Forwind
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Preface

ForWind, the Center for Wind Energy Research at the Universities of Oldenburg and Hannover, was founded at the end of 2003 with assistance from the federal state of Lower Saxony (Ministry of Science and Culture) and by the VW-Vorab-Foundation. ForWind is organized in two parts, namely, a research program and a “center of competence”.

Here we present our second annual report with focus on our research activities. You find detailed reports on the research projects and the transfer projects. In addition to that, information about the organization of ForWind, a chronicle of the year 2005, product descriptions and other projects are given.

The research consists of nine areas of focus, ranging from topics such as wind field description, to structure and constructive aspects, to problems of grid integration.

ForWind is a unique combination in Germany: a composition of several institutions in a university environment offering a fundamental scientific know-how combined with the ability to identify research demands from the industry and to initiate and work on application-orientated projects in the wind energy sector.

A cornerstone for our international appearance was the organization of the Wind Energy Colloquium of “EUROMECH” (European Mechanics Society). This conference addressed the need for fundamental academic discussions and attracted about 100 participants from 16 different countries. The proceeding is in press as a Springer-book, one of the highly recognised scientific publishers. The conference led to planned follow-up conferences, which will take place every one to two years. The organising will rotate among the partners Risø (Denmark), TU Delft (the Netherlands) and ForWind.

The spokesmen want to express their gratitude to the federal state of Lower Saxony for the financial aid and furthermore their cordial thanks to the advisory board as well as to the project partners in science and industry and all staff members for the constructive initial phase.

For the future we wish all the best and success.

Hanover and Oldenburg in March 2006

Prof. Dr.-Ing. Peter Schaumann
Spokesman

Prof. Dr. Joachim Peinke
Vice-Spokesman
1 Organisation
ForWind combines the research activities in the field of wind energy of the universities of Oldenburg and Hannover. The administrative office of ForWind is located in Oldenburg.

It is planned to create a corporate center at both universities.

1.1 Research Institutes
Research activities are done in the following institutes:

**University of Oldenburg:**
- Institute of Physics - working group energy and semiconductor research laboratory
- Institute of Physics - working group hydrodynamics and wind energy

**University of Hannover:**
- Institute for Steel Construction
- Institute of Fluid Mechanics and Computer Applications in Civil Engineering
- Institute of Electric Power Systems
- Institute for Structural Analysis
- Institute of Soil Mechanics, Foundation Engineering and Waterpower Engineering
- Institute of Building Materials
- Institute of Concrete Construction
- Institute for Drive Systems and Power Electronics

1.2 Associated Members of ForWind

- Endowed Chair of Wind Energy, University of Stuttgart
- Institute for Soil Mechanics, Foundation Engineering, Rock Mechanics and Tunneling, University of Duisburg-Essen

1.3 Steering Committee
The Steering Committee of ForWind consists of four heads of enlisted institutes and the CEO. In 2005 the constitution has changed:

Prof. Dr. Peter Schaumann (Speaker)
Prof. Dr. Joachim Peinke (Deputy Speaker)
Dr. Detlev Heinemann
Prof. Dr. Werner Zielke
Dr. Marcel Krämer (CEO)
1.4 Advisory Board

Prof. Dr. Erich Barke                  President of the university of Hannover
Jos Beurskens                        Energieonderzoek Centrum Nederland (ECN) & European Wind Energy Agency (EAWE)
Dr. Jörg Buddenberg                  EWE AG
Prof. Dr.-Ing. Günther Clauss        Technische Universität Berlin
Michael Freisen                      Hochtief AG
Jens-Peter Molly                     German Wind Energy Institute (DEWI)
Prof. Dr. Matthias Niemeyer          Salzgitter Mannesmann Forschung GmbH
Prof. Dr. Jürgen Schmid              Institut für Solare Energieversorgungstechnik (ISET)
Prof. Dr. Uwe Schneidewind           President of the university of Oldenburg
Dr. Hans Schroeder                   Ministry for Science and Culture
Matthias Schubert                    REpower systems
2 List of Activities

2.1 Research Projects

I Turbulence modeling and turbulence interaction
II Offshore meteorology
III Forecasting and Spatial-temporal Structure of Wind Power
IV Environmental Loads on Offshore Wind Energy Converters
V Fatigue Assessment of Support Structures of Offshore Wind Energy Conversion Systems
VI Stability and early diagnosis of damages
VII Modelling Soil-Structure-Interaction for Offshore Wind Energy Plants
VIII Grid Integration of Offshore Wind Energy Parks
IX Integrated modeling of offshore WEC

2.2 Transfer- & Development Projects

EP1 Further development of the wind farm program FLaP for planning, wind farm monitoring and turbine design for offshore applications
EP3 & EP9 - Analysis of wind turbine characteristics and wind turbulence with respect to improve energy output prognosis
EP4 Dynamic load bearing capacity of slip resistant bolt connections in truss towers of WECs
EP5 Hybrid junctions between steel and concrete towers for WEC subjected to fatigue loading
EP6 Improving demand forecast for decentralised energy management (DEMS)
EP7 Usage of combined acceleration and strain sensors for early diagnosis of damages
EP10 Joint design of precast concrete towers for Wind Energy Converters subjected to fatigue loading
EP11 Investigations of new turbulence optimized flow bodies

2.3 Other Projects

• Study on high voltage transmission alternatives
• Decentralised Energy Management (DEMS) Project – Wind power and demand forecast
• Warning System on Deviations of predicted Wind Speeds and Adaptation of Wind Power Forecasts to near-real time Measurements (nowcasting)
• Validation of an air-sea interaction sea drag model with data from a near-shore measurement site
• Research map of wind energy in the States of Lower Saxony and Bremen
• Participation in the EU-POWER-Project (Pushing Offshore Wind Energy Regions)
• Postgraduate professional education “Wind Energy Technology and Management”
• Participation in the EU Marie Curie Research Training Network ‘Wind Energy Assessment and Wind Engineering’

2.4 Available Products
• Wind Farm Layout Programme (FlaP)
• HanOff
• WaveLoads
• Hugin
• nowCash (nowcasting and shortest term Wind Power Facility)
3 ForWind-Development

ForWind started in August 2003 with a staff of 25 (heads of institutes included). By the end of 2005 more than 50 people were in work at ForWind. This is due to additional collected budgets by new projects.

First of all projects funded by administrative organisations have to be quoted: Federal Ministry of Research, Federal Ministry of Environment and Helmholtz Society.

Another budget is coming from direct orders by companies in the wind energy sector.

Third regional organisations like “Regionale Arbeitsgemeinschaft Bremen-Niedersachsen” or the city of Oldenburg have to be mentioned.

Altogether the sum of the budget collected until end of 2005 is as high as the funding of ForWind by the ministry of science and culture in Lower Saxony.

4 Chronicle 2005

January, 4\textsuperscript{th} ForWind Steering Committee Meeting, Oldenburg
January, 24\textsuperscript{th}– 25\textsuperscript{th} Participation 4\textsuperscript{th} National Maritime Conference, Bremen
January, 22\textsuperscript{nd} Annual conference Renewable Energies 2005, Berlin; Panel Discussion: Dr. Marcel Krämer
February, 22\textsuperscript{nd} Renewable Energy Conference, Berlin → podium discussion participation by ForWind
March, 8\textsuperscript{th} 5. FZK-Colloquium 'Seacondition, coastal protection and Offshore construction'
→ oral presentation by ForWind
March, 9\textsuperscript{th} research workshop, fk-wind, FH Bremerhaven
→ oral presentation by ForWind
March, 15\textsuperscript{th}– 16\textsuperscript{th} EAWE national section meeting, Kassel
March, 28\textsuperscript{th} – April, 1\textsuperscript{st} Annual Meeting of association for applied mathematics and mechanics e.V., Luxemburg
→ 3 oral presentations by ForWind
April, 4\textsuperscript{th} – 6\textsuperscript{th} Münster, “Windows to Complexity”
→ Oral Presentation: “Intermittent statistics in complex disordered systems like turbulence and financial market” Joachim Peinke
April, 7\textsuperscript{th} – 8\textsuperscript{th} Fifth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks from Offshore Wind Farms, Glasgow
April, 18\textsuperscript{th} – 22\textsuperscript{th} Ringberg Workshop on Interdisciplinary Aspects of Turbulence, Tegernsee, Oral Presentation: “Measured stochastic processes for turbulence and non-linear dynamics” Joachim Peinke
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<td>April, 24\textsuperscript{th} – 29\textsuperscript{th}</td>
<td>Annual Meeting of the European Geosciences Union, Vienna</td>
<td>3 posters by ForWind, 1 oral presentation</td>
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<td>1 oral presentation by ForWind</td>
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<td>April, 26\textsuperscript{th}</td>
<td>Forum on Wind Energy, FH OOW, Oldenburg</td>
<td>oral presentation by ForWind</td>
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<td>April, 27\textsuperscript{th}</td>
<td>MW Lower Saxony, Workshop “Offshore technology and maritime Technologies in Lower Saxony”</td>
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<td>April, 28\textsuperscript{th} – 29\textsuperscript{th}</td>
<td>Job-exhibition renewable energies, Gelsenkirchen</td>
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<td>May, 12\textsuperscript{th}</td>
<td>ForWind Steering Committee, Hannover</td>
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<td>May, 19\textsuperscript{th}</td>
<td>Opening Ceremony of ForWind-Member Institute for Structural Analysis (Prof. Rolfes)</td>
<td>2 oral presentation by ForWind</td>
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<td>June, 1\textsuperscript{st}</td>
<td>24. Steinfurter seminar on steel construction, town hall Rheine</td>
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<td>Oral Presentation: Windturbines Peter Schaumann</td>
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<td>June, 13\textsuperscript{rd} – 15\textsuperscript{th}</td>
<td>Fourth International Conference on Advances in Steel Structures, Shanghai, China</td>
<td>oral presentation by ForWind</td>
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<td>June, 14\textsuperscript{th} – 15\textsuperscript{th}</td>
<td>Participation BMU expert meeting, Potsdam</td>
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<td>June, 14\textsuperscript{th} – 15\textsuperscript{th}</td>
<td>4. Offshore WindEnergy, Germanischer Lloyd WindEnergy GmbH, Hamburg</td>
<td>oral presentation by ForWind</td>
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<td>June, 22\textsuperscript{nd}</td>
<td>Oral Presentation Erich Hau at University Oldenburg, Invited Talk (Joachim Peinke)</td>
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<td>July, 25\textsuperscript{th} – 28\textsuperscript{th}</td>
<td>XXV Dynamics Days Europe, Berlin</td>
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<td>Oral Presentation: “On different cascade-speeds for longitudinal and transverse structures of turbulence.” Joachim Peinke</td>
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<td>August, 29\textsuperscript{th} – 30\textsuperscript{th}</td>
<td>EU Project WindEng - Final Meeting</td>
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<td>September, 12\textsuperscript{th} – 16\textsuperscript{st}</td>
<td>5\textsuperscript{th} Annual Meeting of the European Meteorological Society (EMS)</td>
<td>3 oral presentations by ForWind</td>
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<td>1 Poster by ForWind</td>
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<td>September, 19\textsuperscript{th} – 21\textsuperscript{st}</td>
<td>International Symposium on Frontiers in Offshore Geotechnics (ISFOG), Australia</td>
<td>oral presentation by ForWind</td>
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<td>September, 20\textsuperscript{th} – 25\textsuperscript{th}</td>
<td>Husum Wind Fair, Husum</td>
<td>participation by ForWind</td>
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<td>September, 22\textsuperscript{nd} – 23\textsuperscript{rd}</td>
<td>European Academy of Wind Energy (EAWE), Athen, PhD meeting, Athen</td>
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<td>September, 25\textsuperscript{th} – 28\textsuperscript{th}</td>
<td>iTi Conference on Turbulence, Bad Zwischenahn</td>
<td>2 Posters</td>
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<td>September, 27&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Gigawind-Symposium, Hannover</td>
<td>1 oral presentation by ForWind</td>
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<td>September, 27&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4. Symposium “Offshore-Windenergy”, Hannover</td>
<td>5 oral presentations by ForWind</td>
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<td>October, 4&lt;sup&gt;th&lt;/sup&gt; – 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>EUROMECH Colloquium 464b &quot;Wind Energy&quot;</td>
<td>organised by ForWind</td>
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<td>October, 4&lt;sup&gt;th&lt;/sup&gt; – 7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>EUROMECH Colloquium 464b &quot;Wind Energy&quot;</td>
<td>3 oral presentations by ForWind</td>
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<td>October, 26&lt;sup&gt;th&lt;/sup&gt; – 29&lt;sup&gt;th&lt;/sup&gt;</td>
<td>First International Meeting on Wind Turbine Noise: Perspectives for Control, Berlin</td>
<td>attending</td>
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<td>October, 26&lt;sup&gt;th&lt;/sup&gt; – 29&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Copenhagen OffshoreWind 2005, Kopenhagen</td>
<td>4 oral presentations by ForWind</td>
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<tr>
<td>October, 26&lt;sup&gt;th&lt;/sup&gt; – 29&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Copenhagen OffshoreWind 2005, Kopenhagen</td>
<td>1 poster by ForWind</td>
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<td>November, 2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>ForWind Steering Committee, Oldenburg</td>
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<td>November, 18&lt;sup&gt;th&lt;/sup&gt; – 21&lt;sup&gt;th&lt;/sup&gt;</td>
<td>APS Division of Fluid and Dynamics 58th Annual Meeting, Chicago</td>
<td>2 oral presentations by ForWind</td>
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<td>November, 29&lt;sup&gt;th&lt;/sup&gt; – 30&lt;sup&gt;th&lt;/sup&gt;</td>
<td>IEA expert meeting on Methodologies to estimate the cost of wind energy, Paris</td>
<td>German representative, oral presentation</td>
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<td>November, 29&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Geophysical Seminar of the University Göttingen</td>
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<tr>
<td>November, 29&lt;sup&gt;th&lt;/sup&gt;</td>
<td>Geophysical Seminar of the University Göttingen</td>
<td>Oral Presentation: „Physical Aspects in Windenergy“</td>
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<td>Stephan Barth</td>
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<td>December, 2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>BMBF-Energy Cluster-Meeting</td>
<td>Wind turbulences and their impact on use of Windenergy</td>
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5 Research Projects

5.1 Turbulence modeling and turbulence interaction (I)

Institute of Physics – working group hydrodynamics and wind energy

Stephan Barth, René Grüneberger, Julia Gottschall, Robert Stresing, Thomas Bohlen, Gerrit Wolken-Möhlmann, David Kleinhans, Joachim Peinke

Description

Wind turbines operate in fluctuating turbulent atmospheric wind fields, which are not as ideal as turbulent flows in laboratory experiments. So this project focuses on the wind description and analysis on micro- and mesoscales and the influence of the fluctuations on wind turbines.

