig. 27 *Seal on a wind turbine foundation in spring 2011 Photo: BSH*

Seabed organisms (benthos: crabs, mussels)

In the area around the foundations (up to a distance of 15 metres), divers have observed a massive community of mussels on the otherwise sandy seabed. The changes in the seabed as a habitat for benthos have already led to changes in the type of species: organisms that like hard substrates, such as the velvet crab, have begun to establish themselves here. Only two years after the wind turbines have been erected, the marine growth on them has developed considerably and comprises species such as blue mussels, diporeia and sea anemone.

Fish

It seems likely that the prohibition of fishing in the wind farm has enabled the fish stocks to partially recover and benefit from the additional food sources. Although the studies made during the first operational year (2010) were not yet able to confirm this more long-term effect, initial indications that this is the case have been provided by investigations with fixed nets. In May 2011, more fish species (18) were found than in the previous year (14). Whether this trend continues will be shown by the results during the next few years.

The occurrence of pelagic fish in the wind farm area (i.e. fish that live in the open ocean) fluctuates in accordance with the seasons and can vary considerably in spatial terms as a result of their high mobility: sprat and herring are predominantly caught in the trawling nets during the spring. During the summer season, mackerel, horse mackerel and large numbers of jellyfish can be found. The fish migrate in early autumn (horse mackerel) and autumn (mackerel).

Resting / Sea birds

How do the sea birds react to the presence of the wind farm in their habitat? Do they avoid the area? Has this led to changes in their behaviour? Are they actually attracted? The intention is to answer these questions using airplane and ship surveys. The preliminary results show that each species reacts differently.
Two examples:

- During the 2009/2010 winter months, the Common Guillemot and the Razorbill showed gaps in their prevalence in the immediate vicinity of the wind farm, although these species otherwise occur very frequently in this area.
- With the Little Gull, which possibly benefits from increased food sources near the wind farm, a certain concentration of them was found in the area around alpha ventus during the 2009/2010 winter months.

Migratory birds

The bird migrations are investigated at the wind farm using various cameras and radar devices. The aim is to determine the extent to which the 150-metre-high wind turbines with their 120-metre rotor diameters act as obstacles for birds migrating through the German Bight in spring and autumn. The bird migration mostly takes place at night and is very dependent on the weather conditions.

Social acceptance

The development of offshore wind energy requires social acceptance. Therefore the expectations and experiences of the population before and after the construction of offshore wind farms have been surveyed as part of an interdisciplinary project funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The project is being coordinated by the Health and Environmental Psychology working group at Martin-Luther-Universität Halle-Wittenberg. Local residents, tourists and regional experts in various coastal regions along the North and Baltic Sea with and without offshore wind farms were questioned in two surveys in 2009 and 2011. Workshops for residents are being held in spring 2012 and a third survey will take place this summer. Interim results indicate that wind farms remote from the coast are more accepted than wind farms near the coast. The project aims to develop recommendations for action for the purpose of increasing acceptance and achieving development strategies that avoid conflicts as much as possible.

Fig. 28 *Benthic organisms Photos: Alfred-Wegener Institute – AWI*

An avoidance of the wind farm or large-scale evasive manoeuvres has not yet been observed. Dead birds on FINO 1 and the wind turbines are registered and documented. Although these are very rare, increased bird strikes occur when there are unusual weather constellations. During the early hours of 2 November 2010, the collision of 88 birds (mainly Red Wings) was observed on FINO 1. During the same night it was also observed how at least 100 birds sped into the base area of FINO 1, who were attracted by the illumination. The birds had started with optimum migration conditions along the coast and were then surprised by a sudden headwind in combination with an increase in wind speed and deterioration in the visibility. The Red Wing is a common species with a stable population. They belong to the nocturnal migrants that regularly cross the German Bight in large numbers.

Fig. 29 *The Northern Fulmar lives most of the year on the open ocean. Photo: Jörg Hempel*

Porpoises

Porpoises (Fig. 21) communicate with clicking noises. They are therefore monitored underwater using stationary click detectors (so-called PODs) and visually from airplanes and ships. The POD-based investigations showed that the mammals avoided the construction area during the noise-intensive pile-driving by a distance of up to 20 kilometres. Occasional porpoises were spotted at the wind farm during breaks in the pile-driving. Porpoise surveys in the first operational year in 2010 and in spring 2011 showed that increasingly more porpoises were underway in the area north of Borkum and around the alpha ventus test field. This is also confirmed by a published study for the Dutch "Egmondaan Zee" wind farm. Whether this trend continues will be shown by the results during the next few years. The wind farm employees also regularly observe at least one seal, who prefers to reside on the northern wind turbines.

