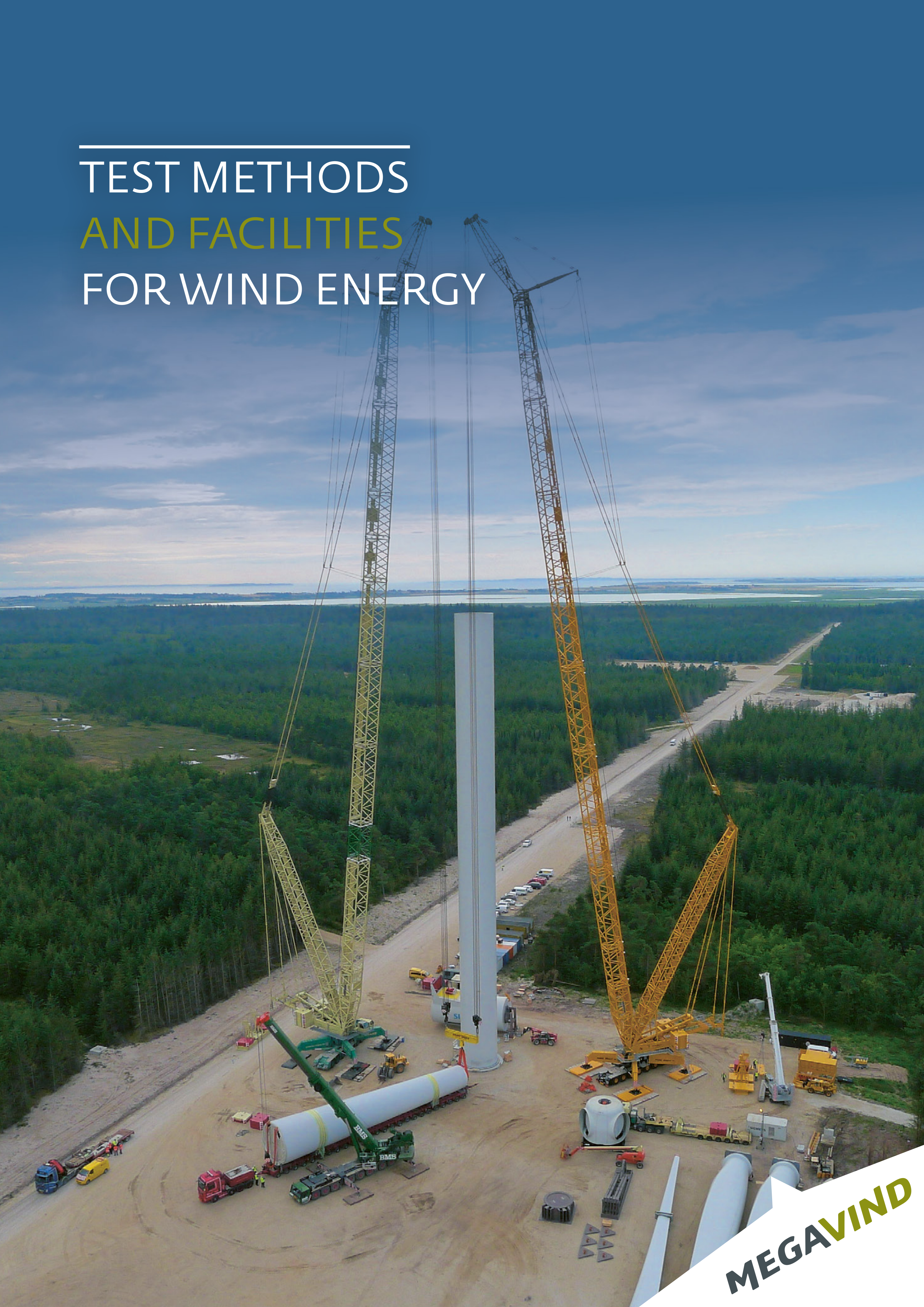
TEST METHODS AND FACILITIES FOR WIND ENERGY



MEGAVIND

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TEST METHODS AND FACILITIES
FOR WIND ENERGY

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PHOTO: NORDMARK

PREFACE

Megavind is Denmark's national partnership for wind energy, and acts as a catalyst and initiator of a strengthened strategic agenda for research, development, and demonstration (RD&D).