Activities

Wind data analysis:
We investigate the scale dependent statistics of atmospheric velocity increments, i.e. velocity differences over a given time \(\tau\), \(v(t+\tau)-v(t)\), and compare them to that of homogeneous, isotropic and stationary turbulence from laboratory experiments. For these flows the probability density functions (PDFs) show a change in shape (Gaussian on large scales, intermittent on small scales). However the measured atmospheric PDFs examined here have the markable feature of a shape nearly independent of the scale. This corresponds to the striking feature of intermittent PDF shapes, i.e. heavy tailed and not Gaussian, but at same time a nearly ideal non-multifractal K41 scaling for the structure functions is obtained. A key to understanding this feature is to interpret atmospheric increment statistics as a large scale mixture of sub-sets of isotropic statistics. When mixing is weak the same statistics as for homogeneous, isotropic and stationary turbulence are recovered while for strong mixing robust intermittency is obtained, further details in publication [1].

Wind data modeling:

To model turbulent winds with these statistical properties it is necessary to find methods that provide time series with the right kind of probability density functions (PDFs). Continuous time random walks (CTRW) have been taken as a good candidate for this. They can be characterized by two coupled Langevin equations: with \(s\) as an inherent time, \(v(s)\) as a Wiener process and \(t(s)\) as an unilateral Levy process. The signal \(v(t)\) can then be obtained as \(v(s(t))\), with \(s(t)\) as inverse function of \(t(s)\). The probability density functions of \(v(t)\) clearly show the intermittent behav-

Fig. 1: PDFs calculated from CTRW processes
ior as it is observed in real turbulence, see figure 1.

**Wind field modeling:**

As next steps based on these CTRW whole two-dimensional wind fields shall be simulated. We started do create wind fields by a method described by Paul S. Veers in the SANDIA Report (1988). With this method one gets Gaussian velocity fields, which imply the right kind of spatial correlation, see figure 2. The CTRW shall be adapted in such a way, that the measured spatial correlations are reproduced and the correct statistics on all scales can be obtained.

**Wind turbine interactions – dynamic stall**

Another part of this project focuses on the influence of atmospheric turbulence on the wind turbine, particularly with respects to turbulence blade interaction. One effect is the dynamic stall phenomenon for airfoils caused by fluctuations in wind velocity and direction. In contrast to static lift forces there is an overshoot of lift if the angle of attack of an airfoil is changed rapidly, like due to gusts. To quantify this effect in wind tunnel measurements, an experimental setup has been constructed in our wind tunnel. The lift coefficient $c_L$ of a wind turbine blade element is determined by the integral of pressure distribution at the wind tunnel walls while rotating the airfoil with defined angular velocities $\dot{\alpha}$ within seconds. For stochastic analysis the experiment is repeated several hundred times. Turning the airfoil forward and backward results in strong hysteresis effects. The maximum lift, the knowledge of which is relevant for the estimation of extreme mechanical loads, depends clearly on the rate of change of the angle of attack, see figure 3. This effect can be interpreted as an amplifier for large velocity fluctuations in the interaction of wind and airfoil. Besides these experimental investigations also numerical simulations of this flow phenomenon have been done. The description and results of the numerical simulations can be found in the part of project IX of this report.

**Turbulent wake:**

For situations in wind parks a wind turbine, in particular the rotor, disturbs the free wind turbulence itself. To understand this additional influence of rotor generated turbulence first steps have been done to establish a field experiment. By means of a small 150 Watt wind turbine and several hotwire probes the changing statistical properties of the wind fluctuations behind the turbine shall be investigated. The setup has been completed and measurements will begin early 2006.
Grants and Cooperations

"Wind turbulences and their meaning for wind energy applications" accredited by the German Federal Ministry of Education and Research, fund initiative "Networks basic research of renewable energy and rational energy applications". This grant is devoted to basic research. The financial support gave the opportunity to employ two further scientists and to do field and wind tunnel measurements. In addition this grant is a joint project between

- ForWind – Center for Wind Energy Research / University of Oldenburg
- Institute of Aerodynamics and Flow Technology, German Aerospace Center (DLR) Göttingen
- Nonlinear Physics, Institute for Theoretical Physics, University of Münster
- Research Group Nonlinear Dynamics and Time Series Analysis, The Max Planck Institute (MPI) for the Physics of Complex Systems - Dresden
- Computational Mechanics Laboratory, University of Applied Sciences Kiel

giving the chance to share data and experiences between this institutions.

Publications


Conference Contributions


5.2 Offshore Meteorology (II)

*University of Oldenburg - Institute of Physics - Energy and Semiconductor Research Laboratory*

*Abha Sood, Jiri Beran, Lorenzo Claveri, Tim de Paus, Barbara Jimenez, Detlev Heinemann*

**Introduction**

Europe needs to develop its own internal energy resources such as the wind power, which is one of the most mature and promising renewable energy technologies. Germany has a goal of 20-25 GW installed capacity at offshore locations until 2030, which will cover more than 15% of the domestic electricity demand. The advantage of more reliable and stronger wind conditions with a suppressed diurnal cycle at the offshore sites, and given the competition in land use or low public acceptance for onshore sites, is expected to offset the disadvantages of higher installation and maintenance costs. A better understanding and measurement of the boundary layer flow in the atmosphere’s lowest two hundred meters where the wind turbines are located in the near offshore (~ 50 km) region will help to optimize the offshore cost benefits.

**Approaches/Activities**

The activities in the research group "Offshore Meteorology" have shifted from calibration and analysis of in situ wind measurements to local and mesoscale atmospheric modelling over the North Sea. Since the observational in situ measurement network over the North Sea and oceans in general is very sparse, numerical mesoscale model simulations, after validating where possible, help to improve the understanding of the flow features at various spatial and temporal scales. The numerical simulations of the atmospheric flow are validated with the observation data and analyzed examining its characteristic features such as the thermal stratification, low level jets and formation of the internal boundary layer.

Marine planetary boundary layer is affected by significantly different physical properties of sea surface compared to the soil and land surface properties onshore. Since radiation penetrates through the transparent water surface, surface energy exchange at the air-sea interface is further enhanced by the turbulent mixing of surface water masses. Additional heat and mass transport occurs driven by sea currents, which introduces changes in sea temperature through advection of water masses. Surface winds also directly interacts with the variable sea surface inducing momentum and energy transport.

We investigate the structure of the offshore boundary layer flow, air-sea interaction and land-sea transition in the mesoscale model (MM5) simulations and observation data over the North Sea. The meteorological and ocean measurement data acquired from various sources and the MM5 model are briefly presented. The added value of the full 3D mesoscale flow is examined and compared with the predictions of wind resources from small scale commercially available 2D Wind Atlas Analysis and Application Program (WAsP). The mesoscale features of the flow over complex terrain onshore are also investigated and validated with in situ datasets. The small scale effects such as wakes in wind farms are investigated using the Ainslie Model and Farm Layout Program (FlaP), and are described elsewhere in this report.
Numerical modelling of the offshore flow

The mesoscale model MM5 (Version 3.7) is a Reynold-averaged, limited area numerical simulation model with the finest horizontal resolution of about 1 km. It includes moist convection and radiation schemes, as well as several liquid and solid water species for surface and cloud layers. The source code of the model is available under GNU licence and can be modified suitably for specific applications. Several gridded meteorological datasets are available which provide the initial and lateral boundary conditions for the limited domain whereas localised unevenly distributed measurements can be assimilated during the simulation. Very high resolution is achieved using the nesting method.

The MM5 model at high resolution requires very large computational resources. The dynamic core of the MM5 model is parallelized but some physical parameterisation were optimized reducing the computational cost significantly by a factor of 2 and increasing the overall model performance by 20%. A number of preliminary studies to investigate the sensitivity of simulations to the forcing fields was undertaken and the accuracy of the simulation was assessed and validated comparing with the in situ measurements.

The land surface scheme simulates the temperature and moisture fields on the lower boundary surface onshore, while the sea surface temperature over the water surface are prescribed and depend solely on the quality and resolution of the available dataset. The landuse dataset are resolved up to 300m whereas the lower boundary temperature fields in standard global model datasets are resolved to about 50 km. To improve prescribed lower boundary condition, more accurate and higher resolved sea surface temperature forcing data are used.

Several physics parameterisation schemes are tested and compared to find the most suitable model set-up. Three selected parameterisation schemes based on 0th-, 1st- and 1.5th-order turbulence closure with additional non-local effects are tested. The robustness and accuracy of scheme outputs is evaluated.

Sea air interaction: The friction at the air-sea interface forces sea surface to move leading to momentum transfer. The surface gravity waves break at higher wind speeds, with additional sensible and latent heat exchange at the interface strongly influencing turbulent features in the moist surface air layer. This complex interaction is affected by a number of fields such as the wind velocity, air and sea surface temperature. Additional information on surface momentum, humidity and heat exchange is necessary to acquire a more complete understanding and to estimate turbulent fluxes across the interface and into the adjacent lower boundary layers.

Land sea transition: Amongst the weather phenomena encountered on the coastline, the sea-breeze is the most cited textbook example. In addition to the thermal distortions of the wind fields along the coast, there are changes in land and sea surface roughness and sea surface temperature pattern. It is expected that the strength of the coastal flow pattern is strongly dependant on the mean flow distorted by the land sea discontinuity and the diurnal cycle.

Meteorological and ocean measurement data

Offshore meteorological measurement data: In order to quantitatively describe and validate the marine and coastal atmospheric boundary layer phenomena, extensive meteorological data are needed. The offshore atmospheric measurements were until recently very sparse. Recent technological advancement in the energy sector has
pushed the frontiers deep into the seas where many offshore platforms provide useful meteorological measurements.

The North Sea region extends over several hundred nautical miles in both latitudinal and longitudinal directions. To cover air measurements across the North Sea, several national weather agencies conduct air measurements in their exclusive economic zones. Most of the data fulfills the standard meteorological data quality requirements (WMO upper air sounding at EKOFISK, surface observation from ENEK, several lightships and buoys in German Bight, aperiodic sea-born measurements from ships en-route), but some provide higher quality information (research platform FINO-1, commercial measurement campaign at Horns Rev). The upper air sounding in the North Sea domain is provided at sites listed below.

<table>
<thead>
<tr>
<th>UPA Station</th>
<th>Country</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>EKOFISK</td>
<td>Norway</td>
<td>56.53</td>
<td>3.22</td>
</tr>
<tr>
<td>Stavanger</td>
<td>Norway</td>
<td>58.88</td>
<td>5.63</td>
</tr>
<tr>
<td>Emden</td>
<td>Germany</td>
<td>53.21</td>
<td>7.13</td>
</tr>
<tr>
<td>De Bilt</td>
<td>The Netherlands</td>
<td>52.10</td>
<td>5.18</td>
</tr>
<tr>
<td>Nottingham</td>
<td>The United Kingdom</td>
<td>53.00</td>
<td>-1.25</td>
</tr>
<tr>
<td>Shetlands Islands</td>
<td>The United Kingdom</td>
<td>60.13</td>
<td>-1.18</td>
</tr>
<tr>
<td>Faeroe Islands</td>
<td>Faeroe Islands</td>
<td>62.01</td>
<td>-6.76</td>
</tr>
</tbody>
</table>

The network of surface observations contains several thousand surface stations world-wide with more than hundred stations in the North Sea region. Weather stations in German Bight are operated mainly by the German Weather service with additional the Dutch Meteorological Institute and Danish weather agency measurement stations in the neighbouring regions. A list of offshore weather stations in German Bight area used for validation is listed below. These data are provided on global basis without restrictions. Since the island stations are expected to represent larger surroundings than islands only, they are included in the table.

<table>
<thead>
<tr>
<th>SFC station</th>
<th>Country</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norderney</td>
<td>Germany</td>
<td>53.7167</td>
<td>7.1500</td>
</tr>
<tr>
<td>Wangerooge</td>
<td>Germany</td>
<td>53.7833</td>
<td>7.9167</td>
</tr>
<tr>
<td>Leuchtturm Alte Weser</td>
<td>Germany</td>
<td>53.8667</td>
<td>8.1333</td>
</tr>
<tr>
<td>Huibertgau Wp</td>
<td>the Netherlands</td>
<td>53.5667</td>
<td>3.4000</td>
</tr>
<tr>
<td>Ufs Tw Ems</td>
<td>Germany</td>
<td>54.1667</td>
<td>8.3500</td>
</tr>
<tr>
<td>Ufs Deutsche Bucht</td>
<td>Germany</td>
<td>54.1833</td>
<td>7.4333</td>
</tr>
<tr>
<td>Helgoland Island</td>
<td>Germany</td>
<td>54.1833</td>
<td>7.8833</td>
</tr>
<tr>
<td>Blaavand</td>
<td>Danemark</td>
<td>55.18</td>
<td>8.08</td>
</tr>
<tr>
<td>List / Sylt</td>
<td>Germany</td>
<td>55.0167</td>
<td>8.4167</td>
</tr>
</tbody>
</table>

Sea observational data: Direct sea surface temperature measurements derived directly from the state of sea are very sparse. Instead satellite retrieval is adopted on a
regular daily basis and sporadic measurements are included via data assimilation methods such as 2DVAR etc. Most of data-sets are based on AVHRR radiometers onboard spacecrafts NOAA-16 and NOAA-17. The final global sea surface temperature data-sets are retrieved from FNMOC NRL and NOAA agencies at quasi-daily basis.

Land and coastal observational data: The inland and coastal measurements have the best observational network density. There are several data sources such as the national weather services (DWD,KMI,DMI), civil and military airports as well as several commercial services. The measurements available on global basis from NCAR cover hourly and half-hourly measurement frequencies at WMO quality requirements. High-frequency data are available from national weather agencies and specialized research campaigns.

**Inter-comparison MM5-WAsP**

To obtain an overview of model output quality mid-term and long-term simulations are conducted. In order to find discrepancies, the model simulations are validated with observation data if they exists and also compared to WasP outputs. WAsP is one of the leading wind resources assessment tools. The MM5 time-series output is compared with the WAsP model output on a sector-wise average basis. Wind roses and wind distribution across domain of interest are compared. The impact of time-series resampling is also taken into account and series of investigations are undertaken. It seems that, under unfavourable conditions such a resampling can introduce significant errors in wind resource assessment.

**Mesoscale modelling over complex terrain**

A validation of MM5 model output (mainly wind speed) for complex terrain with the FZK 200 m mast data at Karlsruhe, Germany was made. Some statistical properties were investigated, such as RMSE, bias and fractional bias. Further, a sensitivity study on the modeled wind speed profile using different settings of the MM5 model was performed. The impact of modified more realistic land use data set in MM5 at the observational FZK meteo mast site location and the surrounding grid cells was investigated.

