IEA Wind Task 23 Offshore Wind Technology and Deployment. Subtask 1 Experience with Critical Deployment Issues. Final Technical Report

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Risø-R-Report

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Risø-R-1755(EN)
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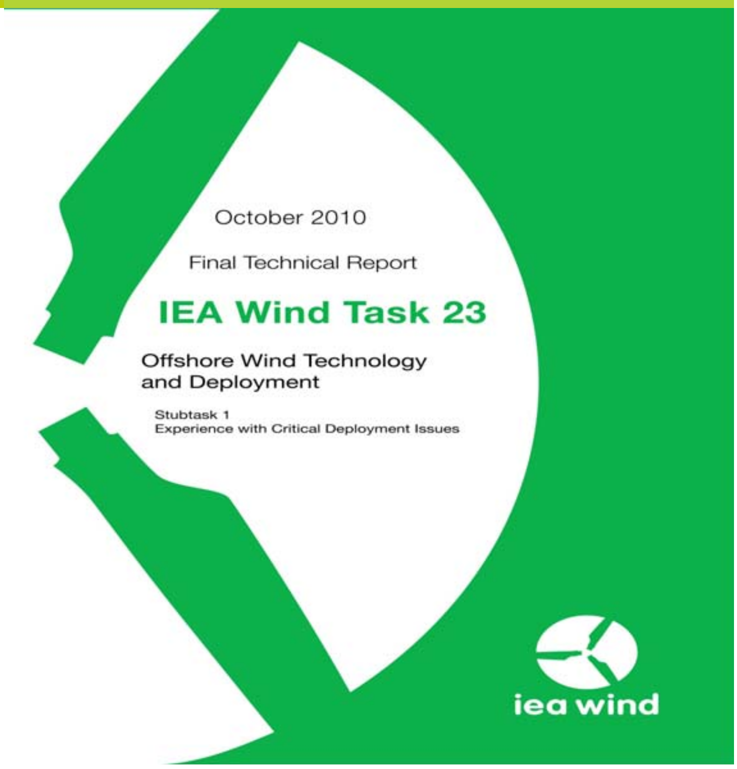

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Contents

1 Preface

The final report for IEA Wind Task 23, Offshore Wind Energy Technology and Deployment, is made up of two separate reports*: Subtask 1: Experience with Critical Deployment Issues* and *Subtask 2: Offshore Code Comparison Collaborative (OC3).* The Subtask 1 report included here provides background information and objectives of Task 23. It specifically discusses ecological issues and regulation, electrical system integration and offshore wind, external conditions, and key conclusions for Subtask 1. The Subtask 2 report covers OC3 background information and objectives of the task, OC3 benchmark exercises of aero-elastic offshore wind turbine codes, monopile foundation modeling, tripod support structure modeling, and Phase IV results regarding floating wind turbine modeling.

Recognizing the interest and challenges of offshore development of wind energy, IEA Wind Task 11 Base Technology Information Exchange sponsored a Topical Expert Meeting (TEM 43) in early 2004 in Denmark on Critical Issues Regarding Offshore Technology and Deployment. The meeting gathered 18 participants representing Denmark, Finland, the Netherlands, Sweden, the United Kingdom, and the United States. Presentations covered both detailed research topics and more general descriptions of current situations in the countries. After the meeting, the IEA Wind ExCo approved Annex 23 (Task 23) to the Implementing Agreement as a framework for holding additional focused workshops and developing research projects. The work would increase understanding of issues and develop technologies to advance the development of wind energy systems offshore. In 2008, 10 countries had chosen to participate in this task, and many research organizations in these countries are sharing their experiences and conducting the work (Table 1).

Table 1. IEA Wind Task 23 Participants in 2008

Country	Participants Party
Denmark	Danish Energy Agency; Risø DTU (OA)
Germany	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Republic of Korea	Government of Korea/KEMCO
The Netherlands	We@Sea
Norway	Norwegian Water Resources and Energy Directorate
Portugal	INETI
Spain	Cener
Sweden	Chalmers University Goteborg
United Kingdom	Department for Business, Enterprise & Regulatory Reform
United States	U.S. Department of Energy; NREL (OA)

This annex was organized into two subtasks to (1) give the participants experience with critical deployment issues and (2) conduct technical research for deeper water applications. The results of this work are presented in the Executive Summary and in the supporting two volumes of this report.

2 Executive Summary of IEA Wind Task 23 Subtask 1

When this IEA Wind Task began in 2005, the people and organizations involved in offshore wind energy were accumulating the first experiences with this technology and the critical issues of its deployment. From 2005 to 2009, *Subtask 1: Experience with Critical Deployment Issues* brought together more than 225 experts from 11 countries for 125 presentations during 7 narrowly defined, highly technical meetings to share their experiences and plan new ways to cooperate. Although no official research efforts were begun under Task 23 Subtask 1, the workshops informed the experts who went on to design national, corporate, and institutional research programs.

The workshops increased awareness of the research efforts in the participating countries and organizations that will advance the technology and deployment of offshore wind development. The invited experts included representatives from wind turbine manufacturers and developers; utility planning, grid operators, and regulatory bodies; national research institutes; engineering and design consultants; environmental planning and regulatory bodies; universities; and wind plant operators. Participants in the task determined the topics, timing, and conduct of the workshops. Three issue areas were selected: Ecological Issues and Regulations, Electrical System Integration of Offshore Wind, and External Conditions.

Under the topic of Ecological Issues and Regulations, one workshop was held:

Offshore Wind Energy Deployment - *Workshop on Ecology and Regulation* was held February 28–29, 2008, Petten, the Netherlands.

Under the topic of Electrical System Integration of Offshore Wind, the following workshops were held:

- *Grid Integration of Offshore Wind,* University of Manchester, Manchester, UK September 12–13, 2005.
- *Workshop/Round Table Discussion on Grid Integration of Offshore Wind,* June 18, 2007, DTI conference center, London, United Kingdom.
  Power Fluctuations from Offshore Wind Farms, Risø DTU Roskilde, February 26, 2009.

Under the topic External Conditions, the following workshops were held:

- *Workshop Programme on External Conditions, Layouts, and Design of Offshore Wind Farms*
  Risoe, Denmark, December 12–13, 2005.
- *Workshop on Wake Modelling and Benchmarking Of Models,* Billund, Denmark, September 7–9, 2006.
- *IEA Task 23 Offshore Wind Energy and Deployment* - *Workshop on Wake Effects,* February 25, 2009, Risø DTU, Roskilde, Denmark.

By the accounts of the participants in the minutes of the discussion sections, these workshops sponsored by IEA Wind provided unique opportunities for diverse disciplines relevant to development of offshore wind energy to learn about the state of the art of each other's work and to have lively discussions of the critical issues faced by the community. While it is difficult to measure, we believe that this active exchange of information at the very early stages of offshore wind deployment has helped avoid repetition of mistakes and has accelerated successful activities.

The official records of these workshops contain valuable technical detail and are now available to any interested party via the Task 23 web pages hosted at www.ieawind.org. More than 125 presentations on topics ranging from aerodynamic modeling to benthic studies to wake effects can be found there for each of the seven workshops organized under the task.

We hope that these technical presentations organized by the critical issues of offshore wind deployment will form the foundation for continued advancement worldwide of this important new energy resource.

3 Summary of conclusions and recommendations

3.1 Ecological Issues and Regulations.

A comprehensive approach to planning is needed that integrates impacts on ecology, the effects of electrical infrastructure, and the layout of wind farms. Governments, which usually finance ecological research, should disclose results for wide dissemination as they become available.

As example the workshop held suggested that documents covering the issues like offshore wind energy legislation, Guidelines for EIAs and SEAs and best practices need to be produced and distributed on a regular basis, as ecological research progresses and experience from the planning and operation of existing wind farms emerges:

R&D results need to be transferred and exchanged faster and more efficiently. Transfer is required between R&D establishments and users. Particularly, there is a lack of knowledge for integrated spatial marine planning, taking into account other offshore activities such as sand mining, shipping, military activities, oil and gas production, and nature conservation.

Existing networks such as in the EU and among wind energy associations should be used to disseminate results as they are achieved. An international review body is needed to learn from and avoid poor decisions. More work is needed to ensure shipping safety when siting offshore wind farms.

3.2 Electrical System Integration of Offshore Wind

Research should help strike the balance between optimum regulation and the need to get projects up and running. Such research is needed to increase understanding of offshore wind metrology and its impact on electrical power fluctuations.

More work is needed to develop special grid code and standards for offshore. The transient behavior of large cable installations (switching / harmonic/ Behavior and modeling of large HV cable systems) must be better understood. Connection and control systems must be developed for large offshore wind farms. Work is needed to develop the technical architecture of offshore wind grid systems.

Projects are needed to model wind power fluctuations, to measure wind speed and wind power, to forecast power production, to measure and predict the impact of wind power fluctuations on operation and control of the power system.

3.3 External Conditions

Public access to measurements (e.g., turbine power output, meteorological masts, buoys) is important, especially for model validation. Determining wake effects is currently the most important challenge in wind engineering. Emphasis should be put into observing and understanding winds 50 m and higher above the surface. The logarithmic wind profile seems to be invalid at these heights, even with neutral conditions.

Problems have been found with wave models in shallow water. An unexpectedly low correlation has been observed between wind data and wave height. Wave spreading and especially misalignment between wind and wave directions needs further investigation and water level transients and coastal currents should be included in models. Slamming and forces from breaking waves and likelihood of breakers must be assessed both in deep waters and in shallower water. Statistics on array efficiency from Horns Rev shows possible effects at corners of the wind farms. Alignment of waves, wind, and current to determine a conservative design case must also include turbine vibrations when wind and wave directions are perpendicular. Data to validate models are needed to contribute to the new IEC-3 standard.

The theoretical and experimental results indicated differences in results from modelling and in the interpretation of measuring data from offshore wind farms, in particular data from the Horns Rev and Middelgrunden wind farms. A format is needed for collecting and benchmarking data related to offshore wind farms and onshore farms in cases when it is considered relevant. Collaboration should be focused on data that are important for power calculations as well as for design loads.

The experiences from offshore wind turbine installations reported and discussed at the workshops provided valuable technical information that will aid future offshore wind developments. To accelerate the successful proliferation of offshore wind worldwide, timely exchange information and lessons learned from existing offshore facilities is essential.

4 Background Information and Objectives

Statistics show a global wind energy capacity in 2008 approaching 1% of the global electricity capacity. Estimates predict a huge increase in wind energy development over the next 20 years. Much of this development will be offshore wind energy. This implies that billions will be invested in offshore wind farms over the next decades.

The aim of Subtask 1, therefore, has been to support this development by arranging workshops in which participants will inspire each other and test and improve research results. The work in Subtask 1 has been divided into three research areas, and a lead country was chosen for each area. Detailed discussions of the workshops are included in Chapters 2–4.

4.1 Ecological Issues and Regulations

Research Area 1 (Lead country the Netherlands), Ecological Issues and Regulations, held a workshop in Petten, the Netherlands, in February 2008, which was attended by more than 20 experts. The workshop objectives were as follows:

- Provide a state-of-the-art overview of knowledge about impacts of offshore wind turbine systems on the marine environment.
- Get a picture of the consequences for regulatory frameworks, such as requirements for environmental impact assessments (EIAs) and protection measures for nature reserve areas.
- Generate ideas for frameworks on how results of nature research can be used to (re)formulate regulations and legislation.

