Fraunhofer IWES

ANNUAL REPORT 2018/2019

FOREWORD

The Wind Energy Industry: Dynamics and Change – Then, Now, and in the Future

The developments seen in this emerging industry have always been extremely dynamic, right since the first phase of commercial utilization of wind energy back in the 1980s. New players sprang up along with the developing markets – some fading into obscurity again as soon as they encountered first turbulences and others subsequently failing when faced with the associated technological challenges. Despite this constant upheaval, the entire industry was moving forward in the same direction: bigger and more cost-effective. Today, wind energy turbines are the largest rotating machines that humankind has ever constructed and the energy they produce is unbeatably cheap.

The dynamics in the industry have remained – and over the last 10 years, the Fraunhofer IWES has been able to utilize the changes and the new demands placed on the technological developments to establish a leading position for itself in the global research landscape from scratch.

Three aspects were particularly important here:

- We managed to secure a great team of employees, who threw themselves headfirst into the "institute-founding" adventure and helped construct the IWES with their boundless creativity and hard work.
- We had and still have backers at a regional and national level, who understood the need for this kind of research institute and provided us with their generous support accordingly.
- Our customers put their trust in our expertise in the scope of joint ventures and have evolved along with us.

I would like to express my heartfelt thanks to all those involved.

Having amassed more than 30 years of experience with and in the wind energy industry, I was constantly aware of one thing: there is a never-ending list of things to be done. And it is safe to say that it will never get boring.

This dynamic perspective presents an array of opportunities and possibilities for the continued positive and exhilarating development of the IWES. In the short-term, we will be expanding our existing infrastructure considerably and offering the industry innovative solutions for the safeguarding of their product development. Not only that: in the years to come, we shall also be addressing novel and interesting topics such as the digitalization of our validation methods, projects for sector coupling (integrated energy), and a larger-scale European cooperation with our research partners in the interest of mastering the great technological challenges in the industry together.

I hope – and this is a hope that I share not only with our highly motivated and skilled employees, but also with a large share of society – that we will be able to pass the world on to future generations in good condition. There's not much time left.

So let's get to it!

PROF. ANDREAS REUTER,
Managing Director Fraunhofer IWES

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2018 FISCAL YEAR FACTS & FIGURES

Budget Progression

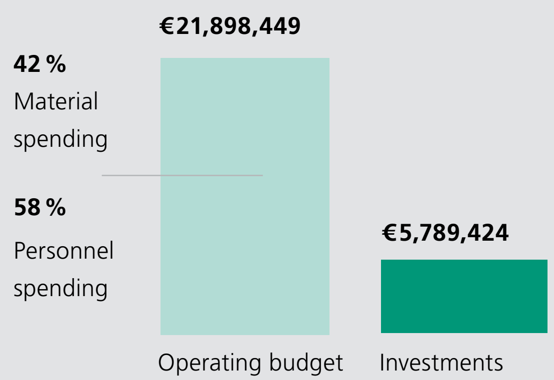
The Fraunhofer IWES' operating budget has more than quadrupled since the institute's foundation. In 2018, the budget stood at almost €22 million, of which 58 % was personnel spending and 42% material spending. The institute also had around €5.8 million in investment resources in 2018.

Sources of Operating Budget Income

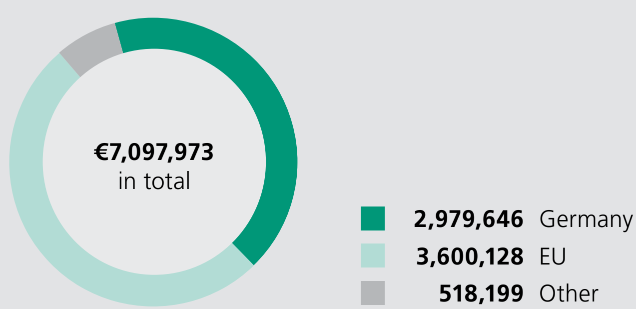
The Fraunhofer financing model comprises contract research for industrial companies, publicly financed (joint) research projects, and core funding for preparatory research. The applicability of the institute's activities for the wind energy sector is a key indicator of success and is apparent from the percentage of industry income relative to total operating budget.

Such industry income has consistently increased since the institute's foundation, reaching a record high of over €7 million in 2018. Industry therefore accounts for 32 % of total operating budget income. Further growth of industrial project income is planned for 2019.

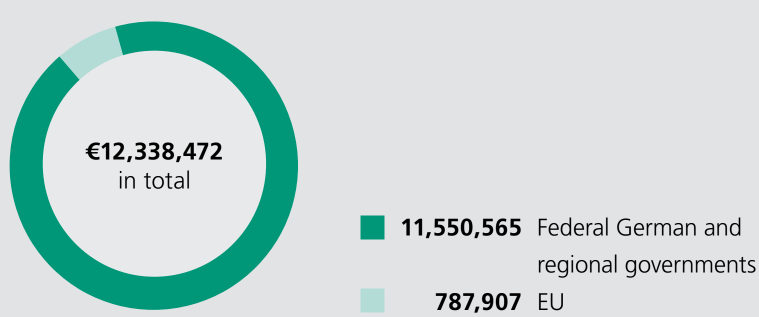
The remaining 68 % of the operating budget comes from public income for project funding, EU income, and other income. Public income of €11.5 million makes up the bulk of this 68 %, the German Federal Ministry for Economic Affairs and Energy (BMWi) being the main client within such research projects. EU income of not quite €800,000 makes up a very small percentage of the operating budget, but, in absolute terms, it has been steadily increasing in recent years too.



Source of industrial income in 2018 in euros



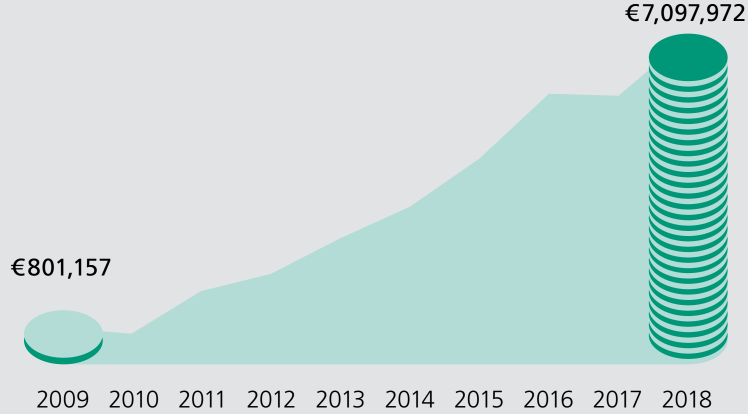
Source of public income in 2018 in euros



Breakdown of Industrial Income in the Operating Budget

In 2018, most of the industrial income came from wind energy companies within the European Union. Projects to the value of €3 million were realized with German companies. The contingent that contributed the highest revenue was wind turbines manufacturers.

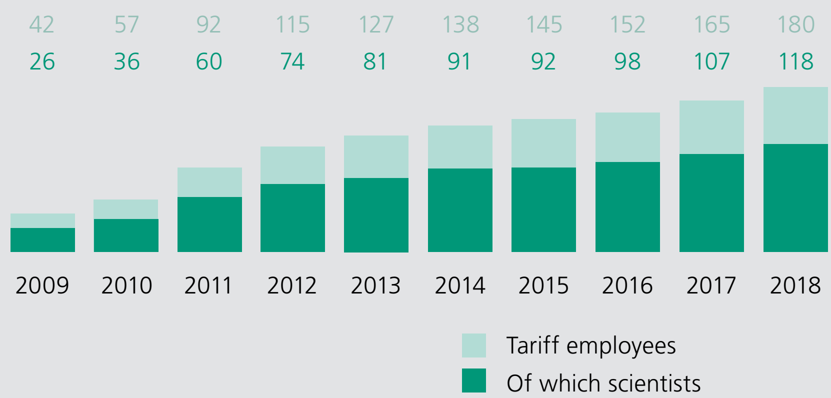
Industrial income



Staff Increases

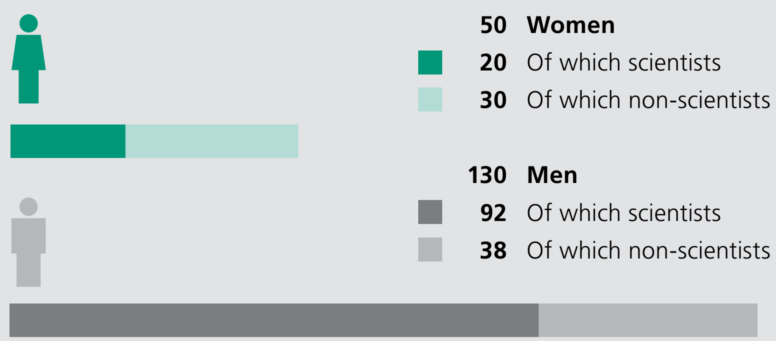
Since the foundation of the IWES and with the number of projects constantly rising, the size of the IWES team has grown consistently too. In its very first year of existence, the institute had 42 employees. Now, there are more than 190 people working for the institute at five sites across Northern Germany. It also proved possible to increase the number of women working at the IWES overall in 2018, and, in terms of the new hires, a third of the positions were filled with women.

