Testing, validation, an opportunity for offshore wind power

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Jan Wenske and Maik Wefer of Fraunhofer IWES, show PES how testing should be regarded as a method to accelerate time to market of new designs and stand out by offering approved overall system reliability – instead of restricting the view to the one-time expenses. An opportunity to improve turbines and technology and enhance the competitiveness. The positive outcomes, however, outweigh this expense by far.

What can offshore wind turbine development and wind farm projects be compared to? Certainly not their onshore counterparts. The differences are obvious and include the following: offshore wind turbines are much larger and more powerful, the wind and environmental conditions are quite different, the foundation structures and installation work are more complex, they are connected to the grid via HVDC (high-voltage direct current transmission) or converter stations, undersea cable must be laid and, last but not least, the technical and economic track record of this comparatively young industry is shorter.

However, probably the greatest difference is that offshore turbines are more difficult to get to and access when in operation. Thus, the operation of a turbine in an offshore wind power plant has more similarities with a space mission than onshore wind developments: once the turbine leaves port, any kind of work becomes infinitely expensive and time-consuming or even impossible for long periods. This is why their ultimate success or failure depends to a very significant extent on the technical reliability of components and systems. In the field of offshore wind, general design flaws, poor maintenance concepts, lack of online monitoring and insufficient reliability of parts and systems are a recipe for technical, and therefore economical, failure. We are talking about enormous investment sums in the multiple billions of euros coupled with limited access depending on the environmental conditions in the event of a fault or failure. The manpower, the logistical expense and cost of transportation, be it ship or helicopter, are considerable.

The failure of the tiniest safety sensors or serious damage to the rotor blades, the foundation, the drive train or the electrical system not discovered during operation

At the Dynamic Nacelle Test Rig, wind loads occurring in the field are emulated by servo-hydraulic actuators in a Stewart-platform configuration transmitting mechanical loading on rotor shaft of the specimen. Photographer: Martina Buchholz

can result in the failure or malfunction of entire turbines.

Testing is a necessity, not a trend

Around the time of the first major space programs in the 1960s, research and industry developed new test standards and methods to increase the reliability of parts, components and systems, informed also by the experience gained in the aviation and automotive industry. The HALT and HASS test standards for validating and generally increasing the reliability mainly of electronic systems were developed and established at the beginning of the 1980s in parallel with the accelerated digital revolution. Sometime later the focus switched to quality management (e.g. Six Sigma initiative, introduced by Motorola) in production. Unfortunately, the terms quality and reliability are today often incorrectly intertwined or even equated with one another, but a strict distinction must be drawn between them! Reliability is always linked in a multi-dimensional way with time and the temporal progression of loading, and operating and environmental conditions. In other words, a high level of product quality in no way guarantees a high level of reliability, but is certainly a prerequisite for it.

Most of the standards for increasing technical reliability in established branches of industry (automobile manufacture, aerospace, railway construction and heavy engineering) are not applicable one-to-one, but demonstrate the general direction and sense of large-scale trials for testing and validating, in particular, for offshore wind turbines, their subsystems and components. In the opinion of Fraunhofer IWES, the combination of various tests and test levels (see below) as well as an overarching exchange of experience and knowledge between test-centred research institutions, industry and certifiers is useful in general, but without parallel for the development and/or optimisation of general standards.

- Special material tests (under complex load conditions and multi-dimensional environmental influences; e.g. UV/cosmic radiation, moisture, salt, temperature, vibration, etc.)
- Tests of components and parts
- Tests of assemblies
- System tests (incl. software, hardware in the loop, etc.)
- Prototype and onshore field tests
- Offshore demonstration turbines
- Data acquisition and analysis of existing installations

"Around the time of the first major space programs in the 1960s, research and industry developed new test standards and methods to increase the reliability of parts"

Exploration and evaluation of support and foundation structures and affiliated construction methods are realised at the foundation test pit. Photographer: Tobias Kleinschmidt

All the significant interfaces of the hub/blade bearing/rotor blade group are tested under realistic conditions.Photographer: Martina Buchholz

Fraunhofer IWES's work focuses particularly on component and system tests on large-scale test benches, and these are presented here.

Rotor blades on trial

IEC 61400/23 requires that newly developed rotor blades must undergo both static and dynamic testing for structural durability. For this, after preliminary static testing in four directions, the rotor blades undergo cyclic testing in two load directions for a certain number of load cycles by excitation at their natural frequency. Finally, static tests must once more be carried out. Fraunhofer IWES currently has two blade test benches performing this kind of certification testing. To date, 20 new designs measuring up to 83 m in length have been tested for various clients.