**Outlook**

In addition to completing the sensitivity and validation studies of numerical simulations of the boundary layer wind field over the German Bight and the North Sea, there are ongoing efforts:

- To improve and modify the lower boundary layer parameterisation in the mesoscale models to suit the marine conditions.
- To study the wind climatology based on the reanalysis datasets and mesoscale simulations of the past climate and the future climate scenarios for the North Sea within the framework of a new EU Marie-Curie RTN project (MODOBS).
- To investigate the air-sea interaction supported by simulation of coupled atmosphere-wave numerical models (WRF-WAM) within the framework of the BMBF e-science project (WISENT).
- To develop an operational setup for short term numerical wind field forecast optimized for monitoring and management of offshore and coastal wind farms.
Project Participations


Organisational work
Final WINDENG meeting at the University of Oldenburg, 29-31 August 2005.

Conference contributions

EGU Vienna:
Durante, F., de Paus, T., Beran, J., Lange B. and M. Strack. A sensitivity study of mesoscale wind profile simulations to PBL parameterization. (Poster)

EWEA German PhD student’s meeting, Kassel:
J. Beran. Marine boundary layer modelling (Oral Presentation)

5th Joint MM5/WRF workshop:

31st International Symposium on Remote Sensing of Environment, Russian Federation:

EU Wind-Eng Meeting Oldenburg:
J. Beran. Marine boundary layer modelling (Oral Presentation)
B. Jiménez. Offshore wind resource assessment at German Bight (Oral Presentation)

Offshore wind 2005 Copenhagen:
F. Durante, L. Claveri, J. Beran, T. de Paus, B. Lange and M. Strack (2005). Offshore wind resources assessment with the mesoscale model MM5. (Poster)

Publications

Accepted paper:

Paper submitted to ejournal windeng:
**Paper submitted to Wind Energy:**
Jiménez, B., F. Durante, B. Lange, T. Kreutzer and Jens Tambke (2005). Wind resource assessment in the German part of the North Sea: Comparative study between MM5 and WasP.

**Papers in preparation:**
Ohsawa, Teruo, Detlev Heinemann, Jens Tambke, Ulrich Focken, Francesco Durante and Bernhard Lange. Verification of offshore winds simulated by MM5 based on measurements from a meteorological mast at Horns Rev.


De Paus, T., A. Sood and Alfredo Lavagnini (2005): Validation of the mesoscale model MM5 for wind speed measurements near Karlsruhe, Germany.
5.3 Wind Power Forecasting (III)

University of Oldenburg - Institute of Physics - Energy and Semiconductor Research Laboratory

Lüder von Bremen, Jens Tambke, Nadja Saleck, Ulf Graewe, Carsten Poppinga, Lorenzo Claveri and Detlev Heinemann

Introduction

The project aims to support scientifically the development of tools and strategies for the integration of wind power into current and future electricity supply structures. The work is focused on two research topics: i) wind power forecasting with currently available data from NWP (Numerical Weather Prediction) centers using statistical and physical approaches and ii) analysis of the influence of fluctuating power on the performance of electricity grids and its optimization.

Activities:

In the reporting period the work was concentrated on the implementation of new wind power prediction models with new forecasting techniques, as it was decided to stop the development of the existing model Previento. It was considered too inflexible to implement and investigate new scientific approaches. Another key activity was the analysis of wind measurement data from offshore research platforms and the comparison with meteorological analysis and forecasts from different NWP (Numerical Weather Prediction) Centers. This work clearly showed that operational wind data from NWP is a very good choice for wind power algorithm development and can serve as a substitute for expensive offshore measurements concerning resource assessment and predictability of offshore wind power.

In the following the new approaches and scientific work on wind power forecasting are described in detail and results are shown.

New Wind Power Forecasting Tool

In contrast to Previento a new and simpler approach of physical wind power model was implemented. There are three key difference compared to Previento: i) the selection of representative reference sites is no longer necessary as regular fields (0.5° x 0.5°) of wind speed and temperature became available. Furthermore ii) wind fields other than the surface 10m wind speed are ready for use, what avoids the extrapolation of wind speeds to hub height taking thermal stratification into account. As a third difference the manufacturer’s power curves are not used any longer as a parameterization was found to describe the power curve of a specific WEC by its maximum power.

The new model was tested for the year 2004 (Fig. 1) with forecast of the European Centre for Medium-Range Weather Forecasts (ECMWF) while comparing forecasted wind power to total wind power production data of Germany.

Figure 1 shows a systematic underestimation of wind power in the afternoon and an overestimation during night. This phenomenon inherits an increase in the RMSE forecast error in the afternoon and a drop in RMSE forecast error during night times. It is believed that these problems are triggered by changing thermal stratification of the lower atmosphere. During night times stable conditions prevail and hence strong
wind shear. Apparently, the ECMWF model overestimate the stability and has to high wind speeds during night times. In the afternoon wind speeds are underestimated leading to a negative systematic error in the wind power forecast. This may be due to overestimation of convection and turbulence resulting in very unstable thermal stratification. The RMSE forecast error increases from 6% at day 1 to about 8% at day 3.

\[ \text{Percent of} \ P_{\text{nom}} \]

Figure 1: Wind power forecast error for Germany against look-ahead time in the year 2004 computed with ‘Hugin’. The systematic error (Bias), RMSE and standard deviation of the error (sde) is shown. The error is scaled with the rated power of approximately 16GW.

### Upscaling of Regional Wind Power

**Introduction:** Typically the wind power of only a limited number (subsample) of reference wind farms is provided on-line via the Supervisory Control and Data Acquisition System (SCADA). These reference wind farms are used to estimate the wind power in a larger region with several hundred wind farms. This is possible as wind situations at different sites show a strong correlation due to large-scale wind patterns by synoptic systems. However, local wind conditions are affected by orography surface roughness and small-scale effects as thermal convection (land-sea breeze). The later is the reason and motivation to account the wind power production of a reference site, that is located in short distance more than a remote reference site, while making the estimate for each WEC of interest. The region of interest is the supply area of the German utility EWE AG that provided production data of 11 reference wind parks in the north-west of Germany.

**Description of Upscaling Approaches:** Two different upscaling approaches are developed and tested. The first approach is multiple linear regression technique between the production data of the 11 reference parks and the total production. In contrast to this pure statistical approach the second approach is considering the actual regional distribution of WECs. In a first step the power of each single WEC in the EWE area is estimated (downscaling) by the 11 reference parks and later all WECs are added (upscaling). The advantages of this algorithm against the linear regression is that subgroups of WECs can be computed to predict regional power, i.e. the wind power from several wind farms connected to the same transformer station.

The estimation of power of each single WEC is done by multiplying the scaled power \[ \text{P}_j = \frac{\text{P}_j}{\text{P}_{\text{nom}}} \] of each reference park with appropriate weights. The weighting depends on the geometrical distance between the WEC site and the reference park. The dependence on distance varies with the chosen weighting function. A Gaussian weighting function is used with half power widths between 12 and 37 km for the reference parks (Fig. 2).
Figure 2: Half power widths of the weighting functions (circles) that are used for the 11 reference wind farms in the upscaling approach. The colored boxes represent the contribution of all WECs in a grid cell of 0.2°×0.2° to the wind power production in the entire EWE region.

Figure 3 shows the upscaling result by weighting to estimate the total wind power production in the EWE region using the production data of the 11 reference parks. The result is in terms of bias (left) and rms (right) considerably better than linear upscaling. Linear upscaling means that the total of the 11 reference parks is linearly scaled to match the rated power in the EWE region. The factor is approximately 8, as roughly 2230MW have been rated by spring 2005 and the 11 reference parks have a total installed capacity of 280 MW.

Figure 3: Bias (left) and RMS (right) of the error in estimating the total wind power in EWE region by wind power measurements from 11 reference wind parks. Bias and RMS are normalized with the rated power of 2.235 GW. The blue line is linear averaging of the reference parks and scaling to rated power. The pink line is the newly developed upscaling algorithm.

Results in regional forecast error smoothing

The newly developed upscaling algorithm with weighting functions is also applied to wind power predictions of the 11 reference wind park sites. Wind speeds in hub height are taken from wind fields (00UTC and 12UTC forecast runs) provided by the European Centre for Medium-Range Weather Forecasts. The forecast range is up to 72 hours with a timely resolution of 3 hours. A simple parameterization was used to
model the power curves in order to calculate the according wind power for each of the 11 reference wind parks (Fig. 4). The average error for the individual predictions increases from 13% at day 1 to 17% at day 3. The black line in Fig. 4 shows the upscaled wind power forecast using the new weighting function approach. The forecast error increases from 6% at day 1 to 12% at day 3. A reduction of forecast error by 46% at day 1 and 71% at day 3 can be concluded due to balancing of inherent forecast errors.

Figure 4: Regional wind power forecast error smoothing effect in EWE region for Jan-Mar 2005. The black line is the newly developed upscaling algorithm while single reference forecasts are shown as thin colored lines. The average RMS error of single predictions is drawn in red. The error is normalized with the rated power of each park and the total capacity of 2.235 GW, respectively.

Offshore Meteorology for Multi-Mega-Watt Turbines

To achieve precise wind resource assessments, to calculate loads and wakes as well as for reliable short-term wind power forecasts, the vertical wind profile above the sea has to be modelled with high accuracy for tip heights up to 160m. For these purposes, it is crucial to consider the special meteorological characteristics of the marine atmospheric boundary layer. Continuing our work in the EU-project ANEMOS, we analysed marine wind speed profiles that were measured at the two masts Horns Rev (62m high) and FINO1 (103m) in the North Sea. We found pronounced effects of thermal stratification and of the influence of the land-sea transition. In many situations, the wind shear is significantly higher than expected with standard approaches in mesoscale models. Nevertheless, the numerical analysis of the marine wind field above the North Sea from the German Weather Service seems to provide a good assessment of wind speeds at 103m height (Fig. 4).

In order to improve simulation of the vertical wind speed profiles, we developed a new analytic model of marine wind speed profiles. The flux of momentum through the Ekman layer of the atmosphere and the sea is described by a common wave boundary layer. The good agreement between our theoretical profiles and observations at Horns Rev and FINO1 support the basic assumption of our model that the atmospheric Ekman layer begins between 10 to 30m above the sea surface (Fig. 5).
Figure 5: Mean measured wind speed profile at FINO1 compared to the result of two mesoscale simulations model (DWD-Analysis and MM5-Simulation) (left). Mean wind speed profile at FINO1 compared to mean profile from ICWP model and offshore WAsP profile. All results for the undisturbed sector (190° - 250°) in year 2004.

Forecast for the Integration of 25 GW Offshore Wind Power

The economic success of offshore wind farms in liberalised electricity markets strongly depends on reliable short-term (48 hours) predictions of their power output. In the EU-project ANEMOS for wind power forecasts, we investigate the short-term predictability of marine wind speeds and wind power. We found that the accuracies of wind speed predictions provided by the European Centre for Medium-Range Weather Forecasts, ECMWF and the German weather service DWD for the offshore sites Horns Rev and FiNO1 are similar or better than for single onshore sites considering that the mean producible power is twice as high as onshore. A weighted combination of the two forecast sources leads to reduced errors: This combined power prediction for a single site in the North Sea with a hub height of 103m shows a relative root mean square error of 16% of the rated power for a look-ahead time of 36h, while the mean producible power amounts to 51% of the rated power. A regional forecast of the aggregated power output of all projected sites in the German Bight with a total capacity of 25 GW benefits from spatial smoothing effects by an error reduction factor of 0.73, showing an RMSE of 2.5 GW at forecast day 1 and 3.5 GW at forecast day 2 (Fig. 6).

Figure 6: RMSE of wind power forecast with ECMWF data validated with DWD Analysis for year 2004 and hubheight of 103m. Thin lines represent all 22 offshore sites in the North Sea. The red triangle line is the average RMSE, while the pink star line is the RMSE of total forecasted production, i.e. the sum of forecasts of all 22 sites is taken.
Publications


U. Gräwe: Characterization of the Marine Boundary Layer using in-Situ measurements above the North Sea – Wind and power prediction using refined and combined methods. *Bachelor Thesis at the University of Oldenburg, ForWind*. April 2005
5.4 Environmental Loads on Offshore Wind Energy Converters (IV)

University of Hannover - Institute of Fluid Mechanics and Computer Applications in Civil Engineering

Werner Zielke, Kim Mittendorf

Introduction

Knowledge of the wave loading is essential for the design of offshore wind energy structures. In the last annual report, the developed methods for this task have been described.

The structural load \( F \) due to waves for hydrodynamically transparent cylinders is calculated with the Morison equation [1], which is a summation of drag and inertia forces. \( F \) is the force per unit length experienced by a cylinder.

\[
F = \frac{1}{2} \rho C_D D \int_{-h}^{0} u |u| \, dz + C_M \rho \frac{\pi D^2}{4} \int_{-h}^{0} \frac{\partial u}{\partial t} \, dz
\]

with \( \rho \) fluid density, \( D \) pile diameter, \( h \) water depth, \( z \) spatial coordinate, \( u \) horizontal particle velocity, \( C_D \) drag coefficient, \( C_M \) inertia coefficient.

The particle kinematics needed for the application of the Morison equation are determined by a suitable wave theory.

This report will deal with the validation of the developed method for the calculation of wave loads. For that the calculated results are compared with measurements in the Large Wave Channel (GWK).

Methods

The validation was performed for the following methods:

- Fourier wave theory in formulation by Sobey for regular waves
- Superposition of linear waves for simulation of irregular sea waves
- Local Fourier approximation by Sobey [2]

Experiments

The Large Wave Channel (GWK) of the Coastal Research Centre provided two different sets of experiments. A detailed description of the experiments will be found in [3].

For the first experiment a partly immersed vertical tube has been used, in the other set-up, a totally immersed inclined cylinder. A summary of the simulated wave parameters is given in Table 1.
Table 1: Simulated wave parameters

Figure 1 shows the set-up for the experiment on a vertical tube which is fixed in the bearing steel truss. The tube with 0.324 m diameter was partly immersed in the channel. At the clamping, the moment was measured. Thirteen wave gauges were installed along the channel as well as velocity gauges in the section of the tube at 1.26 m and 1.76 m below MWL.

Figure 2 shows the other set-up, with a pile of 0.7 m diameter.
Evaluation of the results

For the evaluation of the calculated wave kinematics and wave forces, measurements of horizontal water particle velocity and the moment or force are available. Within the Morison approach, adequate approximations of wave particle velocity and acceleration are important, as the force is calculated through the kinematics. Thus, their correct calculation is required for an exact determination of wave loading.

Quantification of deviation

The calculation of the relative root mean square is used to quantify the deviation of the measurement. This is the root of the mean square deviation in relation to the measured value.

\[ \text{rms}_r = \frac{1}{\bar{f}} \sqrt{\frac{\sum (f_i - g_i)^2}{N}} \]

with \( f \) measured values, \( g \) calculated values, \( N \) number of values, \( \bar{f} \) mean of absolute of \( f \).

