REPORT FROM MEGAVIND
NOVEMBER 2012

WIND POWER PLANTS IN THE ENERGY SYSTEM

MEGAVIND

PREFACE

In May 2006, the Danish Government presented a report on promoting environmentally effective technologies and established a number of innovative partnerships. The partnerships aim to strengthen public-private cooperation between the state, industry and universities and to accelerate innovation for a number of green technologies. The partnership for wind energy is called Megavind.

The Megavind steering committee consists of representatives from Vestas Wind Systems A/S, Siemens Wind Power A/S, DONG Energy, COWI A/S, Fritz Schur Energy A/S, DTU Wind Energy and Aal¬borg University. The national TSO, Energinet.dk, and The Danish Energy Agency participate as observers.

In 2007, Megavind put forward a strategy with a list of recommendations to strengthen Denmark as a leading centre of competence within the field of wind power. One of Megavind's main tasks in this regard is to formulate strategies for validation, test and demonstration. In June 2008 the sub-strategy "Wind Power Plants in the Energy System" concerning the interaction between wind power and the energy system was published.

In 2012, Megavind has initiated a process of updating several strategies. This report is an update of "Wind Power Plants in the Energy System" from 2008.

The working group behind the revised strategy consists of:

- Frede Blaabjerg, Aalborg University
- Erik Koldby, ABB A/S
- Tom Cronin, Poul Sørensen and Jens Carsten Hansen, DTU Wind Energy
- Sven Erling Rye and Vladislav Akhmatov, Energinet.dk
- Peter Weinreich-Jensen, Siemens A/S
- Björn Andresen, John Bech and Per Hessellund Lauritsen, Siemens Wind Power A/S
- Philip C. Kjær, Vestas Wind Systems A/S
- Anja Pedersen, Sune Strøm and Jakob Lau Holst, Danish Wind Industry Association

The strategy has been validated through an open consultation process including a strategy seminar in December 2011.

1 INTRODUCTION

Denmark has the objective to phase out the use of fossil fuels before 2050. The government's latest energy agreement from April 2012, also states that before 2035 electricity and heat supply must be 100% based on renewable energy and that at least half of the traditional electricity consumption in Denmark will be supplied from wind power in 2020.