Megavind was established in 2006 with the aim of strengthening public/private cooperation between the Danish state, businesses, and knowledge institutions to accelerate innovation processes within the wind industry.

Megavind's vision is for Denmark to continue to develop its position as the hub of globally leading companies and research institutions within the field of wind energy and to enable them to be the first to deliver competitive wind energy solutions in the world's main wind energy markets.

This document is an addition to the 2016 Megavind report on test and demonstration.

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INTRODUCTION

Access to test and demonstration is a key prerequisite for R&D departments to stay in Denmark. R&D departments are closely linked to primary production facilities and the continuous feedback loop from testing components, systems and prototype turbines is the core of bringing new products on the market and engineers benefit from being located closely to where turbines are built.

The wind industry is characterized by fierce global competition between several nations aspiring to be home to leading companies. To maintain Denmark's position as a global hub for wind energy, it is essential that Danish-based companies continue to have access to relevant state-of-the-art test and demonstration facilities and test competencies.

The test needs of the industry are dynamic and ever changing so continuous adaptation of test facility access is needed. An example of this is the green transition and the large potential this holds for the wind industry as well as the demands for new test facilities e.g.: In the future there will be new technology combinations like hybrid projects with solar, wind and storage and these may pose new technology requirements that need testing. These combinations may be possible in the test sites for new prototypes. The production of e.g. hydrogen and other electrofuels may demand new off-grid turbine designs.

A holistic test setup

Denmark continues to be the place to visit to learn about wind energy. The main reasons are:

- A strong, complete value chain: Global leading developers and OEMs, supply chain companies with a unique track record in wind, universities with leading wind energy master programmes and 30 to 40+ years of wind energy research constitute an unmatched supply chain of knowledge and competences.

- A show case example of integrating large amounts of wind in the electricity system: Strong cross border connections and a progressive TSO means that Denmark can integrate a lot wind produced electricity in the system.

- Strong sector coupling opportunities: Denmark is also the perfect test laboratory to demonstrating the electrification of our society with e.g. decentralized heating infrastructure to be electrified, and strong agricultural and marine industry that can demonstrate the use of electrofuels etc.

- A stable political landscape and a home market both on- and offshore: Historically, Denmark has demonstrated a long-term consensus-based policy when it comes to energy agreements in Parliament.

All of the above deliver the potential for hosting a holistic test infrastructure for wind energy and this document will deliver test recommendations for test facilities that constitute or interact with the wind turbine:

1. Wind turbine
2. Component
3. Wind farm
4. Integration and electrification

PHOTO WIND DENMARK

KEY RECOMMENDATIONS

Megavind's key recommendations on future national priorities for test and demonstration of wind energy solutions are:

Full scale testing of wind turbines

- A minimum of 20 pads in total for prototype testing of the largest turbines in a terrain with a well-defined wind regime and a height limitation of up to 400 m.

- A minimum of 20 0-series turbines (2-3 wind farms) per year in a terrain with a well-defined wind regime.

Component testing

- Blades: Denmark should always have test capacity available to test the largest prototype blades.

- Blades: Test methods to be developed, standardised and certified for substructure tests on blades.

- Split component testing: Research in developing test methods to test components in sections and simulate full scale tests. The research results need to be demonstrated in full scale.

- Blade bearings: New test rigs for independent testing of blade bearings are established in Denmark over the next years to complement a strong palette of test facilities.

- Nacelle: A new 33 kV, 66 kV or even higher voltage grid emulator to test grid, generator, converter, transformer, control etc. as a mobile unit in a container.

- Nacelle: Validation of electrical simulation models for power quality analysis e.g. voltage/frequency excursion and harmonic analysis must be covered through the emulator capability.

Electrification

Test and demonstration of new wind turbine concepts in off-grid solutions. This could be tested in connection with the test centres mentioned under full scale turbine tests.

Competences

More focus on education within measurement, testing and verification at universities and engineering schools, thereby ensuring the training of more engineers with a strong understanding of the methodologies and competences needed to design, conduct and report tests.