Regular waves

Regular waves are characterised by their height and period, both of these remain constant through time. For these type of waves, several analytical solutions as well as iterative approaches to fulfil the stream function \( \Psi \) have been developed.

The measurements of regular waves have been compared to the regular Fourier Wave Model and to the Local Fourier Approximation.

The Local Fourier Approximation [2] was initially developed for irregular but should also work for regular waves. Here the result over one wave period of a regular wave of 1.4 m height and 6 s period is shown, fig. 3. The rms, for velocity is 0.2, the one for the moment is 0.6. The agreement in kinematics is quite satisfactory. Generally the maximum value of the moment has been reached although shape of the curve differs slightly. The Morison coefficients were determined through a least-square fit.
As an example, the result for a regular wave on the inclined pile is shown in fig. 4. The wave height is 1.4 m, the period 6 s, the resulting \textit{rms}, 0.1.

\textbf{Irregular waves}

Irregular waves can not be characterised by a single wave height or period. Instead they include waves of different frequency and height. Thus they are often computed by superimposing linear waves. This is not the approach used here. Instead the LFA is extended to cover irregular waves.
In fig. 5, the results over one wave period for an irregular wave with a significant height of 1 m and a peak period of 6 s are shown. As for the regular wave, the agreement for velocity is good; the $rms$, in this case is 0.2 as well. The $rms$, for the moment is 0.6. Generally the maximum value of the moment has been obtained although the shape of the curve again differs slightly. Figure shows a longer part of this time series.

Figure 5: Irregular wave: surface, velocity at $z=-1.26m$ and moment; $H_s=1m$; $T_p=6s$; $C_D=1.0$; $C_M=2.1$

Figure 6: Irregular wave: surface elevation, moment; $H_s=1m$; $T_p=6s$; $C_D=1.0$; $C_M=2.1$

**Conclusion**

The comparison shows satisfactory results for velocity calculation for both regular and irregular waves. Using the Morison-equation with fitted coefficients, which are in the usual range, gives time series for the moment with a somewhat different shape but good agreement in maximum values. The resulting force on the inclined pile agrees in shape and quantity. A sensitivity study for the coefficients is currently being done and possibly further improvements of the results by using variable coefficients can be expected.
References


5.5 Fatigue Assessment of Support Structures of Offshore Wind Energy Conversion Systems (V)

University of Hannover - Institute for Steel Construction
Peter Schaumann, Fabian Wilke

Introduction

Support structures of offshore wind energy conversion systems (OWECS) are exposed to high dynamic actions. During their twenty years of lifetime they undergo loadings with a number of cycles more than $10^9$. Concerning the planned German wind farms most of the support structures will be located in regions with water depths between 20 and 50 m with quite far distances from the coast. Therefore access to the support structures and their control is both expensive and difficult. Due to these special conditions the fatigue assessment is a crucial factor for safe and economic design of OWECS.

Activities

Welded Joints

As shown in usually time history based design procedures are used for the fatigue design of support structures. Design optimization requires consideration of multiple time series and numerous possible crack locations. For that reason a software tool has been developed, which can be used for typical offshore joint types (Fig. 1).

![Software tool FALCOS for the fatigue design of offshore joints](image)

Based on a number of calculations for different tubular joints, a new dimensionless parameter has been defined. It considers the different boundary conditions at the brace ends and can be used for correction of the resulting hot spot stresses. The equations are required if short braces are needed to reduce the degrees of freedom for complex, nonlinear calculations, e.g. for pile-sleeve connections. In addition to the state-of-the-art structural stress approach more sophisticated local concepts have been evaluated regarding the application for offshore structures:
• The notch stress approach (acc. to IIW and in the original version acc. to [2]) with fictitious notch rounding to account for microstructural support.
• The notch strain approach, considering stabilized cyclic material data according to the uniform material law (UML) together with the equations by Manson, Coffin and Morrow.

For the material in the heat-affected zone (HAZ) an increased hardness can be considered. Mean stress effects are included by the use of the critical-plane damage parameter $P_{\text{SWT}}$ according to Smith, Watson and Topper [3].

The notch stress approach was verified by comparison with existing data [4]. It showed a good agreement to the results of the structural stress approach (see Fig. 2) which leads to the conclusion that a hot spot method based fatigue design provides crack initiation life for thick plates with dominating notch effect. Plate thickness effects as stated in the offshore codes could be well confirmed (Fig. 2, right side).

The extreme fine FE meshes involving high calculation times for both local concepts make multiple submodelling steps indispensable. At the same time the number of influencing parameters increase which can lead to certain scatter in the results if site specific material data is not available. Contrary both local concepts have the advantage that fatigue design can be carried out uncoupled from the standard S-N-curves for given structural details and the application to any local weld geometry is possible, which was shown by the classification of tubular joints welded from one side.

Grouted Joints

The so-called “grouted joints” of monopile structures are hybrid connections. The gaps of nested steel tubes with different diameters are filled with grout material, usually high strength mortar. It is needed to transfer forces from one steel member into the other. The application for typical support structures for OWECs [5] – especially for monopile structures but also for pile-sleeves of tripods – requires an additional transfer of bending moments. Experience is missing concerning bearing capacity and fatigue strength of this structural detail under the special loading conditions, because the ovalisation, caused by the break up of the bending moment into a pair of forces (Fig. 3), changes the so far analysed load bearing behaviour.
Figure 3: Monopile grouted joint test and numerical model

Further knowledge will be gained by static and dynamic large scale model tests (Fig. 4). The large scale specimen already have been grouted in December 2005 by Densit. The analysis is accompanied by material and small scale specimen tests (normal force test procedures, see left side of Fig. 5).

Figure 4  Left side: Specimen prepared for the grouting operation; Right side: grouted joint test setup

The first results with the small scale specimen indicate differences to the offshore design codes, which only partially can be explained with a different geometric parameter range. A comparison with numerical results shows, that especially the local behaviour in the high stressed area of the shear keys can hardly be modelled with standard material models e.g. like Drucker-Prager. The performed fatigue tests lead to a nonlinear damage process (Fig. 5) which confirms the use of energy based damage models for this type of connection.
Outlook

Future work will concentrate on:

- realization of the large scale tests
- numerical modelling of the damage process
- extension of the design rules to a wider range of geometric parameters

Publications


5.6 Stability and early diagnosis of damages (VI)

University of Hannover - Institute of Structural Analysis
Raimund Rolles, Wolf-Jürgen Gerasch, Johannes Reetz

Introduction

An efficient and reliable use of offshore wind energy requires a condition controlled maintenance. Thereby information about the state of damage and the residual load carrying capacity of the structure has to be provided by means of condition monitoring systems (CMS). Such a system is not yet available. In the following a new method is demonstrated treating this problem. The method bases on the fact, that damages influence the dynamic behaviour of elasto mechanical structures. Turek and Ventura (2005) show that with the aid of a validated finite element model damage detection can be made by means of measured modal quantities. However, their method does not provide information about quantification and localisation of damage. By formulating the identification problem as a multiparameter eigenvalue problem using the finite element model with parameterised model matrices, damage can be quantified and localised, Cottin(2001).

The Multiparameter Eigenvalue Method

Starting from the known linear elastic and lightly damped supporting structure the first step is the approximation as a finite element model. Thereby the model has to be validated with the real structure. It is advantageous to apply pre-existing knowledge about structural parts, e.g. welded or bolted joints or the splash zone, which are prone to damage. For this purpose the portions of the model matrices – particularly of the stiffness matrix – associated with these details are parametrised. Therewith the mathematical model characterising the dynamic behaviour is given. On the other hand, the information about the current dynamic behaviour of the potentially damaged structure is provided by the modal quantities. The modal quantities which are most exactly measurable are the eigenfrequencies. These can be measured by means of ambient excitation. The identification should provide the information about the current stiffness parameters by means of the given model and the measured eigenfrequencies. Due to the formulation as multiparameter eigenvalue problem the ill-posed problem is transformed into well-posed common linear eigenvalue problems. The last step is the diagnostics. Thereby the interpretation of parameters provides detection, quantification and localisation of the damage. To simplify matters the equations hold for a number of two parameters without loss of generality. The problem of identification of the stiffness parameters by means of measured eigenfrequencies is

\[
\begin{aligned}
\left\{ 
\begin{array}{l}
-\ddot{\omega}_1 M + a_1 K_1 + a_2 K_2 g_1 = 0 \\
-\ddot{\omega}_2 M + a_1 K_1 + a_2 K_2 g_2 = 0 
\end{array}
\right.
\]

These eigenvalue equations comprise the known model matrices \( K_i \) and \( M_i \), the known measured eigenfrequencies \( \ddot{\omega}_i \), the unknown eigenvectors \( g_i \) and the unknown stiffness parameters \( a_i \), which have to be identified. The same elements in a generalised notation are given by
with the stiffness parameters $\lambda_i = \lambda_{d_i d_i}$ and the model matrices $\mathbf{A}_{ik}$. Every row is posed in the space of physical coordinates. There is a dependence of the required information on the number of degrees of freedom (DOF) of the model and hence a lack of information. This problem is ill-posed. But with the linear maps $\mathbf{B}$ one can define linear induced maps $\mathbf{B}^\dagger$ as follows

\[
\mathbf{B}^\dagger : R^3 \otimes R^3 \rightarrow R^3 \otimes R^3
\]

\[
\mathbf{B}_1^\dagger : (\mathbf{g}_1 \otimes \mathbf{g}_2) \mapsto \mathbf{B}_1 \mathbf{g}_1 \otimes \mathbf{g}_2
\]

\[
\mathbf{B}_2^\dagger : (\mathbf{g}_1 \otimes \mathbf{g}_2) \mapsto \mathbf{g}_1 \otimes \mathbf{B}_2 \mathbf{g}_2
\]

The maps $\mathbf{B}_1$ and $\mathbf{B}_2$ act on the element $\mathbf{g}_1$ and $\mathbf{g}_2$, respectively and the identity acts on the other elements. The application of this induced linear maps on the problem shows in Equation 4 that if and only if the right hand side holds, also the left hand side holds.

\[
\begin{cases}
\mathbf{B}_1 \mathbf{g}_1 = 0 \\
\mathbf{B}_2 \mathbf{g}_2 = 0
\end{cases} \Leftrightarrow \begin{cases}
\mathbf{B}_1^\dagger (\mathbf{g}_1 \otimes \mathbf{g}_2) = \mathbf{B}_1^\dagger \mathbf{f} = 0 \\
\mathbf{B}_2^\dagger (\mathbf{g}_1 \otimes \mathbf{g}_2) = \mathbf{B}_2^\dagger \mathbf{f} = 0
\end{cases}
\]

The condition written in model matrices is

\[
\sum_{s=0}^{2} \mathbf{A}_{rs}^\dagger \lambda_s \mathbf{f} = \sum_{s=0}^{2} \mathbf{A}_{rs}^\dagger \mathbf{f}_s = 0
\]

This problem is posed in the space of tensor products. In extension from the use of determinants for systems of linear equations one can apply the rules of determinants on this linear induced operators. Then one obtains compositions of maps (see Equation 6) called determinantal maps, i.e.:

\[
\Delta = \det \begin{pmatrix}
\mathbf{A}^\dagger_{11} & \mathbf{A}^\dagger_{12} \\
\mathbf{A}^\dagger_{21} & \mathbf{A}^\dagger_{22}
\end{pmatrix} = \mathbf{A}^\dagger_{11} \mathbf{A}^\dagger_{22} - \mathbf{A}^\dagger_{21} \mathbf{A}^\dagger_{12}
\]

It is shown in [3] that the development of determinants using Cramers Rule and the application of the cofactor to Eq. (5) lead to a problem which is equivalent to Equation 1:

\[
\Delta \mathbf{f}_s - \Delta \mathbf{f}_s' = 0
\]

With a non-singular linear combination of the determinantal maps one obtains linear eigenvalue problems for the model parameters:

\[
\mathbf{f}_s = \Delta^{-1} \Delta \mathbf{f} = \lambda \mathbf{f}
\]

These problems are well-posed. There is no incompleteness of information because the number of required eigenfrequencies depends only on the number of stiffness parameters.

**Numerical Example:** In the current state of method validation measurement data are not yet available. Therefore, artificial measurement data are generated by applying
scatter to the exact eigenfrequencies as resulting from the analysis. It is supposed that the middle area of a cantilever beam model with three elements (denoted by one to three beginning from the bottom) and nine DOF has a stiffness degradation of 10%. In the first column of Table 1 the first three eigenfrequencies for the bending modes are shown with an accuracy of three correct decimal places. The solution of the eigenvalue problems determines the set of stiffness parameters as shown in the second column. A stiffness parameter equal to one refers to an undamaged structural element. The decrease of the second stiffness parameter points to a damage in this region. The value of $a_2=0.897$ indicates a stiffness reduction of 10.3% which is quite close to the damage applied before. Furthermore, damage of the correct structural element is reflected since the stiffness parameters of elements one and three remain almost identical to one.

**Validation of the Method**

A validation of the method by means of a sensitivity analysis was carried out. Therewith the influence of several parameters of the method on the accuracy of the quantification was investigated. The parameters of the method investigated are e.g. accuracy of eigenfrequencies, size of damaged area, stiffness reduction, location, number of damages, number of considered eigenfrequencies. It turned out that the crucial parameter, which essentially influences the method, is the accuracy of the eigenfrequencies. A residual analysis determines the best fit for the simulated data, which is achieved by a linear proportionality function. The confidence interval is unchanged over the area of validity as well as the limit of quantification. Thus detection and quantification have the same sensitivity.

<table>
<thead>
<tr>
<th>Measured Eigenfrequencies [Hz]</th>
<th>Determined Stiffness Parameters [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.407</td>
<td>1.002</td>
</tr>
<tr>
<td>2.782</td>
<td>0.897</td>
</tr>
<tr>
<td>7.618</td>
<td>1.003</td>
</tr>
</tbody>
</table>

*Table 1. Identified stiffness parameters by means of measured (simulated) eigenfrequencies with an accuracy of three correct decimal places*

**Outlook**

The next step of the validation of method is the confirmation of the results of the simulations on test structures. For this purpose scale test models will be established and tests will be carried out in the laboratory and under natural excitation. Before real application on wind turbines further tests on large structures with real or artificial damages are desirable.

**References**


5.7 Modelling Soil-Structure-Interaction for Offshore Wind Energy Plants (VII)

University of Hannover - Institute of Soil Mechanics, Foundation Engineering and Waterpower Engineering

Martin Achmus, Khalid Abdel-Rahman

Introduction

Object of the project VII is the numerical modelling of the behaviour of foundation structures for Offshore Wind Energy Converters (OWECs). For that static, quasi-static cyclic as well as dynamic loads are to be considered. The working steps foreseen for the 5 year-duration of the whole project are shown in Fig. 1.