Discussion and final recommendations fell into three categories. First, the knowledge base for planning and designing offshore wind farms needs strengthening. As ecological research progresses and experience from the planning and operation of existing wind farms emerges, documents covering the following issues need to be produced and distributed about offshore (wind energy) legislation, guidelines for EIAs and strategic environmental assessments (SEAs), and best practices.

Second, transfer is required between research and development (R&D) establishments and the users who include wind farm planners and designers, as well as authorities responsible for approving wind farms and specifying EIAs and SEAs. A lack of knowledge for integrated spatial marine planning was identified compared to other offshore activities such as sand mining, shipping, military activities, oil and gas production, and nature conservation.

Third, specific areas of and methods for co-operation between countries were identified during the workshop:

- Regular meetings of multidisciplinary research and industry groups, representing disciplines in the fields of ecology and wind energy technology. (It appeared that the Task 23 workshop was one of the rare opportunities for representatives from both fields to meet and exchange views.)
- Cumulative effects of an increasing number of wind farms on the marine ecosystem. (There is an urgent need to address this issue for spatial planning purposes.)

- Integral risk analysis as part of the planning process and SEA.
- Geographic Information System (GIS) mapping as a basis for representing R&D results.
- Integration of the three major issues for offshore wind energy planning: impacts on ecology, electrical infrastructure, and wind farm layout. (This requires integration with other activities of IEA Task 23.)
- Co-operation on the government level—governments, which usually finance ecological research, should facilitate the exchange of information by disclosing results as they become available.
- Database formation.
- How to use ecological and environmental networks within the European Union (EU) (such as the Environmental Impact Information Tool [EIIT], which the European Wind Energy Association is designing, and possibly the Global Wind Energy Council [GWEC]) and other countries for the benefit of making knowledge available to potential users.
- Reviewing of siting decisions by international experts with the aim of learning and criticizing possible poor-quality decisions.
- How to deal with shipping safety and siting of wind farms with respect to shipping lanes.

4.2 Grid Connection

Research Area 2 (Lead country the United Kingdom): Grid Connection held a workshop in September 2005, at Manchester University in the United Kingdom. There it was decided to focus the work program on five issues: (1) offshore wind meteorology and impact on power fluctuations and wind forecasting, (2) behavior and modeling of high-voltage cable systems, (3) grid code and security standards for offshore versus onshore, (4) control and communication systems of large offshore wind farms, and (5) technical architecture of offshore grid systems and enabling technologies. A planning meeting at Risø in 2006 set up workshops where the five issues would be addressed. Also, participants agreed to supply information about projects in the member countries, including results, to help coordinate activities between participants under this IEA Wind task.

A workshop called Grid Integration of Offshore Wind conducted in June 2007 in London included a brief overview of the situation in the UK. In that country, a number of early (Round 1) offshore wind farms are already connected to the onshore grid via low-voltage connections (33 kV). Larger Round 2 projects will be connected via offshore transmission systems (132+ kV). Significant work had been undertaken by the Department for Trade and Industry and the industry regulator, Ofgem, to develop an appropriate regulatory framework for offshore transmission. The UK government announced the appropriate model to follow for offshore, tenders will be held for regulated licenses to connect specific offshore projects, and minimum security standards which should apply to offshore have been consulted on. A final workshop, Power Fluctuation, took place in Denmark February 2009.

4.3 External Conditions Layouts and Design of Offshore Wind Farms

Research Area 3 (Lead country Denmark): External Conditions, Layouts, and Design of Offshore Wind Farms held a workshop in December 2005 at Risø, Denmark, where wake modeling and benchmarking of models, marine boundary layer characteristics, and met-ocean data and loads were identified for inclusion in the future work program. As a result, another workshop on wake modeling and benchmarking of models was held at the Danish test station for large wind turbines, Billund and Høvsøre, in Jutland, Denmark. A great need was identified for further collaboration and exchange of data to develop and verify computational models and to understand the physics of wakes and meteorological backgrounds.

In addition to the work of IEA Wind Task 23, the EU R&D project UpWind includes similar activities. To multiply the benefits from both activities, during 2008, the benchmarking experience and results obtained from collaboration with UpWind were analyzed and discussed.

For marine boundary layer characteristics and met-ocean data and loads, a collaboration between two IEA Wind tasks (Task 11 Base Technology Information Exchange and Task 23) resulted in a Topical Expert Meeting under Task 11 in January 2007. The meeting was titled The State of the Art of Remote Wind Speed Sensing Techniques Using Sodar, Lidar, and Satellites. These are very important techniques to explore boundary layer characteristics and offshore loads to wind turbines. Additional collaboration took place when an IEA Wind Task 23 meeting was held in February 2007 in conjunction with a German offshore conference and the EU policy seminar on offshore wind.

A follow-up workshop with focus on continued benchmarking was scheduled to take place in Denmark during the second half of 2008. However, it was postponed to February 2009 and held in conjunction with the workshop on power fluctuation as a back-to-back workshop, Wake Effects and Power Fluctuations.

5 Ecological Issues and Regulations

Offshore wind energy is essential for meeting the renewable energy targets in many countries as the limits of land-based wind power plants come within reach. This is particularly the case in northwest Europe. Also, countries with large wind resources both on land and along their coast lines consider the offshore option with increasing priority as a way to proceed faster. Many implementation problems of installing wind power on land can thus be avoided. This, for example, is the case for countries like Spain, China, the United States, and India. However, in developing the offshore resource, completely different technical, environmental, infrastructural, and institutional requirements have to be met in comparison with land based wind energy systems. In order to gain a better insight in the environmental aspects, the IEA Executive Committee of the IEA Wind Energy program decided to organize a workshop on the effects of offshore wind turbine facilities on marine and human systems and the associated regulatory consequences.

Offshore Wind Energy Deployment – Workshop on Ecology and Regulation was held February 28–29, 2008, Petten, the Netherlands. The presentations are posted in full at www.ieawind.org on the Task 23 web pages.

5.1 Nature Concerns

In all countries that have been building wind farms offshore and the countries that are on the brink of realizing the first farms, an EIA is obligatory as one element in obtaining building consents. For the EIA, the possible impact of the planned wind farm on the marine ecology has to be assessed, among other issues. A significant problem, however, is that uncertainties surrounding many potential impacts and risk decision making are not applied in the wind industry as it is commonly applied in other conventional energy industries. As a result, the national requirements and assessment techniques for EIAs are often conservative. Although ecological research, initiated by the need of the wind energy sector to gain a much better insight into potential effects of wind farms on the ecology, is providing the first results, authorities are slow in incorporating new risk information and adaptive management practices into EIA requirements and conservation best practices.

Although selective results from ecological research are applicable to similar ecosystems in various regions in the world, some experts would argue that each ecosystem is unique and cannot be applied across ecosystem boundaries. Despite that debate, the wind energy community has a keen interest in sharing the results, coordinating research and methodological approaches, and stimulating the appropriate authorities to immediately incorporate new information into evolving EIA and national regulations. This will lead to better decision making, better informed communities, and ultimately lower costs during the preparatory phase of realizing an offshore wind farm.

Various countries have national research programs addressing the impact of wind energy on the marine environment, notably Denmark, Germany, the United States, and the Netherlands. Recently four books were published on the results of research in Denmark, Germany, and the United States.

From present research it can be concluded that from the long theoretical list of potential impacts, the most critical ones are as follows:

- Impact on birds (collisions, migration routes, habitat)
- Impact of acoustic noise from construction on sea mammals (seals, porpoises)
- Public perception and community concerns
- Visibility and aesthetics

Other aspects that might need further investigation include the following:

- Impact on fish
- Impact on sea bottom morphology and benthos
- Effects of toxic agents possibly used in the construction of support structures
- Shipping safety
- Risk decision making with a range of uncertainties

Monitoring of the impacts after commissioning of offshore wind farms, as is usually necessary and enforced by law, is labor intensive and thus expensive. Therefore, the development of monitoring equipment is important, and different systems are being developed. Some examples are: automatic monitoring of birds collisions and migration routes, tracking migration paths of sea mammals, underwater acoustic sound measurements. Exchange of information on the suitability and reliability of these systems is very useful for both the ecological research community and the wind energy sector.

As offshore wind energy is only at the very beginning of its development (approximately 1,000 MW installed at the end of 2007, compared to many thousands of megawatts within 20 years from now), many more offshore wind farms will be realized in the future. For this reason, it is essential to also know the cumulative effects of wind farms. This area of research is still unexplored. The effects of wind farms on the ecology is one element of an integral risk assessment that financiers are applying in assessing the economic feasibility of offshore wind. Research results should be fed into the methodology of integral risk assessment.

The objectives of the workshop were as follows:

- Providing a state-of-the-art overview of the knowledge of potential impacts and benefits of offshore wind turbine systems on the marine environment and human systems
- Better assessment of significant risks and uncertainties associated with siting of wind energy facilities, in light of international and national regulatory frameworks, such as requirements for EIAs and protection measures for nature reserve areas.
- Generate ideas for frameworks on how results of nature research can be used to (re)formulate regulations and legislation, such as adaptive management principles. The conclusions and recommendations generated by the workshop may serve as an initiator for both national research and policy development and future IEA activities.

5.2 Recommendations

5.2.1 Knowledge for Planning

The knowledge base for planning and designing offshore wind farms needs strengthening. Documents covering the following issues need to be produced and distributed on a regular basis, as ecological research progresses and experience from the planning and operation of existing wind farms emerges:

- The development of offshore (wind energy) legislation
- Guidelines for EIAs and SEAs
- Best practices

5.2.2 Transfer and Exchange of R&D Results

R&D results need to be transferred and exchanged faster and more efficiently. Transfer is required between R&D establishments and users. Users include not only wind farm planners and designers but also authorities responsible for consenting wind farms and specifying EIAs an SEAs. Particularly, there is a lack of knowledge for integrated spatial marine planning, taking into account other offshore activities such as sand mining, shipping, military activities, oil and gas production, and nature conservation.

5.2.3 Areas of Cooperation

The specific ways and areas of cooperation between countries identified during the workshop include the following:

1. Regular meetings of multi-disciplinary research and industry groups, representing both disciplines in the field of ecology and wind energy technology. At the IEA Task 23 workshop, it appeared that the workshop was one of the rare opportunities that representatives from both fields met and were given the opportunity to exchange views.
2. Cumulative effects of an increasing number of wind farms on the marine ecosystem. There is an urgent need to address this issue for spatial planning purposes.
3. Integral risk analysis as part of the planning process and SEA.
4. GIS mapping as a basis for representing R&D results.
5. Integration of the three major issues for offshore wind energy planning: impacts on ecology, electrical infrastructure, and wind farm lay out. This requires integration with other activities of IEA Task 23.
6. Cooperation on government level. Governments, which usually finance ecological research, should facilitate the exchange of information by disclosing results as they become available.
7. Database formation.
8. How to use (ecological and environmental) networks within the EU (such as the Environmental Impact Information Tool [EIIT], which the European Wind Energy Association [EWEA] is designing and possibly the Global Wind Energy Council [GWEC]) and other countries for the benefit of making knowledge available to potential users.
9. Reviewing of siting decisions by international forum with the aim to learn and criticize possible poor quality decisions.
10. How to deal with shipping safety and siting of wind farms with respect to shipping lanes.