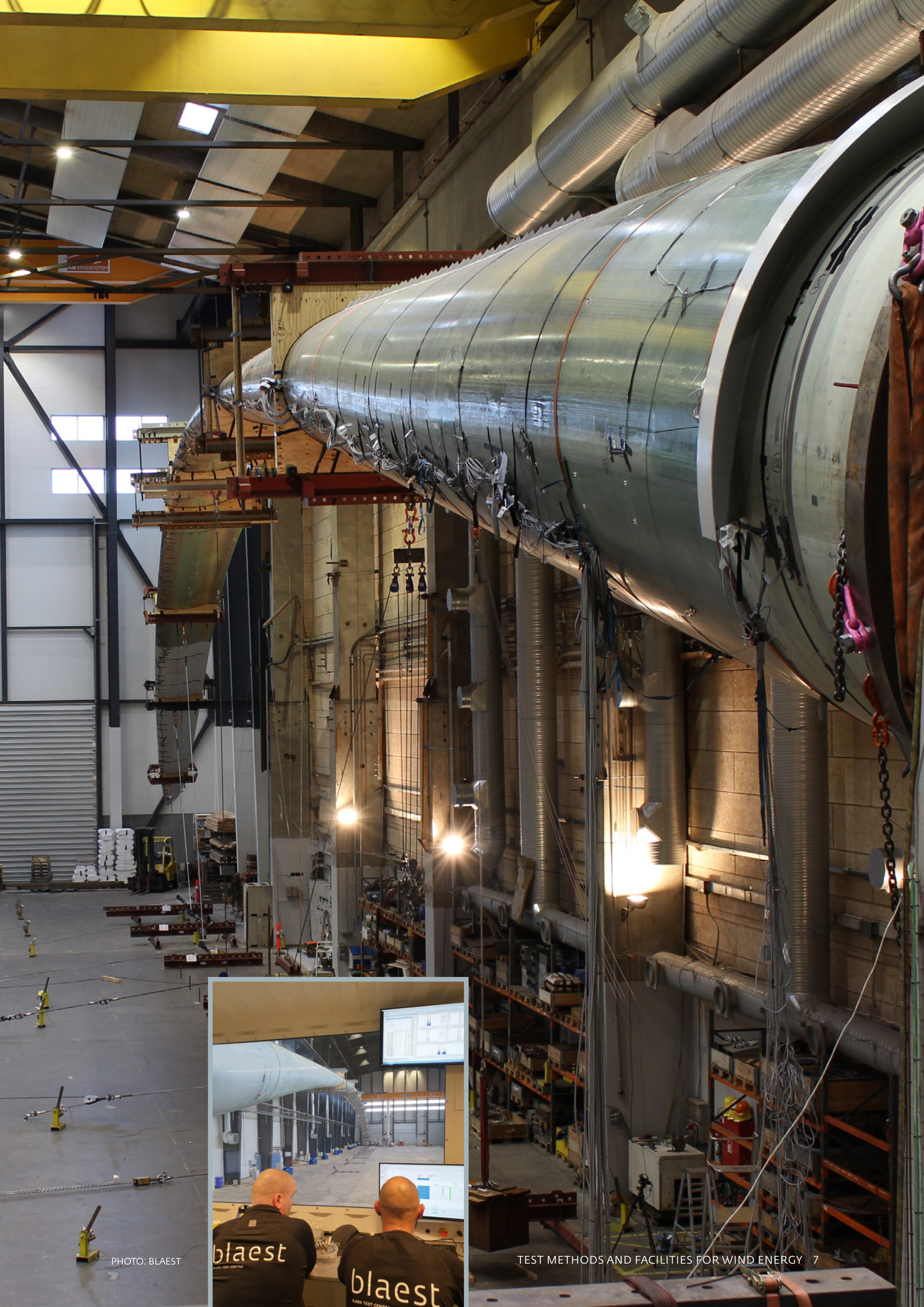


PHOTO: BLAEST

TEST METHODS AND FACILITIES

3.1 WIND TURBINE FULL SCALE TESTING

Full scale testing of new wind turbines has always been an unconditional part of the development process for the OEMs. The first test station for wind turbines was established at Risø in 1979. As the turbines have increased in size, it became necessary to plan and establish larger permanent test facilities; the first in Høvsøre in 2002 followed by Østerild in 2012.

In 2018, it was decided to expand the two centres with two test pads each and increase the existing limitations of the turbine sizes.

The wind turbine OEMs have two sets of test requirements when testing new turbine designs: prototype testing and 0-series testing.