1 Model generation
   Gravity, monopile, tripod structures
   Behaviour under static loads

2 Modelling for cyclic loading
   Soil material laws for cyclic loading
   Implementation in numerical models

3 Identification of typical loading conditions
   Simulation of long term behaviour

4 Modelling for dynamic loading

5 Validation of simplified models

6 Software modules for integral modelling

Figure 1: Working steps foreseen in the project VII

In the first year numerical models for the monopile foundations, which are thought to have very good potential for safe and economic OWEC structures, have been established and their behaviour under static loads has been investigated. In the second year of the project this work was continued and parametric studies were carried out in that respect. Furthermore, methods to deal with the behaviour under cyclic loading were considered and analyzed.

Also numerical models for suction bucket foundations were established and the performance of such foundations was compared to that of monopiles. The results obtained so far are summarized in the following sections.

Results

Numerical Modelling of Monopile Behaviour under quasi-static Loading

For the investigation of the behaviour of laterally loaded monopiles with large diameters, a three-dimensional (3-D) numerical model was developed, in which the complex nonlinear elasto-plastic behaviour of soils is taken into account. The computations were done using the finite element program system ABAQUS (Abaqus 2005). In most cases, an idealized homogeneous soil consisting of medium dense or dense sand was considered.
For a specific design problem load-head displacement and load-head rotation curves can be helpful, because especially the limitation of head rotation is of importance for the serviceability of the wind energy plant. As an example, such curves are given for \( D = 7.5 \, \text{m}, \, L = 30 \, \text{m}, \) dense sand in Figure 2. Comparison is made with results of the usual design method in offshore engineering, the API method (API 2000).

![Graph showing load-head displacement and rotation curves for API and FEM methods.](image)

**Fig. 2:** Exemplary comparison of the pile deflection according to API method and numerical simulation for monopiles in dense sand \((h = H/H)\).

The findings from extensive parametric studies give rise to the conclusion that the API method for large-diameter piles yields too low deflections in most cases and should thus be used with great care (refer to Abdel-Rahman & Achmus 2005).

Regarding the parametric studies, different pile diameters \( D \), different pile lengths \( L \) and different heights of point of load application \( h \) were numerically simulated. Diagrams representing the pile head displacement \( w \) and the pile head rotation \( \phi \) at seabed level as a function of the horizontal load were determined. It was found that the overall stiffness of a monopile foundation can be roughly described by integral stiffness parameters defined as follows:

\[
C_w = \frac{H}{w} \quad (1) \\
C_\phi = \frac{H}{\phi} \quad (2)
\]

\(C_w(h)\) and \(C_\phi(h)\) diagrams can be derived by evaluation of a number of numerical calculations and can give a good overview on the behaviour of monopiles with different diameters and lengths. In Figure 3 such diagrams are given for the case of monopiles in dense and medium dense sand. The integral stiffness values were calculated for a load of \( H = 8 \, \text{MN} \).

For a specific site similar or comparable soil profile, a pre-dimensioning of a monopile foundation for static load design can be carried out on the basis of such diagrams.
Figure 3: Integral stiffness diagrams for monopiles in dense and medium dense sand.

**On the influence of quasi-static cyclic loading**

During the lifetime of an OWEC billions of loading cases induced by wave and wind actions apply to the structure. Thus, the loading has to be classified as intensely cyclic and fatigue design is of great importance.

Concerning the foundation structure, cyclic loading leads to an accumulation of permanent displacements. According to the German offshore regulation (GL 1999), the effect of cyclic loading of the foundation structure has to be taken into account.

Unfortunately, concerning monopiles no approved method exists to estimate the permanent displacements due to cyclic loading.

The method in API (2000) to deal with cyclic loading is of more or less empirical nature. It was derived by means of loading tests on smaller piles in which mostly less than 100 load cycles were applied. The number and amplitudes of load cycles are not taken into account. This method is not suitable for the estimation of accumulated displacements of monopiles.

In fact, strain accumulation does not stop reaching 100 cycles. Hettler (1981) proposed the following equation for the displacement of a pile in sand loaded by \( N \) cycles of the same horizontal load:

\[
w_N = w_1 \left( 1 + C_N \ln N \right)
\]

Herein \( w_1 \) is the displacement for static loading and \( C_N \) is a factor which for sand lies in the range of 0.20.

Long & Vanneste (1994) proposed a subgrade reaction method with linear increasing subgrade modulus with depth, in which the moduli decrease with the number of load cycles due to the following equation (see Fig. 4 left):

\[
k_s(z) = N^{-t} n_{h,1} z
\]

Herein \( t \) is a factor dependent on the pile installation method, the load characteristic (one- or two-way loading) and on the relative density of the sand. For a driven pile
with one-way loading in medium dense sand \( t = 0.17 \) is recommended. With this value an example was calculated. The results are given in Fig. 4. It was found that after 5000 cycles the displacement at the pile top is more than 3 times the static displacement.

![Graph showing cyclic one-way loading](image)

**Fig. 4:** Influence of cyclic one-way loading due to the method from Long & Vanneste (1994) for a monopile \( D = 7.5 \text{ m}, L = 30 \text{ m} \) in medium dense sand.

In reality, the amplitude of the load is varying with the wave heights and the wind velocities. For loads of varying amplitudes Lin & Liao (1999) proposed a strain superposition method to determine the resultant permanent displacement. For that the following equations apply:

\[
 w_{Ges} = w_{1,1} \left[ 1 + t \ln \left( N_1 + \sum_{k=2}^{n_k} N_k^* \right) \right] 
\]  
\[ \text{(5.1)} \]

\[
 w_{Ges} = w_{1,1} \left[ \frac{1}{t} \left( \frac{w_{1,k}}{w_{1,1}} (1 + t \ln N_k) - 1 \right) \right] 
\]  
\[ \text{(5.2)} \]

Herein \( w_{1,i} \) is the static displacement due to a load \( B_i \), which can be obtained by the calculation of the static load-displacement curves like the one given in Figure 2.

However, due to Lin & Liao the displacements obtained with this method overestimate the real displacements for large numbers of cycles. Additionally, in reality also the directions of the loads are varying. For two-way cyclic loading it is known that the cyclic displacements are significantly smaller than for one-way loading due to densification effects in the soil (see Hettler 1981, Long & Vanneste 1994). But at least the pile behaviour under general variation of loading directions and amplitudes is an open question, which will be object of further research.

**Suction Bucket Foundation**

The suction bucket was developed from the suction caisson foundation already used in the offshore technology (Ibsen et al. 2004). In principle its behaviour can be considered as a combination of a gravity base and pile foundation systems. For installa-
tion an underpressure is applied in the cavity between the top plate and the seabed (Fig. 5).

The mobilized penetration force results from the actual negative pressure multiplied with the internal cross-section area of the bucket plus the dead weight of the bucket foundation. The penetration resistance results from the skin friction mobilised along the outside and inside surface of the bucket as well as the base resistance at the bucket sleeves' toe.

![Diagram of suction bucket during installation](image)

*Figure 5: Suction bucket during installation*

For sandy soils the soil resistances can be calculated as for vertically loaded piles in accordance with API. Feld (2001) suggests a set of correction factors to compensate the effect of the water flow produced by the negative pressure during the penetration procedure of the bucket into the seabed.

According to the water flow from outside into the bucket it could come to large hydraulic gradients which cause a hydraulic shear failure of the soil in the bucket. This would lead to a loosening of the subsoil and to uncontrolled penetration of the bucket. Therefore a permissible under-pressure, which is dependent on the current penetration depth, may not be exceeded during installation.

Analyses of the installation process of suction buckets in medium dense sand were carried out. It was found that the reachable depth and thus the maximum height of the bucket lies in a range of 70 to 80% of the bucket diameter. Similar results were reported from Houlsby & Byrne (2004).

Numerical models were established to analyze the behaviour of suction buckets in sand soil under static load and to compare the performance with that of monopile foundations. In Figure 6 the results are shown as load-displacement curves.

It is evident that suction bucket foundations behave under smaller load levels as stiff or even stiffer than alternatively usable monopiles. However, under higher loads the deformations increase strongly, what can be explained with the much smaller embedded length of the bucket compared to the monopile. The bearing capacity regarding the horizontal displacement and rotation of this foundation under horizontal loads is smaller than for monopile foundation systems.

According to these results, suction buckets surely represent an alternative solution to monopiles. But, under higher loads, i.e. for example in case of large water depths,
monopiles are to be preferred in order to achieve the required limitation of deformations of the foundation construction.

Figure 6: Load-deformation curves for suction bucket and monopile foundations in medium dense sand.

References


5.8 Grid Integration of Offshore Wind Energy Parks (VIII)

University of Hannover - Institute of Electric Power Systems
Bernd R. Oswald, Jörn Runge, Ara Panosyan

Introduction
The research activities of sub-project VIII are divided into two main sub-topics:

- Grid connection and operation
- Wind energy generators and their control

Work on the research topics started in 2004 was continued and further extended. Additionally, new research topics were investigated and covered within this sub-project. The research activities in 2005 were centred on the following fields.

Frequency Transients in Interconnected Systems:
The rapid and ongoing development of wind energy in Germany accompanied by the liberalization of electricity markets in Europe has given a new significance to the problem of frequency stability. The general shift to more distributed generation is leading to a more diverse but less estimable generation. The increasing amount of unpredictable generation and the growing number of distant large off-shore wind-parks, connected to the grid through long and stressed transmission lines, will most probably further aggravate the problem of frequency stability. The wind electric-generating capacity in Germany today already exceeds the 3 GW primary control reserve of the European UCTE grid. This poses a major challenge for the grid operation, particularly in the event of a power failure. This is due to the fact that wind power plants do not contribute to the same extent towards stabilising the grid frequency and to voltage stabilising as is the case with traditional power stations, which are actively involved in grid control. Even more serious is the fact that so far wind power plants disconnect themselves from the grid even in the event of minor, brief voltage dips.

Aside from wind power, the unfolding liberalization of electricity markets in Europe has contributed greatly to the problem of frequency stability. The trip of overloaded interconnecting lines can trigger a chain reaction of grid areas disconnecting from interconnected grid leading to major blackouts (USA & Canada 2002; Italy 2003).

To illustrate and analyse the effects of disconnecting large wind-parks or power plants and the tripping of different interconnecting lines on the frequency behaviour of a grid model, an adequately accurate mathematical model was developed. By assessing the coupling admittance between the feeding buses of power plants, it was possible to identify different groups of generators that are strongly interconnected through the grid. The rotor angles of each such group have similar dynamic behaviour. Thus, each group was combined into an aggregated generator model. Consequently, the state differential equation system was considerably reduced through the model order reduction using the Singular Perturbation Method. The system in whole was nevertheless adequately represented, as only the fast transients between the generators in each group were neglected.
HVDC and FACTS

The increasing electricity trading in the liberalized electricity markets and particularly the supply from future large off-shore wind parks require innovative and reliable measures to optimize the capacity utilization of the existing interconnected European transmission grid. New strategies and advanced solutions like HVDC (High Voltage DC) and FACTS (Flexible AC Transmission Systems) are needed to support and maintain node voltages through dynamic reactive compensation, and relieve critical bottlenecks through power flow control. These can only be partially reached in the conventional networks.

To study the behaviour of HVDC and FACTS and their impact on the power flow and node voltage, new mathematical models are required to adequately represent these non conventional systems and enclose them into existing simulation tools.

New models for thyristor-based HVDC (“Classic”) and FACTS (SVC, TCSC, TCPS) devices were developed for static network calculations. The different models were then tested both separately and in combination with other non conventional devices on a test system. The different control modes of each device were also implemented and its effect on the overall power flow and node voltages analysed. In future work, similar models representing the new converter-based HVDC (“PLUS”, “Light”) and FACTS (STATCOM, SSSC, UPFC) should respectively be developed and added to the simulation tool. Similar evaluations will then be carried out on a complete test system.

Wind energy generators and their control

Due to the increased share of wind power in electricity generation, the Fault-Ride-Through ability (Fig. 1) of wind energy generators becomes important to avoid dangerous substantial loss of generation in cases of voltage drops caused by short circuits. Another necessary requirement for wind energy generators, which are substituting conventional power plants, is the support of power system operation. Frequency stability can be supported with active power control (pitch control or Decoupled Stator Voltage Oriented Control) and voltage stability with reactive power control (DSVOC). The use of converter technology for machine control and grid connection enables even more possibilities. For example, the crowbar control can provide adjustable short circuit power participation to match the particular compromise between locally isolated voltage sags and controllable short circuit currents (Fig. 2).

Figure 1 shows the momentaneous value characteristics of the rotor current (a) and the reactive Power (b) during a „Fault-Ride-Through“ simulation of a doubly fed induction generator. The reactive power control is equipped with a PI-controller and its reference value is zero. The simulated machine is not equipped with a crow bar control. In this regard, attention should be drawn to the peak value of the short circuit rotor current $i_p$. The possibility to damp this value of the simulated generator by utilising the crow bar control with varying resistances is diagrammed in Fig. 2.

In Fig. 3 the activation of the pitch control due to a step of wind speed from 10 m/s to 13 m/s is illustrated. The reference value of the mechanical power $P_m$ is 5 MW and a PI-controller is used.
Fig. 1: Starting and Fault-Ride-Through behaviour of rotor current and reactive power control; start: $t = 5 \text{ s}$, short circuit: $t = 10 \text{ s}$, short circuit length: 150 ms

Fig. 2: Influence of varying crowbar resistance on the peak current $i_p$

Fig. 3: The affect of Pitch control on the generated power

References:


5.9 Integrated modeling of offshore WEC (IX)

University of Hannover – Institute of Fluid Mechanics and Computer Applications in Civil Engineering
University of Oldenburg – Institute of Physics – Hydrodynamics and Wind Energy

Werner Zielke, Joachim Peinke, Martin Kohlmeier, Abderrahmane Habbar, Bernhard Stoevesandt

Introduction

The aim of the research project IX is to meet the demand of an integral simulation of offshore wind energy turbines. In an integrated model results of the research work should be incorporated and linked together.

The achievement of an integrated (IM) model suffers from the diversity of different processes and process interactions to be taken into account for the analysis of an offshore wind turbine and its associated sub systems. The models used by research teams and consulting engineers are usually heterogeneous. Therefore, a flexible structure of the integral model is the main target of current research. A well designed object-oriented and easily extendable set of models and interfaces have to be developed in order to fulfill future demands.

Approach

The basic principles of the integrated model are related to the members of the ForWind projects and their needs according to their research work and their simulation tools. Some important aspects are summarized as follows: programs used by the research teams are of different types, the data formats are inhomogeneous, data exchange is necessary during simulation.

Thus, the overall project is characterized by the distinct interactions of the other projects. In order to reduce the effort in data exchange, data conversion and modelling two approaches are being performed, i.e. (i) the set-up of a data exchange facility (meta data base ‘MetaWind’) and (ii) the development of an integral model for the coupling of simulation programs used or developed by the research teams.