5.3 Workshop Participants

Denmark: Niels Erik Clausen, Flemming Oester, Risø DTU; Jesper Kyed Larsen, Vattenfall; Henrik Skov, DHI

Germany: Roland Krone, Alex Schroeder Alfred, Wegener Institute for Polar and Marine Science; Stefanie Hoffman, BMU

Netherlands: Sjoerd Harkema, Commissie MER (Environmental Impact assessment); Reinier Hille Ris Lambers, Mardik Leopold, Han Lindeboom, IMARES; Jan Dam, Ecofys / Evelop; Heinrich Duden, Blue H Technol.; Jos Beurskens ECN; Chris Westra, Wea@sea; Eeke Mast, TU Delft/We@Sea; Blanca Perez-Lapena, University Twente

Sweden: Kjell Grip Swedish Environmental Protection Agency

United States: Bonnie Ram, Energetics, Incorporated

5.4 Workshop Presentations

The following presentations are posted at www.ieawind.org on the Task 23 web pages:

- *Offshore Wind Energy Technology and Deployment*, Operating Agents Jørgen Lemming Risø DTU, Walt Musial, NREL, United States
- *We@Sea Introductory Note*, Jos Beurskens, Scientific Director We@Sea, the Netherlands; Bonnie Ram, Program Manager and Senior Analyst Environmental Science and Policy, Energetics Incorporated, United States
- *Research in Offshore Windparks*, Han Lindeboom, IMARES, the Netherlands
- *Environmental Impact of Offshore Wind Farms the Danish Experience*, Niels-Erik Clausen, and Risø DTU, Denmark
- *Research Programme on Environmental Effects of Windpower Parks*, Grip
- Vindval
- *Strategic Environmental Assessments as a Tool For Improving Planning Of Offshore Wind Developments*, Henrik Skov, DHI, Denmark
- *Are Available Knowledge On Environmental Impacts Being Applied? ,* Jesper Kyed Larsen, Vattenfall, Denmark
- *Strategies for Risk Assessment for Ocean and Tidal Energy*, Bonnie Ram, Energetics, Inc., United States
- *Offshore Wind Farms and Marine Mammals*, Mardik Leopold, IMARES, the Netherlands
- *Analysis of Change in the Marine Environment Support for Environmental Monitoring Procedures*, Blanca Pérez Lapeña, the Netherlands, Univesity of Twente
- *German Offshore Wind Energy Research - Funded by the Federal Government*, Stefanie Hofmann, BMU, Germany
- *Effects of Offshore Constructions on Benthos: Experiences from the research platform FINO1 in the German Bight*, Alexander Schroeder, Alfred Wegener Institute for
- Polar and Marine Science, Germany
- *Offshore Wind Farm EIA Issues Practical Experiences In Some Countries*, Jan Dam, Ecofys / Evelop, the Netherlands

5.5 References

[1] Marine mammals and seabirds in front of offshore wind energy', to be published in February 2008. (Teubner Verlag, Wiesbaden, ISBN 987-3-8351-0235-4)

[2] Julia Köller, Johann Köppel, Wlofgang Peters (Editors); Offshore Wind Energy; Research on Environmental Impacts. 2007. Springer Verlag. ISBN-10 3-540-34676-7, ISBN-13 978-3-540-34676-0.

[3] Dong Energy, Vattenfall, Danish Energy Authority, Danish Forest and Nature Agency; Danish Offshore Wind; Key Environmental Issies. 2007. ISBN: 87-7844-625-2.

[4] Various EIA reports on (presently) operating offshore wind farms, e.g. Horns Rev (DK), Beatrice (Scotland), OWEZ (NL) U.S. Documents:

[5] Minerals Management Service, Programmatic EIS

[6] Cape Wind Draft EIS (just released)

[7] NREL White Paper (forthcoming 2008) Large Deployment of Offshore Wind in the US; Opportunities and Barriers [Walt Musial and Bonnie Ram)

The following book only addresses impacts of wind turbines on land:

[8] The National Research Council of the National Academies; Environmental Impacts of Wind-Energy Projects. 2007. ISBN-13 978-0-309-10834-8 (Book), ISBN-10 0-309-10834-9 (Book), The National Academies Press, 500 Fifth Street, NW, Box 285, Washington, DC 20055.

6 Electrical System Integration of Offshore Wind

In order to facilitate the deployment of offshore wind generation satisfactory solutions to a number of technical, commercial, and regulatory issues associated with the connection and integration of this resource with the existing network infrastructure will be critically important. The purpose of the workshops were to explore these key issues and highlight the topics to be taken forward under the grid integration of offshore wind sub-task of Task 23 of the IEA Wind R&D Implementing Agreement. The presentations, programs, and summaries are posted in full at www.ieawind.org on the Task 23 web pages.

6.1 Workshop 1: Grid Integration of Offshore Wind

Grid Integration of Offshore Wind, University of Manchester, Manchester, UK September 12–13, 2005.

Current experience with offshore wind turbine installations provided valuable technical information that will aid future offshore wind developments. Although some of the existing offshore wind installations have faced similar technical issues, there will be a considerable variability in the local conditions and solution adopted, and the workshop provided a review of lessons learned from the existing offshore wind farms.

The design of offshore connections and power collection infrastructure, while recognizing the stochastic nature of wind power output, will be driven by a number of factors including the size of the resource area, location, and diversity between wind regimes in different locations. The workshop discussed the technical options and the role of enabling technologies in achieving reliable design of offshore connections including the development of offshore grids for collection and transport of significant amount of power to the shore and the integration with the onshore transmission network. Cost effective integration of offshore wind generation will require the development of systematic and consistent approaches to resolving a number of technical, commercial, and regulatory issues, including license conditions, offshore security standards, transmission charges, grid code, connection and use of system codes, all of which will be included in the scope of the workshop.

6.1.1 Conclusions

6.1.1.1 Setting the Scene Discussion

A number of important issues were raised during the discussions. John Nielson of Energynet.dk observed that we are venturing into an unknown environment where interaction of onshore and offshore needs to be understood. Nick Jenkins Manchester University asked whether based on the Econnect work and consultation there was robust conclusion. In response, Giles Stevens Ofgem stated that there was need to undertake further work on technical assessment. Beyond Round 2, onshore transmission constraints will need to be considered. The marginal capacity of extra capacity on offshore cable in networks is high due to higher risk and complexity of these networks.

It was observed that a lack of clear technical vision could lead to regulatory rules with perverse outcomes. The economics of the project is the deciding factor. There is a balance to be struck between optimum regulation and the need for speed to get projects up and running. Another consideration is the certainty of the wind resource versus the uncertainty in fossil fuel costs.

6.1.1.2 Lessons from Existing Large Offshore Wind Farms Discussion

Metering should be located onshore for single connection and offshore for connection via off grid.
Turbine warranty is crafted to exclude major risks—cable failure rate is currently more risky. There is a need to determine how to deal with fishing in wind farm areas. Owner/operators must deal with the risk of damage to wind farm monopoles/cables by ships. An EU project is under way on aviation marking of turbines. The cost of cables and installations will also affect design options.

6.1.1.3 Areas of Further Research

Regulatory studies should include: scope for sharing experiences; codes and standards (i.e., the need for flexibility); point of compliance with codes (i.e., the need for operational data); IEC communication protocol; link offshore transmission to onshore grid operation; and build offshore grid for specific purpose or with considerations for longer term.

Lessons learned from existing wind farms include: design of substations (high-voltage direct current [HVDC]); correlation of speed and electrical output; and transformer performance offshore.

6.1.1.4 Technical issues of Offshore Integration

In conclusion and discussion the following points were noted: doubly-fed induction generators (DFIG) provide a direct connection to the system; work is ongoing using Bladed software to address conflicts between turbine requirements and system; and operators must specify requirements on inertia. Power System Stabilisers (PSS) are site specific. Inertia is more global, which this is still under focus /review. Work done at the DG Centre indicated that a12-second inertia would reduce response by 30%. To allow response converter must run below its limit which would incur a penalty as the DFIG would have to be de-loaded.

6.1.1.5 Commercial and Regulatory Issues for Integrating Offshore Wind Farms

The following main issues were identified: grid codes; forecasting; control models; techniques for cable installation; who pays for grid connections (merchant versus regulated approach); ramping up from big wind farms; alternating current / direct current (AC/DC) and HVDC; Strategies for offshore connections (AC can be used of connections close to the shore); power fluctuations and frequency control; contribution to system performance; design of collection systems; understanding offshore wind metrology (is it different to onshore wind?); transient behavior of big, off shore arrays; and forecasting timescales seconds, minutes, days (forecasting for offshore wind is different characterization of offshore wind power fluctuation and impact on system).

The following areas of needed work were identified:

- Understanding offshore wind metrology and impact on electrical power fluctuations

- Understanding transient behavior of large cable installations (switching / harmonic / behavior and modeling of large, high-voltage cable systems)
- Grid code and standards for offshore versus onshore
- Connection and control system for large offshore wind farms
- Technical architecture of offshore wind grid systems

6.1.2 Workshop Participants

Denmark: Joergen Lemming, Risø; John Eli Nielsen, Energinet; Poul Sørensen, Risø

Finland: Bettina Lemström, VTT

Germany: Bernhard Lange, ISETeV

Ireland: Emma Fagan, ESB National Grid; Oatrick, O'Kane, Airtricity

Italy: Gaetano Stefano Elia, GRTN

The Netherlands: Chris Westra, Energy Research Centre

Sweden: Ake Larsson, SwedPower; Ola Carlson, Chalmers; Thomas Ackermann, Royal Institute of Technology

United Kingdom: Alan Hannah, RWE npower; Antony Johnson, National Grid Transco; David Porter, KEMA Ltd.; Frans Van Hulle, EWEA; Frederick Groeman, KEMA NV; G. Ramatharan, University of Manchester; Giles Stevens, Ofgem; Goran Strbac, Univeristy of Manchester; Guy Nicholson, Econnect; Graham Ault, University of Strathclyde; John Overton, DTI; Kees-Jan Van Oeveren, KEMA NV; Keith Bell, University of Strathclyde; Lewis Dale, National Grid Transco; Mike Hughes, University of Manchester; Nick Jenkins, University of Manchester; Olimpo Anaya-Lara, University of Manchester; Paul Gardner, Garrad Hassan; Phill Cartwright, AREVA T&D; Richard Hair, Eon Power Technology; Steve Argent, Ofgem; Tim Green, Imperial College London

6.1.3 Workshop Presentations

The following presentations are posted in full at www.ieawind.org on the Task 23 web pages:

- *RWE npower Susidiary Company*, Alan, UK
- *Electrical System Design for the Proposed 1GW Beatrice Offshore Wind Farm*, Graham Ault, University of Strathclyde, UK
- *Design and Operation of Power Systems with Large Amounts of Wind Power Production*, Bettina Lemström, VTT, Finland
- *Integration of Wind Power by DC-Power Systems*, Ola Carlson, Sweden
- *The Development of Grid Code Requirements for New and Renewable Forms of Generation in Great Britain*, Antony Johnson, National Grid, UK
- *Commercial and Regulatory Issues for Integrating Offshore Wind Farms*, Lewis Dale, National Grid, UK
- *Experiences with Offshore Windfarms*, John Eli Nielsen, Energinet, Denmark
- *Overview of offshore wind developments in the UK*, Paul Gardner, Garrad Hassan and Partners, UK
- *Grid integration of offshore wind power in The Netherlands*, Frederik Groeman, KEMA, the Netherlands
- *Scroby Sands*, Richard Hair, Eon, UK
- *Dynamic Performance of DFIGs and System Support*, Nick Jenkins, DTI, UK
- *Offshore Wind Energy Technology and Deployment*, Jørgen Lemming, Riso DTU, Denmark

- *Study on the Economics of the Offshore Grid for Connection of the Round Two Wind Farms*, Guy Nicholson, Econnect Ltd, UK
- *Workshop on Wind Integration of Offshore Wind Power*, John Overton, DTI, UK
- *Future Design and Control Strategies to Improve Integration of Large Wind Farms*, Poul Sørensen, Risoe, Denmark
- *The Regulator's Perspective*, Giles Stevens, ofgem, UK
- *Nysted Off-Shore Windfarm*, Jan Havsager, Elkraft System, UK
- *Horns Rev Offshore vindmøllepark*, Jesper R. Kristoffersen, Elsam, Denmark
- *Design of the Horns Rev Offshore Wind Farm*, Aksel Gruelund Sorensen, Eltra, Denmark
- *Predicting Offshore Windpower*, U. Focken, University of Oldenburg, Germany
- *UK Offshore Wind 2005*, Egon Poulsen, Vestas Northern Europe

6.2 Planning for Followup Activities

6.2.1 Introduction and Recommendations

At a planning meeting for grid issues at Risø on August 16, 2006, supplementary activities were discussed, and it was agreed to collect information on national projects within the five areas identified at the workshop in 2005.