Underwater noise

Using hydrophones positioned on the seabed, the underwater noise is measured before and during the pile-driving work as well as during the normal operation of the wind turbines. The measurements currently made during the normal operation of the wind turbines show that the operating sounds can only be heard by porpoises up to a distance of 100 metres away. These measurement results confirm that once the noise-intensive pile-driving into the seabed has been concluded, the wind turbines do not emit extensive noise emissions during operation.

www.rave-offshore.de

This is the Web address for the RAVE research initiative's online portal. It provides an overview of the complete spectrum of topics and, in addition to information sheets (RAVE Info), it also provides scientific documentation with unique photos of alpha ventus, selected research projects and 3D animations.

The alpha ventus test field is also presented online. www.alpha-ventus.de provides a comprehensive overview of the construction and operation of the test field as well as the latest news.

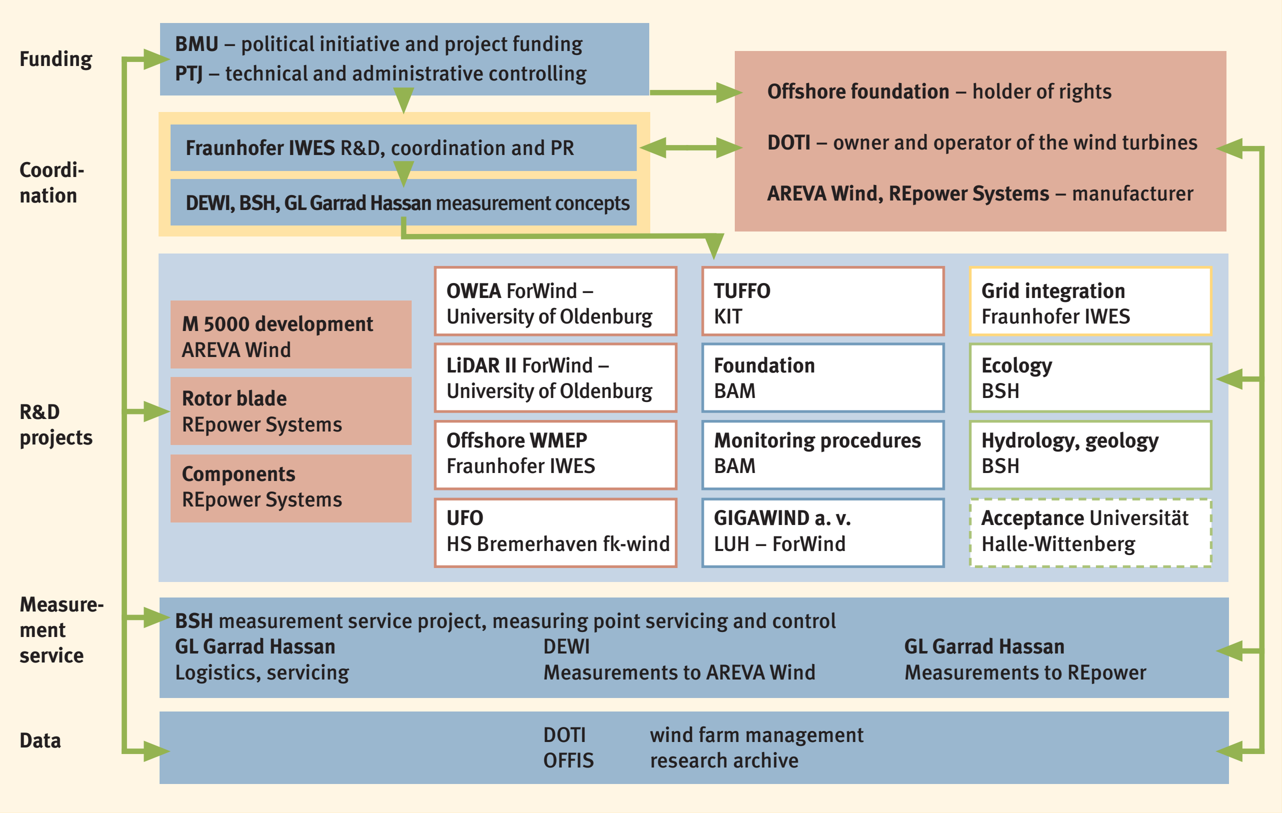


Fig. 30 *Structure of RAVE*
Source: Fraunhofer IWES

In practice

The world's largest wave channel

The forces exerted by waves and currents create considerable loads on offshore wind turbines. The support structures have to be able to withstand the interaction between wind and waves as well as all maximum wave heights. As a result of the waves, tides and sediment structure, each building structure causes changes to the seabed. The foundations are even partly uncovered over time as a result of scouring.