Høvsøre

TEST PADS: 7
HEIGHT LIMITATION: 200 m

GRID INFRASTRUCTURE

- Plan to increase voltage levels from 10 kV to 33 kV.

Østerild

TEST PADS: 9
HEIGHT LIMITATION: 5 pads up to 330 m, 4 pads up to 250 m.

GRID INFRASTRUCTURE

- Plan to increase voltage levels from 33 kV to 66 kV.

The test centres are owned and operated by DTU except for 4 pads at Østerild where Vestas Wind Systems and Siemens Gamesa Renewable Energy own and operate 2 pads each.

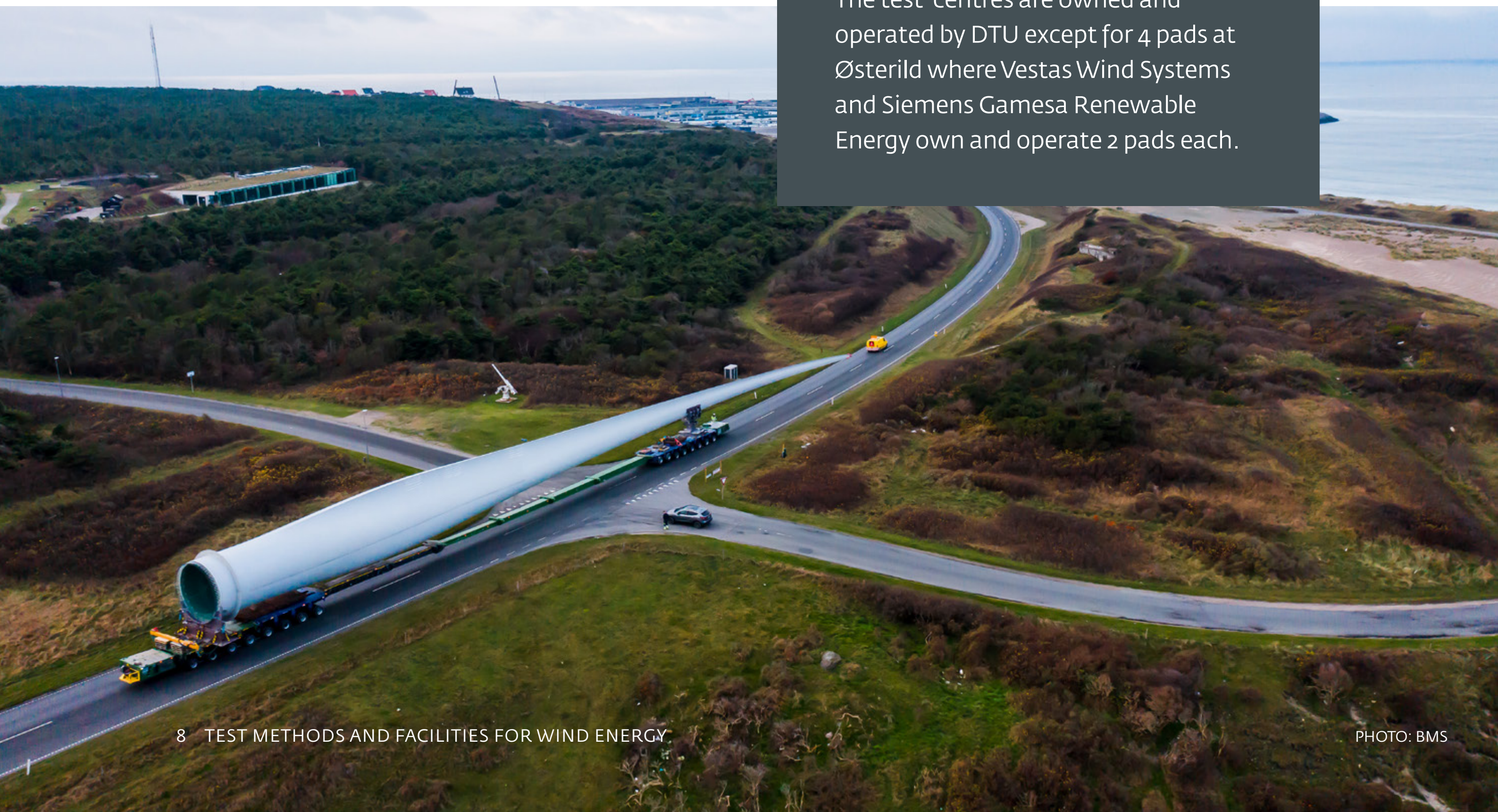


PHOTO: BMS

PROTOTYPE DEFINITION: A prototype is the first specimen of a new turbine model. There can be various prototype versions if the original design is altered. The purpose of testing a prototype is e.g. to verify loads and overall function.