Five issues or categories identified as important for work in electrical integration of offshore wind energy were reformulated slightly:

- Technical architectures and planning standards for offshore grid systems
- Grid codes for offshore wind grid systems
- Understanding offshore wind metrology and impact on electrical power fluctuations
- Connection and control system for large offshore wind farms
- Understanding transient behaviour of large cable installations

Based on the results of the Manchester grid connection workshop in 2005, and the discussions at the planning meeting, the Operating Agent drafted the following introductions and recommendations for each area for the coming workshops. The areas were addressed in workshops organized in 2007 and 2008, as described below.

6.2.2 Technical Architectures and Planning Standards for Offshore Grid Systems

For connection layouts that enable cost-effective and efficient control, operation and maintenance of offshore grids are fundamentally important. This part of the project should establish alternative architectures of offshore networks, including network topology, the appropriate voltage levels for connection, HVDC transmission technology, cable techniques, reactive power compensation schemes, and number and location of offshore and onshore substations.

The design and establishment of layout configurations should take into consideration power transfer levels, security margins, points for connection, and cable routes. Architectures within and between large wind farms in one area are important. Generic cases specific layout configurations form proposed wind farm developments should be examined.

Technical, economic, and environmental assessments should be conducted for the offshore network architectures identified. The capability and flexibility provided by each layout with regards to system operation and control, in normal and contingency situations, should be determined. The potential benefits including security and reliability performance provided by each layout, possibility for future expansion, environmental impact and associated technology requirements should be analysed. The impact of losses and requirements for reactive power compensation should be also considered in the overall assessment. The trade-offs between conflicting technical, economic and environmental objectives should be addressed directly.

Security and quality of supply standards for offshore networks are likely to be different to those for onshore networks for two main reasons: (1) unlike onshore networks, there are no demand customers connected to offshore networks and (2) wind, the primary energy source for shore grid-connected generators is intermittent. A comprehensive evaluation addressing both security and economic implications of alternative security standard options for offshore networks should be undertaken.

6.2.3 Grid Codes for Offshore Wind Grid Systems

Assessment of options for grid codes for offshore networks should be done. Consistency with onshore networks also should be examined. Particular emphasis should be on the need for reactive compensation and voltage control of offshore grids. Both steady state and dynamic aspects of voltage control should be examined. The point at which the compliance to grid code for offshore system should be tested should be a key aspect of this examination. In particular, fault-ride through requirements should be investigated in more details.

Costs and benefits of the needs to comply with various grid code requirements should be examined.

6.2.4 Understanding Offshore Wind Metrology and Impact on Electrical Power Fluctuations

The experience with the fluctuations in the electrical power from existing offshore wind farms have indicated that large-scale, offshore development will have a significant influence on regional power balancing and frequency control in the power systems. Experience from West Denmark has shown that wind power production variations are larger and faster offshore than onshore. An important reason for that difference is that a large capacity of wind power is concentrated in a small geographical area offshore, while the onshore turbines are distributed over a much larger area. Another reason for the difference could be the special meteorological conditions offshore. This work item should deal with and connect two major areas: (1) understanding offshore wind meteorology and (2) modelling of wind power fluctuations.

The idea of the first area is to involve wind meteorology specialists in an improvement of the understanding of offshore wind meteorology. The question is how the special meteorological conditions offshore influence on the wind fluctuations, and how this can be quantified theoretically and experimentally.

The second area should look into modelling of wind power fluctuations from large offshore wind farms. The validation of models based on real data from existing offshore wind farms should play an important role.

The suggested form is to organize topical meetings. The meetings should establish a forum where wind power meteorology researchers interact with power system researchers, with the aim to support development of models and analytical tools that are useful in power system planning and operation based on meteorological expertise. The actual deliverables (models and data) will be specified at the first meeting based on the identified expertise of the participating institutions.

6.2.5 Connection and Control System for Large Offshore Wind Farms

Large offshore wind farms should be comparable to power plants. Therefore, some grid codes require that the large wind farms can be controlled like other power plants. This involves contribution to the fast primary (automatic, local) control and slower secondary (manual or automatic, remote) control of power. Also reactive power and voltage control is required. Such control has been implemented in large wind farms (e.g., in Denmark and Spain. Besides, dynamic modelling of large controllable wind farms is ongoing, and these models provide useful tools to simulate the impact of controllable wind farms on a power system of parts of it), especially cases where the running capacity of conventional controllable power plants is reduced because wind power production is high are interesting.

In the future, several large offshore wind farms can be expected to feed into a single or a few grid points, which can cause additional loading of parts of the grid. It is therefore a special offshore-related issue how the controllability of the large wind farms can be used to support the integration of wind power.

The suggested form is to organize topical expert meetings on the controllability of large offshore wind farms and how this controllability can be used to support the integration. Also, here the actual deliverables (models and data) will be specified at the first meeting based on the identified expertise of the participating institutions.

6.3 Understanding Transient Behavior of Large Cable Installations

Large, offshore wind farms are likely to have lengths of extra high-voltage (EHV) cable not seen in any terrestrial installation. Given the high level of shunt capacitance of these very extensive high-voltage AC submarine transmission networks, the objective of this work is to investigate the major technical issues associated with non-50-Hz phenomena in high-voltage submarine transmission networks, including unusual conditions of faults, switching transients, and harmonics. This work should include an assessment of how these networks may be modelled and an assessment of alternative solutions.

In this task, typical offshore networks should be identified and modelling approaches that adequately represent their non-50 Hz behaviour should be investigated. The network representation should include the shunt reactors that will probably be required as well as the transformer and cable representations for transient behaviour. Modelling tools such as PSCAD/EMTDC and EMTP/RV will be evaluated for this purpose.

The performance of the networks during network switching should be investigated. There is anecdotal evidence that turbine transformer failures on wind farms may be associated with over-voltages from switching transients and phenomena of this type would be very damaging on very extensive EHV submarine cable circuits. The insulation co-ordination requirements of the offshore substations should be evaluated. In addition there is a requirement to define the duty that should be seen by the switchgear and other equipment. The effect of faults at various locations should be investigated and the transient behaviour of the network simulated.

The very large shunt capacitance of submarine cables, together with shunt reactors and transformers has the obvious possibility of forming resonant circuits at harmonic frequencies. This should be investigated and the potential for resonance identified. Mitigation measure including filters (active and passive) should be investigated.

6.3.1 Collaboration Projects

Also, at the working group meeting at Risø, the participants agreed to supply information about national projects that should be part of the collaboration. The collection of information was not finalized, but initial collected project data from UK, Denmark, and Sweden showed that many interesting member country projects could be included in the collaboration. The projects shared are listed below.

Table 2. Collaboration projects

Project title	Description	Period, value, effort, country
Handling sudden disconnection of a doubly-fed induction generator (DFIG) wind turbine cluster feeder and its reconnection	Design a model of a DFIG wind turbine with ride through system. Compare with measurements	2007–2008, 210,000$ 2½ person-year Sweden
Analysis of wind park high-frequency electrical transients	Model transients in offshore turbine and transmission system	2007–2008, 210,000$ 2½ person-year Sweden
DC/DC-converters in wind farms	Identify the most cost effective converter design, construct and test prototypes	2005–2007, 210,000$ 2½ person-year Sweden
Study development of the offshore grid for connection of Round II farms	Assessing costs of offshore connection of farms Thames Estuary, Greater Wash, and off coast North West of England	2004–2005, 65,000$ 5 person-month UK
Methodology to develop network design standards for offshore transmission networks	Economically efficient offshore networks are designed and proves to be very different to onshore cabling	2006, 260,000$ 20 person-month
Grid integration options for offshore wind farms	Analysis of offshore grid networks based on a cost-benefit methodology. Radial designs are suggested.	2006, 25,000$ 3 person-month UK
Grid codes for offshore grids	Investigate appropriate grid code requirements offshore, assess influences and needs for consistency with onshore networks	2007–2008,130,000$ 1½ person-year UK
Switching transients and harmonics in offshore networks	Investigate faults, switching transients, and harmonics from long lengths of EHV cable offshore	2008, 130,000$ 1½ person-year UK
Power fluctuations of large offshore wind farms	Development of simulation models for offshore wind farms as a planning tool for calculating the regulating power and ramp capability necessary in the grid system	2005–2007, 525,000$ 3 person-year DK
Meso scale meteorology	Provide improved predictability of short term power variations due to local wind speed variability (time and spatial scales 10-30 minutes and 2-20 km, respectively	2007–2010, 395,000$ 2½ person-year DK

6.4 Workshop 2 Grid Integration of Offshore Wind

Workshop/Round Table Discussion on Grid Integration of Offshore Wind, June 18 2007, DTI conference center, London, United Kingdom.

The workshop reviewed the technical options and the role of enabling technologies in achieving reliable design of offshore connections, including the development of offshore grids for collection and transport of significant amount of power to the shore and the integration with the onshore transmission network. A number of technical, commercial, and regulatory issues including license conditions, offshore security standards, transmission charges, grid code, connection, and use of system codes were discussed.

In order to facilitate the deployment of offshore wind generation satisfactory solutions to a number of technical, commercial, and regulatory issues associated with the connection and integration of this resource with the existing network infrastructure will be critically important. The purpose of the workshop is to discuss the key issues of grid integration of offshore wind identified by the corresponding sub-task of Task 23 of the IEA Wind R&D Implementing Agreement. Participation in the workshop will be by invitation of the appropriate country member of the IEA Wind Executive Committee and experts interested in this subject. Participants should also prepare for discussion on their experience or studies undertaken in relevant areas.

The design of offshore connections and power collection infrastructure, while recognizing the stochastic nature of wind power output, will be driven by a number of factors including the size of the resource area, location, and diversity between wind regimes in different locations. The workshop will review the technical options and the role of enabling technologies in achieving reliable design of offshore connections, including the development of offshore grids for collection and transport of significant amount of power to the shore and the integration with the onshore transmission network. Cost effective integration of offshore wind generation will require the development of systematic and consistent approaches to resolving a number of technical, commercial and regulatory, including license conditions, offshore security standards, transmission charges, grid code, connection and use of system codes, all of which will be included in the scope of the workshop.