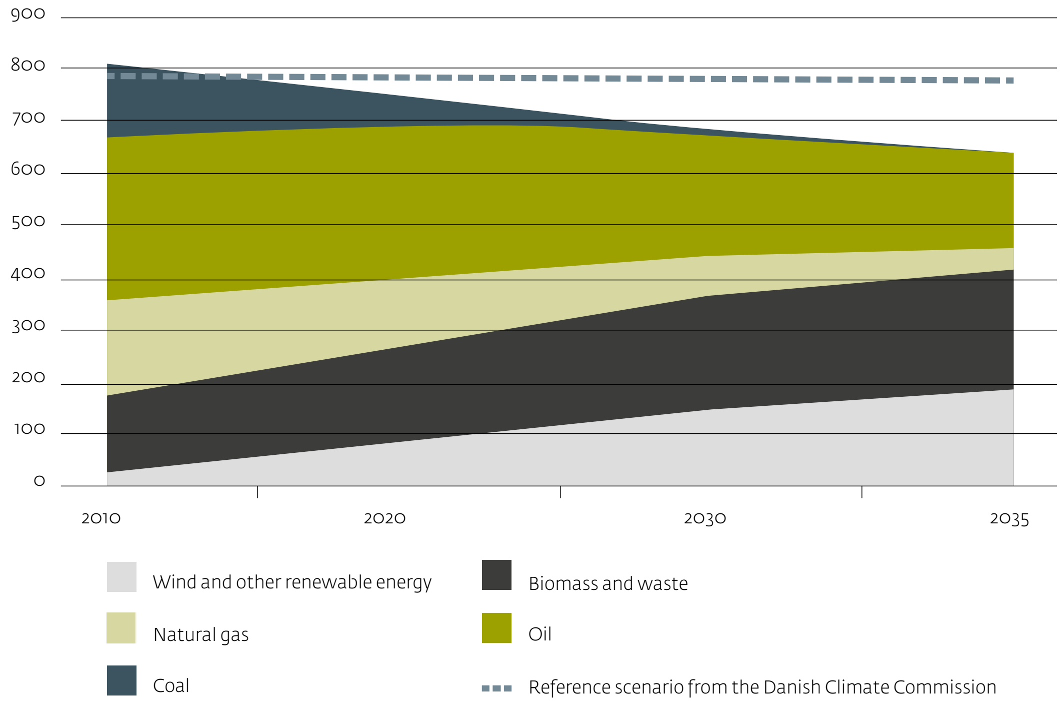

FIGURE 1

Development in Denmark's gross energy consumption from 2010 to 2035

SOURCES: OUR FUTURE ENERGY, NOVEMBER 2011 (FIGURE 3.8), AND THE DANISH COMMISSION ON CLIMATE CHANGE, SEPTEMBER 2010

The Danish objectives contribute to the achievement of the combined EU objective of 20% renewable energy in 2020 and several other countries have similar objectives. A development like the one in Denmark can be seen in the countries around us – within and outside the EU. This has effectively stimulated the market for renewable energy.

Increased focus on electricity as an energy carrier has led to an intensified focus on both the physical and market-related development of each country's energy system and in particular the electrical system and the transnational connections including offshore transmission grids between countries and connections to large offshore wind power plants[1].

Offshore transmission grids are largely expected to contribute to a well-functioning electricity market and the elimination of bottlenecks in the overall electricity system. Without an effective electricity market operating with the physical grid, restrictions are created in the system, and the transfer to renewable energy will be strikingly more expensive – for consumers as well as electricity companies.

Large-scale integration of wind power – just as any other energy technology – requires an energy system with well-functioning interplay between the various energy technologies and based on a modern grid. Wind power is expected to play a pivotal role in future energy systems. From covering only 6.3% of the European electricity consumption in 2012, it is expected that wind will supply what corresponds to about 25% of the overall European electricity consumption in 2030[2]. This considerable increase places new demands on both wind technology solutions and the development of system solutions that can absorb production.

1 ENTSO-E "Offshore Transmission ",11. 24.2011, Prepared by the Regional Group North Sea for NSCO-GI (North Seas Countries' Offshore Grid Initiative Technology).

2 EWEA, http://www.ewea.org

Denmark is a leading centre of competence for wind power, and with 28% of the Danish electricity consumption covered by wind power in 2011, Denmark is by far the most experienced country on system solutions in the world. This gives us a unique position to develop and test new technologies and methods for large-scale integration of wind power for the global market. Firstly, towards the objective of 50% in 2020 and from there on onwards.

Development, test and demonstration of new system solutions and technologies in Denmark will both contribute to promoting a better integration of wind power in the Danish energy system and creating new international business areas for Danish companies. We have the opportunity to lead the way and demonstrate intelligent system solutions which will ensure that the positive grid supporting capabilities of wind power will be exploited. We must also contribute to the finding of sustainable solutions for periods without wind power production, and also show how wind power can contribute actively to system integration in the flexible energy system of the future.

A part from the technology development itself, an important product of demonstration and research projects within the prioritised areas is their contribution to attract and educate candidates with the necessary competencies in order to develop future energy systems.

2 MEGAVIND VISION AND MAIN RECOMMENDA-TIONS

A future energy system with a large amount of wind requires a wide and binding cooperation between public authorities, grid companies, energy companies, research institutes and technology suppliers across the energy sector.

These parties must together carry out large investments in research, development and demonstration (RD&D) and tests. Historically the Danish energy sector has been capable of solving similar challenges which gives Denmark unique qualifications to create tomorrow's energy system.

Wind power has a strong presence in the global competition between energy technologies. In terms of price, onshore wind power can already compete with other new power plants and offshore wind power is among the cheapest of other renewable energy technologies. Wind power will thus most likely be a dominating technology in the world's energy supply in the 21st century.

Megavind's vision is that Denmark must maintain its global position as a leading centre of competence within the field of wind power.

To support this vision, this report describes and recommends strategic targets that create new solutions to large-scale integration of wind power including RD&D of power plant functionality. The recommended targets are aimed at making turbine production more cost-effective[3] and hence contribute to an increased competitiveness both for Denmark and the companies that participate in development activities.

3 Cost-effective in this connection should be regarded as technological solutions that contribute to bringing down costs of supplying a kWh to the consumer including solutions that increase the value of the produced electricity from wind turbines.