Most important aspects are the realization of model interactions or couplings, using different strategies. Thus, the development of the integrated model will be done step-by-step in the following way: (i) independent models without any couplings, (ii) iterative coupling with exchange of input and output data and (iii) fully and direct coupling in simplified models.

Meta Data Base: MetaWind

According to the above mentioned strategy the integrated model has to be build up step-by-step. The first step is concerned with the access of data. The data compiled by the research teams are usually stored locally on personal computers or data servers. In order to provide the possibility to exchange these data the meta data base ‘MetaWind’ has been developed and is accessible via the link www.metawind.uni-hannover.de (see also Kohlmeier et al. 2004). Its decentralized concept is given in Fig. 1a. Interfaces to the integrated model (see Fig. 1b) can be added in future developments.
Integrated Modeling

Introduction

The numerical simulation of coupled processes (see Fig. 2a) is essential for optimization purposes and for prediction of the breakeven performance of offshore WEC. A variety of commercial simulation tools for fluid dynamics, multi-body dynamics or structural mechanics are available. Additional sophisticated tools for specific demands are being developed or self-improved. In order to serve several purposes an alternative use of different models is required to fulfill a wide variety of modeling and simplification strategies.

As already mentioned above, the set-up of a comprehensive model suffers from the multitude of heterogeneous modeling frameworks involved. The integrated model, to be developed within the research activities of ForWind, is supposed to reduce these shortcomings. Especially, the data management and the preparation or automation of simulation sequences are important aspects (Fig. 2b).

Thus, the IM has to be developed in terms of a flexible compound of modular simulation models combined with control, data base and interface units. These interfaces are one of the main targets as they will improve and accelerate interacting simulations. A modular concept will also enable independent code developments of several research teams.

Model concept

The IM research work is aimed to get together the diversity of different processes and process interactions which have to be taken into account for the analysis of an offshore wind turbine and its associated sub systems. Therefore, a flexible structure of the integrated model is the main target of current research. The current approach is depicted in Fig. 3. It combines the following features within development and application area:

Development: embedding of programming libraries (data base, GUI, OpenGL, data export or import and storage) on different computer platforms

Application: usability, flexibility, adaptability

The program is build up in an object oriented language (C++) using an application development framework (Qt®) for a GUI based cross-platform application with graphical visualization.

Current model development

Within this reporting period first couplings between sub models have been achieved. Thus, a linkage of the load module Wave Loads to the commercial code ANSYS® is available.

The current status of development of the IM allows to define geometric data, its discretization and the belonging material properties for the transformation to the wave load module (WaveLoads) followed by the specification of input files for a dynamic analysis using a finite element solver. Thus, the user is assisted in three ways. These are the geometric and material data transformation, the transformation (global/local) of the loading data and the evaluation of resulting values. With increasing amount of integrated sub-modules the usefulness of having graphical modules (see Fig. 4) available in the IM gets more apparent as well as the need of data format transition.
An application of the current model was shown by Mittendorf et al. (2005). The structural behavior of a monopile loaded by irregular waves with and without directionality of the wave field was analysed for investigation of the influence of the assumption of long or short crested waves on the structural response.

Another example was carried out using data of the research platform FINO1 to demonstrate a dynamic analysis. Preliminary results due to a prescribed wave load are given in Fig 5. In the next step the model will be validated with the strain gauge measurements of the platform. The objectives are (i) the transient analysis as needed for the fatigue analysis in time domain and (ii) the validation of the frequency domain methods. Commonly in frequency domain the structure stress response is related to the wave parameters using a transfer function.

**Future model development**

The next milestone will be the implementation of an aeroelastic model for the dynamical analysis of the structure due to combined wind and wave loads. Aeroelastic modeling is not part of the ForWind research projects. Therefore, free and commercial codes will be used. Available codes for this purpose are for example:

- AeroDyn: aerodynamic loads on a wind turbine blade element
- FAST: modal and multi-body dynamics
- MSC.ADAMS®: multi-body dynamics (MSC.Software)

The development will benefit from a cooperation with the MSC.Software Corporation initiated in 2005. In order to get an insight in multi-body simulation using MSC.ADAMS the seminar ‘Basic ADAMS Full Simulation’ was attended.

**Summary**

The configuration of a framework for the development of an integrated model is set up and the integration of sub models, interfaces and tools are being carried out.

First approaches in developing and using the integrated model are presented. Wave load prediction on offshore support structures and the dynamical analysis of the structure are performed and compared to experimental data.

Further steps are the incorporation of fatigue analysis as well as the implementation of a model for aerodynamic loads.

Finally, a coupled aeroelastic formulation is necessary for the analysis of the interacting turbulent aerodynamics and blade deflections in order to get resulting aerodynamic loads for the prediction of the response behavior of the overall WEC structure.

**Affiliation of the Wind Field to the Integrated Model**

The task of the partial project is to integrate the different partial projects with the aim of a modelling an integrated offshore wind turbine. As the main focus of research in Oldenburg lays on the analysis of the wind field, the objective is to model the wind-rotor interactions.

**Turbulent Wind and the Dynamic Stall Effect**

To implement the wind-rotor interaction a standard blade-element code is being developed. Into this model the effects of turbulence are to be integrated. Until now, the effects of the turbulent wind on the blade have not been sufficiently explored. This
causes the manufacturers to estimate the loads caused by turbulent inflow. Therefore the emphasis of the project was set on research considering the loads caused by wind turbulence on the rotor, especially due to the dynamic stall effect.

This effect describes the flow separation due to unstable inflow on an airfoil. Rapid wind speed and direction changes are typical sources for dynamic stall effects causing a strong, sudden increase of loads on a blades. The aim is to develop a reliable model for the dynamic stall effect caused by a turbulent wind field to integrate it in the blade-element code.

Simulating Turbulent Flow

A general model dynamic stall for different types of airfoils and changing wind fields is conveniently being developed by the use of a numerical simulation. As a base of this simulation the turbulent wind field investigated in partial project I is to be set as a boundary condition.

The numerical simulation is being done in close cooperation with the DLR in Göttingen. Together a code for numerical simulation has been chosen. Since for turbulent flow the approximations done by Reynolds averaged numerical simulations (RANS) reach their limits, the scientific „NekTar“-code has been chosen to simulate the effects of turbulent flow on an airfoil. For the code a direct numerical simulation (DNS) and a large eddy simulation (LES) version for 2D and 2.5D exist. Also a 3D version is available for DNS. The code uses a highly sophisticated spectral/hp method in the solver. This was considered to be the most promising and flexible approach to the problem. It combines spectral CFD methods with the use of unstructured meshes. So far the 2D DNS code has been tested on its abilities. Now a comparison of the 2.5D DNS and LES code are being prepared. As the use of DNS is still limited to lower Reynolds numbers in the long term the use of LES for the comparison with wind tunnel measurements is planned. Yet the code has to be modified to include turbulent inflow into the boundary conditions of the simulation.

Further Steps

For the simulations a proof of concept has been done so far. The simulation code is to be enhanced implementing also options for flexible objects. The simulation also has to be verified with measurements also conducted as part of partial project 1. As this is done finally the simulation is to be used to develop the flow and load model for blades.

The outcome of the research is to be integrated in a general blade element model used for modelling the rotors of wind turbines. Further development on such a code is also projected, since these codes are mostly the base for aeroelastic models.

References


Figure 1. (a) Decentral data base MetaWind. (b) MetaWind’s linkage to sub models incorporated in the integrated model.

Figure 2. (a) Components of the integral model: processes, loads and sub systems. (b) Coupled processes and sub modules of the IM.
**Figure 3.** Layout of C++ classes for sub modules and tools in the frame of the integrated model.

**Figure 4.** Visualization in the integrated model: discretized structure of FINO1 platform.
Figure 5. Finite element calculation using ANSYS and WaveLoads: (a) time histories of the water surface elevation, global bending moments and total forces and (b) the model of the FINO1 platform together with the deformed structure at time t = 15.5 s.

Fig. 6: Mesh and symbolic plot of nodes due to the order of the polynomial expansion (left) around a fx79-w151a airfoil.
Fig. 7: 2D-DNS calculation of pressure by NekTar (right).
6 Development Projects

6.1 Further development of the wind farm program FLaP for planning, wind farm monitoring and turbine design for offshore applications (EP1)

University of Oldenburg - Institute of Physics - Energy and Semiconductor Research Laboratory
Arne Wessel, Juan José Trujillo, Bernhard Lange, Joachim Peinke
Partner: GE Wind, Salzbergen; Overspeed, Oldenburg
2004 – 2005

Introduction

The maintenance of the wind turbines is one of the big problems for offshore wind farms. The accessibility is strongly dependent on weather conditions. Therefore a condition monitoring of the wind turbines is recommended. The monitoring tool for the wind farm should also be able to calculate the expected power output of the wind farm and compare it with measured values to detect deficits.

The wake situations inside wind farms increases the loads at the wind turbines. Very simple models are used to calculate these effects and better models are needed.

The aims of the project is to use the software FLaP (Farm Layout Program) of the University of Oldenburg for the calculation of the turbulence intensities inside wind farms in respect to loads and enhance the capability of FLaP for wind farm monitoring. The focus is laid on offshore wind farms, where the difference between the turbulence inside the wind farm and the surrounding is quite high.

Approach / Activities

The aims were bundled as a development project together with two commercial companies as partners: Overspeed GmbH & Co KG and General Electric Wind Energy. The project started 1.9.2004 and was finished at 31.09.2005. The work is structured in four subprojects:

- Subproject I: Modeling of turbulence intensity
- Subproject II: Modeling of fatigue loads
- Subproject III: Use for wind farm monitoring
- Subproject IV: Graphical user interface and marketing

The work in this project is performed within the Offshore Wind Power Meteorology and Wind Farm Modeling group of ForWind in close connection with the PhD project Modeling of Turbulence in Wind Farms.

Interim results

A short description of the most important results is given in the following section.
Subproject I: Modelling of the turbulence intensity
A new model for the calculation of the turbulence intensity inside wind farms was developed. The model consists of two parts: A model for the turbulence intensity profile inside the wake of a single wind turbine and a model to superpose the wake for wind farm situations. The model has been verified with measurements from Nibe, Sexbierum and Vindeby wind farms with good agreement [Wessel and Lange, 2004a], [Wessel and Lange, 2005b], [Wessel and Lange, 2004b], [Wessel et al., 2005], [Wessel and Lange, 2005a]. The model was included in FLaP. The calculation of turbulence should also increase the accuracy of the estimation of the wind speeds and powers at the wind turbines inside a wind farm.

Status: finished

Subproject II: Modelling of fatigue loads
Due to change in personnel and a different company structure a cooperation with GE Wind Energy could not be performed until the end of the project.

Status: interrupted

Subproject III: Use for wind farm monitoring
The software FLaP has been extended to wind farm monitoring and validated with measurements from the wind farm Bassens.

The following enhancements have been included in FLaP:

- Processing of time series in DEPRI format
- Correction of power curves for different ambient air densities
- Using nacelle anemometers for input wind speed. Uses always the nacelle of the wind turbine, which is in free stream situation.
- Switched off wind turbines are not taken into account for farm calculation

The influence of the new features and the new model for calculating the turbulence intensities inside the wind farm have been compared to measurements from the wind farm Bassens [Trujillo et al., 2005].

The turbulence intensity model increase the accuracy of the calculation of the wind speeds inside the wind farm and therefore the accuracy of the power estimation of the wind turbines. Another benefit of the new approach is a lower number of external parameters for FLaP. The overall accuracy of the power prediction inside the wind farm is good at the wind turbines at the border and lower for the wind turbines deeper inside the wind farm.

Status: finished

Subproject IV: Graphical user interface and marketing
The competence center decided not to go ahead with the original plan to develop a new graphical user interface. Therefore, instead of supporting the development of a new GUI, the existing GUI and the program code have been ported from MS DOS to Windows OS and actual compiler standards.

Status: finished
Figure 1: Comparison of averaged measured and modeled power at Bassens wind farm for an average ambient wind speed of 6.75 m/s. Data modeled with FLap and turbulence intensity model. The values are absolute power in kW.

References


6.2 Development of a nowcasting and shortest term Wind Power Facility (nowCash) (EP2)

University of Oldenburg - Institute of Physics - Energy and Semiconductor Research Laboratory

Detlev Heinemann, Carsten Poppinga, Lueder von Bremen, Nadja Saleck

Partner: Meteocontrol GmbH, Augsburg

2004 – 2005

Description

EP2 aimed to combine latest wind measurement of the network of the project partner Meteocontrol with recent wind forecast. The weather information provider Meteocontrol has a very dense network of wind observations over all Germany and provides these data in approximately one hour after the measurement. Therefore this data is ideal to update wind forecasts, which are already about 10 hours old after they had been released by weather forecast centers.

In the frame of this development project a new product with the name ‘nowCash’ was implemented at ForWind. ‘nowCash’ stands for nowcasting and shortest term and the entire program is a Wind Power Facility, as nowcasted winds and shortest term wind forecasts are transformed into wind power. ‘nowCash’ is designed for Germany.

The name ‘nowCash’ was chosen to stress the importance of most actual wind power forecasts for the energy industry. Every little imbalance between grid load (consumption) and scheduled production by conventional power plants and renewable energy sources must be regulated by the transmission system operator with the help of regulative power that can be bought on the intra-day spot market. Regulative power is very expensive; its use is strictly to be minimized. As wind power production can not be scheduled but only forecasted, the accuracy of wind power forecasts is vital and can be worth as much as “cash” money.

Approach

The ‘nowCash’ facility combines wind measurements and NWP forecasts for nowcasting and very short term forecasts. Within years Meteocontrol has built a network of 10m wind speed measuring stations. Meteocontrol makes this measuring network available for the project. In a first step measured wind speeds are extrapolated to the average hub height and then interpolated to a regular grid over Germany. This interpolation is done by a Kernel Interpolation technique. Gaussian Kernel weighting functions have been chosen. Examples of these weighting functions are shown in Figure 1. The half power width can be adjusted individually for each measuring site.

The regular grid of wind speeds is then used as input for the wind power forecasting, which works with parameterized power curves and gridded values of installed wind power capacities for Germany. Gridded values of forecasted wind power are returned as output.

For the short term forecasting application the deviation of observation and forecast at the time of observation is added to the forecast with larger time steps. An exponential
decay of the deviation is implemented at the moment, i.e. the correction is equals zero for a forecast step of 24 hours.

Figure 1: Gaussian weighting functions with different half power widths that are used for Kernel Interpolation of wind speeds to a regular grid over Germany.

Results

The nowcasted wind power and shortest term wind power forecasted is visualized as bars on a map of Germany. The bars are valid for a region of 40x40km. The total estimated wind power is also given in the header of the plot (Figure 2). Optionally the wind forecast can be plotted as well. The application to subregions of Germany is possible and can be used for regional nowcasting and forecasting.