Personnel



New hires in 2018

Number of female and male employees



WIND ENERGY RESEARCH 2009 – 2019

Current Status and Prospects

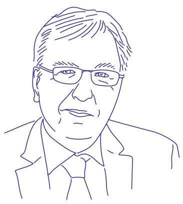
By DR. NORBERT ALLNOCH

The founding of the Fraunhofer Institute for Wind Energy Systems IWES 10 years ago marked the visible result of an extended development process. It was preceded in 2007 by an evaluation performed in collaboration with the IWR of the 4th energy research program for the renewable energy sector conducted by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU). At that time, the investigation provided unique insights into the focal areas of the numerous research projects funded by the BMU. The heterogeneous image which emerged resulted in the systematic approach developed by the IWR of holistically structuring the concluded funding projects in the wind energy sector using an analysis matrix and across the most important components and parts of a wind turbine. As such, in light of the numerous projects, a content-based research structure became evident for the first time. The primary focus of the BMU funding plan at that time was individual aerodynamic and physical wind issues as well as numerous environmental biological studies prior to the use of offshore wind energy. Research issues relating, for example, to engineering were barely addressed. The results also clearly indicated that, in terms of wind energy, the German research landscape was very heterogeneous, technically fragmented, compartmentalized, and lacking a central anchor institute.

Ultimately, the results from the evaluation of the projects funded by the BMU led to a central question and task: how can the structures in the German research landscape be designed in such a way that sustainable wind research with international appeal can develop and thrive in Germany? Merely the announcement of the follow-up IWR study looking into the structure of wind energy research in Germany triggered a dialog dynamism amongst the research players the likes of which had never been seen before. The IWR analysis matrix was an essential aspect of the study. It was this systematic approach which revealed the strengths and weaknesses of wind energy research in Germany, initially in terms of content and then based on regions. Another important step was the classification of research institutes and structures using defined model types depending on the degree of centralization. With the research institutes of structure model type I (decentralized, project funding only) to model type IV (centralized, a large centralized institute), it became possible to visualize the entire spectrum of existing research structures across all states. Against this backdrop, the wind research structures in eight European states and the USA were analyzed and classified in terms of their strengths and weaknesses. Following on from this, recommendations for action were derived for Germany.

The IWR essentially recommended pooling and developing wind research efforts while avoiding negative knock-on effects for the decentralized research landscape. With the expansion of the current research portfolio in connection with the test centers in past years, the Fraunhofer I WES has successfully filled precisely this gap and has significantly boosted Germany's standing as a wind energy research location. This international alignment was also necessary since it was already evident back in 2008 that the research market and the industrial production and sales market for wind turbines in Germany were drifting apart.

When one considers wind research and the overall wind sector in Germany today, it is clear that, with respect to the challenges posed by the future, further development remains a dynamic process.



DR. NORBERT ALLNOCH

International Economic Forum for Regenerative Energies (IWR)

17 MICROMETERS: THAT'S THE THICKNESS OF THE GLASS FIBERS EMPLOYED IN OUR ROTOR BLADE PRODUCTION. *A human hair is more than 5 times as thick.*

Changes on the national and international markets demand that a flexible approach be taken at both (research) content and structural level. Moreover, new analysis instruments are also required.

For example, the SLAM (Standard Location Asset Model) approach, which has been advanced by the IWR, allows visible rendering of the strengths and weaknesses of entire sectors in a region or countries in a holistic manner. According to the SLAM concept, the four key parameters of expansion, business, research, and education as well as their interactions are decisive for the industry rating of a country or location. These country assessments with respect to Germany as a location can form a solid foundation for future-oriented courses of action, not only with regard to wind research but also beyond.

The future of the wind sector in Germany depends on the national market and, in particular, on the successful interrelations between industry, research, and education as well as the internationally oriented expertise of the market players. Policies in Germany are currently focused on governmental regulation and control of national expansion. A holistic and systematic industry approach is not evident. Yet within the national, European, and global context, such an approach would seem more necessary than ever. However, politicians cannot be held solely responsible for managing this process. While structural changes are virtually impossible to implement without a political declaration of will, trend-setting impulses are also required from the wind sector. However, at present, such impulses barely go beyond the known demands for expansion targets and climate protection.

The regenerative age has long since begun. An increasing number of countries now rely on wind energy and are focusing on regional value creation. In terms of scope, the global wind energy market has now achieved an impressive level of maturity which, in turn, has led to a higher degree of market stability. Nevertheless, signs of changes are becoming apparent. For wind turbines well in excess of the 10 MW class, test benches and new test fields have to be designed which are able to compete at a global level. The deployment and development of new simulation models and software to reduce the risks associated with new products and projects is gaining in importance. The enormous global potential of offshore wind energy, especially in deeper waters, will probably mean that there will be an increasing focus on floating offshore wind farms in future. In addition, as the size of projects increases, the arrival of new players on the market is also a likelihood.

Just as the automotive industry has to take on the challenge of switching from fossil fuels to electric cars, the multi-billion offshore oil and gas industry will want to help shape the future of offshore wind energy. Given their current pioneering position, the players from the wind sector and politicians are still able to determine which role Germany will assume in the future. A strong research location could help to secure the loyalty of the wind industry sector. We can now only hope that far-sighted and structural policies will set the right course for the success of the wind sector in the future.

BY DR. NORBERT ALLNOCH

— More and more countries are utilizing wind energy and focusing on regional value creation. —

Dr. Norbert Allnoch
IWR

THE LEADING EDGE OF A ROTOR BLADE PROFILE SPINS AT A SPEED OF 550 KM/H (342 MPH) IN THE RAIN EROSION TEST BENCH *– that’s almost as fast as a TGV high-speed train, which holds the world record for rail transport at 574 km/h (357 mph).*

History: Laying the Foundations for a Smart Future

By BRITTA ROLLERT and PROF. ANDREAS REUTER

BRITTA ROLLERT

Head of Marketing and Communication

PROF. ANDREAS REUTER

Managing Director Fraunhofer IWES

The International Economic Forum for Regenerative Energies (IWR) conducted a study on behalf of the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) in order to investigate the structure of wind energy research in Germany. One fundamental finding was the discovery that a wide variety of entities were involved with wind energy, but pooling and coordination – also essential for international competition – was lacking. Large research institutes also collaborating very closely with industry in certain fields had been in existence in neighboring countries for several decades in some cases.

The Fraunhofer IWES was thus founded in 2009 as a central research institute and charged with bringing together and driving forward the activities in the key region of Northwest Germany. In addition, the institute's tasks also extended to the installation and operation of large test benches for the purpose of industry-relevant testing and the development of corresponding methods expertise.

The nucleus was formed by the Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT) – a joint facility belonging to the Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM) and the Fraunhofer Institute for Structural Durability and System Reliability (LBF). This precursor institute was developed into a Fraunhofer institute in its own right, and the sites in Northwest Germany specializing in mechanical engineering as well as the Kassel site with its focuses on network integration and storage were brought together under its roof.

Institutional ties to the activities of the ForWind research center – and with it the universities of Hanover, Oldenburg, and Bremen – reinforced the institute's presence in the states of Bremen and Lower Saxony. Activities promoting the common further development of wind energy research in the region were established in a cooperation agreement. This collaboration has continued to this day in the scope of the Research Alliance Wind Energy (FVWE), with the German Aerospace Center (DLR) having joined as a third partner in 2012.

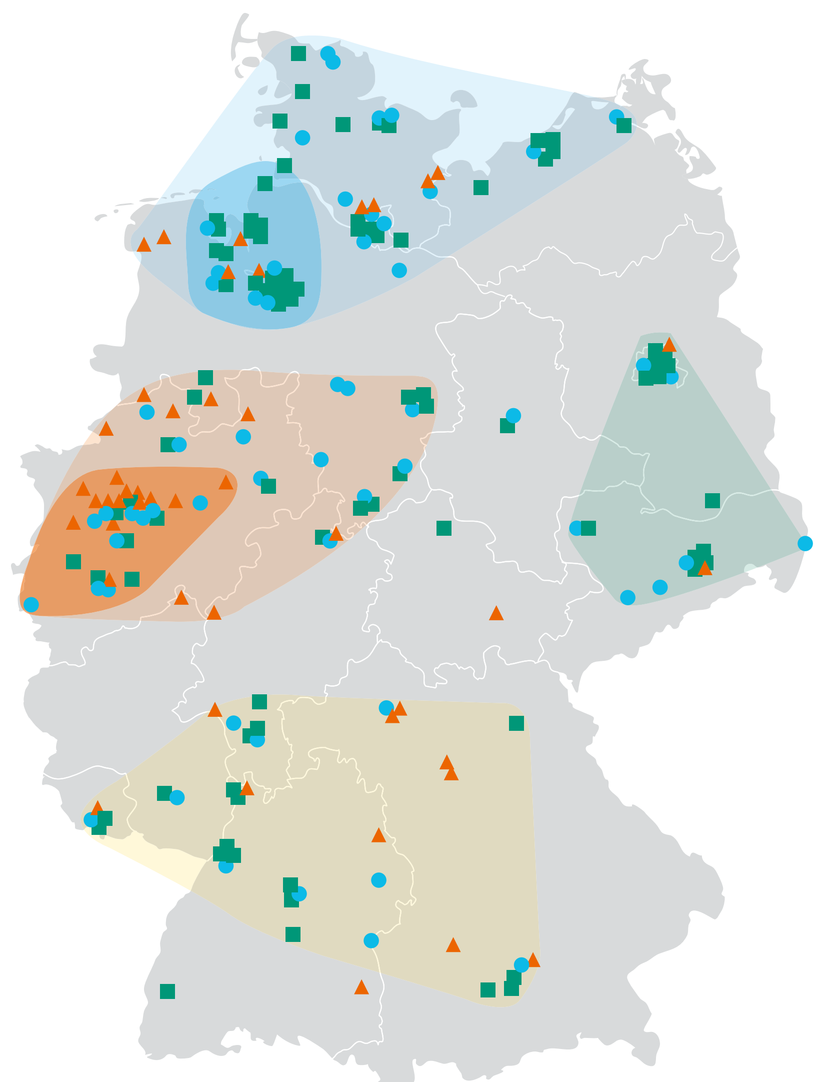
The German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) approved funding on a project basis to the tune of €25 million for the financing of the institute's development up to 2013. Additional funding for the development of the infrastructure and smaller development projects was provided by the states of Bremen and Lower Saxony as well as the Fraunhofer Society itself.