More cost-effective solutions depend on the possibility for domestic technology development and demonstration and Megavind has recommended the following activities to achieve this:

- In 2012, a decision is made on the establishment of **an advanced grid test facility at the national test centre in Østerild** so that by 2014 full-scale testing of short circuit faults, frequency variations and overvoltage, among others, is possible. In 2009, the Energy Technology and Demonstration Programme (EUDP) financed a pilot project evaluating the needs for such a stationary grid test facility. The facility will be an important add-on facility to the Østerild test centre for large wind turbines and will contribute to keep productive research, development and verification of grid supporting capabilities in Denmark (see section 3.1).

- In 2012 and the following years, projects that test and demonstrate possibilities for a **market-based supply of system services from wind power plants** will be prioritised. Project activities can for example be the usage of five minute forecasts for wind power to minimise imbalances, supply of system services such as frequency control and black-start from a dead grid (see section 3.1).

- Demonstration of **new methods of meteorological forecasting** in order to secure an optimum exploitation of wind systems that pass over Denmark (see section 3.2.).

- A project that develops and demonstrates the **control of more wind turbines of the same or different brands as a single power plant unit**. Developing improved control tools and thereby giving the companies with responsibility for power system management better opportunities to exploit the turbines' positive grid supporting capabilities together with other power plant units will increase the value of wind power (see section 3.2).

- To further develop and standardise **new models to simulate wind turbine and wind power plants' characteristics in the grid** including modelling, simulating and calculating qualities of future wind power plants in the grid (see section 3.3).

- To carry out demonstration projects of **66 kV-solutions in Danish waters partially at turbine level and in the collection grids** of the offshore wind power plants. An increased voltage level will in some cases eliminate the need for an offshore transformer station. This applies especially to near-coast wind farms. A 66 kV solution will also enable the connection of considerably more turbines to the same cable. The amount of cables in an offshore power plant is thus reduced, and the use of e.g. copper can be halved per installed MW. Detailed desk studies of preconditions and technology potentials are prerequisites for this recommendation (see section 3.4).

- Denmark will work for the establishment of **a joint European full-scale test facility for HVDC VSC converter-based solutions** e.g. in connection with the installation of Krieger's Flak. It is proposed that all Denmark's offshore wind power plants in the future will be made accessible and ready for connection for grid technological demonstration projects both in terms of the wind power plants' internal collection grid and the converter stations that connect to the electricity grid (see section 3.4).

- Universities gives **greater priority to engineering degrees within electrical power system engineering,** specifically including the development of professional testing competencies and the development of a test engineering degree (see section 4).


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3 RESEARCH AND DEMONSTRATION FOCUS AREAS

Developing both wind turbine technology and the Danish energy system with more intelligent solutions are necessary steps if the Danish and European political objectives for wind power are to be reached. And it is essential that technology solutions can be demonstrated and verified domestically.

Two national test centres with a total of 12 test beds

The establishment of full-scale demonstration sites in terms of new national test centres is an important precondition for carrying out projects within strategic research and demonstration areas, as described in this report. In 2008, Megavind recommended that a new national test centre for large wind turbines with 5-10 test sites should be established. The test centre with 7 test sites was inaugurated in October 2012. A test facility from 2002 at Høvsøre holds five test sites. Foreign manufacturers can also rent test sites at both Østerild and Høvsøre and this open access helps attract and maintain R&D competencies in Denmark.