The GIGAWIND sub-project within RAVE is focusing on these aspects. The ForschungszentrumKüste (FZK) in Hanover is developing numerical models and conducting tests on what is currently the world's largest wave channel. This channel consists of a roofed over trough structure with a length of 307 metres and a depth of 7 metres. A hydraulically driven wave machine (900 kW) can generate waves up to 2 metres in height as well as diverse wave spectra. This system is used to test, among others, the build up of scouring on support structures in a 1:17th scale.

Fig. 31 *A model of a tripod foundation is tested in the large wave channel.*
Photos: Franzius-Institut Hannover

Fig. 32 *Laying the grid cable*
Photo: DOTI 2009

Feeding wind power into the grid

In 2011, wind energy made a considerable contribution to Germany's electricity supplies with an annual capacity of 46.9 TWh and an installed output of 29 GW. This share will continue to grow in future. In order to integrate this wind power optimally into the electricity grid in accordance with needs, new approaches to grid integration are being developed and the further development and restructuring of the electricity network is being progressed.

In an electricity grid with predominantly thermal power plants, consumers are the only non-foreseeable and therefore highly probability-based factor. As a result, the fluctuating loads caused by consumers have to be predicted in order to draw up power plant schedules for the following day. Through the development of renewable energies, wind and solar power have been added as new fluctuating components. In order to be able to forecast these, knowledge about the expected wind levels and solar radiation is required. The schedules for the remaining thermal power plants can then be adjusted using special forecasting systems. In order to keep the discrepancies between the actual and forecast wind and solar power as low as possible, and thus the need for balancing energy, precise forecasting systems are being developed.

A further possibility for aligning the schedules in accordance with the actual requirement is provided by the use of energy storage systems. Such storage systems enable energy to be quickly accessed to align the schedule with the current load curve. This reduces the need for balancing energy, which can be considered the last adjustment level. Storage concepts include pumped storage power plants, compressed air energy storage systems and biogas plants. In future the so-called “Power to Gas” method could also become relevant in this regard.

Ancillary services

The electricity grid must be kept stable at all times in terms of frequency and voltage. In order to maintain the frequency, all electricity consumption must be balanced by electricity production. On the one hand, this is achieved by using a fixed schedule for the power plants, which is based on the forecast behaviour of the consumers and the wind and solar power, and on the other by providing reserve power from conventional power plants. This balances out the remaining short-term fluctuations. The increased use of wind energy will increasingly supplant the use of conventional power plants so that in future wind turbines will also have to be able to provide balancing power. This requires both forecasts for the wind energy fed into the grid, so that it can be determined whether a wind farm can provide balancing power during the next few hours, as well as suitable control concepts for individual wind farms or those combined together as clusters.

In order to maintain grid voltage stability, wind farms must also be able to provide reactive power in future. Each power line and transformer in the electricity transmission network requires reactive power to switch its electromagnetic fields. The transport of reactive power causes additional active power losses and thus places an additional load on the supply network. Reactive power therefore cannot be transferred over large areas for economic reasons but has to be provided locally. Up to now it has been mostly provided by conventional power plants or by compensation systems.

In order for wind turbines to contribute to ancillary services in the future, tools are required that can take on this task and control the process.