Today, the Fraunhofer IWES employs 190 members of staff at six sites across the Northwest of Germany. Its trademark is a one-of-a-kind testing infrastructure allowing large-scale testing for the validation of models for new rotor blade, nacelle, support structure, and bearing designs. Thanks to the consistent focus on industry-relevant topics and the further development of sound key competences, the institute is now a recognized research partner of the market leaders in the wind industry.

The development and expansion of academic excellence and application expertise is systematically continued thanks to the close cooperation with the universities in the Northwest and internationally renowned facilities alike. Synergies from this network are evident in the performance of large-scale research projects, with a wide range of different disciplines all making a contribution. The complementary testing infrastructure portfolio ensures that the latest questions posed by the industry are addressed systematically and new solutions developed together.

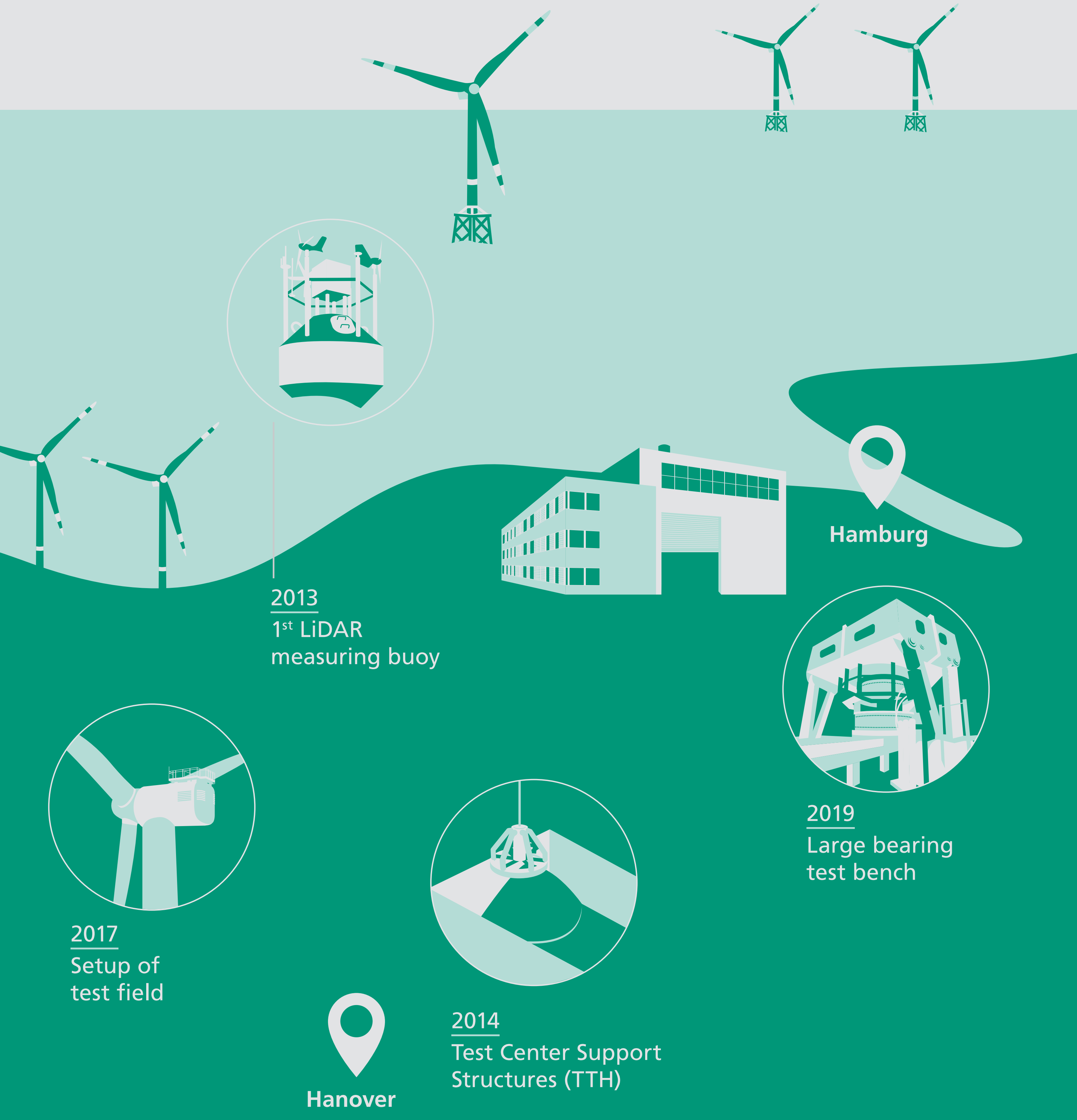
Topics such as digitalization, virtual test benches, and projects in the field of sector coupling are paving the way to a smart future – one for which we are already equipping ourselves today.

By BRITTA ROLLERT and PROF. ANDREAS REUTER



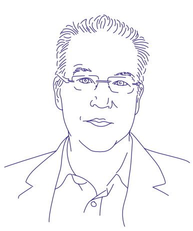
BUNDLED WIND EXPERTISE.
The foundations were laid by a study conducted by the IWR.

IWES MILESTONES


2013
1st LiDAR
measuring buoy
Hamburg
2019
Large bearing
test bench
2017
Setup of
test field
2014
Test Center Support
Structures (TTH)
Hanover

10 Years of Wind Energy – A Period with Fundamental Changes

By MATTHIAS SCHUBERT



MATTHIAS SCHUBERT

Managing Director
wyncon GmbH

The founding of the IWES in 2009 came in the direct aftermath of the global financial crisis. This triggered problems for a large number of project funds and the wind energy sector experienced a serious decline in sales, primarily with regard to the orders being placed and then, as of 2010, as regards the actual installation figures too.

Three years of dynamic growth in the Western markets with annual growth rates of almost 30% were followed in 2010 by a slump of almost 25%, followed by a lateral trend in the years thereafter. Companies implemented austerity policies. The primary measures more often than not affected their innovation budgets: by no means ideal starting conditions for the IWES' sector-oriented business model with research geared toward economic interests!

In contrast, the years from 2008 to 2010 heralded a breakthrough for wind energy in Asia, and in China in particular, with gargantuan growth rates that the grid expansion simply could not keep up with until 2010. In 2009, China led the global statistics for the annual installation figures for the first time, and by 2010 it already represented around 50% of the market share. Driven on by the ambitious intentions of local provincial governments, more than 70 new manufacturers appeared during China's booming growth phase, of which three, namely Sinovel, Goldwind, and Dongfang, have since established themselves as frontrunners in the global top 10.

With that, the golden years of double-figure growth became a thing of the past for the wind energy sector. All in all, the global market maintained a consistent level of approx. 40 GW from 2009 to 2013, as a result of which the sector now had to deal with serious overcapacities following hectic investment in new capacities during the boom years which preceded the financial crisis, overcapacities which were now further exacerbated by the innumerable new manufacturers and suppliers in Asia. This took its toll on prices: the costs per installed service plummeted by more than 30% between 2008 and 2013.

The difficult market conditions put pressure on many manufacturers and, in subsequent years, resulted in market shakeouts and severe crises such as that experienced by market leader Vestas from 2011 to 2013. In the wake of this crisis, Vestas sought itself a joint venture partner for the offshore business and was successful in this respect together with MHI in 2014. Alstom, which had only just broken into the wind business in 2007 after being taken over by Ecotecnia, sold its wind activities again in 2015, this time to GE. Nordex also merged with Acciona in 2015; followed by Gamesa joining forces with Siemens' wind operations in 2017.

However, above all, the enormous variety of manufacturers in China reduced dramatically in the first half of the 2010s as a result of a tough "Darwinistic process of natural selection". Only in recent years did a certain stability among the top 5 manufacturers finally establish itself on what has been the largest individual market for ten years now.

Even if the drastic drop in prices which began in 2009 was at least to some extent a correction for the excessive prices attained in the preceding boom years, the manufacturers and their development departments had to work hard to reduce costs. The majority of European manufacturers pursued the concept of modular platforms and equipped turbines with different rotor diameters depending on the prevailing wind conditions.

The 2 MW platforms with approx. 80 m rotor

CLOSE INSPECTION *even of the large components.*

diameter introduced in the early 2000s were upgraded in 2009 to a 100 m diameter for low-wind locations (e.g., Vestas V100). In the ten years afterwards, these platforms were developed further and further in an evolutionary fashion with the result that, today, at diameters of up to 120 m, an excellent ratio of turbine costs to annual electricity yield is ensured.

The 2 MW platforms have now held their ground in the industry for 20 years. The development from the 80 m to the 120 m rotor blade diameter seen today (equivalent to more than doubling of the rotor surface) translated to an enormous yield increase on an architecture that admittedly had to be improved time and again for certain load regimes (e.g., drive torque) but was ultimately completely "bled dry" with the developmental advances and knowledge gained over the last two decades for perpetual increases in yield.

When one considers the development of the average turbine output in the annual new installations on the German market, which has always been a reliable indicator for the latest turbine generation, it is clear to see that the market virtually asymptotically settled on the 2 MW class in 2010, in order to move on up to the next performance category with vehemence as of 2011. Senvion (still REpower at that time) had already introduced the new turbine category back in 2008 with the 3.4M104 (3.4 MW at 104 m rotor diameter).