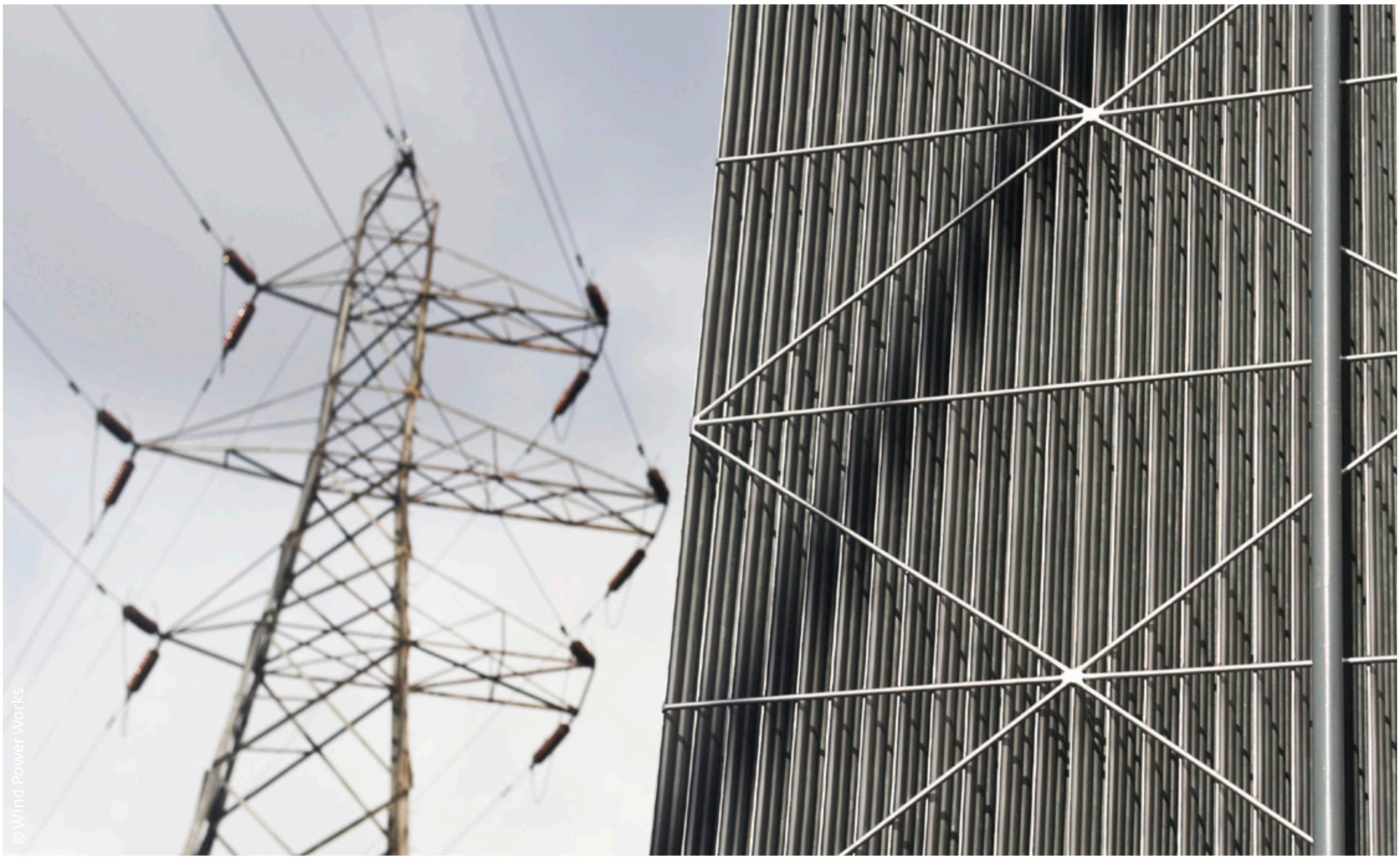
The national test centres will enable the industry to develop intelligent system solutions and verify that the turbines and wind power plants meet the grid connection requirements – a necessary requirement in the global market. Even today there are a number of grid-connection requirements that the turbines must meet, e.g. in case of grid faults and for grid-support capabilities at the wind power plant level. The national test centres will thus be used to develop a whole range of RD&D projects, among them recommendations from this strategy. The proposed new test facilities described in section 3.1 will make it possible both to verify compliance with the existing requirements and to develop more intelligent solutions.

The needs for national test facilities

It is crucial that the test centres have facilities for the full-scale testing of grid connection conditions both for individual turbines with power plant controllers and other equipment, and also for groups of turbines from the same or different manufacturers. Additionally, the test centres must be able to verify the joint control of the turbines' ability to deliver grid-supporting services – including voltage and frequency regulation as well as active and reactive power control at a wind power plant level. This is called a park controller. It is important to ensure that the grid support services can be supplied by turbines of same and different manufacturers, and that turbines from different manufacturers can be safely operated by the same park controller.

The wind power plant must be controlled and operated as a joint unit in spite of the fact that it will consist of several more turbines than that of the current offshore wind power plants. The size of e.g. London Array in Great Britain and other planned offshore wind power plants may require various turbine suppliers within the same farm. Especially if an area is developed in stages, it can be expected that the owner of the farm will want the possibility of placing orders with different turbine manufacturers.

Within the following areas of research and demonstration, Megavind has identified particular initiatives that can increase the value of large-scale integration of wind power in the energy system.