Wind farm clusters

A controllable and as far as possible constantly available energy source is required for providing ancillary services. The energy generated by wind farms can be quickly and

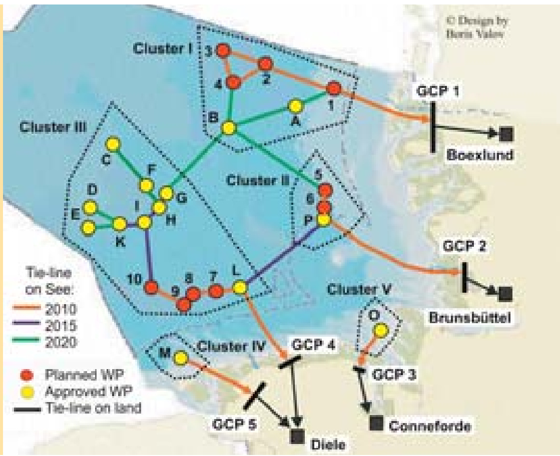


Fig. 33 *Concept for an offshore network in the North Sea*
Source: Fraunhofer IWES

easily controlled, and the resulting increased mechanical loads on the wind turbines are manageable and easy to handle. However, the variation in the wind speeds in accordance with the current weather conditions means that the electricity fed into the grid from the wind farms fluctuates to greater and lesser extents.

In order to reduce this effect, groups of wind farms called "clusters" are formed (Fig. 33). These are designed to mutually balance out the respective fluctuations caused by the different geographical locations and thus different wind conditions (aggregation effect). Clusters can then provide joint balancing power (here it is sufficient when the generators are in the same balancing zone), help maintain the voltage by providing reactive power (here all generators should be connected to one grid connection point) or be involved in managing grid bottlenecks.

Such wind farm clusters are controlled via central control units that, depending on the application, are installed by either the wind farm operator (balancing power) or the grid operator (ancillary services). These units must be able to communicate with one another so that in the event, for example, of a grid bottleneck and the resulting output limitations, the provision of balancing power is not endangered.

The main challenge facing the software concepts is the coordination of the individual control units, which encompasses the control algorithms, uniform communication interfaces and calculating the condition of the electrical network within the cluster.

Within RAVE, such tools are being developed as wind farm cluster management systems (WCMS; Fig. 35) for the ancillary services, while in other projects from Fraunhofer IWES, such as the Harz model region, they are being developed in the form of combined power plants for providing balancing power.

Wind output forecasts

The forecasts for the amount of electricity fed from wind farms into the electricity grid are based on weather fore-

In portrait

The energy supplier and the researcher – two expert opinions

Where do I see offshore wind energy in 2020?

Jörg Buddenberg (Dr.-Ing.)
(EWE)
Studied mining engineering at Clausthal University of Technology He was Managing Director of NiedersächsischeEnergieAgentur GmbH from 2001 to 2003. Since 2004 he has headed the Environmental Technology division at EWE AG.

It is intended to develop renewable energy during the next few decades to become the backbone of the energy industry in Germany. To achieve this, all renewable energy forms must be further developed in a targeted manner and the overall structure of the energy supply system needs to be adapted to meet the resulting demands.

Offshore wind energy plays a substantial role in the German government's scenarios because, with its high annual utilisation efficiency, it can make a considerable contribution to achieving stable renewable electricity production. Based on the current development of the still very young offshore wind energy sector, an installed capacity of more than 8,000 MW can be achieved by 2020 that will then contribute 33 TWh each year to Germany's electricity provision. In order to achieve these goals, sustainable and stable frameworks must be provided, since it is only then that corresponding structures can be developed and the considerable investment requirements can be financed. The most important goal in this regard must be to lower the average electricity generation costs for offshore wind energy.

Dr Bernhard Lange
(Fraunhofer IWES)
Studied physics at University of Konstanz, University of Edinburgh and University of Oldenburg. He is head of the Energy Meteorology and Systems Integration department at Fraunhofer IWES.

In 2020, offshore wind energy will already contribute to an important part of Germany's electricity supply. The greatest challenges in this regard will be concerned with reducing the electricity generation costs and integrating the electricity produced offshore into the energy supply system.

Research will play a vital role here. The experiences and findings that have been gained, for example, through the RAVE research at the alpha ventus wind farm will be used to optimise the offshore technology in terms of reliability, economic feasibility and system compatibility. Close cooperation between research and industry is essential here.

It is only then that the technological development in planning, designing, constructing and operating offshore wind turbines and wind farms can be progressed rapidly in order that significant technological progress can be achieved by 2020. The speed of the technological development will be decisive here in determining whether industry and research in Europe and Germany can maintain their leading positions.