After a rather slow rate of development in the years from 2009 to 2014, the 3 MW platforms dominated the ultimately rapidly accelerated cycle times for product innovations. Generator power and then rotor diameter were improved in alternation, with the latter often going hand in hand with a leap

THE ROTOR BLADE DIAMETER OF THE WIND TURBINES WE MEASURE CAN ALREADY REACH UP TO 180 METERS. *In comparison: two A380 airplanes flying alongside each other in formation through the turbine's rotor circle would reach the same dimension.*

— In the offshore segment, manufacturers continually outdid each other with new size records. —

Matthias Schubert
wyncon GmbH

in type category: the largest rotor diameter to date was developed further for higher wind speeds while the next largest rotor generation was introduced for the low-wind locations

For example, Vestas further developed the 3 MW platform introduced in 2010 with the V112-3.0 to the V136-3.45 (2016) and finally the V150-4.2 (2018).

The year the IWES was founded marked a watershed in another regard as well: the offshore market surpassed the 2 GW mark for total installed power around the world in 2009 and thus became a relevant "individual market" with what remains to this day impressive growth development leading to almost 22 GW of installed power today.

The greater plurality of markets with the simultaneous pressure to increase market share by driving out the competition inspired many manufacturers to diversify their product portfolios. Instead of global one-size-fits-all designs, they now targeted a range of market segments: high capacity factors in the U.S., maximized annual yield in Western Europe with its limited available locations, low costs per installed kilowatt in China, capex optimization in India with its high interest rates, etc.

In the offshore sector, conversely, size was the only thing that mattered: until the commissioning of offshore prototypes of the GE Haliade 150-6.0 in early 2014, Senvion had held the size record for turbines in water since 2007 with the 5M126, which was connected to the grid in the scope of the offshore demonstrator project "Beatrice". The series launch of turbines with diameters above 126 m actually began offshore as late as May 2015 with the commissioning of the new generation of Siemens' SWT-6.0-154 direct drive turbines in the Westernmost Rough offshore wind farm.

However, in recent years, the development has been rapid and the two largest rivals in the offshore segment, SGRE and MVOW, in particular continually outdid each other with new records. At present, Siemens-Gamesa is leading the field with the announced SG 10.0-193 ahead of MHI Vestas (V164-10.0 / V174-9.5).

In the onshore market, in contrast, two parallel fronts have developed over the past decade. In the U.S., wind turbines with a high capacity factor have established themselves in the spacious, rural Midwest especially. Turbines in the 2 MW category with slight performance improvements to between 2.3 and 2.7 MW generator power still dominate here today too. In contrast, rotor diameters have increased massively and can now extend to around 130 m.

This trend is even more pronounced in certain areas of India and China with less wind. While turbines for low-wind regions were still specified with a specific rotor performance of 250 W/m² 10 years ago, extremely designed turbines such as the Envision EN141-2.5 for example attain just 160 W/m² today.

In Western Europe especially, another trend became apparent and resulted in the introduction of the 3 MW category in a stand-alone development path: the goal here is absolute yield optimization in a wind farm project. That doesn't just have to do with the limited locations available in these markets, but also with the business model typically encountered there in which project developers (often also smaller ones in fact) secure the locations and are thus the driving force – and the project developers' margin depends proportionally on the realized annual energy yield.

Wind turbines beyond 3 MW capacity have triggered yet another trend in recent years: a considerable increase in hub height. The higher yields from the individual turbines mean that the specifically higher costs for very high towers start to become profitable and make raising the rotors to heights with decent wind conditions feasible, even at otherwise average locations.

From a technical perspective, the high towers pose a challenge, as the steel tube towers usually employed have to be limited to a base diameter of max. 4.3 meters due to transport restrictions. Such geometries result in very "soft" towers with corresponding challenges in dynamic operation and the control of the turbines (soft-soft design). This technology has now been employed at hub heights of up to approx. 130 m.

Early towers with high hub heights and those intended to reach even higher hub heights today at more than 160 m, employ technologies which avoid transport restrictions for large base diameters. The pioneers were so-called hybrid towers, in which the tower base was made of stacks of ring-shaped concrete segments on top of which the familiar steel tube tower segments were placed. Other solutions employ lengthwise split tube segments or braced tube towers.

In the past five years in particular, manufacturers have been involved in a high-investment race for continuously larger, higher and more powerful systems for the market segment with few locations. Vestas, for example, set up its new V150-4.2 with a yield increase of a good 10% in 2018 as a prototype, although the V136-3.45 installed as a prototype in 2016 had only just gone into production in relevant volumes, only to announce a completely new platform as the next step in the form of the V164-5.6 just a few months later.

The fast pace of innovation is driven by a development that has taken hold in a number of markets in parallel in recent years: the introduction of auctions for the funding of wind energy projects. This halved remuneration tariffs for the fed-in electricity in next to no time, making the levelized costs of energy the unrivaled primary parameter for the evaluation of wind turbines.

At the same, an enormous drop in the price of photovoltaic modules in recent years also adds to the competitive pressure. As such, this technology poses a threat to the wind energy segment in bids for renewable energy where no technology is defined.

For decades, the race for ever larger turbines was the reliable solution for better cost-efficiency. Aside from the fact that it is already foreseeable

— These innovations can also be employed for old turbines. —

Matthias Schubert
wyncon GmbH

today that this development strategy is finite for the onshore industry at least, larger – higher – more powerful on its own is no longer enough to seize and retain the leading competitive position. At the same time, the specific costs need to be decreased significantly.

Looking back over the past ten years, a number of developments have been essential for the realization of larger turbines with lower specific costs. This is particularly true in the case of those components where the physical laws of dimensions have been leveraged – i.e., the costs increase disproportionately to the size and, as a result, carefully developed improvements are at risk of disappearing again as soon as the next generation emerges.

This concerns the slowly turning, mechanical drivetrain, especially the gearbox, for example. As the blade tip speed of the rotor blades cannot be increased further for noise protection reasons, larger rotors rotate more slowly and therefore generate additional torque not just due to the higher power, but also because it passes through the drivetrain at a lower speed. As such, the gearbox torque is one of the characteristics which increases disproportionately with the size.

Over the years, gearbox producers have managed to increase the power density of these components (transmissible torque in relation to the total weight) considerably. At approx. 180 kNm/t, the latest gearboxes transmit approximately 50% more than just ten years ago. In other words, the gearbox of a multimegawatt turbine would weigh a good 15 t more and cost tens of thousands of euros more accordingly if it were to employ the technology from back in 2009. This scenario was counteracted with a wide range of innovative key technologies such as the use of sliding bearings instead of bearings with roller elements.

In 2009, many market observers would have put their money on gearboxes disappearing from wind turbines altogether. Ever more manufacturers began changing their portfolios over to direct drive machines in which the rotor drives a slow-running generator directly. However, it is much more difficult in this kind of generator to counteract the higher costs with innovative concepts because of the disproportionately increasing torques, which is why this configuration has not been able to establish itself across the board.

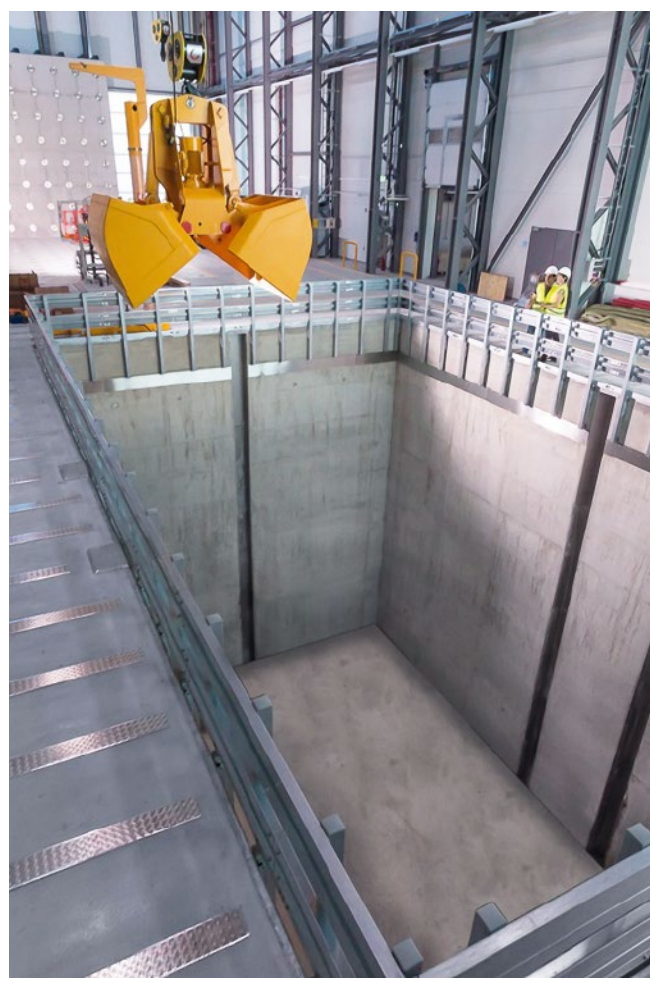
In contrast, there is a clear trend toward the use of carbon fibers for the load-bearing structure of rotor blades in larger turbines, although the specific costs for this structure are actually increasing, even in comparison with those with glass fibers. However, the mass of the rotor blades has an enormous effect on all the loads to which the rest of the turbine is subjected – in particular also because the rotor with its millions and millions of revolutions over the course of its operating time exposes all other materials to high levels of fatigue. Lighter blades also translate to lower costs for all the other components of the wind turbine.

A third field which has seen enormous developmental advances in the last decade is the operation and control of turbines. Of course, it is most efficient not to let loads develop in turbines in the first place. They can be considerably reduced by smart algorithms or innovative control architectures with feedback signals or model-based specifications.

These innovations can also be employed for old turbines, which are retrofitted with software and controller upgrades. In recent years, many manufacturers have begun selling such improvements as service products in their portfolio. In this way, the latest innovations can be used to improve the cost-efficiency of turbines which have already been in operation for ten years.