3.1 SYSTEM CONTRIBUTIONS FROM WIND TUBINES AND WIND POWER PLANTS

When the requirements for grid-support services are strengthened, turbines and wind power plants have a number of technical solutions to contribute far more actively to the energy system. The generation of electricity is still the primary product from the turbines, but grid support services that are essential for the stable and reliable operation of the overall energy system are becoming increasingly important. The value of the turbines in the energy system can be increased significantly if the turbines and the wind power plants can regulate their electricity production up and down, contribute to frequency control and perform voltage- and reactive power regulation etc. The turbine's and wind power plant's value to the electricity system can be strengthened by focusing on the following areas:

- Grid-support capabilities at wind power plant level
- Frequency control and frequency support
- Voltage regulation and recovery after power system faults
- Integration of wind power in future converter-based offshore transmission grids
- Robust solutions and controllers in converter to converter systems
- Transition to higher voltage levels in wind power plant collection-grids
- Control of wind power plants with turbines from different manufacturers
- Improved production forecasts with analysis down to 5 minutes and the ability to handle deviations and imbalances
- Optimisation of operation in relation to peak periods in consumption
- Optimisation of dealing with extreme loads
- Development and demonstration of "storm ride through" capabilities at wind speeds above 25 m/s

- Regulating power at turbine and wind power plant level
- Market regulation
- Technical specifications at turbine and wind power plant level
- Operation and grid activities in decentralised system/islanding
- Start-up at blackout/ blackstart by using converter technology
- Storage technologies that contribute to the integration of wind power

By a more effective exploitation of these qualities and a proper valuation of the services provided, both individual turbines and wind power plants can contribute significantly to large-scale integration of wind power in the electricity system and in future offshore transmission grids.

In order to verify the developed methods, there is a need for both practical demonstration projects and theoretical studies of the economic aspects, response times etc.

Possible development projects

There are a number of relevant development projects that fit within the common title: "How can turbines and wind power plants best be developed so that they actively interact with the system". Some examples are:

- Analysis of an optimum operation strategy for wind turbines and wind power plants, analysed in connection with the entire energy system, regulating power market, peak periods etc.
- Cost-benefit analysis of operation at low and high wind speeds and regulation of turbines at normal operation in relation to up- and downward regulation when the consumption changes.
- System services in extreme situations both in relation to production (extreme wind conditions) and the consumers (peak consumption periods).
- R&D and verification of grid support services for wind power plants – e.g. through the use of test facilities for grid connection of wind power plants.
- Technical analysis and cost-benefit analysis of wind power plants and their grid-supporting capabilities for the electricity system with turbines from different manufacturers.
- Integration of large wind power plants in future offshore transmission grids, coordination and role assignments in controller actions carried out by the wind power plants and the converter stations for the offshore transmission grids.
- Minute by minute production forecasts from wind power plants and the handling of deviations and imbalances.
- Transition to using higher voltage in the internal collection-grids of the wind power plants.

There will be both economic and system-aspect analysis and tests of what is physically possible for one turbine and for a group that represents a wind power plant with its overall controller. The systems that will be developed are to be tested and verified at full-scale, which once again underlines the need for national test centres in Denmark.

Test facility for emulation of grid conditions

The development and verification of system services and other electrical characteristics of turbines and wind power plants will require more advanced testing equipment than what is used today. Functional tests such as active and reactive power control are today carried out with standard measuring equipment. Tests of a wind turbine's response to voltage drops are carried out using specialised impedance-based testing equipment, which allows the verification of the turbine's low-voltage-fault-ride-through characteristics. However, more advanced equipment is needed in order to develop and verify other significant aspects such as frequency support and the contribution of virtual inertia from wind power plants.

The new test centre at Østerild will naturally play a central role in the development and testing of future wind turbines. Prototypes will be tested here for performance and mechanical loads among other things.

An advanced grid test facility in connection with Østerild will ensure that grid-support services can be developed and tested at full-scale at the test turbine site. These full-scale tests enable the possibility for testing electrical characteristics in realistic conditions. Furthermore, full-scale tests give the best possibilities to examine what impacts different grid situations and turbine requirements will have on other parts of the turbine, including mechanical loads, operations and protection.

An EUDP[4] financed pilot project "Test Facility" has examined the following aspects with reference to the development of a plan for implementing an advanced test facility for the new test centre at Østerild:

- Functional descriptions of the test facility: Based on existing and future requirements for wind power plant characteristics, a detailed list has been formed of the type of tests that will be carried out.