Figure 2: Example of visualization of wind power shortest term forecasting for Germany with the 'nowCash' facility. The forecast step is +3h and is valid for 21:00:00 UTC. The given bars represent the power within a 40kmx40km box.
6.3 Analysis of wind turbine characteristics and wind turbulence with respect to improve energy output prognosis (EP3 & EP9)

University of Oldenburg – Institute of Physics – Hydrodynamics and Wind Energy
Edgar Anahua, Julia Gotschall, Stephan Barth, Frank Böttcher, Norbert Zacharias, Joachim Peinke


Description
One of the main characteristics of wind as energy source is its variability in space and time. For physical reasons the power of wind is proportional to the wind velocity cubed. Therefore these fluctuations, i.e. due to complex terrain, can lead to very large fluctuations in power. For a genuine estimation of energy output and a reduction of fluctuations within the electric grid it is indispensable to understand the influence of turbulence on wind turbine characteristics. The knowledge of which can then be used to determine power curves not only more accurate, but also much faster as it is commonly done.

Activities
The proper estimation of the wind turbine-specific power curve, i.e. the functional relation between the (averaged) wind speed $u(t)$ and the corresponding (averaged) power output $P(t)$: $<u(t)> \Rightarrow <P(u(t))>$ is crucial. On the basis of this relation and the expected annual wind speed distribution at a specific location the annual energy production (AEP) is estimated. The main problem of a proper determination of the power curve (officially regularized in IEC 61400-12) is its non-linearity in combination with the turbulent wind field. It is well known that to characterize a fluctuating non-linear quantity higher order moments have to be considered. In view of the determination of a proper power curve this means that the association of an averaged power to an averaged wind speed is not unique but will depend at least on the intensity of fluctuations. To circumvent this difficulty it was suggested to expand the power curve into a Taylor expansion. This leads to an expression, which shows that the 'real' power curve (as it would be realized in laminar wind flows) has to be modified. This modification is the stronger the larger the variance of the fluctuations. We proposed an alternative approach (based on the theory of Langevin processes) to determine the 'real' power curve even for very noisy (turbulent) wind conditions and tested it with a simple synthetic power curve model. The results from this Ansatz look convincing, see Fig. 1.
Fig. 1: The thick solid line indicates the ‘real’ power curve. Open symbols represent the reconstructed curves according to the IEC-standard for turbulence intensities of 10%, 20% and 30%. Filled squares represent the new method, based on Langevin processes.

Fig. 2: Stationary power curve given by fixed points method for all wind velocity intervals (black line). The arrows represent the deterministic dynamical relaxation of the power output given by a two-dimensional analysis.

These promising results are the basis for further analyses of real experimental data-sets. We started with pairs of variables \((u, P(u))\) measured at a metmast and at a 2MW wind turbine located in Tjareborg, Denmark and were able to evaluate the advanced power curve model. Results show a more proper power curve compared to
IEC ones. In addition this power curve can be derived from less data points as necessary after IEC standard. Especially the sharp kink at the rated power can usually not be seen in IEC power curves due to averaging, see figure 2.

We also applied a different model, proposed by Rauh and Peinke, to this dataset. This model describes wind fluctuations and the according delayed wind turbine’s response. A combination of both methods has been achieved leading to valuable progress in the analysis.

To acquire further meteorological datasets as well as the electrical power output of a more modern wind turbine a metmast of 100m heights has been installed beside an ENERCON E66 plant (rated power: 2MW), which is located in a wind farm in the complex area of Meerhof close to Paderborn, Germany. In order to cover the whole wind profile the metmast is equipped with anemometers, wind vanes, temperature- and humidity probes on 2m, 10m, 33m, 50m, 66m, 80m and 98m. The temporal resolution of the setup is 1Hz in general and 50Hz for the used ultrasonic anemometers and the electric power output. After several technical problems in the campaign’s beginning some parts of the measurement system had to be changed. At the same time a remote monitoring system has been developed, allowing checking and resetting some crucial parts via Internet. Currently standard analyses of measured datasets are going on in order to check quality and consistency.

Fig. 3: PDFs of horizontal velocity increments at hub height, for time delays of 1s, 3s, 23s and 1024s (from top to bottom). The PDFs have been shifted in vertical direction for presentation and all of them have been normalized to their standard deviation.

In the following, a brief description of these preliminary analyses is given. The horizontal wind velocity fluctuations within the wind turbine’s rotor swept area is analyzed by means of velocity increments, i.e. \( u(t+\tau)-u(t) \), with \( \tau \) varying from 1 day to 1 second. The probability density functions (PDFs) of these velocity increments show the expected non-Gaussian, heavy-tailed behavior, known as intermittency, see figure 3. The values in the heavy tails correspond to events of very large velocity fluctuations or gusts. These fluctuations are not only responsible for mechanical fatigue but also for fluctuations in power output and therefore have to be taken into account when estimating wind turbines’ power curves.

To check consistency of velocity and power output two exemplary time series are shown in figure 4. As can be seen fluctuations in power output correspond to fluctuations in wind velocity.
Preliminary investigations of these measurements show that we are able to derive the power curve with our models from datasets taken over a few days. This gives the chance to check wind power plants several times, e.g. each week, during their life-span allowing to estimate if a lack in efficiency is due to unusual wind situations or to non-optimal behavior of the wind turbine itself.

For the next period of the project analyses will go on, allowing getting more information about local wind conditions and further meteorological variables as well. These additional quantities will be included in the method in order to derive a multidimensional power curve.

So far the analyses have mainly been focused on deterministic parts of the processes. Beyond the improvement of this technique further steps shall also look at diffusive parts, i.e. noise.

Cooperation
This ForWind development project has been integrated in the framework of the European Wind Energy Academy (EWEA). So doing collaborations with other national and international research institutions have been established thorough seminars, colloquia and conferences. These collaborations allowed to exchange information, new methods and experiences in wind energy research.

A cooperation with ‘Institut für Solare Energieversorgungstechnik’ (ISET) has been established, giving access to supplemental datasets, which can be used for further testing and improving of our new methods.

Publications


**Conference Contributions**


6.4 Dynamic load bearing capacity of slip resistant bolt connections in truss towers of WECs (EP4)

University of Hannover - Institute for steel Construction
Peter Schaumann, Tim Rutkowski
Partner: SeeBA Energiesysteme GmbH, Stemwede
2003 - 2005

Description

Pre-stressed slip resistant bolt connections are increasingly applied in truss towers for WECs (Fig. 1). An actual construction contains around 10,000 bolts in one tower. The load bearing capacity of these connections may vary due to bolt pretension and surface properties of the connected components.

In operation under dynamic loads the load bearing capacity of the connection is reduced because settlement effects lead to lower clamp forces. On the other hand the ultimate slip load can be increased. Dynamic loads below than the limiting friction increase interlocking of the surfaces and raise the coefficient of friction.

To investigate the effect of different material properties and varying load levels on the connection’s bearing behaviour, an experimental testing program was set up which was supported by numerical investigations.

Testing Program

In the testing program different surface coatings were tested to examine their influence on the bearing behaviour. The experiments included components which were hot dip galvanized and ASI-coated with various layer thicknesses. The decrease of bolt pretension due to settlement and the influence of dynamic preload of different load levels on the friction coefficient were tested. The results show greater loss of pretension but better friction coefficients after dynamic preload for thick coatings (Fig. 2).

Figure 2: Results of settlement and tension tests
A spring washer was developed to reduce the decrease of bolt pretension. It compensates settlement effects by its flexibility and reduces the loss of pretension (Fig. 3).

![Figure 3: Decrease of bolt pretension under dynamic loads with / without spring washers](image)

**Numerical Investigations**

The positive effect that dynamic loads have on slip resistant connections is well known and was verified by the project’s test program but is difficult to describe by physical laws or simplified engineer-models. To reproduce the effect of a dynamic pre-load numerical, an adhesive power module has been developed for the FE-Program ABAQUS®. The module has been verified by tests (Figure 4).

![Figure 4: Load deformation diagram for different levels of adhesive power, testing configuration](image)

The positive effect that preload has on the limiting friction force could be simulated by a FE-analysis with a random generated surface (Figure 5).
Results / Outlook

Tests on slip resistant bolt connections show the impact of settlement and interlocking effects on the load bearing capacity of the connection. To reduce the loss of pretension a spring washer was developed which partly compensates the decrease.

FE-simulations can reproduce dynamic interlocking effects by high computational costs. Further investigations could lead to a multi-scale model of the connection for the consideration of dynamic effects on the micro-scale in design-calculations.

Publications


[3] Dynamische Tragfähigkeit gleitfester Schraubenverbindungen in Gittermasten für Windenergieanlagen, EAWE-Dokorentreffen, Kassel, 2005

6.5 Hybrid junctions between steel and concrete towers for WEC subjected to fatigue loading (EP5)

University of Hannover - Institute of Concrete Construction
Jürgen Grünberg, Joachim Göhlmann
Partner: Oevermann GmbH & Co. KG, Münster
2003 - 2005

Implementation of a multi-stage fatigue damage model for concrete at the finite-element program ABAQUS

A new damage approach for concrete subjected to multi-stage fatigue loading, already described in detail in [1], is implemented by associating an external damage algorithm with the elastoplastic material law for concrete providing of the finite element-program ABAQUS.

This concrete model considers the inelastic behavior of concrete by an isotropic damage formulation combined with isotropic plasticity and a non-associated flow rule, Fig. 1. The material formulations are based on a damage model by and the extension by [3]. Its execution for concrete under uniaxial monotonic and cyclic loading as well as multiaxial loading was proved and extensively tested in [4,5], and [6].

In general, the damage state is described according to the common procedure of the continuum damage mechanics by introducing a damage variable $d_c$ into the constitutive equations, see eq. (1). Therefore, the damage value expresses the rate of damage in terms of degraded elastic stiffness.

Fig. 1: ABAQUS damage model for concrete under compression
\[ \sigma_c = (1 - d_c) \cdot E_0 \cdot (\varepsilon_c - \tilde{\varepsilon}_{pl}) \]  

\[ E_0 = \text{initially elasticity modulus} \]
\[ d_c = 0: \text{undamaged material behavior} \]
\[ d_c = 1: \text{completely stiffness degradation} \]

The implementation of the external damage algorithm into the concrete model is arranged by a user-subroutine. In principle, the finite-element program ABAQUS provides application of user-subroutines e.g. to affect a running analysis process, modifying solution dependent material properties during non-linear analyses or to implement self-developed material models and many others more.

In this regard, the user-subroutine USDFLD was applied, which calculates the current damage state due to the fatigue process at the beginning of each iteration step and restores the degraded stiffness \((1-d_c) \cdot E_0\) to the elastoplastic damage model for the next iteration step. This operation is carried out at each integration point of the finite elements.

The procedure is illustrated in Fig. 2, exemplarily for a concrete column subjected to four uniaxial load cycles in compression. Therefore, the damage state is modified by the user – subroutine USDFLD. The load history is applied time dependent, so that the execution of the damage calculation inside of the user–subroutine could be regulated and controlled by the process time of the finite element analysis.

After the first loading, the stresses are computed at all integration points of the elements and saved as field variables. Following, the column is completely unloaded. After unloading the damage state \(d_c\) is affected by the user-subroutine depending of the stresses in the field variables. Subsequently, the current elastic stiffness degradation is restored to the concrete model. Then, the following second loading could be applied considering the modified material stiffness. According to this procedure, the calculation is continued for the next two load cycles. In this context, you should recognize, that time dependent plasticity strains due to fatigue process can not be taken into account.
Fig. 2: Modifying of the current damage state

For computation of life time of a concrete tower for wind turbines and its respective fatigue damage evolution, the real load history is divided into a number of life cycle terms. Within one life cycle term a constant stress level and unchanged damage state is assumed for a certain defined number of load cycles.

During the non-linear calculation each complete loading and unloading cycle represents one life cycle term. After each loading the stresses are read at each element integration point of the structural model and saved being available for the damage algorithm in the user-subroutine USDFLD after unloading. The corresponding numbers of load cycles are allocated directly to the user–subroutine depending of a loading-time function. The procedure is illustrated in Fig. 3.
Fig. 3: Overview of the fatigue damage analysis with ABAQUS
Damage evolutions calculated for a concrete column under a constant compression fatigue loading, and a three-step compression fatigue process respectively, are illustrated in Fig. 4 and Fig. 5. It is evident, that the external damage algorithm as well as the regulation of the fatigue calculation are implemented in the user–subroutine correctly. Adjusting the size of the life cycle terms, the damage evolution could also represent in the beginning of the fatigue process very exactly.

Subsequently, the user–subroutine was extended for the application of shell and solid elements, so that spatial concrete constructions and especially hybrid junctions for towers of WEC can be investigated numerically.

A simplified preliminary investigation of a prestressed concrete tower for a multimegawatt wind turbine is illustrated in Fig. 6, for instance. From the finite element computation a significantly lower damage value has been achieved compared with the Palmgren – Miner accumulation law. Only a marginal change of the stress distribution could be detected.

The aim of this research part is the quantification of the fatigue damage evolution and the resultant rearrangement of the stress distribution in concrete towers for wind turbines.

![Fig. 4: Computed fatigue damage evolution in concrete by the external damage algorithm associated with the finite element program ABAQUS](image-url)
Fig. 5: A computed three-step fatigue process with the external damage algorithm associated with ABAQUS

Number of load cycles: $N = 10^9$

Damage value: $D = 0.1$

Degraded elasticity modulus: $E_{c,da} = 0.9 E_c$

Fig. 6: Preliminary investigation of the damage evolution in a prestressed concrete tower for a multi-megawatt wind turbine.
Publications


6.6 Improving demand forecast for decentralised energy management (DEMS) (EP6)

ForWind
Rainer Klosse, Marcel Krämer
Partner: EWE AG, Oldenburg
2004 – 2005

Introduction

The project’s object/goal was to optimize the used parameter of the load forecast system „LPS-Prophet“ by the company VA TECH SAT Ltd to predict the consumption of electricity consumption in the supply area of the EWE AG.

Additionally within the scope of this project also the impact of weather effects on the electricity demand was analyzed and was used in a separate procedure for the improvement of the forecast.

In conjunction with the project partner EWE theses were worked out, which by experience of the EWE and ForWind show dependencies of the electricity demand to different weather effects. These dependencies were to be verified with the aid of the software tool “Prophet“ and special research methods.

Prophet optimizations

For all modules used for the software tool „Prophet“ (Fuzzy logic, recursive regression, comparative day prognosis, artificial neural networks) settings or alternatively ways of proceeding were found, which improved a load prognosis on average noticeably towards a persistence forecast. Rarely greater variances were observed.

For each of the three modules Fuzzy logic, recursive regression and comparative day prognosis spaces of time were found, which in comparison to other modules can be forecasted particularly well.