Prototypes are typically tested on sites with a well-documented wind regime with precise wind data. The current 2 test centres have permanently installed wind measurement masts with accurate data.

0-SERIES DEFINITION: The 0-series is the first limited series of a new turbine model typically 5-10 turbines. The purpose for 0-series testing is to document and verify operational conditions e.g. service and maintenance as well as quality and optimisation of the technical issues.

The 0-series turbines are typically tested in cooperation with an energy company or a large private developer that handles site and project planning.

3.1.1 Prototypes

Wind, terrain, and access are key elements in testing prototypes and the following conditions must be met to ensure a satisfactory test regime:

- Wind and climate conditions must be known, complex and well defined
- The wind conditions must be excellent to allow the test programme to be completed within an acceptable time frame
- The selected sites must have wind directions with varying complexity with regard to turbulence, so fatigue loads are thoroughly tested
- Good access conditions so large transports, personnel and cranes can access and install new prototypes. Modern turbine components have XXXL dimensions (e.g. blades of 100+ m, tower sections of Ø 7+ m) and require special transports and a well-planned access route from either the nearest harbour or production site
- To ensure that the site can accommodate still increasing turbine sizes, the height restriction for future sites must be 400 m

Distance and environmental conditions

All distance and environmental requirements must be met when new sites for prototype and 0-series testing are established. Locations with ample distance to neighbours must be found to achieve optimum dimensions for the individual pads e.g. height requirements. Environmental Impact Assessment (EIA) reports must be carried out for the selected locations.

Over the last few years, demand has exceeded supply with regard to available test pads that meet the needed requirements. The delay in the design and testing process – time to market – is very costly for the OEMs and may prompt them to scout for available test pads in Europe or globally.

At the moment, there are 16 prototype test pads available in total at Høvsøre and Østerild but the sites at Høvsøre are not ideal as the height limitation of 200 m excludes the testing of new large turbine models. The industry therefore needs an additional 7 pads.

The two existing sites at Høvsøre and Østerild cannot be expanded any further but one solution could be to reduce the 7 existing test pads at Høvsøre to 5 and thereby increase the space between the pads and extend the current height limitation to 330 m.

A reduction of the current number of pads will lead to the need for a new test centre with test pads dimensioned for modern and future turbines and a height restriction of 400 m. The organisational set up of this new site could be like the existing sites where a university owns and operates the site and the OEMs send in bids to rent the pads or that the OEMs own the individual test pads and the overall site is operated by an independent 3rd party e.g. an university or others. A separate test centre for testing different technologies could be added to existing test centres or existing wind farms.

Historically, the support scheme behind full scale testing of wind turbines has been an add-on to the electricity price per kWh produced by the test turbine. There are other ways to structure the support scheme; it could be linked directly to the test pads and not the turbine or, to the test centre.

Megavind recommends

- A minimum of 20 pads in total for prototype testing of the largest turbines in a terrain with a well-defined wind regime and a height limitation of up to 400 m.

3.1.3 0-series

The requirements for wind, terrain, access, and EIA process are the same for 0-series as for prototypes. The turbines must be sited in areas with strong wind conditions and preferably in a complex terrain, so they are exposed to as much load and turbulence as possible.

Megavind recommends

- A minimum of 20 0-series turbines (2-3 wind farms) per year in a terrain with a well-defined wind regime.

3.2 COMPONENT TESTING

Denmark houses a cluster of independent facilities for component testing that can offer market leading services; some are owned and/or operated by universities and GTS institutes.[1] But development in turbine sizes, new market opportunities and an intense industry focus on sustainability require new facilities for component testing.