The IWES' support in the development and validation of its customers' innovative solutions thus unites earlier and current challenges.

By MATTHIAS SCHUBERT



THE TEST PIT FOR OFFSHORE SUPPORT STRUCTURES HAS A VOLUME OF 1,260,000 LITERS. *That is the equivalent of around 90 truckloads of sand.*

Rotor Blade Expertise – Development and Perspectives

By NIELS LUDWIG

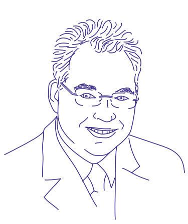
Since it was founded back in 2009, the Fraunhofer Institute for Wind Energy Systems IWES has grown continuously and now employs almost 190 members of staff. SINOI GmbH has accompanied this growth right from the very beginning. Our collaboration actually began even before the institute was founded – with the technical consultancy services and assistance of the IWES' predecessor, the Fraunhofer Center for Wind Energy and Maritime Engineering (CWMT).

The CWMT had developed out of an initiative launched by the rotor blade manufacturing industry, which had joined forces to form a consortium known as the Rotor Blade Alliance (formerly Rotor Blade Expertise Group). This platform gave the industrial partners the possibility to voice their wishes and suggestions right from the beginning. Lively and interesting discussions concerning the requirements on the test bench in particular were a common feature.

It soon became apparent that this was the perfect way to establish this kind of center of expertise in Germany. The test benches were – to the initial amazement of all those involved – utilized to almost complete capacity.

The test portfolio was developed in close cooperation with leading industrial companies, who had also accompanied the development of the test methods and processes right from the design stage. In the early days, SINOI contributed to the development of the test benches and measuring technology with the uncomplicated provision of a 34-meter-long rotor blade to offer the possibility of performing practical tests.

In the years that followed, the IWES' cooperation with the industry developed further beyond rotor blade tests and their components, giving SINOI GmbH and the institute the opportunity to work together on a number of shared research and development projects. Of particular note in this respect is the BladeMaker project, in which the foundations for automated rotor blade production were developed. It was successfully completed with the creation of a ready-to-use project demonstrator. The follow-up project, BladeFactory, is now under way and promises to be yet another advance in the industrial production of rotor blades. SINOI has been involved in both projects as an associated partner and offered helpful input from a rotor blade manufacturer's perspective.



NIELS LUDWIG

Technical Director of SINOI GmbH, Nordhausen

A BLADE TIP TRAVELS 50,000 KILOMETERS DURING A ROTOR BLADE TEST. *That is 10,000 kilometers more than the circumference of the Earth.*

— The IWES’ cooperation with the industry has developed further beyond rotor blade tests. —

Niels Ludwig
SINOI GmbH

WE USE UP TO 5,980 INDIVIDUAL PROCESSORS – CORES – FOR THE CALCULATIONS WHEN SIMULATING WIND AND AERODYNAMICS. *That corresponds to the processor capacity of 1,495 laptops.*

All of the joint research projects in which SINOI GmbH has participated or is still participating have been characterized by successful cooperation built around mutual trust.

In the beginning, advice from SINOI's side formed the basis for the collaboration: the wealth of knowledge gained from many years of experience in the development and production of rotor blades made it possible to offer practical instructions and tips, which helped the engineers at the IWES to better understand the fine details and challenges encountered in the production of large fiber composite components and implement them for their own requirements. At the same time, there was a prevalent spirit of optimism, which really drove forward the development and realization of the test benches and testing facilities.

The structure of the IWES evolved over the following years. Further experts and new tasks resulted in a differentiated realignment. Whereas the collaboration was initially more characterized by pragmatism, with time this transformed more into an optimized approach. And personal contact was never in short supply. Quite the contrary, in fact: the direct contact with our partners in the institute has got better and better over time as our trust in each other deepened.

Today, a rotor blade test center has developed into a true center of expertise for rotor blades, which no longer focuses exclusively on the testing of rotor blades and their components. In fact, the expansion in the field of material and process engineering has established the foundations for offering an attractive portfolio for the rotor blade industry in the area of industrial production in the future too. Renewable energies and wind energy in particular are currently in the midst of a process up to industrial production linked to the development of medium-sized companies into corporations. Rotor blade production is particularly affected by this. From the perspective of the rotor blade manufacturers, this change can only be successfully mastered with industrial rotor blade production.

The IWES boasts a unique selling point in this respect, making it optimally equipped for the challenges of the future. SINOI is very interested in developing this field even further with the aim of making it possible to research and test the preindustrial development with regard to new production methods and materials further on a large scale.

Despite the growth and the expansion of the tasks and fields, the collaboration has not changed significantly from our perspective. The IWES remains an expert contact partner for SINOI, including for matters outside the scope of our day-to-day activities.

We wish the IWES all the very best on the occasion of its 10th anniversary and look forward to continuing our excellent work together.

BY NIELS LUDWIG

The IWES spirit – diversity is our strength

— We take the time to discuss problems and always take the benefit for the industry into consideration. —

Dr.-Ing. Steffen Czichon
Multiple years of industry experience,
Head of Rotor Blades at Fraunhofer IWES

— You feel integrated and soon develop the feeling of being a part of something bigger. —

Dr. Aligi Foglia
Multiple years of research work in Denmark, Senior Scientist at Test Center Support Structures.
Undergraduate studies: University of Bologna / Postgraduate studies: University of Aalborg

— I can choose to work in my cozy office or on the top of the tower of one of the largest turbines in the world.—

Dipl.-Phys. Alkistis Papetta
Multiple years of research work in Denmark, Research Associate for Wind Farm Planning and Operation. Undergraduate studies: University of Cyprus & Oldenburg

VIRTUAL FUTURE

Digitalization at the IWES – Merely a Follower or an Influencer Too?

By PROF. JAN WENSKE and PROF. ANDREAS REUTER

Digitalization and digitalization strategy are on everybody's lips at present, yet these terms are mostly only used superficially and nonspecifically. The measures, ideas, and specific objectives themselves are only named rarely, which means the terms are at risk of deteriorating completely into merely yet another nondescript, en vogue expression peppering the latest discussions in both the industrial and also the public sector. In the context of this digitalization, in its navigable waters so to speak, one also comes across other buzzwords: Industry 4.0 and smart home/grids are already all but archaic, although they have not yet been completely developed and introduced; the next round of this merry "I want to play too" bingo is already raring to go with the "Internet of things, digital twin, 5G, blockchain, and KI". Some of these terms refer to specific digital technologies, while others such as digital twin remain relatively undefined and appear with a wide variety of very different interpretations. The IWES is also faced with the challenge of identifying a feasible and serviceable means of entering this field. To ignore the technologies associated with the variants of digitalization and thus miss out on genuine growth opportunities for the Fraunhofer IWES would be more than just negligent, and the same is true of pursuing said goal aimlessly and without setting a sure course. For this reason, we are committed to actively filling the superordinate concept with real projects and specific technological developments, with the aim of giving the topic a face, and – far more importantly – a true significance at the IWES. This article on the occasion of our 10-year anniversary marks the start of our journey to define our position; further, more detailed examinations are set to follow.

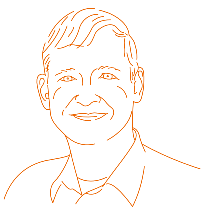
Let us begin with an overview of the current situation: over the next few years, the IWES will primarily be actively addressing the following technologies and approaches:

- virtual test methods and benches with the aim of expanding, scaling, and optimizing our existing lab and large-scale test benches;
- specific digital twins for wind turbine components, systems, turbines, or wind farms, employed for the estimation of the remaining lifespan, online optimization, and forecasts as well as scenario simulations and improved system integration;
- application of machine learning and artificial intelligence methods to our test, measurement, and field data for optimized operation, O&M services, and planning (site assessment – ground, wind, waves), complemented by the development of shared software and data standards (IWES Data Space);
- probabilistic design and modeling of wind turbines, their components, and their environmental influence classes with the aim of pushing back current design limits even further, recording risks more effectively on the basis of their stochastic nature, and minimizing and thereby reducing manufacturing costs even further;
- use of flexible and agile cooperative strategies in the scope of New Work via the consequent implementation of new digital possibilities.

These technological approaches are not completely strictly definable and sometimes overlap, or, indeed, some mutually influence one other to some extent (e.g., virtual test methods and digital twins). On the occasion of this, our 10th anniversary, we would like to seize the opportunity to delve into these topics from the IWES' perspective and to outline and explain the specific activities being undertaken at the IWES as well as their benefits for us and our customers step by step. We are getting under way with a focus on the virtual test methods and environments currently being developed at the IWES.

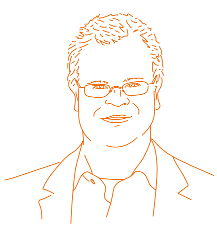
Virtual Test Environments

Current test and inspection procedures are characterized by requirements derived directly from a standardization and certification process. They ultimately represent a minimal consensus between different economic interests and often make technical issues subordinate to this consensus. Yet, even if one views the current approaches completely independently of this, it soon becomes evident that an actual validation and statistically significant experiment-based evaluation of a new design for a wind turbine or one of its components is often still subject to very strict limitations.



PROF. ANDREAS REUTER

Managing Director
Fraunhofer IWES



PROF. JAN WENSKE

Deputy Director
Fraunhofer IWES &
Technical Director

There are a number of reasons for this:

- The massive size of the original components and the immense loads to be applied render testing less precise and the corresponding test bench technology elaborate as well as resource- and energy intensive, and thus very expensive.
- The experiment-based verification of assertions concerning component fatigue is fundamentally tainted by considerable uncertainties (as a result of intrinsic variance in the test specimen characteristics, the testing facility itself, the not-exactly-the-same testing conditions, and the merely estimated, time-variant, and thus imprecisely defined real environmental conditions). The very high number of required load cycles also reduces the accuracy of the results of material tests, for example.
- Complex manufacturing processes involving a high share of manual tasks produce a wide spectrum of qualities, which are also not documented or can only be documented with great difficulty and result in considerable variance in the respective component characteristics.
- The low number of test specimens in the original size – some test batches comprise just 1 – allowing no form of statistical evaluation.