As an indication of the issues to be discussed the following provisional programme has been prepared, but this will be subject to change and dependent upon responses received to this invitation to participate and submit contributions.

6.4.1 Conclusions

6.4.2 Discussion of Lessons Learned from Existing Large Offshore Wind Farms

Faults in Offshore Grid:

- In the UK, distributed generation connected to the transmission system must have fault ride through capability, while generation connected to distribution system should trip (shut down). The Denmark Grid Code specifies an impedance for offshore transmission in order to ensure fault ride through capability. However, in the UK such impedance is not defined.

A generic test that will enable testing and certifying in the factory is an option for dealing with this issue.

- Loss of 20–30 MW from wind farm, will cause some losses in revenues but certainly does not collapse a whole system

Offshore Network Layout:

- Layout of network? Any other than radial?
- Some experience with open points in AREVA
- Radial solution is the cheapest solution for the developers and they do not have a time for new options

Wind Turbines Models:

- Models should be verified by the utilities
- Verification of dynamic wind turbines model, set up a benchmarking models for wind turbines model
- Proposal for a standardization of the models
- Spain is active in verifying of dynamic models; there are 32 tests at place but there is not international agreement for that
- Some commercial benchmarking models are available
- What is the real problem is that the producers are not open in terms of wind turbines models
- National Grid, NGT does not accept “black box” in terms of wind turbines models. Therefore, situation in UK is changing, detail models are required to be submitted. They are confidential and still intellectual property of producers of wind turbines.

Discussion of Technical Issues for Offshore Integration:

- Comparison of SVC and STATCOM characteristics. The capability of the STATCOM to operate at low voltage allows it to contribute to the low voltage ride thought requirement
- UK has adopted regulator approach for offshore transmission networks. NGT will be offshore transmission operator (TO). Owners of offshore transmission networks can be someone else and they will apply on competition tender.
- Danish network. Voltage control. Always three units of 8 MW should be running. Small units always running due to market. The Danish TO should buy some power from big units to keep system stable.

Cost-Benefit Analyses:

- Cost-benefit analyses in UK is driven by legislation
- One of the key aspects of cost-benefit analyses is compensation regime. Currently, onshore generators pay penalties if they do not deliver the required amount of power.
- Data for cost-benefit analysis are obtained in consultation with manufacturers and literature. Sensitivity analyses around input data, for failure rate, mean time to repair, and cost of energy were carried out. Conclusions are very robust

- Capitalization of cost of losses in UK is very high, £300/kW. If ROC's is added it will increase. The ownership boundaries are not taken into account in allocation of cost of losses.
- Cost-benefit analysis has looked at social perspective and macroeconomics. Results of cost-benefit analyses give a central planning view and interested parties should try to find very best solution from this starting point
- Proposed UK offshore grid code does not to specify fix impedance, simply because this value is unlikely to be applicable to all offshore transmission systems.
- Metering point is not taken into account in cost benefit analysis, as it does not change the benefit to society.
- Cost-benefit reports are on DTI website.

HVDC solutions:

- There was an improvement in the losses in HVDC VSC technology, and there is a potential to reduce it further. It has been stressed out modularity of HVDC VSC solutions and extensibility to carry power from long distances to a shore connection point. Possibility that environmental issues will drive transmission networks towards DC solutions, as generally they require smaller number of cables. Fault on onshore will increase voltage on offshore.
- Comment about interesting solution from Ecofys, close cables, no magnetic field, not appropriate for long distances as capacitance of 400-kV cables are still high. This is very new project as it is started in May and full analysis is not available yet.
- It was queried an availability of models, especially transformers, to do coordination of isolation.
- Floating turbines. It has been queried has a cost benefit analysis been carried out.

6.4.3 Discussion of Commercial and Regulatory Issues for Integrating Offshore Wind Farms

UK Regulatory Issues:

- From the beginning, regulators have to protect the customers, then facilitate renewable sources.
- Which part of the cost will be transfer to the system of use charges?
- Are standards enough or maybe organization like CIGRE/CIRED is necessary to share the knowledge?
- Does regulator support "socket" arrangements?
- How the panel has been formed as there is no enough qualified personnel? Ofgem is seen as an option.
- Lead time for transformers and cables are in order of 24 months. In one build season at around 60 turbines can be erected offshore

6.4.4 Workshop Participants

Denmark: Jan Havsager, Energinet; Jorgen Lemming, Risø

Germany: Karstem Burges, Ecofys Germany

The Netherlands: Chris Westra, We2sea

Norway: John Olav Tande, Sintef

Sweden: Lars Stendius, ABB; Michael Lindgren, Vattenfall; Ola Carlson, Chalmers, Urban Axelsson, Vattenfall

United Kingdom: Biljana Stojkovska, Imperial College; Bridget Morgan, Ofgem; Georgia Richards, DTI; Giles Stevens, Ofgem; Goran Strbac, Imperial College; Ham Hamzah, RWE; Joe Duddy, Renewable Energy Systems; John Overton, DTI; Laura Jeffs, Centrica Energy; Lewis Dale, National Grid; Liangzhong Yao, Areva; Masoud Bazargan, Areva; Matthew Knight, Siemens; Nasser Tleis, National Grid; Nick Jenkins, University of Manchester; Norman Macloed, Areva; Olimpo Anaya-Lara, University of Strachlyde; Paul Newton, EON; Peter Jones, ABB; Phil Baker, DTI; Predrag Djapic, Imperial College; Richard Cooke, Areva; Richard Hair, EON; Robert Longden, Airtricity; Sara White, Econnect

6.4.5 Workshop Presentations

The following presentations are posted in full at www.ieawind.org on the Task 23 web pages:

- *Background to Annex XXIII, The Importance of the Topic and the Expected Outcomes*
- *Key Issues of Integrating Offshore Wind: Overview of the Technical, Economic and Regulatory Issues*, Giles Stevens, Ofgem, UK

Lessons learned from existing large offshore wind farms:

- *Critical Assessment of Connection Solutions, Technical Performance, Grid Codes, Impact on the Grid Operation*, Sara White, Ecconect, UK
- *Experience on Technical Solutions for Grid Integration of Offshore Windfarms*, Liangzhong Yao, Areva, UK

Technical issues for offshore integration:

- *Overview of the Technical Issues of Connecting Wind Farms to the Grid*, Norman McLeod, Areva
- *Design Standards for Offshore Transmission Networks And Options For Round II*, G Strbac, Centre for DG&SEE, UK
- *The Development of the GB Grid Code For The New Offshore Regime*, Nasser Tleis, NG, UK
- *Danish Grid Connection Code for Offshore Installations*, Jan Havsager, Energinet, Denmark
- *Technology Options for Connecting Offshore Wind Farms*, Lars Stendius, ABB, Sweden

Technical issues for offshore integration:

- *Isolation Coordination of the Electrical System of Wind Farms,* Michel Lindgren, Vattenfall
- *Wind Farm Modelling,* Ola Carlson, Chalmers, Sweden
- *AC Based Options for Connecting of Offshore Wind Farms,* Karsten Burges, Ecofys
- *Grid Connection of Deep Sea Wind Farms - Options and Challenges,* John Olav Tande, Sintef, Norway

Commercial and regulatory issues for integrating offshore wind farms:

- *Grid Integration of Offshore Wind*, Bridget Morgan, Ofgem, UK
- *Issues for Transmission Network Operators*, Lewis Dale, NG, UK
- *Commercial and Regulatory Issues for Developers*, Ham Hamzah, RWE, UK
- *Ensuring Suitable Solution for Offshore Wind Farms, Commercial Risk for the Supply Chain,* Richard Cooke, Areva, UK

6.5 Workshop 3 Power Fluctuations from Offshore Wind Farms

Power Fluctuations from Offshore Wind Farms, Risø DTU Roskilde, February 26, 2009.

This workshop dealt with measurements, modeling, prediction, and validation of power fluctuations from large offshore wind farms, and the impact that these fluctuations have on power system operation and control. Experience with the first large offshore wind farms indicate that power fluctuations in a time scale from minutes to a few hours can become quite substantial with large offshore wind farms. An example of this is the experience of the Danish transmission system operator, Energinet.dk, with the operation of the West Danish power system after commissioning of the first large 160 MW offshore wind farm in this system, Horns Rev.

These observations, combined with ambiguous plans for further development with large offshore wind plants, particularly in Europe, have initiated an increased interest in modeling and validation of wind power fluctuations, and for possible ways to mitigate the impact of such fluctuations. An important aspect of the modeling is the effect that the concentration of the wind power in relatively small areas has on the smoothing of the power fluctuations from a large number of wind turbines. Another relevant aspect is the difference in offshore and onshore climate, and the impact that this has on the wind variability. Finally, there is an interesting link to the impact of wakes on power fluctuations when wind direction and thus wakes are changing.

The increased variability of the wind power following with large offshore wind farms will also have an impact on the predictability of wind power. On one hand, increased variability is likely to make the predictions less accurate, but on the other hand, an extensive offshore wind power development will provide much more comprehensive information about the wind conditions, which can support better predictions. Presentations within the following areas were welcomed at the workshop:

- Modeling of wind power fluctuations
- Wind speed and wind power measurements on large offshore locations

- Prediction of wind power from large offshore wind farms
- Impact of power fluctuations on power system operation and control

The workshop was attended by 47 experts from 9 countries.

6.5.1 Conclusions

The workshop dealt with the following topics:

- Modelling of wind power fluctuations. Poul Sørensen and Nicolaos Cutululis (Risø DTU, DK) presented model and validation of Risø Wind Power Time Series (WPTS) simulation model. Øyvind Byrkjedal presented Vindteknikk (NO) presented meso scale modelling and verification of variation in wind power production for the North Sea, using Offshore WRF simulations. Jan Dobschinsky, (ISET e.V, DE) presented a model for the reduction of wind power variability by aggregation of wind farms.
- Wind speed and wind power measurements on large offshore locations. Claire Vincent, (Risø DTU, DK) presented analysis of variable wind speeds at Horns Rev offshore wind farm in Denmark. Antonio Vigueras Rodríguez (University of Castilla-La Mancha, Spain) presented a comparison of power fluctuations from land sites in Spain to offshore sites in Denmark.
- Prediction of wind power from large offshore wind farms. Arno J. Brand (ECN, NO) presented studies of forecasting wind power in Dutch Offshore Wind Farm Egmond aan Zee. Caroline Draxl, (Risø DTU, DK) presented plans for her PhD study on new data assimilation techniques for short-term wind energy forecast models with a rapid update cycle. Pierre Pinson, (DTU IMM, DK) presented regime switching models for prediction of wind power fluctuations, based on measurements on Danish offshore wind farms.
- Impact of power fluctuations on power system operation and control. Ola Carlson (Chalmers, SE) presented design and control issues concerning wind farms with internal DC grids. Poul Sørensen (Risø DTU, DK) presented the effect of geographical spreading on wind power shut down during a storm passage. Michael Brower (AWS, USA) presented the Eastern Wind Integration and Transmission Study (EWITS)