- Technical solutions: Possible technical solutions have been examined based on the functional description. The conclusion was a recommendation for provision of both an impedance-based short circuit equipment and a frequency converter-based test facility.

- Economic assessment: The total capital cost in connection with the establishment and running costs for the operation of the recommended test facility have been calculated.

- Administrative and contractual terms.

- Schedule for establishment of the test facility.

It is recommended that the results of the pilot project form the basis of the decision to build a test facility at Østerild before the end of 2012. The pilot project shows a clear need for a stationary grid test facility with the opportunity of expansion as new needs arise. This facility will help ensure that the necessary R&D and verification of grid supporting capabilities will take place in Denmark.

3.2 WIND TURBINES AS COMPONENTS IN A WIND POWER PLANT

The ability to control individual turbines and wind power plants with the same turbine types and turbines from different manufacturers is an important step for wind power to be able to naturally contribute to system integration both from an economic and a system perspective. By developing and ensuring better controllers in large wind power plants i.a. with the ability to handle turbines from different manufacturers, the TSOs will have far better tools to exploit the positive qualities of wind power in combination with other power generation units and the rest of the electrical energy system. Large wind power plants with different turbine types and manufacturers require a joint infrastructure for communication with, and operation of, the individual turbines from a central control system. The following areas are especially important to develop:

4 EUDP 2009-2: EUDP stands for The Energy Technology Development and Demonstration Program which supports the development and demonstration of new energy technologies.

- Standardised infrastructure for communication and communication interface between turbines and wind power plants which enables the exchange of data between different manufacturers and product types[5].

- Automatic control

- Multi-optimised operation to improve reliability of wind power as a source of energy, e.g.:
  - Stable and reliable minute-by-minute production forecasts
  - Supervision and control possibilities
  - Voltage and frequency regulation
  - Fault Ride Through (FRT) – continuous operation during grid faults
  - New methods for operation and optimisation

- Use of meteorological forecasts for balancing the electricity production from wind turbines.

- Knowledge of the interaction of the turbines during normal operation and in case of faults, especially between turbines from different manufacturers.

- Modelling of the mutual impacts between turbines and the grid at fluctuating grid frequencies, at higher nominal frequencies and in cases of grid disruptions.

- Modelling of large wind power plants with additional overall control including that of different turbine types and manufacturers in one power plant.

- Modelling and regulation of large wind power plants in future offshore transmission grids.

- Handling of imbalances and use of energy storage.

Additionally, research in better forecasts of wind power production (both long-term and short-term) is essential in order to increase the stability and the value of wind power in the power system.

Possible development projects

All the mentioned areas are relevant RD&D project initiatives, but it will be of particular interest to carry out a demonstration project focussing on the control of turbines as a virtual power plant. A project of this sort can help provide TSOs with an instrument to predict and manage the wind energy production more efficiently than today. One of the big challenges in this project will be to create a system that can balance the effect over large areas, while simultaneously taking the need of local regulation at the distribution level into consideration.

3.3 DEVELOPMENT AND STANDARDISATION OF MODELS FOR SIMULATION OF WIND POWER PLANT CHARACTERISTICS IN THE GRID AND MODELS FOR POWER SYSTEM ANALYSIS

The development of and the appropriate definition of models for simulating wind power plant qualities in the power system will result in new possibilities for analysing and developing the overall energy system. Currently models of wind power plants with turbines from the same manufacturer are used as well as detailed models of the overall control system. In grid analyses such models represent the whole wind power plant as an upscaled turbine. But the models lack simple and robust set-ups of plants with turbines from different manufacturers as well as standardised models of the overall control systems of the power plants. Grid analyses are thus currently difficult to perform without an over-emphasis on what influence turbines from different manufactures have for the overall control system of large wind power plants.

5 This work must be strengthened through international cooperation. Under the auspices of IEC (International Electrotechnical Commission, http://www.iec.ch/) several examinations of a standard within the area have been made, which is also carried through as a research project.

Standardised methods and models are needed to demonstrate the operation of large wind power plants with turbines from different manufacturers with the same controller. Apart from that, methods and models of wind power plants that are to be connected to future converter-based and converter-controlled offshore transmission grids are needed. The calculation models must include all operational situations: normal operation, failure modes, peak periods etc. – in brief the interplay between the wind power plant and the energy system in all plausible situations.