Improved test methods simulate realistic loads

However, as blades get longer, the standards currently in use are themselves being put to the test. The increasing size results in very large test loads and low natural frequencies, which pushes up the cost and extends the time it takes to test. Besides the challenges for blade certification as a direct result of the longer blades, there is an array of disadvantages with the standards used today. The blade properties are usually only tested in two directions using simplified load scenarios, which means that it is not known what

Two test rigs for rotor blades of up to 90 m in length are available for testing the latest generation of rotor blade designs. Photographer: Dieter Hergeth

happens over the entire cross-section of the blade. Furthermore, depending on the test method, deviations between test loads and rated loads occur, with the consequence that some types of damage that arise in the field cannot be observed in a blade test. An improvement in the blade test in these respects is leading to more realistic loading and is thus better serving blade designers, manufacturers and operators.

In the past Fraunhofer IWES has tried various methods, including biaxial tests. However, most concepts still address only some of the current challenges. For this reason, Fraunhofer IWES has developed a new method, which addresses the concerns of the offshore industry in particular: one project is currently looking at segmented blades as the basis for certification. The advantage with this method is that segmented blades do not take as long to test, as the natural frequencies are higher. The experience gained and the development of new test standards based on extensive experiments, facilitate a quicker and more accurate response to customer demands.

Scrutinising concepts for support structures

The support structures and foundation systems are often the most expensive parts of an offshore wind turbine. In some cases they account for 40% of the total cost, so the industry is constantly looking for economical concepts for this. Broadly speaking, there are two different support concepts: those designed for predominantly normal/axial loads and those designed for predominantly lateral loads. Monopiles typically take the loads laterally. While the theory has been that monopiles with a diameter of approx. 5-6 m and up to 25 m water depth are economically viable, in the last five years the practice has painted a different picture. While the average monopile in 2011 had a diameter of five meters, today there are monopiles with a diameter of eight meters at a water depth of around 40 m in the Veja Mate wind farm. This year, a Dutch company presented monopile concepts with diameters of up to 11m. Monopiles currently have a market share of around 97%.

The disadvantage is that there is no universal dimensioning basis for XL monopiles, as the standard p-y method [DIN EN 19902, 2014] was calibrated for “long slender jacket piles with diameters of less than 1 meter” [DNV, 2014]. As such, this method is not applicable without prior validation. Since the field tests required for this are very costly, reproducible large-scale tests can be an economical alternative. What is undisputed is that the scale effect works. One solution to this issue is to revise the existing p-y curves both under static and cyclic loading. For this, Fraunhofer IWES runs a test centre for support structures in Hanover, in which new dimensioning methods can be developed or existing ones can be validated based on large-scale tests on foundation and support structure elements, with the purpose of deriving dimensioning proposals backed by experiments. These will enhance turbine/power plant safety and enable the manufacturers to achieve economic optimisations.

Field testing of blade bearings and pitch systems

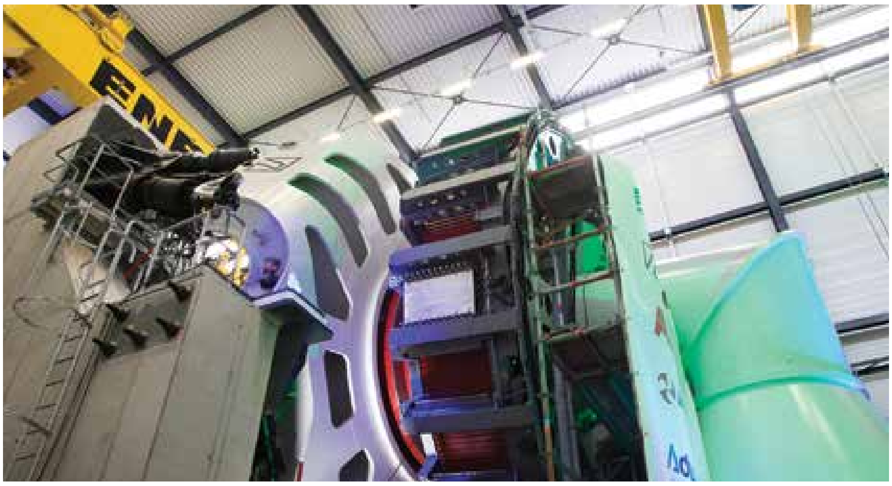
Statistics from field tests prove that the pitch system including the blade bearing is one of the wind turbine subsystems with the highest failure rates at present. At the same time, the blade bearing in particular is seen as a key chokepoint or risk factor, especially for the development of future generations of turbines with capacities well over 7 MW. In order to reduce the specific tower head masses and resulting direct and indirect costs, there is no alternative to modern control methods like IPC (Individual Pitch Control). However, these bring about additional mechanical, tribological loads – which cannot be reliably calculated at the moment – in the blade bearings and the pitch drives. There are two factors at play here: the increase in size and the atypical operating loads due to the use of new control methods. Currently failure causes and mechanisms primarily in the main bearings and the pitch drives are not fully understood.