6.5.2 Workshop Participants

Denmark: Ole Rathmann, Risø-DTU; Jørn Scharling Holm, DONG Energy Power; Nina Le, DONG Energy; Ioannis Antoniou, Siemens Wind Power; Jochen Cleve, Siemens Wind Power; Hasan Ghulmi Hanany, DONG; Sten Frandsen, Risø DTU; Jørgen Lemming, Risø DTU; Poul Sørensen, Risø DTU; Gunner Larsen, Risø DTU; Helge Aagaard Madsen, Risø DTU; Niels Troldborg, Risø, DTU; Robert Mikkelsen, DTU; Christian Leegaard Thomsen, Vestas Offshore A/S; Pierre-Elouan Rethore, Risø DTU; Laust Olsen , Siemens Windpower; Nikolay Dimitrov, Siemens Windpower; Claire Vincent, Risø DTU; Pierre Pinson, DTU IMM; Caroline Draxl, Risø DTU; Nicolaos Cutululis, Risø DTU; Nick Allen Johansen, Risø DTU; Francois Anton, DTU IMM; Pierre-Julien Trombe, DTU IMM

Germany: Clarissa Belloni, GE Global Research; Wolfgang Schlez, Garrad Hassan; Jan Dobschinski, ISET; Juan José Trujillo, University of Stuttgart

Greece: Evangelos S. Politis, CRES

The Netherlands: Gerard Schepers, ECN; Benjamin Sanderse, ECN; Brand, A.J. (Arno) ECN

Norway: Georgio Crasto, WindSim; Øyvind Kristiansen, Statkraft Development; Øyvind Byrkjedal,Kjeller Vindteknikk; Finn Nyhammer, Kjeller Vindteknikk; Elly Karlsen Statoil/Hydro

Spain: ntonio Vigueras Rodríguez, University of Castilla-La Mancha; Daniel Cabezon Martinez, CENER

Sweden: Ola Carlson, Electric Power Engineering, Gøteborg; den Jan-Åke Dahlberg, Vattenfall Vindkraft AB

United Kingdom: Gerd Habenicht, Renewable Energy Systems Ltd.; Andy Poon, Renewable Energy; Brian Gribben, Frazer-Nash Consultancy; Charlotte Higgins, TNEI Services Ltd

United States: Rebecca Barthelmie, Indiana University; Pat Moriarty, NREL; Michael Brower, AWS.

6.5.3 Workshop Presentations

The following presentations are posted at www.ieawind.org at the Task 23 web pages:

Modeling of wind power fluctuations:

- *WPTS – Wind Power Time Series simulation model,* Poul Sørensen, Risø DTU, Denmark
- *Validation of power fluctuation simulation model,* Nicolaos Cutululis, Risø DTU, Denmark
- *Power Fluctuations,* Arno Brand, ECN, the Netherlands

Wind speed and wind power measurements on large offshore locations:

- *Claire Vincent, Risø DTU: Favourable meteorological conditions for severely variable wind speeds at Horns Rev"*
- *Antonio Vigueras Rodríguez, University of Castilla-La Mancha, Spain: Comparison of power fluctuations from offshore and offshore*

Future projects:

- *Jørgen Lemming, Risø DTU: Offshore wind power development in Denmark*
- *Oyvind Kristiansen, Statkraft: Statkrafts Wind Power plans*

Prediction of wind power from large offshore wind farms:

- *Pierre Pinson, DTU IMM: Regime switching models for prediction of wind power fluctuations*
- *Caroline Draxl, Risø DTU: New data assimilation techniques for short-term wind energy forecast models with a rapid update cycle*

Impact of power fluctuations on power system operation and control:

- *Ola Carlson, Chalmers: Offshore grids and wind power control (to be confirmed)*
- *Øyvind Byrkjedal, Vindteknikk: Offshore WRF simulations: geographical variation in wind power production for the North Sea"*
- *Jan Dobschinsky, ISET e.V.: Reduction of Wind Power Variability by Aggregation of Wind Farms to Large Interconnected Offshore Grids*
- *Poul Sørensen: The effect of geographical spreading on wind power fluctuations*

7 External Conditions

The purpose of the workshops in Research Area External Conditions, Layouts, and Design of Offshore Wind Farms was to explore the key issues and highlight the topics related to the following areas:

- Exchange, validate, and evaluate wind resource data and wind maps specific to regions with high potential for wind development.
- Share databases and innovations to enhance measurement accuracy of marine buoys pertaining to long-term sea-state and MET-Ocean data.
- Exchange technical information of wave loading prediction methods and validation experience of wave loading on wind turbine structures.
- Share experience with long-term measurement techniques and instrumentation at offshore stations.
- Evaluate various turbine array configurations in large, closely spaced farms and examine critical parameters such as mutual shadow wake effects, affect on energy production, fatigue, and ultimate loading.
- Exchange technical experience with offshore forecasting to predict wind plant output.
- Each of these research areas will be narrowed in scope after a discussion to identify appropriate areas for collaboration among Task participants.

The programs, summaries, and all the presentations are posted in full at www.ieawind.org on the Task 23 web pages.

7.1 Workshop 1 Layouts and Design of Offshore Wind Farms

Workshop Programme on External Conditions, Layouts, and Design of Offshore Wind Farms
Risoe, Denmark, 12-13 December 2005.

The purpose of the workshop was to identify key issues and highlight the topics related to External Conditions of Offshore Wind Farms. Current experience with some of the existing offshore wind installations have provided valuable knowledge on some issues and provided a review of lessons learned so far. Nearly 30 experts from 9 countries participated in the workshop and gave presentations on studies they already have undertaken. These presentations, listed in section 4.1.3 below, can be viewed at www.ieawind.org Task 23 web pages.

7.1.1 Conclusions

Four presentations were made on the exchange, validation, and evaluation of wind resource data and wind maps specific to regions with high potential for wind development. They concluded that public access to measurements (e.g., turbine power output, meteorological masts, buoys) is important, especially for model validation. They stated that measurements of wind at different levels are needed as are temperature measurements. Determining wake effects is currently the most important challenge in wind engineering. Emphasis should be put into observing and understanding winds 50 m and higher above the surface. Apparently, the logarithmic wind profile is invalid at these heights, even with neutral conditions. Well-defined targets should be set for the accuracy of measurements and model predictions. Wind energy developers are interested in accuracies of approximately 2%. On the other hand, masts will always be available in large-scale wind energy projects because the cost of a mast is relatively small compared to the entire wind farm budget. Developers are also interested in the additional information provided by atmospheric models and remote sensing techniques (for example), even at a lower accuracy than the nominal.

Four presentations were made on sharing databases and innovations to enhance measurement accuracy of marine buoys pertaining to long-term sea-state and MET-Ocean data. They urged development of remote sensing devices, standardization and calibration, best practices and use of databases with models, etc.

Four presentations were made on the exchange of technical data on wave loading prediction methods and validation experience of wave loading on wind turbine structures. They concluded that there are problems with wave models in shallow water. The maximum waves are more affected by water depth than by significant wave height. An unexpectedly low correlation has been observed between wind data and wave height. Wave spreading and especially misalignment between wind and wave directions needs further investigation and water level transients and coastal currents should be included in models. Slamming and forces from breaking waves and likelihood of breakers at or in the vicinity of the wave-power foundations must be assessed both in deep waters and in shallower water. There is a risk of just taking over guidelines and rules from the (oil) offshore industry (e.g., in offshore guidelines alignment of waves, wind, and current is assumed to be a conservative design case, while for wind power the worst case for vibrations is when wind and wave directions are perpendicular). Run up on foundations should be investigated. Hind cast models are not accurate but 15 years of hind cast is better than one year of measurements, except perhaps in very complicated topography.

Four presentations were made on sharing experience with measurement techniques and instrumentation at offshore stations and developers’ experiences from offshore areas. They concluded that from the developer point of view there was a need for better design parameters, more R&D, data etc.

Seven presentations were made on layout, array, and wake effects (energy production, fatigue, and ultimate loading within wind farms, mutual shadow effects of large, closely-spaced farms). They emphasized the need to evaluate changes in extreme and fatigue loading when moving offshore. It was noted that fatigue increase 10–15% and also that the extremes during normal operation increases but with less than the fatigue. Also, the co-directionality of wake direction and wave direction can be expected to be of some importance. Statistics on array efficiency from Horns Rev shows possible effects at corners of the wind farms. Data with which to validate models were mentioned again, and work is needed to cover the gap of the joint probabilities of things like wind and waves in the new IEC-3 standard. Many interesting wake modeling activities are going on and wake modeling is probably one of the most important issues (also offshore). It was concluded that a “wake benchmarking” including issues like wind resources, relationship between wind and waves, wake, wake loads and energy could be of interest. A status of the issues pointing to a kind of best practice was suggested.

During the session to develop final conclusions, it was decided to focus Subtask 1 on the following three subjects, on which separate work programs will be drafted:

1. Wake modeling and benchmarking of models
    - First Step: Workshop on status of existing works
    - Second Step: Workshop on evaluating the quality of models and results

2. Marine boundary layer characteristics
    - The marine boundary layer is defined here as the lowest ~1 km of the atmosphere between the height of the geostrophic wind speed and the wave surface of the ocean
    - The role of the sub-task could be:
        - To review current experience particularly with regard to developing wind farms in coastal areas (~50 km from the coast)
        - To assess the reliability of remote sensing methods offshore including satellite observations, sodar and lidar where the aim is to observe wind and turbulence profiles at 100 m and above and to include tall mast measurements where available
        - To assess the accuracy of model predictions including local scale, mesoscale, and LES models as available

3. Met-ocean data and loads
    - To be formulated by a working group

7.1.2 Workshop Participants

Denmark: Helge Gravesen, Carl Bro; Leo Enrico Jensen, Elsam; Knud Erik Thomsen, Vestas; John D. Nielsen, AU; Rebecca Barthelmie, Merete Bruun Christiansen, Jake Badger, Morten Nielsen, Kenneth Thomsen, Hans Chr. Jørgensen, Niels Jacob Johansen, Sten Frandsen, Lars Landberg, Jørgen Lemming Risø.

Germany: Martin Küehn, Juan José Trujillo, SWE Stuttgart; Matthias Tuerk, Forschungszentrum Karlsruhe; Tom Neumann, DEWI; Werner Zielke, Kim Mittendorf, University of Hannover.

Italy: Anna Maria Sempreviva, ISAC-CNR.

Korea: C. Y. Son, INHA, South Korea.

The Netherlands: Gerard Schepers, ECN; Jan Coelingh, Ecofys.

Sweden: Lars Bergdahl, Jenny Trumars, Chalmers; Robert Kapper, Vattenfall.

United Kingdom: Joseph Phillips, Garrad Hassan.

United States: Walt Musial, NREL; Chris Elkinton, University of Massachusetts at Amherst.