3.2.1 Blades

Modern offshore wind turbine blades have exceeded 100 m in length and all future projections indicate that they will continue to grow in size. Prototype blades of 107 m are already mounted on a 12 MW test turbine; the blades have been tested in the UK and a 14 MW turbine has been announced with 108 m blades. Germany and the UK have independent blade test facilities; Fraunhofer IWES have tested blades up to 83 m and Catapult can test 100 m blades.

In Denmark, the independent test provider Blaest has 8 test rigs for blade where testing, the largest can handle blades up to 100 m. The facility is prepared to accommodate an additional test rig with a 120 m capacity.

Two leading OEMs of offshore turbines have their R&D departments and blade production facilities in Denmark and a leading blade manufacturer has its headquarter and technology center in Denmark. To keep a full design, test and production cycle for blades in Denmark, the industry needs to be able to test the largest and most modern blades close to R&D competences and production.

1) GTS institutes deliver a technological infrastructure of facilities, laboratories and competences to support companies in their R&D processes

BLADE BEARING TEST FACILITY.
PHOTO: SIEMENS GAMESA RENEWABLE ENERGY

Full scale testing of blades is a costly process that can be reduced if some tests are performed as substructure tests where a part of the blade is tested and then coupled with a numerical simulation. The test methods for this process need to be developed and included in the IEC standard 61400-23:2014 *Full-scale structural testing of rotor blades* which is currently under revision and then certified by certification bodies.

Megavind recommends

- Denmark should always have test capacity available to test the largest prototype blades.

- Test methods to be developed, standardised and certified for substructure tests on blades.

3.2.2 Split testing of large components

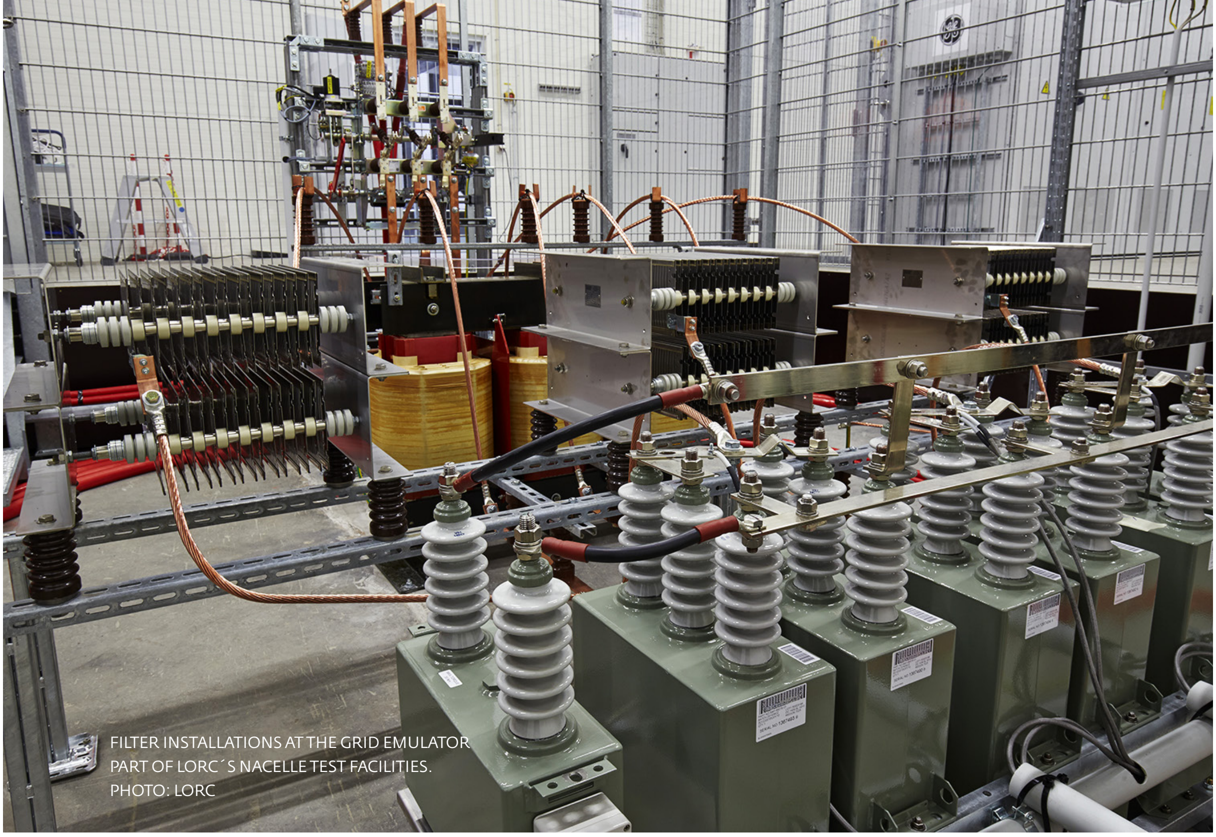
The still increasing dimensions of modern turbines also mean still larger components that require testing and still larger test facility setups. This in turn means that the testing of individual components becomes still more costly to perform, like the blade example mentioned above. The cost of testing could be brought down if the very large components are divided into less expensive and more manageable sections and tested separately with a simulated full-scale test like the blades. This requires new test method descriptions and computer models to simulate full scale testing.