Consequently, tests performed on original wind turbine components on test benches can only provide an initial indication of a system's performance or component design's efficiency at present and can be drawn upon for the improvement of modeling. Definitive claims regarding the reliability and expected lifespan under specific operating and environmental conditions are barely possible.

To improve the informative value of experiment-based investigations in a challenging environment, the IWES has already been working on optimized testing methods going beyond the already standardized procedures for years – for example, the biaxial testing of rotor blades, where the loads from 20 years of turbine operation are applied realistically and, at the same time, in an accelerated format, thus making it possible to identify critical zones with more certainty.

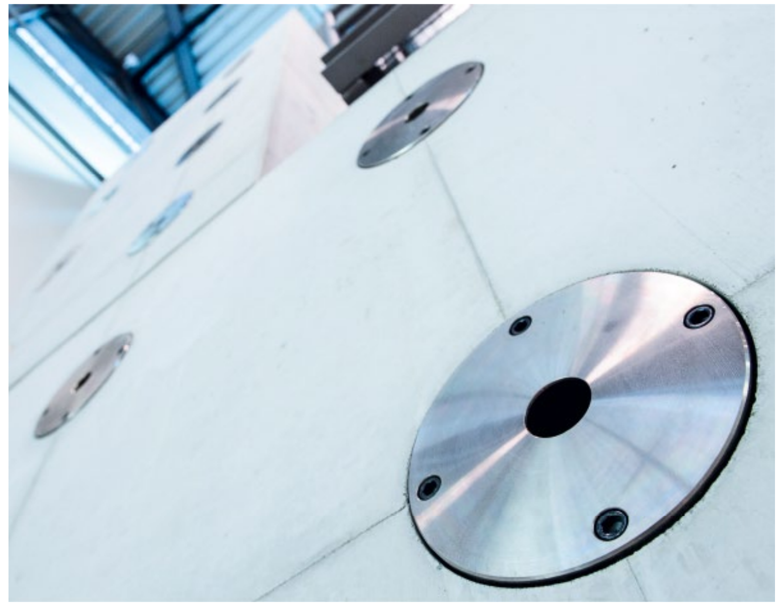
Further improvements (e.g., with regard to the durations of the tests) are made possible by dismantling the original components to be tested into segments, sections, or subsystems and then – repeatedly, if necessary, for higher statistical reliability – applying the respective specific loads and stiffness emulations to their interfaces.

All these experiment-based approaches are generally associated with increased efforts and costs, usually in the form of highly specialized testing equipment. As a result, they cannot be subsequently extended and modified if and as required.

However, an approach which expands upon and complements this promises significant improvements: the virtualization of tests and experiments using digital modeling in advance and their verification in parallel (in situ) to the tests on the test bench offer these possibilities, for example via the feeding back in of the experiment results, with subsequent variant calculations (taking inaccuracies into consideration) for sensitivity analysis, for additional model tuning, or test planning for verification of the failure mechanisms.

In principle, the digital modeling of a system or component is, of course, nothing new; ultimately, every rotor blade or drivetrain starts life as a computer model at the beginning of the design process. This approach only yields additional findings if

- the existing development models are utilized as a basis to represent the behavior of the component in the actual, planned test bench scenario,



FOR THE SIMULATION OF WIND LOADS IN THE NACELLE TEST BENCH WE EMPLOY HYDRAULIC FORCE APPLICATION WITH SIX BOOSTER CYLINDERS; EACH INDIVIDUAL CYLINDER TRANSFERS 3,000 KILONEWTONS OF FORCE. *That is enough to lift 100 elephants.*

— Pushing back boundaries with innovations. —

Prof. Andreas Reuter
Managing Director Fraunhofer IWES

– the measuring results from the real tests are integrated directly into the design model (online tuning), and
– the fatigue behavior and other component behaviors are documented in detail in combination with additional calculation and analysis methods.

If additional process information concerning the origin of the test specimen is still available, it is possible to make a statement about the statistical classification of the respective few or even single tests with far greater accuracy. In this respect, it soon becomes clear what this approach requires: the interlinking of a number of complex models (statistical and dynamic characteristics, material characteristics and imperfections, models for the description of the fault progress, production process information) and the efficient and intelligent handling of large quantities of data. This produces a parallel, virtual test environment, which is fed with information on the test bench, for example, but also during the production of the components and subsequent operation of the wind turbine. As such, these “virtual test benches” feature a far more comprehensive design than a single experiment on a test bench. However, the real hard work is now largely in generic development work and data management, and, to a lesser extent, in concrete blocks as well as hydraulic and electric actuators. This makes the urgently required new insights affordable and, at the same time, decouples them from the still-ongoing system evolution. Nevertheless, the necessary initial research and development efforts are considerable.

What Does That Mean for the IWES?

Complex toolchains are being installed at the IWES on an ongoing basis. They use FE and MBS programming systems as their numerical basis, expanded with a range of proprietary computational, analytical, and physical/empirical software modules. These toolchains are predominantly controlled via Python scripts all across the institute.

The methodology behind this becomes evident from the development and validation of foundation and supporting structures, for example.

The geotechnical and engineering models already in existence at the IWES are being integrated in a shared software system, with the aim of mapping the entire supporting structure (ground, foundations, any transitional components, tower) statically, cyclically, and dynamically. The validation is performed via large-scale tests on the horizontal clamping field and in the geotechnical test pit at the Test Center Support Structures (TTH) in Hanover. This approach, coupled with the experiment-based possibilities, thus represents a unique selling point. To date, the industry standard is simply the validation of engineering models via numerical calculations and, to some extent, small-scale testing, with the associated challenges such as imponderables and uncertainties of the boundary conditions and the constraint of too high and thus more complex and less reliable scaling.

Furthermore, this methodology can be employed to define and make available interface models for other modules of the IWES' continuously expanding test environment with ease: in the simplest case via complex stiffness matrices or as reduced, modal models in the scope of an integrated overall simulation.

The possible fields of application are very varied and multifaceted: within the institute for the improved planning of experimental campaigns and the validation of experiment results right up to the "teaching" of digital twins during tests on the test bench and minimizing of scaling influences there where even the IWES with its large-scale test benches can only test scaled test specimens or perform testing with reduced loads.

Innovative marketing options are also emerging in the outside world. With their more efficient test planning, the virtual test bench environments allow more cost-efficient validation of components and systems. Some already validated models for the processing of tasks can be employed directly from the industry, i.e., without performing prior testing. The customer's objective is often to develop an analytical, practical, simplified engineering model for the measurement and design phase for their own further use. There are no plans for the time being to pass on or market the IWES' virtual test environments even as a product.

This methodology of the virtual test environments in combination with extensive, real testing and experimentation options, and the continuously increasing insights into the relevant damage mechanisms ensure the IWES is well prepared for future challenges and offer great potential for our customers too.

A wide range of the IWES' major projects are already focusing on these approaches, take for example the binational project Reliablade, a collaboration with the Technical University of Denmark (DTU) and various industry partners working on the requisite digital building blocks for this type of virtual rotor blade test bench.

What Comes Next – Digital Twin and Reliability Control

Once there are already a large number of verified, specialized models available for a particular component or system, the question quickly arises of how additional added value can be generated from the amassed knowledge. This is where the "digital twin" concept comes in: every component is digitally accompanied or mapped from its production through its use right up to its eventual disposal. Information regarding the production process parameters, deployment conditions, and services is collected, assigned, and evaluated continuously. This makes it possible, for example, to use specific models for fatigue or other failure mechanisms to make predictions regarding the future behavior of the component, its current probability of failure, its remaining lifespan, or its service requirements. This helps with the cost-efficient optimization of the operation of a wind turbine. In comparison with the concepts of the virtual test methods/benches, the quantity of data collected is rising again enormously. Ultimately, there are a great deal of systems with a very high number of components which need to be documented and digitally mapped over extended periods of time. So far, the existing, classic approaches have only pursued this way of thinking rudimentarily: for example, there are already condition monitoring systems continuously making information available, which can be utilized to optimize the service process, for example. However, the methods being employed are still comparatively

THE HYDRAULIC CYLINDERS IN OUR BLADE BEARING TEST BENCH CAN GENERATE 20 MEGANEWTONS OF FORCE. *That is enough to lift three ICE trains at full seating capacity.*

— Virtual test environments offer enormous potential. —

Prof. Jan Wenske
Deputy Director Fraunhofer IWES and Technical Director

simple, the data incomplete or too imprecise, and a large share of the analysis work is performed by employees via remote monitoring based on their own experience. Here, one encounters a challenge for the use of the digital twin: enormous quantities of data must be efficiently collected, saved, and analyzed using automated systems. It is to be expected that methods of artificial intelligence and advanced pattern recognition (machine and deep learning) will make a decisive contribution to the solution of these challenges.

The IWES has also investigated the possibilities offered by the digital twin and developed new concepts for its cost-effective utilization. In this respect, the individual wind turbine/farm adapts itself specifically based on the prevailing wind conditions, operating data, and available failure and fatigue models via automatic adaptation of the individual management and control and the economic yield is optimized by utilizing the actual "failure profile", the individual fatigue budget. The goal of the concept of "reliability control" is a truly smart wind turbine/farm, where all the components are optimally utilized specifically for the respective location in accordance with their individual properties and in almost any variable environmental conditions, so as to be able to generate a maximum yield over a period of time to be defined or, perhaps, to be able to satisfy certain temporary requirements such as the optimal handling of load demand peaks in the power grid or in the system service for grid stabilization.