7.1.3 Workshop Presentations

The following presentations from workshop on external conditions, layouts, and design of offshore wind farms, December 12–13, 2005, posted at www.ieawind.org Task 23 web pages:

- *Risø National Laboratory*, Jørgen Lemming, Risø, Denmark
- *Introduction to Annex XXIII, Offshore Wind Energy Technology and Deployment*, Jørgen Lemming, Operating Agent, Denmark
- *Satellite Imaging Techniques Applied For Offshore Wind Resource and Wake Loss Assessment – What Can Be Done And Where Are The Problems?* , Merete Bruun Christiansen, Risø, Denmark
- *The Mediterranean Wind Climate Using Models and Satellite Data and Comparison with Available Buoy Measurements*, Anna Maria Sempreviva, ISAC-CNR, Italy
- *Why Is Atmospheric Stratification More Important Offshore Than Onshore And Where Are The Potential Problems?,* Rebecca Barthelmie, Risø, Denmark
- *Mesoscale Modelling For Offshore Wind Farms*, Jake Badger, Risø, Denmark
- *Summary of Offshore Wind Characterization Research in the U.S.*, Walter Musial, NREL, United States
- *Offshore Wind- and Turbulence-Profiles from the FINO1-Mast,* Matthias Türk, IMK-IFU - Forschungszentrum Karlsruhe GmbH, Germany
- *Remote Sensing In Offshore Wind Climatology– LIDAR/SODAR Techniques,* Hans Jørgensen, Risø, Denmark
- *How Can Project Developers Predict Wind-Related External Conditions? ,* Morten Nielsen, Risø, Denmark
- *Wave Predictions in Baltic Coastal Waters*, Lars Bergdahl, Chalmers University of Technology, Sweden
- *The Effect of Wave Modelling On the Calculation of Fatigue Loads*, Jenny Trumars, Chalmers University of Technology, Sweden
- *Accuracy in Wind Loads, Wind and Wave Forces*, Helge Graversen, Carl Bro Intelligent Solutions
- *Aspects of determine the design parameters and Design Loads for OWECS*, Werner Zielke, Kim Mittendorf, ISEB, University of Hanover, Germany
- *Offshore Wind design Parameters (OWID)*, Tom Neuman, DEWI, Germany
- *Reducing Energy Uncertainty throughout Offshore Wind Farm Development*, Joe Phillips, Garrard Hassan, United Kingdom
- *Vattenfall Wind Experience and Foreseen Need of R&D In The Future*, Robert Kapper, Vattenfall, Sweden
- *Risk Management, Stochastic Analyses of Constructions,* John D. Sorensen, Aalborg University, Denmark
- *Structural Loads From Wakes – What Are The Potential Problems Offshore?* , Sten Frandsen, Risø, Denmark
- *Wake Losses and Turbulence within the Horns Rev Off-Shore Wind Farm*, Leo E. Jensen, Elsam, Sweden
- *Dynamic Wake Model for Aeroelastic Simulation of Fatigue and Extreme Loads*, Kenneth Thomsen, Risø, Denmark

- *Wake Measurements in The 2x 2.5 MW Wind Farm ECN Wind Turbine Test Park, Wieringermeer – EWTW*, Gerard Schepers, ECN, the Netherlands
- *Using the Cost of Energy to Analyze and Optimize the Layout Of Offshore Wind Farms,* Chris Elkinton, University of Massachusetts at Amherst, United States
- *Influence Of Near Wake Modeling On Prediction of Energy Yield and Dynamic Loading In Wind Farms,* Juan-José Trujillo, University of Stuttgart, SWE, Germany
- *Description Of The Load Cases In IEC61400-3 And Identification Of Difficulties And Pitfalls In Relation To Assessment Of External Conditions*, Niels-Jacob Tarp-Johansen, Risø, Denmark

7.2 Workshop 2: Wake Modeling and Benchmarking

Workshop on Wake Modelling and Benchmarking Of Models, Billund, Denmark, September 7–9, 2006.

In large wind farms with standard layout, wake losses are expected to be 10–20% of total power output and wake generated turbulence significantly exceeds ambient turbulence which is critical for design loads. There is therefore considerable interest in accurately modelling wakes prior to wind farm construction to optimize wind farm layouts and for examining wakes during wind farm operation in order to evaluate optimal control strategies.

Current wake models were mainly developed during the 1980s when the main issues related to single or double wake situations on land. Higher levels of turbulence over land at the small number of turbines meant that wake generated turbulence was rarely dominant and unlikely to impact the structure of the over-lying boundary layer. Evaluation of state of the art wake models in the EU ENDOW project indicated large differences between the models, and between models and measurements even for single wake situations. Best agreement was at moderate wind speeds and levels of turbulence. Models of wake-generated turbulence generally give good overall agreement for average turbulence levels in small wind farms, even offshore, but predicting extreme loads is also subject to large uncertainty. It is characteristic that most of these early models are dedicated models that focus on either power losses or the increased turbulence driven fatigue loading, and furthermore that the output from these is statistical mean values of wind speed and/or turbulence intensities.

Recently, a consistent unifying model for computation of both instantaneous power reduction and increased turbulence loading in wake situations has been developed and subsequently implemented in an integrated model complex for performing aeroelastic simulations of a wind turbine subjected to wake conditions. The model is based on a detailed stochastic description of the wake deficit meandering phenomenon as well as of the wake deficit expansion described in the moving frame of reference, and besides load and power prediction it has an obvious potential for application in optimisation of wind farm topology, wind farm operation, and advanced control strategies, respectively. Preliminary verification of the model has shown promising results, both concerning the basic physical mechanism, partial wake loading, and extreme loading.

In addition to multiple wakes, a major issue for wake model evaluation and development of new wind farm models that can simulate both turbine wake interactions and feedbacks to and from the boundary layer is that turbine hub-heights are now close to 100 m at a level which is less well understood than the near-surface layer. This is particularly true for marine and complex coastal environments but also in complex terrain. Measuring wakes accurately at these heights presents a new challenge. There has also been a general problem for modellers to access wind farm data in order to better understand how models should be modified for multiple wake situations.

These issues were discussed in some detail at the workshop, and we anticipate that many state-of-the-art models will be presented and discussed in terms of how they simulate both fatigue and extreme loading in addition to power loss prediction. Since a number of major national and international projects are underway to calibrate and develop new models the workshop will be a good occasion for both modellers and experimentalist to meet and discuss issues relating to model benchmarking. This IEA Annex represents a unique opportunity for both communities to participate in a model benchmarking exercise, which will be a major player in developing and evaluating the next generation of wind farm models for use in optimising layouts of large wind farms in complex terrain and offshore.

7.2.1 Conclusions

In large wind farms with standard layout, wake losses are expected to be 10–20% of total power output and wake generated turbulence significantly exceeds ambient turbulence, which is critical for design loads. There is therefore considerable interest in accurately modelling wakes prior to wind farm construction to optimize wind farm layouts and for examining wakes during wind farm operation in order to evaluate optimal control strategies. Wake models developed during the 1980s were mainly related to onshore single or double wake situations.

Evaluations of state of the art for wake models have indicated large differences between the models and also between models and experiments. Also, there exist theoretical and experimental evidence of significant differences from onshore to offshore conditions. These divergences were evident from the contributions and discussions at the wake workshop where 27 participants representing the scientific world, manufacturers, developers, and power companies met to review the knowledge of today and to look for possibilities for improvement of models by comparing the models in a future benchmarking process.

A variety of modelling efforts were presented at the workshop, including analyses of data not least from the two large demonstration wind farms in Denmark, Horns Rev, and Nysted. The modelling efforts range from CFD studies of the wake flow structure and Ainslie-type wake modelling for wind speed deficit to simpler but extensive modelling of complete wind farms and their interaction with the atmosphere. The aim of such research spans from pure research to the development of engineering tools for determination of array efficiency and structural loads.

These and many other interesting results on structural loading and wind farm layout as separate subjects were presented before the final discussion on benchmarking of wake models. The theoretical and experimental results indicated differences in results from modelling and in the interpretation of measuring data from offshore wind farms, in particular data from the Horns Rev and Middelgrunden wind farms.

The presentations and the discussions indicated a great need for further collaboration and exchange of data in order to develop and verify computational models and to understand the physics of wakes and meteorological backgrounds.

The EU R&D project UPWIND includes similar activities to the ones discussed at the workshop and coordination is suggested to take place between the members of IEA Task 23 and partners of UPWIND.

In conclusion it was agreed to prepare a format for collecting and benchmarking data related to offshore wind farms and onshore farms in cases when it is considered relevant. The format will be suggested to the participants in the workshop and member countries of Task 23. The collaboration will be focussed on data, which are important for power calculations as well as design loads. Within the next year the benchmarking experience and the results obtained from the continued collaboration also with UPWIND will be analysed and discussed at a second workshop.

7.2.2 Workshop Participants

Denmark: Rebecca Barthelmie, University of Edinburgh/Risø; Ole Rathmann, Risø National Laboratory; Sten Frandsen, Risø; Jens Nørkær Sørensen, DTU; Kenneth Thomsen, Risø; Gunner C Larsen, Risø; Raymond Downey, Elsam Engineering A/S (part of DONG Energy)Volker Riedel, DEWI

Germany: Juan-José Trujillo, University of Stuttgart

The Netherlands: Sander van der Pijl, ECN

Spain: Daniel Cabezon Martinez, CENER

United Kingdom: Joe Phillips, Garrad Hassan; Peder Enevoldsen, Siemens Wind Power A/S

United States: Patrick Moriarty, NREL; Douwe Renkema, GE Infrastructure; Mike Carter, npower renewables

7.2.3 Workshop Presentations

The following presentations are posted at www.ieawind.org on the Task 23 web pages:

- *Workshop Introduction*, Sten Frandsen, Risø, Denmark
- *Wake meandering – a pragmatic approach*, Gunner C Larsen, Risø, Denmark
- *Aeroelastic Simulations With The New Wake Meandering Model*, Kenneth Thomsen, Risø National Laboratory
- *Modeling Wind Farm Interactions Using CFD*, Patrick Moriarty, NREL
- *Simulation And Modelling Of Turbulence In Wind Farms*, Jens Nørkær Sørensen, DTU
- *CFD Calculations For Wake Effects In An Offshore Wind Farm (OWID)*, Volker Riedel, DEWI
- *Analysis Of Array Efficiency At Horns Rev And The Effect Of Atmospheric Stability*, Raymond Downey, Elsam Engineering A/S (part of DONG Energy)
- *Wind Farm Layout Optimization And Benchmarking Of Models*, Mike Carter, npower renewables

- *Validation And Development Of Wake Models For Array Efficiency Prediction In Large Wind Farms*, Joe Phillips, Garrad Hassan, UK
- *Modelling Of Wind Speed Deficit In Large Wind Farms*, Sten Frandsen, Risø, Denmark
- *Implementation Of A Turbine Wake Model For Wind Resource Software,* Ole Rathmann, Risø, Denmark
- *Wake Model Verification Using Data From Danish Wind Farms*, Rebecca Barthelmie, University of Edinburgh/Risø, Denmark
- *Wind Farm Simulation For Power Surveillance And Development For Loading Calculation*, Juan-José Trujillo, University of Stuttgart, Germany
- *Improvements of the WAKEFARM Wake Model*, Sander van der Pijl, ECN, the Netherlands
- *Wake Modelling And Validationvalidation Calculations*, Douwe Renkema, GE Infrastructure
- *Wake Model Development And Verification Using Siemens Offshore Wind Farm Projects*, Peder Enevoldsen, Siemens Wind Power A/S, Germany
- *Modelling Wake Effects Using Two CFD Techniques*, Daniel Cabezon Martinez, CENER, Spain
- *Wake Model Benchmarking*, Rebecca Barthelmie, University of Edinburgh/Risø, Denmark

7.3 Workshop 3: Wake Effects

IEA Task 23 Offshore Wind Energy Technology and Deployment – Workshop on Wake Effects, February 25, 2009, Risø DTU, Roskilde, Denmark.

The technical/scientific societies working with wind turbine wake effects on energy production and structural loading rarely interact with those studying the effect of wakes on (electrical) power prediction and quality. Workshops on these two topics were held adjacent to each other to provide an opportunity to meet and discuss with colleagues.

The first offshore wind turbine installations were made around 1990 with the purpose of demonstrating the practical feasibility, surveying the problems attached to offshore wind farming and to compile experimental evidence on various effects related to the clustering of the wind turbines. Already at that time the expectations regarding the future of offshore wind power were large, but more than a decade should pass before larger offshore wind farms were realized.