Megavind recommends

- Research in developing test methods to test components in sections and simulate full scale tests. The research results need to be emonstrated in full scale.

3.2.3 Blade bearings

Blade bearings connect the root of the blade to the wind turbine hub. The continuing increase in blade root diameter, blade length and weight result in higher loads on the bearings. Blade bearings have to withstand high bending moments while standing still or rotating at very low speeds. Major bearing manufacturers and some OEMs have inhouse blade bearing test rigs. But there are also independent test providers e.g. Fraunhofer IWES in Hamburg and Windbox in Bilbao who



FILTER INSTALLATIONS AT THE GRID EMULATOR PART OF LORC´S NACELLE TEST FACILITIES.
PHOTO: LORC

have blade bearing test facilities. Fraunhofer IWES can test bearings of turbines up to 10 MW and Windbox can test bearings for 2-8 MW turbines. The strong floor at Lindø has also been used to test blade bearings and can accommodate bearings up to Ø 8-9 m. There is an increasing need in the sector for access to test facilities and more accurate test methods.

Megavind recommends

- New test rigs for independent testing of blade bearings are established in Denmark over the next years to complement a strong palette of test facilities.

3.2.4 Nacelles

The sector is facing an overall upgrade of the electrical systems (transformers, switch gears and array cables) from 33 kV to 66 kV and in the future even higher voltage levels are desired.

With the update of main electrical components or systems follows a need to test and validate these, and how they comply with the grid code demands.

Also new and more advanced control features in the wind turbines and wind power plants are used when integrating more wind power into the power systems, and in future grid configurations to integrate energy storage and conversion systems. Therefore, upgraded test equipment and facilities are necessary.

Until now it has been state of the art to test grid compliance on sites, that are usually connected at the medium voltage side in front of the wind turbine on a test site. The possibility to perform test and emulations for validation of electrical simulation models is essential to ensure proper power system analysis tools and calculation methods.

With a grid emulator it will be possible to change e.g. both voltage and frequency on a laboratory-based nacelle test. As the emulator is electronically controlled, a variety of grid connection types and grid events can be programmed, and even emulated in real time using Hardware in the Loop simulations.

The grid emulator could be a stationary facility located strategically in Denmark, or it could be a mobile unit that can be moved around and connected to various full-scale wind turbine test areas. The latter – a mobile unit solution is preferable as this ensures the highest degree of flexibility.

Megavind recommends

- A new 33 kV, 66 kV or even higher voltage grid emulator to test grid, generator, converter, transformer, control etc. as a mobile unit in a container.

- Validation of electrical simulation models for power quality analysis e.g. voltage/frequency excursion and harmonic analysis must be covered through the emulator capability.

MCARTHUR WIND FARM IN AUSTRALIA OF 420 MW
PHOTO: VESTAS WIND SYSTEMS

3.3 GREEN TRANSITION AND ELECTRIFICATION

The global climate alert and Danish goal of a 70% CO_2 reduction by 2030 require a radical transition of our electricity and energy systems. Handling large amounts of electricity production based on fluctuating wind and solar power in the electric grid is a challenge and requires not only direct electrification of transport and heating but also introduction of novel technologies for balancing the electricity grid and for electricity back-up at times with insufficient production in order to meet demand.

The sector is looking into solutions both for storage, hybrid projects and hydrogen production that can be further converted into various other fuels e.g. ammonia, methanol and other electrofuels all belonging to the Power2X category.