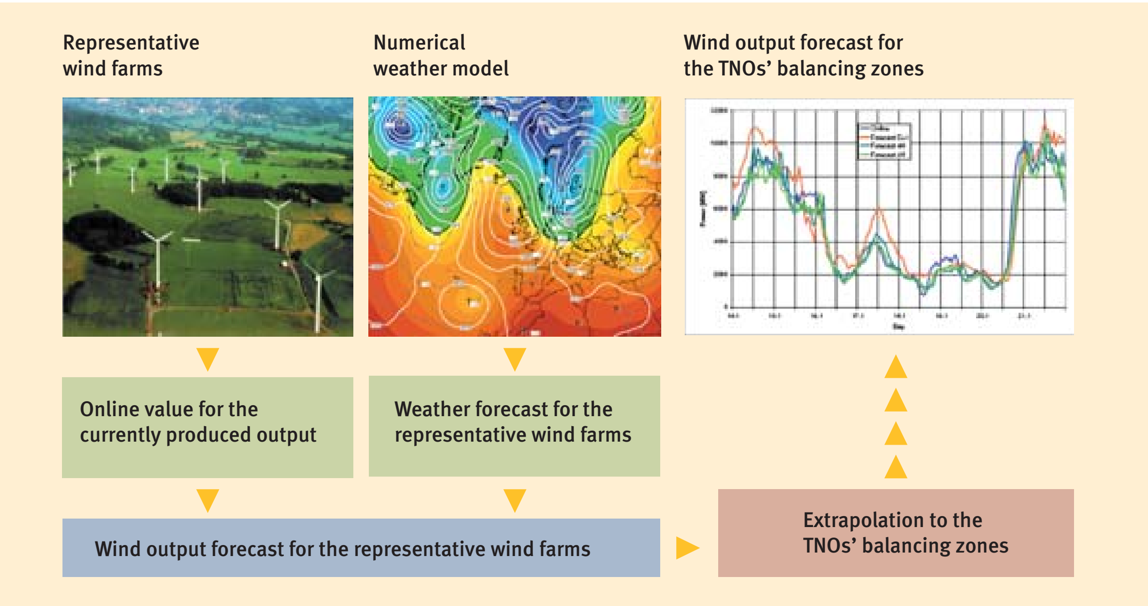


Fig. 34 *Diagram showing a short-range forecast with weather data and data measured at the wind farms, whereby forecasts for individual reference wind farms in Germany are produced that are then extrapolated to the balancing zones of the transmission network operators (TNOs). Source: Fraunhofer IWES*

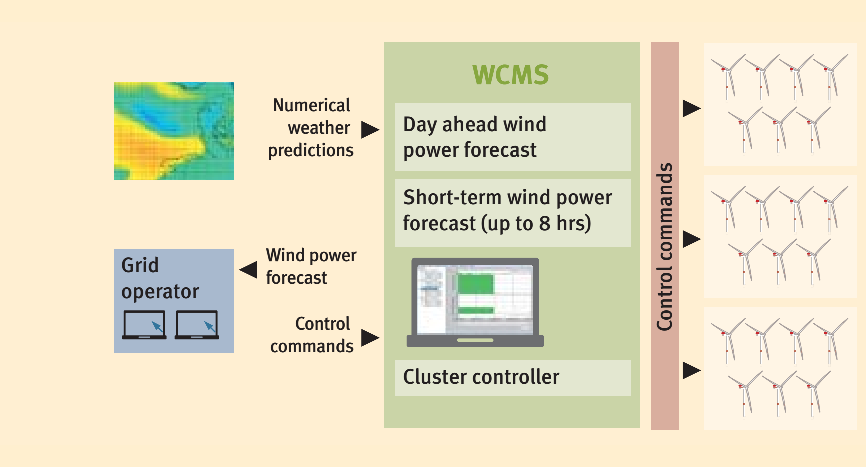
casts and, for short-range forecasting, on the measured output values for the wind farms. Typical forecast periods range from less than an hour to several days. Short forecast periods of just a few hours, which are updated every fifteen minutes, are particularly required for intraday power trading.

In the RAVE Grid Integration project, the wind output forecasts are applied to the Cluster Control sub-project. This enables the control software to determine how much energy will be provided by the cluster during the next few hours. For this purpose, short-range forecast models are used that have a very rapid update cycle of just a quarter of an hour.

Particularly the combination of wind farm cluster management systems with offshore sites, which mostly have higher wind speeds than on land, presents forecasting models with new challenges. At sea the wind output forecast models have to work in a higher output range and therefore have to be further optimised. In addition, wind farms are more frequently shut down during storms, i.e. there are more safety shutdowns with high wind speeds. This has to be correspondingly taken into account.