New Work

Digitalization does not just mean additional scientific potential for the optimization of technical issues for the IWES, but rather is also a tool which can be employed to master the future challenges of a world of work which is becoming ever more complex. The IWES is committed to putting the opportunities offered by digitalization to work for its employees, with the aim of strengthening team spirit and making workplaces more flexible so as to foster creativity and motivation.

With its five sites at present, the IWES employs – taking its size into consideration – a very decentralized infrastructure. The employees' existing and future demands with regard to further flexibility in their work, improved possibilities for cooperative work independent of the respective location, resource-saving methods and approaches for achieving goals, and an improved work-family balance pose the institute the challenge of continuously optimizing work processes. The options offered by digitalization should be employed to precisely this end. Our customers in the midst of the accelerated globalization of the wind energy sector also expect flexibility and efficiency in the solution of future, scientific matters.

So, what does that mean in precise terms? For example, how can employees, customers, test facilities, data, and software tools be brought together at different locations with a minimum of time requirements, expense, and detriment to the environment?

The initial step needs to be taken first of all by every member of staff at the IWES and consists in their opening themselves up to the challenges and opportunities of new IT solutions. The requisite tools, which, to some extent, have already been tried and tested in other companies, can then be introduced step by step: Skype conferences instead of business trips, the cloud-based storage of research results, combined edge and cloud computing, remote testing and measuring at all sites, the agile, virtual building of teams across organizational units – there are a whole world of new possibilities available.

Of course, there will still be a demand for face-to-face meetings in the workplace; working from home the whole time is not the solution we are aiming toward, but rather merely an individual, temporary option. The IWES is already experimenting with alternatives. For example, the institute's first co-working space is currently being set up in Bremen, where it will offer appropriate workstations for all working situations – be that a team meeting at a central location between Bremerhaven, Oldenburg, Hanover, and Hamburg, collective working in groups, or even just a telephone or video conference without interruptions.

In this way, little by little, a provisional image of the future IWES begins to take shape from the variety of different approaches for the use of digital opportunities. There will presumably be no disruptive effects at the institute. Rather, the potential for optimizing existing business models and working methods should be tapped step by step in order to comply with our stakeholders' requirements and wishes. Our industrial customers should be provided with reliable information concerning their demanding development projects, the utilization of wind energy should continue to develop more competitively, and we want to remain an attractive employer for our staff now and in the future.

BY PROF. JAN WENSKE AND
PROF. ANDREAS REUTER

The IWES spirit – diversity is our strength

— It’s a wonderful feeling to see how my ideas are turned into reality. —

Dipl.-Ing. Muhammad Omer Siddiqui
After studying in Aachen, now a Research Associate for Test Systems at the IWES

— The IWES’ size and spectrum of duties has the entire wind energy portfolio covered. —

Dipl.-Ing. Dirk Sandhop
Multiple years of research work in aerospace, Head of Department Test Systems at the IWES

— Everyone works together: scientists, students, and technical colleagues in order to achieve optimal results, for example in test specimen production. —

Holger Bannies
Multiple years of industrial experience, Technical Employee in Test Operation at the IWES

THE BOARD OF TRUSTEES

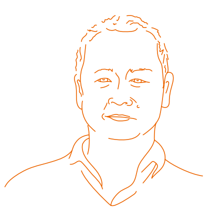
MEMBERS OF THE BOARD OF TRUSTEES

The Board of Trustees advises the Fraunhofer IWES with regard to its strategic orientation and supports the institute in its long-term positioning in the wind energy market. A board of trustees is the equivalent of a supervisory body in an industrial company and is composed of notable individuals from industry and academia. The members of the IWES Board of Trustees are representatives of our main sponsors, cooperation partners from the field of research, and industry representatives. The Board convenes annually.

Members of the Board of Trustees

The strategy is tailored to the industry

An interview with JOHN FENG



JOHN FENG

Chairman of Titan Technologies Co., Ltd.

John Feng tells us about his role as a member of the Board of Trustees.

Editorial team: Mr. Feng, could you tell us a little about your professional background?
— Titan Technologies Co, Ltd in Hangzhou, China, is active in the field of renewable energies. I am the Chairman and I completed my Master of Business Administration (MBA) at the University of Toronto and Tsinghua University. With my extensive international experience, I have been working together with the Fraunhofer IWES for seven years now. —

Editorial team: How do you see your role as a Member of the Board of Trustees?
— My primary role on the Board of Trustees is as an international adviser and consultant. With my experience and expertise – especially concerning the large Chinese wind energy market – I contribute my skills with the aim of actively supporting the strategic orientation of the Fraunhofer IWES. At the same time, I also benefit from the institute's wealth of knowledge and expertise. —

Editorial team: In your opinion, what challenges will the IWES have to face in the wind energy industry?
— I think challenging times lie ahead for the IWES: on the one hand, global wind turbine production is becoming ever more concentrated, and, on the other hand, new technologies are becoming relevant in the context of impending digitalization. I already see a whole range of opportunities for fruitful discussions at the upcoming meetings of the Board of Trustees and will be happy to impart my sizable experience, especially via my role in my company in the wind energy and IT industry. —

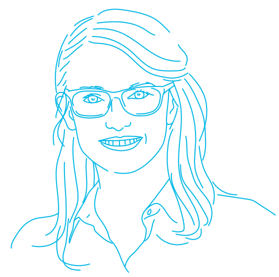
Editorial team: Thank you very much for your time, Mr. Feng.

An interview with JOHN FENG

John Feng is the Chairman of Titan Technologies Co., Ltd. He completed his Master in Business Administration at the University of Toronto, Canada, and at the School of Economics and Management at Tsinghua University, China. In North America, Mr. Feng was initially employed as a Strategic Planning Manager in the WHITING Group's subsidiary. He then went on to work for the PFAFF Group in Germany, where he held the positions of Chief Representative and General Manager. John Feng founded his own company, Titan Technologies Co., Ltd., in the field of renewable energies in 2009 and is also celebrating his 10th anniversary this year.

TALENTA SUPPORT PROGRAM

One of the Fraunhofer Society's important goals is to attract more women to applied research, and the Fraunhofer IWES is successfully working toward achieving this goal with a comprehensive support concept for female scientists. TALENTA is a support program aimed at helping scientists develop in the different phases of their careers. TALENTA *start* is aimed at university graduates poised to take their first steps in their research careers. TALENTA *speed up* aims to support female scientists in the final phase of their doctoral studies and with the transition to a post-doc role. TALENTA *excellence* is aimed at women assuming responsibility in a managerial position or aspiring to do so in the future.



Karoline Pelka

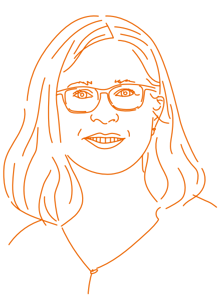
— TALENTA *start* helped me for two years when I landed my first job as a research associate at the IWES. The support and development program aims to assist female university graduates taking their first steps in applied research and launching their careers at Fraunhofer. Being released from my duties during working hours allowed me to explore wind energy topics thematically – with a degree in mathematics – to develop my specialist knowledge further, and, building on this and in parallel to it, to take my first steps in research practice through qualifications. In addition, I took a lot of inspiration and concepts for my personal professional development away from the kick-off event, especially from the contact with other TALENTA participants. —

Mareike Leimeister

— When I joined the IWES as a research associate, I was also accepted into the TALENTA program, as I was working towards a doctorate in engineering at a university in the UK in parallel. The additional working hours that I was granted via TALENTA *start* were invaluable for me: I was able to utilize them to attend professional training courses and conferences as well as for the obligatory courses offered in the scope of my doctoral program and my research work. As such, participation in the TALENTA program allowed me to combine my university studies with the work on applied research projects at the IWES. —

Mareike Collmann

— The financial support in TALENTA *speed up* frees up extra time for me in regular project work. I am utilizing this personal career time to focus on my research work and earn my doctorate. I am particularly grateful for this opportunity. Additionally, TALENTA also forms an extensive network of female scientists from all disciplines within the Fraunhofer Society. I found it a relief and also somewhat of a source of motivation to discover that many women are concerned with the same sort of day-to-day challenges. —



Julia Gottschall

— I took part in TALENTA *excellence* from 2016 to 2018. I put the additional career time that the program allowed me towards refining my specialist profile and developing my expertise as a senior scientist in the field of wind farm planning and operation. In addition, I also found the contact with other female scientists at Fraunhofer particularly valuable, as, although working at other institutes and in other fields, we are all pursuing similar goals. —

Katharina Fischer

— Between 2015 and 2017, I spent two years participating in TALENTA. As the specialist career had only been established at a few Fraunhofer institutes at that time, as a senior scientist, I was one of only a few participants with a specifically scientific focus in the TALENTA *excellence* program, which is generally aimed at women in (HR) managerial positions. I put the support in the form of around 20% comprehensive additional funding for the position – to free up extra time for professional, scientific further development – and an extensive qualification budget to use for specialist work, exchange, and team development in the field of reliability, and always found it immensely valuable. —

WIND-
ENERGY
2035

Mechanical and Electrical Trends

By EIZE DE VRIES

Semi-standard three-bladed upwind turbine technology for the onshore and offshore wind sectors is continuing to develop at a breathtaking pace and is perhaps even gaining additional momentum. This contribution to Fraunhofer IWES' 10th anniversary celebration focuses on mechanical and electrical trends as well as possible future developments between now and 2030/35.