The significance of such models is essential, not only in Denmark, but in all of Europe. The models will provide the fundamental basis for analysing how much wind power actually can be integrated into the European system, so that the TSOs can assess wind power on a qualified basis.

Possible development projects

Megavind recommends that a development project is created with the aim of developing and verifying generic standardised models for wind power plants with different turbine types and manufacturers. Furthermore, models of the overall controller must be developed and verified which can be used by all turbine manufacturers.

The project must define which components are needed in a standardised model for assessing a wind power plant's characteristics in the grid. The work should be based on those areas that can be standardised today, so that the common denominators are the foundation and the more advanced questions can follow.

Standardisation must take place at the international level, but Denmark should be front-runner and initiator in developing this standard. An international study and cooperation must contribute by defining what the models should be used for and how the simulation models should be validated. The validation procedure ensures a consistent qualification of the models. Moreover, the standard can create a basis for a subsequent certification. The work must be conducted as pre-standardisation work and the models that are developed must follow the international standards, developed by IEC.

The models should include:

- Classification of control principals in a wind power plant.
- Requirements for models and model validation.
- Analysis of model types to be used and what type of analysis they can be used for.
- The models must be usable in existing power system analysis tools.
- Standardised models must be able to be used for verification of electrical performance and "best practice" for verification.
- Models and structures must be developed that only depend on standardised input from suppliers, so that comparison is possible.
- A further development will be to expand the wind power plant models to be used with HVDC VSC converter-based systems – future offshore transmission grids. Planning tools for the modelling of wind power variability and optimizing the expansion of the Danish power system with high wind power penetration are Danish requirements in a European power system.

3.4 COLLECTION AND TRANSMISSION GRIDS

The increased expansion with new large offshore wind power plants, including increased expansion with offshore transmission grids, will result in new requirements for hardware, operation and control of offshore turbines, as well as converter stations offshore and onshore.

Future Danish offshore wind power plants should therefore be made ready for full-scale grid demonstration projects, ideally as projects that can facilitate Denmark's connections to new offshore transmission grids in the North Sea and the Baltic Sea. Below is a recommendation for establishing a test facility that can monitor and test the new technology needed for the above mentioned full-scale demonstration facilities.

The internal collection grids within offshore wind power plants make up a significant share of plant capital costs. By increasing the voltage and thereby reducing the number of transmission radials needed, sizeable cost reductions are achievable from reduced transmission losses, reduced costs in the collection grid and collection platform design.

When the turbines become bigger and can produce significantly more electricity, it can be expected that they will be connected to the collection grid at higher voltages. These new and larger turbines must be able to be tested and type approved for connection at higher voltages and that the voltage level in the collection grid is increased from 33 kV, as in the existing wind power plants, to 66 kV. One or more of the test centres must therefore have the necessary facilities for connecting and testing the turbines at higher voltages.

HVDC VSC test facilities

How should wind power plants be controlled and managed in future offshore transmission grids? It is very likely that offshore transmission grids will be constructed with HVDC VSC converter-based connections, in which DC voltage and power flows are controlled, while the HVDC stations regulate AC voltage, frequency and reactive power on both the onshore and offshore AC grid.

When future offshore plants are connected to the offshore transmission grids, there will be more converter-to-converter systems in which the turbine converters are connected to the grid converter station. In such converter-to-converter systems, the converters must not interfere with each other's function and that the roles between the different converter controllers should be agreed in advance, so that controller conflicts are avoided. A controller conflict will mean that the converters begin acting against each other at the risk of the whole system failing.

In practice, this means that one or more test centres should have the necessary authority approvals, as well as space and capacity for the installation of a small HVDC VSC test facility where more turbines can be connected. Such HVDC VSC test facilities can also be used for testing of AC-grid based characteristics with a proper de-coupling from the rest of the electrical system – to produce voltage dips as experienced during short circuit faults, without applying short circuits, and voltage or frequency fluctuations at the turbine terminals and without affecting the rest of the electricity system.