Fraunhofer IWES operates a pitch bearing test bench for smaller onshore wind turbines. Based on the experience accumulated so far, another large-scale test bench especially for blade bearings and pitch drives for the next generation of offshore turbines up to approx.10 MW is currently being designed and set up. The project is flanked by broad-based, corresponding research activities in conjunction with industrial partners and the Institute of Machine Elements, Engineering Design and Tribology (IMKT) of Leibniz University Hanover. They range from preliminary tribological investigations, adapted, novel modelling for simulations as well as the development of suitable special sensor applications for online 2D lubricant film thickness measurements through to the development of appropriate test methods for accelerated life testing of blade bearings with a diameter of up to 5 meters.

Testing is scheduled to begin in mid-2018 with test durations of max. Six months per blade bearing currently expected for the accelerated life test. In addition to state-of-the-art functionality (incl. IPC, dyn. 6-dof load application system), this test bench will feature a realistic simulation of the individual blade and hub interface stiffnesses.

Validation of nacelles, drive trains and direct drive generators

Examining the fatigue behaviour of large components under multi-axial loading. Photographer: Jan Meier



The comprehensive medium voltage grid emulator for electrical system testing covers all possible grid events and characteristics and helps shortening the certification process. Photographer: Martina Buchholz

Larger rotors require more powerful drive trains; this is a matter first and foremost not just of adapting the nominal output, but of improved concepts, detailed solutions and component development; e.g. in relation to main bearing, lubricant supply, cooling, couplings, gearbox and generator utilisation/efficiency coupled with increasing reliability in order to reduce the specific life-cycle costs. Due to the exponential growth of the static and dynamic drive train loading, the reliable and economical dimensioning of parts and assemblies is approaching the limit of the scope of current calculation models and practical experience.

The use of scaling and other safety factors is threatening to become an intolerable technical risk, or no longer allow for the economical use of material. Such simulation and calculation models in this area have been validated not with one-to-one tests but with the aid of standardised material specimens, at best on highly scaled-down experimental models or on standardised parts such as screws and bolts. At Fraunhofer IWES various large-scale test benches for components and systems are used in addition to special material tests in order to validate calculation and simulation models.

Central to this is the dynamic nacelle-testing laboratory (DyNaLab) for testing drivetrains, direct-drive generators and complete nacelles between 2 and 8 MW. Its core components are: a high-dynamic direct-drive in excess of 10 MW nominal and 15 MW peak output, force-controlled servohydraulic load application system for the main shaft hub interface of up to 2 MN and 20 MNm in the frequency range up to approx. 2 Hz as well as an artificial medium-voltage grid (grid simulator) for voltages up to 47 kV – one of the most powerful and functional in the world – with an installed converter power of 44 MVA.

On this system test bench all current offshore turbines as well as next-generation turbines can now be subjected to extended function tests, development tests as well as accelerated tests or stress screenings. The test bench and its implemented, dedicated hardware-in-the-loop system are designed for realistic test scenarios (turbine operation). These kinds of tests facilitate the concrete analysis of the dynamic interaction of individual components on the real nacelle-mainframe, with the original power cabling as well as using the real wind turbine controller. Possible fault or wear causes and mechanisms can be localised early and be observed thanks to the use of special sensor technology and many measuring points. The turbine controller and safety systems can also be efficiently optimised and validated in relation to simulated failures modes (on rotor and grid side) on that test bench.

Life time testing of sub-systems is essential

Fraunhofer IWES does not see the point in trying to perform accelerated life testing of systems on the full nacelle test bench considering the length of time it takes and the cost involved. It does, however, advocate smart stress tests, which, similar to the HAST (Highly Accelerated Stress Tests) of electronic assemblies, target failures early on in product use, or which, when used in such cases, result in much-reduced failure rates.

Fraunhofer IWES believes that the recommended scope of testing for a new offshore wind turbine includes much more than just system tests on a full nacelle test bench. System tests are predestined to find weaknesses in general; only tests of assemblies and parts, e.g. for the main shaft bearing, the gearbox, coupling and generators, derived from such system tests provide the required safety and indicate the status of entire reliability. These accelerated endurance tests at assembly and part level thus fill in the gap that still exists in validation for later phases of product operational life, similar to the well-known HALT (Highly Accelerated Life Test) methodology for electronic assemblies.

Fraunhofer IWES operates several flexible component test benches that can be modified for the individual installation, and is planning to set up further facilities of their kind in the coming years. The advantage of these test facilities is, that they are specialise and more efficient to operate.

Summary

Of course, the comparison, made at the outset, between a space mission and offshore wind turbine development is flawed. But one thing they do have in common that cannot be dismissed is the extreme focus on the need for technical reliability and maximum availability. Fraunhofer IWES is of the opinion that, especially before the market launch of newly developed or modified prototypes for offshore applications, the need for extensive tests and the feedback of experience gathered in the field is essential and deserving of special attention. The often automatic criticism of additional costs for testing does not seem justified when compared with the investment sums and the potential subsequent costs in later operation.

Testing should be seen not as a burden for the offshore wind industry but as an opportunity to improve the turbines and technologies in use to make them go further and faster in the future, to increase their reliability and thus to reduce inherent development risks and the cost of offshore wind power utilisation further. ■

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