If the amount of electricity fed into the grid from the wind farms fluctuates considerably as a result of the weather conditions, more balancing energy must be provided for the electricity grid in order to compensate for the fluctuations. In view of the large volumes of energy that are intended to be fed into the grid with the planned expansion of offshore wind power, it is particularly important that the extent of these fluctuations can be forecast. Initial parameters and forecast methods are therefore already being developed in projects within RAVE.

Fig. 35 *Diagram of the WCMS: It forms the interface between the wind farms grouped into clusters and the grid operators. Source: Fraunhofer IWES*



Connecting offshore wind farms

Wind energy generated offshore has to cover long distances before it reaches the consumers:

- A distance of between 50 and 120 km between the wind farm at sea and the transformer station on land
- An additional distance of up to 50 km between the transformer station on the coast and the main connection point to the electricity grid
- The main connection point has a limited transfer capacity
- Transfer via the distribution and transmission networks to the end users

One of the greatest technical challenges is the transmission of the electrical energy from the offshore wind farms to the consumers on land. Here it is possible to choose between high-voltage three-phase alternating current (HVAC) and high-voltage direct current (HVDC) transmission. Because of the required power line lengths, the transmission network operator TenneT is relying on HVDC for the North Sea while the "50-Hertz" company is relying on three-phase current for the Baltic Sea. The advantage

Fig. 36 *Transformer station for alpha ventus*
Photo: DOTI 2009

of the three-phase current transmission is that it has lower installation and servicing costs. However, with three-phase current connections inductive compensation units have to be installed at regular intervals (approximately every 50 km) as a result of the capacitive reactive power import in the submarine cable. This is particularly complex with offshore wind farms. Although this is not required with HVDC cables, their sea platforms are more complex in technical terms – and thus require more expensive and complex servicing.

Future offshore network and the "Supergrid"

In 2010, Fraunhofer IWES developed a concept for connecting future offshore wind farms. This is based on two main connection points on land and an additional connection to the trans-European "Supergrid". The total capacity of the approved and planned offshore wind farms is currently more than 40 GW.

The approach groups the individual wind farms into separate clusters that – in addition to the two transfer points for the two main tie-lines near Norden and Büsum – are also interlinked together. This enables more flexible distribution of the electricity fed into the grid at the main connection points, which have different feed-in capacities. This also means that the wind farms do not have to be shut down in the event of grid faults. Instead, the electricity they generate is rerouted into the grid via other main connection points.

Additional operational flexibility for the offshore grid can also be achieved by incorporating it in a future trans-European "Supergrid", for example a European-wide network of extra-high voltage grids belonging to the countries bordering the North Sea. This can help reduce the expansion needs of the existing national grids. The more powerful and flexible main connection points would enable a Supergrid to absorb the peak outputs from individual offshore wind farms. A European-wide grid network would also increase the reliability of the offshore transmission network.

In practice

Alternating or direct current?

Offshore wind farms require new transmission technologies. Whereas onshore wind farms are connected to the existing three-phase system, the limited transmission capacities of AC cables mean that high-voltage direct current (HVDC) transmission is being increasingly used for offshore systems. In contrast to alternating current, this only experiences ohmic losses. During the last few decades, traditional HVDC transmission has proven itself in practice when it comes to the transmission of large amounts of power, the asynchronous connection of three-phase grids and cable transmission over large distances. In addition to thyristor valves, the main elements of a traditional HVDC system include two converter transformers as well as filters, smoothing reactors and compensation units.

The second HVDC generation consists of voltage-controlled transmission systems that are based on disconnectable transistor valves. In contrast to traditional HVDC technology, VSC-HVDC technology (VSC = Voltage Source Converter) is self-controlled and thus independent of external grid voltages. Therefore, this technology offers many advantages: in addition to the ability to control the active and reactive power independently, conduct black starts and operate stand-alone grids, the low space requirements make this technology ideal for connecting to large offshore wind farms.

The economic analyses of the individual variants in accordance with the distance of wind farms from the coast can be depicted in diagram form as shown in Fig. 38. The three-phase grid connection is cheaper up to a specific critical distance of around 80 km, both in terms of the investment and loss costs. Beyond this distance, the HVDC option is more economic. Traditional HVDC transmission is now successfully used around the world. A current example is the grid connection for the Bard Offshore 1 wind farm, which is currently the furthest wind farm from the German coast.