Much of this is known technology and needs "only" to be scaled up and coupled between sectors. But an important feature is the new role that wind turbines potentially could play in off-grid production.

According to the International Energy Agency there is a future scope for initiating very large off-grid hydrogen production facilities e.g. early sketches for hydrogen production plants in the gigawatt range in Australia. For stand-alone off-grid plants either on- or offshore, new types of wind turbine designs are required for off-grid production only. Eliminating all grid compliance technology from the turbine will result in a simpler design, a cheaper turbine and thus reduced cost of green hydrogen production (further reading: Megavind's report on Renewable Hydrogen in the Danish Energy System).

Megavind recommends

- Test and demonstration of new concepts in off-grid solutions. This could be tested in connection with the test centres mentioned under full scale turbine tests.

FUNDING OPPORTUNITIES

There are several funding opportunities to be pursued to finance test facilities in Denmark. The most accessible are:

Energy Technology Development and Demonstration Program (EUDP)

EUDP supports private companies and universities to develop and demonstrate new energy technologies.

EUDP can support energy technologies widely such as renewable energy technologies, energy efficiency technologies, conversion technologies such as fuel cells and electrolyzers, integration of energy systems including storage, more efficient methods for recovery of oil and gas and storage of CO_2.

EUDP also hosts the Green Labs DK programme that supports large scale test facilities for energy technology.

Innovation Fund Denmark

In both 2019 and 2020, Innovation Fund Denmark had a call for Green Growth – Grand Solutions. In 2021, funding will primarily be allocated to 3 areas, one of which is green research and innovation projects to develop technologies and solutions that can support Denmark in the green transition. The other two focus areas are life science and automated production technologies.

Apart from the green research and innovation projects, Innovation Fund Denmark will also support partnerships with focus on CO_2 capture, storage or use, Power2X, green agriculture and circular economy.

The Danish Parliament has agreed to allocate a total of DKK 2.7 billion to research and development of green technologies in 2021 and have also agreed that the amount will be DKK 2.28 billion per year in 2022-2024.

Innovation Fund Europe

Innovation Fund Europe supports projects that may develop the next generation of technologies needed to deliver EU's green transition and give EU companies a first mover advantage.

The EU Emissions Trading System (EU ETS), the world's largest carbon pricing system, is providing the revenues for the Innovation Fund from the auctioning of 450 million allowances from 2020 to 2030. The Fund may amount to € 10 billion depending on the carbon price. The project grants cover up to 60% of the capital and operational costs.

The Innovation Fund focuses on highly innovative technologies and big flagship projects with European value added that can bring on significant emission reductions. Project risks are shared with project promoters to help with the demonstration of innovation projects.

The Fund is also open to small-scale projects with total capital costs under € 7.5 million which can benefit from simplified application and selection procedures.

COMPETENCES

Universities and engineering schools should be encouraged to generally increase their focus on education within reliability engineering and product verification methodologies. These are important competences for all design engineers.

Testing is a key verification method. For a number of years, there has been a gap in the educational value chain, especially for engineers with testing knowledge, resulting in Danish companies starting to recruit qualified employees from other countries. The lack of competent resources causes bottlenecks at the test facilities and makes it more difficult for suppliers to deliver orders. The shortfall in recruiting qualified employees poses a risk to the upcoming growth in the wind industry, so the industry must help by making it more attractive for engineers to specialize within test disciplines, for example by offering internships and masters/PhD projects.

In some countries, test engineering is a specialisation. Denmark is likely to be too small to offer such degrees, but its universities and engineering schools should establish relevant courses and other opportunities for specializing within test engineering. Test engineers need a balance between theoretical understanding and the ability to do hands-on work in the laboratory. Student collaboration with the industry is thus particularly relevant.

Wind turbine test engineers need competences within the following technical areas:

- Reliability engineering
- Scaling laws
- Test standards and methods
- Mechatronics and programming
- Control systems
- Measurement theory and systems
- Data management
- Reporting

Megavind recommends:

- More focus on education within measurement, testing and verification at universities and engineering schools, thereby ensuring the training of more engineers with a strong understanding of the methodologies and competences needed to design, conduct and report tests.

PHOTO: BMS

Megavind
Vordroffsvej 59
DK-1900 Frederiksberg

Web: megavind.winddenmark.dk

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