As recently as 4 to 5 years ago, there was widespread consensus that 3 MW+ turbines with rotors of around 120 meters would dominate the onshore industry into the 2020s, yet 4-5 MW+ systems emerged much earlier than expected. In the offshore segment, in contrast, parties working within the EU-backed "Upwind program" expected 20 MW offshore turbines to take on a major role by 2020 as early as a decade ago – a prediction which has proven far too optimistic.

Auction Systems

The increasingly shorter life cycles of onshore turbines have, essentially, been the result of the worldwide introduction of auction systems and the downward pressure this exerts on LCOE performance (€/MWh). The current turbine height record stands at 5.8 MW with a 170 meter rotor diameter and 'maximum' 165 meter hub height offering 250 meter tip height. The new generation of high-performance gearboxes under development for onshore turbines of up to 7 MW and rotor diameters of up to 180 meters indicates further scaling increments to come in the future. The corresponding massive component dimensions and masses create huge parallel challenges across existing and new value chains. This puts enormous cost pressure on gearbox suppliers to reduce the cost per unit input torque (€/Nm) further. Additional suppliers must develop new, longer blades and higher, cost-effective tower concepts in order to optimize transport logistics and installation methods at the same time. One central question is whether this ongoing scaling will continue or face serious limits in the future as a result of technical, economical, and/or permit-related factors. Another such question is whether the record for road transportation of single-piece blades could be extended further to lengths of perhaps 85-90 meters or more, and, if so, what cost penalties would be involved. Or might it prove essential to reintroduce segmented blades with mechanical joints or develop new solutions with separate mechanically or chemically bonded tip segments of variable lengths?

Geographical Differences

In the near future increasing differences will be seen among the onshore turbines deployed in various geographical regions around the world, such as the low and ultra-low wind markets of China and India. A Chinese 2.5 MW turbine with a 141 meter rotor offering a 160 W/m² specific power rating is proof that this is already happening. This shift away from the "traditional" megawatt-based focus is also apparent in the offshore segment in China. The latest Vestas V162-5.6 MW for low and medium-wind, focusing on Central and Northern Europe, has 272 W/m² by comparison.

In general, lower specific power ratings offer higher capacity factors, which contribute positively to base-load capacity and grid stability, and could reduce storage needs with growing renewable energy penetration rates. Product adaptation and fine-tuning offer further benefits in liberalized electricity markets with high wind power penetration, where electricity prices could shoot sky-high during combined low wind and high power demand conditions.

For many years, incremental innovation and evolution of high-speed geared technology has been the norm in onshore wind. It typically involved evolutionary scaling of non-integrated high-speed drivetrains with either 3-point or 4-point gearbox

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support and often double-fed induction generators (DFIGs). Early this year, Vestas introduced a new EnVentus modular medium-speed platform incorporating a permanent magnet synchronous generator (PMSG).

Modular Design

While modular design approaches have become a leading principle in onshore wind, it is too early to indicate a clear future winner between high-speed geared and medium-speed geared technology. DFIG-based electrical systems remain cost-effective and a formidable competitor to any "full converter" solutions including in the currently highest-performing onshore segment, and perhaps still for future generation 6–7 MW high-speed geared turbines.

The onshore direct drive segment is largely subdivided between Enercon and Goldwind, with the former currently in the midst of a major technology transition process.

The compact drive EP3 platform is aimed at better positioning in the auction system and competing with high-speed and medium-speed geared equivalents. One possible further step would be a change to high-density PMSGs. Lagerwey already deploys these, having been acquired by Enercon back in 2017. Market entry level for newcomers is and will likely remain higher for direct drive than for geared equivalents, which benefit from a large, mature, and diversified multi-source global supply chain.

Last year also marked the installation of the world's first superconductor generator in a 3.6 MW onshore turbine. The generators can be designed to be very compact and efficient, but the superconductors must operate at temperatures of around minus 240°C. Their commercial future scaling and chances of market entry will therefore depend at least on whether sufficient cooling system reliability can be achieved in combination with substantial cost reductions.

Main Offshore Players

Europe's offshore wind volume market is dominated by two main players, 7-9.5 MW range three-bladed upwind turbines, and is characterized by small-step technology evolutions of the original 6-7 MW models introduced in 2011/12. The successful combination of increasing rating and rotor sizes stepwise made it possible to construct a mature supply chain with extended utilization, while simultaneously limiting product development costs, time required, and risks.

This "comfortable status quo" was disrupted in March last year when GE announced its 12 MW GE Haliade-X turbine for high-wind IEC IB. A prototype is planned for this summer, and series production should start in 2021. Publicly accessible prototype building permit documents indicate a 600 tonne nacelle mass, 107 meter blades each with a 55 tonne mass, rated power between 12 and 14 MW, and a 218.2 meter rotor diameter.

There is major consensus that optimal specific power values for high-wind North Sea sites should be in the 375-425 W/m^2 range. GE's 14 MW configuration would offer 374 W/m^2 and a 15 MW uprate of 401 W/m^2; MHI Vestas' latest V174-9.5 MW technology evolution would, in turn, yield 400 W/m^2. Siemens Gamesa's announced 10 MW+ SG 10.0-193 has 342 W/m^2 and a possible 12 MW uprate of 410 W/m^2.

Current offshore drivetrain preferences focus on medium-speed geared and direct drives, both with permanent magnet synchronous generators (PMSG). A ZF drivetrain expert recently said that irrespective of drivetrain preferences no intermediate rating steps should be made from current levels toward 15 MW.

Scalability

The same expert added that the current medium-speed gearbox for 9.5 to 10 MW is well scalable to input torque and gearbox step-up ratios for 15 MW, while retaining the gearbox outer diameter of 3 meters. As rotor size increases, rotor speed decreases. A rated tip speed of 90 m/s seems to be the state of the art for offshore wind for preventing premature blade erosion. This contradicts optimistic predictions from a decade ago suggesting quick, adequate solutions allowing rapid tip speed increases well above 100 m/s. The maximum step-up ratio of "conventional" two-stage, medium-speed planetary gearboxes is limited to the range 1:41 – 1:44.
If turbine sizes continue to grow, technology developers could accept a further lowering of generator

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speed, but with higher generator mass and perhaps a cost penalty. Alternatively, adding an extra gear stage for increasing generator speed results in higher gearbox cost and complexity. Journal bearings are rapidly becoming semi-standard solutions in gearboxes and considered an essential precondition for achieving 150 to 175 Nm/kg maximum input torque and likely even higher in future. New gearboxes in general have achieved a high maturity level, and increasing gearbox design life up to 30 years is now considered feasible.

The Haliade-X direct-driven PMSG for "12-14 MW" has an outer diameter of around 11 meters, but Enercon built an electrically-excited synchronous generator with an outer diameter of around 12 meters back in 2002. One key overall challenge for large-scale direct drive generators is shape retention under continuing changing combinations of mechanical, electrical, and thermal as well as dynamic loads. A second scaling-related challenge results from the excessive mass increment with size, but Haliade-X's 600 tonne nacelle mass (estimated 850-tonne head mass) indicates that such an objective is possible.

New Levels

The new 10-15MW + class with rotor diameters likely up to 230 meters and above in future will propel offshore wind to new levels of technological advancement, thereby benefiting fully from the ongoing industrial digitalization revolution. Following their expected market introduction between 2021 and 2025, these offshore turbines will be only at the start of their learning curve. It is likely that most future 10-15 MW+ product developments will repeat the technology scaling and optimize the approaches that have proven so successful for the current offshore class. The combination with long project lead times is expected to create a lasting market impact until 2030 and perhaps beyond.

The installation jack-up developer and market leader, Dutch marine-engineering consultancy GustoMSC, is already looking beyond that stage, as this dedicated equipment is developed for an operating lifetime of 20 to 25 years. The new vessels in development anticipate 20 MW offshore turbines featuring rotor diameters of more than 250 meters (approx. 407 W/m²) in the future, based on a reference turbine from the Danish Technical University (DTU). The jack-ups will be fitted with a telescopic crane for up to 2,500 tonne monopiles with a retracted beam length and maximum 1,250 tonne nacelles with a fully extended beam.

Rethinking

Offshore project statistics suggest that the current 7-9.5 MW offshore class might be installed until at least 2023. This speaks in favor of a more relaxed strategy with regard to the timing for the upcoming new 10-15MW+ superclass.

An even more carefully outlined strategy and rethinking of the best approaches for leaping into the 20 MW+ class would allow more time for entering into large-scale volume production, develop confidence and learn from experiences with smaller platforms. And it is not only the turbine itself that must be considered, but also the full package including foundations, cables, installation, grid connection, risk perception, and real risks.

Radical Concepts

Two-bladed single-rotor turbines still represent a niche segment. Aerodyn, through former licensee Ming Yang, expected the main benefits for its downwind configuration in typhoon-prone conditions. However, Ming Yang has decided to switch to three-bladed upwind "because Chinese clients do not want two-bladed turbines."

Multi-rotor turbines have remained a dream and a source of inspiration for pioneers since the early 1930s. In 2016, Vestas erected a 900 kW multi-rotor concept turbine with four 225 kW turbines, which was dismantled again upon conclusion of the test program.

Aerodyn's 15 MW twin-rotor SCD Nezzy2 floating concept featuring two 7.5 MW two-bladed downwind rotors is a radical vision of next-generation floating offshore wind turbines "in 2025 or earlier".

New 5-6 MW+ vertical-axis wind turbines (VAWTs) could experience a revival, especially in floating wind farms, because their inherently lower aerodynamic efficiency is compensated by a smaller cheaper floater. VAWTs can accept oscillations of up to 10-11 degrees compared to ideally max. 3.5-4 degrees for horizontal-axis turbines.

The technical challenges for large-scale VAWTs include that they are often not self-starting, require stable rotor attachment and reliable 'fail-safe' power output control.

By EIZE DE VRIES

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