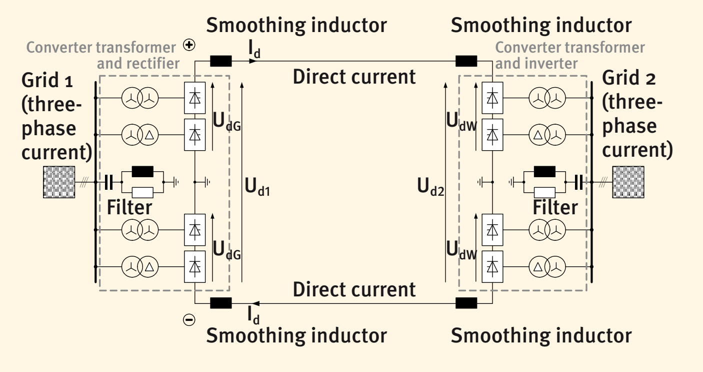


Fig. 37 *Structure of an HVDC transmission system*
Source: Fraunhofer IWES

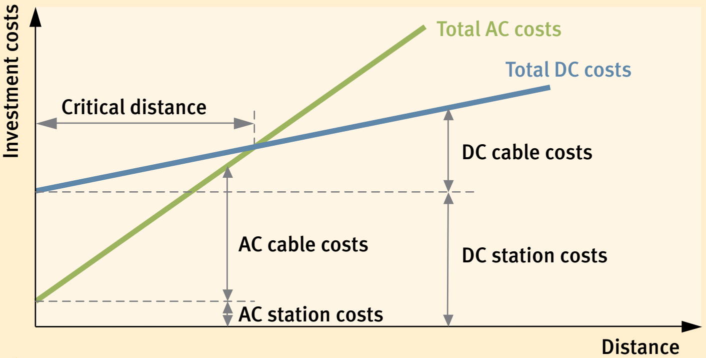


Fig. 38 *Distance-dependent costs (schematic) for direct current and three-phase alternating current transmission*
Source: Dorman Wensky

Outlook

On 27 April 2010, the utilisation of offshore wind energy in Germany became reality when 12 wind turbines at alpha ventus commenced operation. Further commercial wind farms are either currently under construction or their planning is almost completed. Wind power is therefore becoming an increasingly important pillar in Germany's future renewable energy provision.

As a pioneer project, alpha ventus had to first of all solve various organisational and legal difficulties. There were also many technological challenges. It required several months until all questions were clarified and the project management consortium was able to begin the actual work. New ground was also broken in terms of the cooperation with the certification and approval bodies, whereby basic regulations had to be first of all developed during this pilot process. A serious problem concerned the maritime logistics. Port and transport capacities as well as floating cranes for such heavy loads were not yet available on a sufficient scale. What is more, the test field was constructed during an economic upturn, which also led to delays, including for supplies, and additional costs. The frictional losses that still occur with alpha ventus, the previously insufficient grid infrastructure and the logistical gaps have been identified and will be optimised for future wind farm projects. The experience has shown that offshore wind farms do not consist of onshore wind turbines with wet foundations but are a very specific, new and technically very complex application area.

The RAVE scientific support project was forced to adapt to this underlying situation. In the next few years, the focus will be on further optimising the technology. Each small increase in efficiency and reduction in the specific investment costs will achieve a large overall impact on the 5,000 wind turbines scheduled to be constructed in German waters by 2030. Particularly important topic areas include the testing of new support structures and the optimisation of existing ones, the further development of simulation tools, improved yield forecasts taking so-called farm effects into consideration as well as research into new materials and anticorrosion strategies. The further development of remote sensing methods for measuring wind and the environmental compatibility also continue to be ongoing research topics.

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- Heier, Siegfried: Nutzung der Windenergie. FIZ Karlsruhe. BINE Informationsdienst, Bonn (Hrsg.). Stuttgart: IRB Verlag, 2012. 6. erw. und vollst. überarbeitete Aufl. 160 S., durchgehend farbig. ISBN 978-3-8167-8607-8. BINE-Fachbuch. 29,80 €. Erscheint im IV. Quartal 2012

Links and literature (in German)

- www.rave-offshore.de
- www.alpha-ventus.de
- www.bsh.de
- www.gigawind.de
- www.fzk.uni-hannover.de
- www.forwind.de
- www.fino-offshore.de
- www.erneuerbare-energien.de
- www.forschungsjahrbuch.de (→ Windenergie)

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