The expansion of offshore transmission grids will spur the integration of offshore wind power, but will also set new and unseen demands for hardware and for operation and control of offshore wind power plants. The purpose here is to ensure that Danish companies, research institutes and authorities build up the necessary competencies in order to optimise and advance Danish connections to a new offshore transmission grid in the North Sea and the Baltic Sea. This type of test facility will support common European priorities and should therefore be prioritised in relevant European research programmes and action plans, including *TYNDP (Ten Year Network Development Plan), TEN-E,(Trans-European Energy Networks), NSCOGI (North Seas Countries' Offshore Grid Initiative) and ENTSO-E (European Network of Transmission System Operators for Electricity).*

4 KNOWLEDGE AND COMPETENCIES

A prerequisite for the Danish industrial and technological development within the field of wind power and other renewable energy technologies is that the Danish wind turbine manufacturers, subcontractors and R&D institutions can attract and maintain the right candidates and experts.

The wind industry is experiencing an increasing need for engineers – Bachelors, Masters and Ph.D.'s with solid technical knowledge. Engineers who develop the electrical system and wind power plants in the electrical system, must have a strong technical foundation within maths, mechanics, electrotechnical areas, power system engineering, electrical engineering, converter technology, control system engineering, testing, etc.

Wind energy research is conducted in close collaboration with educations at Master's level within this field to ensure a continuous update of the content of the courses. This approach should be intensified with integration and development of skills according to sector requirements.

It is a huge challenge to attract a sufficient number of master students and the education of engineers should be given greater priority.

Engineering students must be introduced to wind power technology in their studies. Wind power should be the natural choice in the selection of project assignments and course selection during the education. Companies in the wind industry and the energy sector must be the natural choice for the students, when company visits and visiting lecturers are to be chosen. The wind sector will thus become an integrated and natural part of the education of engineers and the graduates will become even more useful for the industry.

The wind industry and universities must subsequently take on the task of turning skilled candidates into experts. This process takes place through knowledge sharing and introducing the future engineers to industrial work processes, project assignments and project management, product development, further education and a necessary research commitment.

Danish wind energy competencies are created and developed in direct competition with graduates from all over the world. Thus, Danish students must also be prepared to learn about cultural understanding and negotiation techniques.

The most skilled students should not only be educated and kept in Denmark but we must also attract global candidates. This is crucial for the future of the Danish wind industry. Therefore, Denmark must be a country, where state-of-the-art research and development is conducted. Experts must be able to use their professional competencies, test ideas and transform those ideas into ground-breaking commercial products that create value and satisfy the customer.

The establishment of one or more test centres for wind turbines and wind power plants with access to the latest technologies will contribute to keep the Danish wind industry and wind energy research at the top. But the test centres must also be used to educate potential engineering graduates. Cooperation with foreign centres and research institutes cannot be underestimated. Positive experiences and job satisfaction from guest lecturers at the Danish test centres will increase the interest and desire to come to Denmark and contribute with international knowledge. By learning and sharing knowledge with foreign experts, the professional competencies will be improved.

Competency requirements

A main precondition for maintaining the position as a global centre of competence for integrating wind into the electrical system is to have the right competencies. The right competencies must be developed, attracted and maintained with Danish wind turbine manufacturers, subcontractors and research institutes. The necessary conditions for this development of competencies are:

- To educate a sufficient number of engineers with a solid professional basis within electro technology areas, converter technologies, control techniques etc. The base of recruitment must be global and not only in Denmark.

- Through focused professional and personal development, knowledge sharing and research related cooperation to develop world class wind power specialists.

- To make Denmark a more attractive country to work and do research in a world class environment and to attract experts with a solid knowledge to Denmark.

- The test centres with the latest facilities and wind turbine technologies will contribute to and strengthen this development in order for Denmark to remain one of the leading wind power nations.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5 INTERACTION AND COORDINATION WITH OTHER TECHNOLOGIES

Already today, a number of external technologies exist which can contribute to a significantly better integration of wind power. The development of these technologies will play an important role in the future energy system. It is therefore important to make use of the technologies available. There is a special need for flexibility in the energy system when European wind power penetration increases in the coming years.

The most important technologies are:

- Centralised and decentralised heating- and cooling systems
- Electrification of the transport sector
- Intelligent energy consumption in households and industry
- Interconnected transmission grids in Europe including offshore transmission grids
- Electrical energy storage

In the development the above mentioned technologies, it is important that each technology is designed so that it performs in the best possible way with wind power.

In the long term, the development of further storage technologies which can hold wind produced electricity is necessary. These technologies could be fuel cells, hydrogen, compressed air storages, batteries etc. Large-scale development requires, however, more energy efficient technology solutions and that the market develops so that the projects become economically feasible.

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