From experience—both onshore and offshore—it has become clear that existing engineering software tools for determining the array efficiency of large wind farms are too optimistic. In addition to the present deficiencies of existing engineering methods, these do in reality not take into account the effect of neighboring wind farms, poetically expressed as cases on wind theft.

Many offshore wind farms are under construction or planning and with the present political pro-renewable-energy climate, large areas of the North Sea could be clustered with wind turbines over the next one to two decades. Thus, the need for a new and more accurate generation of models for wind farm efficiency is more eminent than ever.

Also, the structural loading resulting from wake effects is an important wind turbine design driver and both structural loading and wind farm array efficiency should be discussed at the workshop.

Presentations within the following areas were invited for the workshop:

- single- and multiple-wake of wind turbines
- small and large clusters of wind turbines
- intermediate-scale and meso-scale modeling of wind farms

Both results from modeling efforts and experimental evidence were welcome.

7.3.1 Conclusions

As hope for, all scales and aspects of the wake issue were covered by a total of 16 interesting presentations, most followed by lively discussions. For day 1, the primary observations made by the organizers of the workshop:

- With the increasing rate of wind farm build up—not least offshore—the wake issue has become also a key issue/problem in the commercial part of the wind energy sector
- This is reflected in the increasing R&D activity, which in turn is seem (e.g., by the considerable interest in the present workshop)
- There are surprisingly many open ends in the science of modeling wakes, considering the significant effort invested in this problem over the resent three to four decades. Progress is made, but the engineering models are still too uncertain relative to the commercial needs

7.3.2 Workshop Participants

Denmark: Ole Rathmann, Risø-DTU; Jørn Scharling Holm, DONG Energy Power; Nina Le, DONG Energy; Ioannis Antoniou, Siemens Wind Power; Jochen Cleve, Siemens Wind Power; Hasan Ghulmi Hanany, DONG; Sten Frandsen, Risø DTU; Jørgen Lemming, Risø DTU; Poul Sørensen, Risø DTU; Gunner Larsen, Risø DTU; Helge Aagaard Madsen, Risø DTU; Niels Troldborg, Risø, DTU; Robert Mikkelsen, DTU; Christian Leegaard Thomsen, Vestas Offshore A/S; Pierre-Elouan Rethore, Risø DTU; Laust Olsen , Siemens Windpower; Nikolay Dimitrov, Siemens Windpower; Claire Vincent, Risø DTU; Pierre Pinson, DTU IMM; Caroline Draxl, Risø DTU; Nicolaos Cutululis, Risø DTU; Nick Allen Johansen, Risø DTU; Pierre-Julien Trombe, DTU IMM.

Germany: Clarissa Belloni, GE Global Research; Jan Dobschinski, ISET; Juan José Trujillo, University of Stuttgart.

Greece: Evangelos S. Politis, CRES

The Netherlands: Gerard Schepers, ECN; Benjamin Sanderse, ECN; Brand, A.J. (Arno) ECN.

Norway: Øyvind Kristiansen, Statkraft Development; Øyvind Byrkjedal,Kjeller Vindteknikk; Finn Nyhammer, Kjeller Vindteknikk; Elly Karlsen Statoil/Hydro.

Spain: Antonio Vigueras Rodríguez, University of Castilla-La Mancha

Sweden: Ola Carlson, Electric Power Engineering, Gøteborg; den Jan-Åke Dahlberg, Vattenfall Vindkraft AB

United Kingdom: Andy Poon, Renewable Energy; Brian Gribben, Frazer-Nash Consultancy; Charlotte Higgins, TNEI Services Ltd

United States: Rebecca Barthelmie, Indiana University; Pat Moriarty, NREL; Michael Brower, AWS

7.3.3 Workshop Presentations

The following presentations are posted at www.ieawind.org on the Task 23 web pages:

Single- and multiple-wake of wind turbines:

- *Wake model evaluation in the UPwind and POW'WOW projects,* Rebecca Barthelmie IU
- *WindPRO wake model validation,* Clarissa Belloni, GE
- *Wind Farm and Wake Modeling at NREL,* Patrick Moriarty, NREL
- *Wake modeling,* Arno Brand, ECN
- *Wake meandering modeling for wind turbine* loading, Juan José Trujillo, Stuttgart Uni.
- *Wind farm and wake modelling at DTU,* Jens Nørkær Sørensen, DTU MEK

Small and large clusters of wind turbines:

- *Wake effects in the closely spaced Lillgrund wind farm,* Jan-Åke Dahlberg, Vattenfall Vindkraft AB *TOPFARM – background and vision,* Gunner Larsen, Risø-DTU
- *Development and calibration of an engineering model for computation of wake velocity deficits,* Helge Aagaard, Risø DTU
- *Wake measurements in a research farm consisting of 5 turbines with a rated power of 2.5 MW and a diameter of 80m. 4 years of data,* Gerard Schepers, ECN

Intermediate-scale and meso-scale modelling of wind farms:

- *Plans/ideas for Wind farm CFD,* Benjamin Sanderse, ECN
- *Not LES modeling, mesoscale modeling at relatively high (~100-200 m) resolution,* Michael Brower AWS
- *CFD modelling of the interaction between the Surface Boundary Layer and rotor wake,* Daniel Cabezon Martinez, Cener
- *CFD Model of wind turbine wake in atmospheric turbulence using body forces,* Pierre-Elouan Rethore, DTU

8 Key Conclusions of Subtask 1

Subtask 1 to Task 23 has gave the workshop participants an overview of the technical and environmental assessment challenges encountered in offshore applications and helped them to understand the areas of further R&D needed.

The overall objectives of Task 23 were as follows:

- Conduct R&D activities of common interest relating to wind turbine facilities operating in offshore environments in order to reduce costs and uncertainties.
- Identify a number of joint research tasks among interested countries based upon the broad range of issues identified at the Technical Experts Meeting #43 on Critical Issues Regarding Offshore Technology and Deployment (see Appendix 1 and description in Section 3).
- Organize several workshops relating to critical research areas relating to offshore wind deployment issues, including technical research on deeper water structures. The goal of the workshops is to identify R&D gaps in various research areas that are of interest to participating countries, publish proceedings, and identify specific joint research areas needing further investigation.
- In year one of the Annex, identify interested participants, project leads for each research area, and prepare separate work programs and budgets for each collaborative research areas.

Within Subtask 1, important issues were identified and possible joint research tasks between interested countries were outlined. The workshop presentations gave participants the state-of-the-art understanding of offshore development, experiences, and needed research. Technical proceedings have been published by the operating agent in cooperation with the host country of the specific workshop (the lead country) and reported to the Executive Committee.

The most important outcome of the work has been the discussions at workshops themselves, which gave the experts within the different areas opportunities to present their work to other experts and discuss problems and results of ongoing projects. As mentioned in this report all the workshop programs, the presentations and the summaries can be found at the IEA Wind web site.

The aim of identifying participants that would be interested in preparing new work programs within specific issues has not be fulfilled, mainly because of lack of time at key persons in the specific areas, but also because of changes in personal in the lead countries. Many projects which are facilitated and financed by national programs and EU programs like UP-Wind have been identified, but the time needed to contribute further and report to more organizations have been hard to find.

The content and primary results of the Subtask have been presented at several occasions (e.g., with a poster at the Copenhagen Offshore Conference, September 2005, at the OWEMES April 2006, and at the Global wind Energy Conference September 2006 and in the IEA Wind Annual reports).

8.1 Ecological Issues and Regulations

More cooperation among countries is needed to address ecological and regulatory barriers to offshore wind energy development. Research and industry groups in the field of ecology and wind energy technology should meet regularly to exchange research results to advance offshore development. For spacial planning, the possible cumulative effects of an increasing number of wind farms on the marine ecosystem must be assessed. The planning process should integrate risk analysis. Wider use of geographic information systems should represent R&D results. A comprehensive approach to planning is needed that integrates impacts on ecology, the effects of electrical infrastructure, and the layout of wind farms. Governments, which usually finance ecological research, should disclose results for wide dissemination as they become available. Existing networks such as in the EU and among wind energy associations should be used to disseminate results as they are achieved. An international review body is needed to learn from and avoid poor decisions. More work is needed to ensure shipping safety when siting offshore wind farms.

8.2 Electrical System Integration of Offshore Wind

Research should help strike the balance between optimum regulation and the need to get projects up and running. Such research is needed to increase understanding of offshore wind metrology and its impact on electrical power fluctuations. The transient behavior of large cable installations (switching / harmonic/ Behavior and modeling of large HV cable systems) must be better understood. More work is needed to develop special grid code and standards for offshore. Connection and control systems must be developed for large offshore wind farms. Work is needed to develop the technical architecture of offshore wind grid systems. Projects are needed to model wind power fluctuations, to measure wind speed and wind power, to forecast power production, to measure and predict the impact of wind power fluctuations on operation and control of the power system.

8.3 External Conditions

Public access to measurements (e.g., turbine power output, meteorological masts, buoys) is important, especially for model validation. Measurements of wind at different levels are needed as are temperature measurements. Determining wake effects is currently the most important challenge in wind engineering. Emphasis should be put into observing and understanding winds 50 m and higher above the surface. The logarithmic wind profile seems to be invalid at these heights, even with neutral conditions. Wind energy developers are interested in accuracies of approximately 2%. Monitoring and recording masts will always be available in large-scale wind energy projects because the cost of a mast is relatively small compared to the entire wind farm budget. Additional information provided by atmospheric models and remote sensing techniques would be welcome, even at a lower accuracy than the nominal.

Problems have been found with wave models in shallow water. An unexpectedly low correlation has been observed between wind data and wave height. Wave spreading and especially misalignment between wind and wave directions needs further investigation and water level transients and coastal currents should be included in models. Slamming and forces from breaking waves and likelihood of breakers must be assessed both in deep waters and in shallower water. Because of turbine vibrations, it is unwise to simply adopt guidelines from the oil industry. Changes in extreme and fatigue loading must be evaluated when moving offshore. Fatigue can increase 10-15%. Extremes during normal operation also increase but less than fatigue. Statistics on array efficiency from Horns Rev shows possible effects at corners of the wind farms. Alignment of waves, wind, and current to determine a conservative design case must also include turbine vibrations when wind and wave directions are perpendicular. Data to validate models are needed to contribute to the new IEC-3 standard.

The theoretical and experimental results indicated differences in results from modelling and in the interpretation of measuring data from offshore wind farms, in particular data from the Horns Rev and Middelgrunden wind farms. A format is needed for collecting and benchmarking data related to offshore wind farms and onshore farms in cases when it is considered relevant. Collaboration should be focussed on data that are important for power calculations as well as for design loads.

The experiences from offshore wind turbine installations reported and discussed at the workshops provided valuable technical information that will aid future offshore wind developments. In general, many wind installations face the same technical issues, but variability in the local conditions for each individual wind power project can add a high degree of uncertainty. This variability may influence the success of a particular project.

To accelerate the successful proliferation of offshore wind worldwide, timely exchange information and lessons learned from existing offshore facilities is essential. This mutual exchange within this Subtask has contributed to a better understanding of offshore siting and design requirements, and objective sharing of information has identified R&D gaps.

Risø DTU is the National Laboratory for Sustainable Energy. Our research focuses on development of energy technologies and systems with minimal effect on climate, and contributes to innovation, education and policy. Risø has large experimental facilities and interdisciplinary research environments, and includes the national centre for nuclear technologies.

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