These conclusions however are only based upon tests in the month of march. If the prognoses of the different methods get combined, the square or average deviation to the measured value as an overall prognosis can be further reduced. Therefore it makes sense to operate the modules Fuzzy logic, recursive regression and comparative day prognosis parallel to each other, even if as a single modul they do not work precisely. The exactness of the manual forecast by the EWE, which next to the use of calculation tools is also based on the experience of the employees, was not accomplished.

One cause of the lack of exactness is seen in the limited possibility to integrate more than one exogenous factor into the prognosis. Additional information as the beginning of vacations or other outstanding occurences, cannot be taken into account.

Meteorological impacts on load prognosis

It was verified, that especially at night the temperature and in the afternoon, global radiation have a great impact on the load. The development of a filtered temperature time series, taking into account the time offset on the output, bears room for im-
provement for the output prognosis. Concerning the load a logarithmic dependency to global radiation was noted/found.

The impact of wind or rain on the demand curve was not taken into account so far. Especially during phases of strong wind an increased accounting error due to the wind power input has to be anticipated.

During the hours of night or dusk exogenous factors have an especially strong effect on the power demand. Particularly these time periods are often very poorly forecasted by the modules of the „Prophet“ system. For these reasons we recommend it is recommended to further examine the meteorological impacts on the demand curve.

Publications

Schönwiese Christian-Dietrich; Praktische Statistik für Meteorologen und Geowissenschaftler; Verlag: Gebrüder Borntraeger Berlin Stuttgart 2000

Prof. Dr. Andreas Zell, Universität Tübingen, Simulation neuronaler Netze

Dipl. Ing. Chr. Meisenbach, Dr.-Ing. S. Gnüchtel, Dresden, Lastprognose konventionell oder mit neuronalen Netzen – ein Vergleich
6.7 Usage of combined acceleration and strain sensors for early diagnosis of damages (EP7)

University of Hannover - Institute of Structural Analysis
Wolf-Jürgen Gerasch, Stephan Zerbst
Partner: Hottinger Baldwin Messtechnik GmbH, Darmstadt
2004 – 2005

Description
Regarding extreme dynamical loads on offshore wind turbines there is surely a need of a functional system for structural monitoring of the tower and blade construction. The claim is to detect growing damages as soon as possible, because it will not be possible to access these farms at any time for visual inspection. However, the existing intensity of loads affecting these structures can only be estimated until now.

A certain theory has been investigated which bases on the proportionality of maximum dynamic stress and velocity [1] [2]. Therefore laboratory tests on special tower-models (scale 1:25) have been made.

![Figure 1: Test-models (scale 1:25)]

Activities
The function of this particular theory for the undamaged state is briefly explained: dynamic stress, measured by strain gauges, is proportional to dynamic velocity, which can be derived from measured acceleration signals. This relation is valid when sensor locations are in line with the eigenform occurring.

The sensor locations have to be chosen according to the maximum eigenform amplitudes and the maximum stress locations. Looking at tower structures of megawatt wind turbines loaded by dynamic wind and wave forces, one can expect that only the
two lowest eigenforms prevail. So the locations for sensor application are not difficult to find. For both, the first and second eigenform the location of maximum stress is the bottom of the tower. Maximum amplitudes occur at the top and approximately in the middle of the tower for the first and second Eigenform, respectively.

After investigating the dynamical behaviour of the tower model structures regarding eigenfrequencies, eigenforms, damping and verifying the theory for the undamaged state, artificial defects were applied. By slowly weakening the cross-section-area of the pipe structure the change of proportionality was observed and re-related to the dynamic behaviour of the structure. The pipe was weakened stepwise up to 50% of the cross-section. Load was applied by impulses and by an imbalanced harmonic exciter at different locations. Altogether four model structures have been damaged.

Preliminary Results

A well-known effect in case of damage is the decay of the eigenfrequencies. Observing the eigenfrequencies is therefore often applied in today’s structural monitoring systems and can be considered as a state-of-the-art method. Nevertheless it has to be mentioned that a change of eigenfrequency mostly can be noticed only when damage has already reached a certain magnitude. This project certainly has the goal to detect defects at an earlier state, so that simple measures can still be taken and there is no danger of a total loss or of defects which cause longer terms of standstill.
The tests revealed that this method could be a reliable tool for early damage detection because the change of proportionality was spotted much earlier than a change of eigenfrequency. The tables below show the stepwise weakening of the pipes cross-section concerning the first and second eigenform.

This method is obviously more sensitive than a pure eigenfrequency-method.

<table>
<thead>
<tr>
<th>Damage</th>
<th>Change Proportion. [measured]</th>
<th>Change Eigenfrequency [measured]</th>
</tr>
</thead>
<tbody>
<tr>
<td>undamaged</td>
<td>0,00%</td>
<td>0,98Hz</td>
</tr>
<tr>
<td>10%</td>
<td>2,54%</td>
<td>0,98Hz</td>
</tr>
<tr>
<td>20%</td>
<td>4,31%</td>
<td>0,98Hz</td>
</tr>
<tr>
<td>30%</td>
<td>6,13%</td>
<td>0,96Hz</td>
</tr>
<tr>
<td>40%</td>
<td>8,30%</td>
<td>0,88Hz</td>
</tr>
<tr>
<td>50%</td>
<td>13,40%</td>
<td>0,78Hz</td>
</tr>
</tbody>
</table>

Table 1: First eigenform, change of eigenfrequency vs. change of proportionality

<table>
<thead>
<tr>
<th>Damage</th>
<th>Change Proportion. [measured]</th>
<th>Change Eigenfrequency [measured]</th>
</tr>
</thead>
<tbody>
<tr>
<td>undamaged</td>
<td>0,00%</td>
<td>21,09Hz</td>
</tr>
<tr>
<td>10%</td>
<td>1,24%</td>
<td>21,09Hz</td>
</tr>
<tr>
<td>20%</td>
<td>3,38%</td>
<td>20,90Hz</td>
</tr>
<tr>
<td>30%</td>
<td>4,45%</td>
<td>20,90Hz</td>
</tr>
<tr>
<td>40%</td>
<td>8,72%</td>
<td>20,70Hz</td>
</tr>
<tr>
<td>50%</td>
<td>9,66%</td>
<td>20,32Hz</td>
</tr>
</tbody>
</table>

Table 2: Second eigenform change of eigenfrequency vs. change of proportionality

**Outlook**

The next step of the method’s investigation is moving from indoor to outdoor conditions. It will be interesting to check whether this method can also be applied under ambient wind excitation conditions. A new scaled test-model is now installed on the institute’s test site and will soon be used for further investigation. Future tests will show if the theory could be a reliable alternative method for early damage detection.
Figure 4: Scale-model at outdoor test site

References


[2] Gasch, R., Dr.-Ing.: Eignung der Schwingungsmessung zur Ermittlung der dynamischen Beanspruchung in Bauteilen

University of Hannover - Institute of Fluid Mechanics and Computer Applications in Civil Engineering

Martin Kohlmeier, Abderrahmane Habbar, Werner Zielke
Partner: MSC.Software Corporation
2005 - 2006

Introduction

The aim of this project is to get together the objectives of the commercial software developer MSC.Software and the research work of ForWind in the field of integrated modeling of offshore wind energy converters (offshore WEC). In particular, the objectives of MSC are (i) to intensify their field of business activity according to wind turbine simulations and (ii) and to introduce reliable, well-integrated simulation tools, powered by a uniform architecture and interface.

The transition from disparate point solutions to integrated modeling is an important point of the research activities. ForWind’s objectives are (i) the orientation of his research towards current needs and (ii) the use of interfaces to commercial simulation software for the development of an integrated model. Thus, the main target is the combination of own research software and highly validated widely used commercial software.

Furthermore, the work of ForWind’s project IX ‘Integrated modeling of offshore WEC’ will benefit: Among available non-commercial tools also commercial tools are available and will considerably improve the integrated model development.

Approach

This development project is based on a cooperation with the MSC.Software Corporation initiated in the fall of 2005 which provides access to MSC software and allows joint development and research accompanied by the research of project IX in the field of integrated modeling. This framework is supposed to combine research codes, non-commercial and commercial codes. Next development activities will be concentrated in the field of wind-structure interactions and the simulation of the dynamic behavior of rotor blades, gearbox and the electric generator. Available codes for the purpose of aeroelastic simulations are for example:

- AeroDyn: aerodynamic loads on a wind turbine blade element
- FAST: modal and multi-body dynamics
- MSC.ADAMS®: multi-body dynamics (MSC.Software)

In order to get an insight in multi-body simulation using MSC.ADAMS the seminar ‘Basic ADAMS Full Simulation’ was attended. Further knowledge in interface development will be provided in ensuing seminars.

Using this knowledge, commercial as well as non-commercial code can be linked together in the framework of an integrated model. Within a step-by-step approach existing and new modules and interfaces will be added and finally complete the functionality of the integrated model.
Next Steps
During the ongoing development of the integrated model the wave load prediction and the dynamic analysis modules (Mittendorf et al., 2005) will be linked to the wind load and aeroelastic modeling performed by FAST or MSC.ADAMS®.

References
6.9 Joint design of precast concrete towers for Wind Energy Converters subjected to fatigue loading (EP10)

University of Hannover - Institute of Concrete Construction & Institute of Building Materials

Jürgen Grünberg, Ludger Lohaus

Partner: Oevermann GmbH & Co. KG, Münster

2005 – 2006

Introduction

Due to the ongoing development of wind energy converters with increasing power capacity, the structural requirements especially concerning the towers rise as well. These towers are increasingly designed as hybrid structures made of precast concrete elements in the lower part of the tower and prefabricated steel sections in the upper part. Concerning the connection of the precast concrete elements the question of the maximum transferable shear stress in the joints between the precast elements arises, especially regarding fatigue loading. These joints are usually filled using ready-mixed high-strength grouts.

Approach / Activities

Grout-Material


The DBV recommendations were published at the beginning of the 1990’s in order to unify the testing methods and testing procedures for industrially produced ready-mixed grouts. According to the DBV grout is composed of cement, aggregates with a maximum grain size of 4 mm and chemical additives. In addition to minor changes the revision of the recommendations in 1996, the validity was extended to concrete for grouting with a maximum grain size of 8 mm. Similar requirements concerning the constituents can be found in DIN 1045-2.

The former german regulation DIN 18557 “Mortar, manufacture, inspection and consignement”, which was usually applied by the ready-mix-concrete industry was withdrawn in 2003 and included in DIN EN 998 with stronger emphasis on masonry structures.

The somewhat similar ready-mix mortar guideline by the DAfStb is currently revised to comply with fundamental changes in European regulations.

Regarding the calculation and dimensioning of precast structures and their joints particularly DIN 1045-2 section 5.3.8 defines whether or not grouts may be included in the calculation, depending on their composition. Most important, the properties of the cement, the aggregates and the durability of the concrete have to be ensured by
complying with the corresponding regulations. In addition, the quality of the concrete used for the precast elements has to be within the range of normal-strength concrete. Therefore their compressive strength is limited to C50/60. Furthermore, the DBV recommends using grouts with a compressive strength exceeding 55 MPa.

**Design of Joints**

The current design rule for concrete constructions in Germany is DIN 1045-1. In chapter 10.3.6 the transfer of shearing forces in joints between precast concrete elements and in-situ concrete is given.

There is a difference between reinforced and non-reinforced joints.

The shearing force design value of non-reinforced joints $V_{Rd,ct}$ consists of static friction and crack friction. The friction coefficient depends on concrete surface property.

In DIN 1045-1 the surface conditions of gaps are divided into teethed, unsmooth, smooth and very smooth. Furthermore information about the relation of surface property to the types in design rule (DIN 1045-1) can be found in publication No. 525 DAFStb.

But there are no further information, weather the recommended friction coefficient for static loads can also be used for low cycle or high cycle fatigue loading.

For concrete constructions a well known stiffness degradation under fatigue loading has to be taken into consideration. Most probably there will also be a decrease of shear force transmission in the mortar joint.

Therefore, the application of such static design rules could result in unsafe constructions for precast concrete towers of Wind Energy Converters (WEC).

Neither in design rules nor in literature there are information concerning the change of friction coefficient in mortar joint under high dynamic load.

**Specimen development**

Regarding the requirements for grout named above, only few commercially available products can be chosen. For this project a mortar was selected, because it complies with the following requirements:

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Requirement</th>
<th>Selected mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum grain size</td>
<td>≤ 4 mm</td>
<td>∅ 1 mm</td>
</tr>
<tr>
<td>DBV recommendations, 1996</td>
<td>≤ 4 mm</td>
<td></td>
</tr>
<tr>
<td>DIN 1045-2/A1, issue:2005-01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slump flow (spread)</td>
<td>$a_{30} \geq 450$ mm</td>
<td>$a_{50} = 680$ mm</td>
</tr>
<tr>
<td>DBV recommendations, 1996</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive strength</td>
<td>$\geq 55$ N/mm²</td>
<td>87 N/mm²</td>
</tr>
<tr>
<td>DBV recommendations, 1996</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Tab. 1: Requirements for ready-mixed grouts according to german regulations*
Furthermore the manufacturer ensures that the grout complies with DIN 1045-2 and may therefore be used in the joints between precast elements. The mean maximum grain size of 1 mm was chosen, since our industrial partner suggested joint thicknesses with a minimum of 10 mm.

In addition, our industrial partner intends to use high-strength concrete, because the weight and thickness can be reduced and the precast elements can be larger in size. Furthermore the quality of high-strength concrete is easier to ensure in the precast industry compared to in-situ applications.

To keep close to the industrial research needs the precast elements in this investigation will be made of concrete C 70/85, even if the limits given by DIN 1045-2 for the application of the grout are exceeded.

**Stresses in the projected joints**

To choose loads with practical relevance for experiments on small specimens, it is necessary to calculate joint loads of WEC.

The calculation will be done for a multi-mega-watt WEC in hybrid construction with a tower height of 90m.

As a result of calculation for static loading the ultimate shearing force according to DIN 1045-1 was almost reached. For this reason it is necessary to investigate whether the transferable shear force decreases under dynamic loading.

**Projected Specimens**

The general shape of the specimens is designed according to the idea of the tests for the load-carrying capacity of headed stuts in ENV 1994 for composite structures.

![Projected Specimens](image)

*Figure 1: Projected Specimens*

In cooperation with OEVERMANN GmbH & Co. KG the following joints were developed to investigate the influence of an increasing surface roughness of specimens subjected to static and finally fatigue loading.
In addition, the most suitable of the displayed joint-types will be tested again using additional assembly-bolts. Resulting horizontal forces due to inclined surfaces in the joint will be transferred to external, horizontal bars without initial prestressing.

Firstly two specimens of each joint-type will be subjected to static loading. In these tests the stiffness (Young’s modulus), the stress-strain curve as well as the development of cracks will be investigated.

Finally one of the joint-types will be subjected to low- and high-cycle fatigue loading.

References


7 Other Projects

7.1 Study on high voltage transmission alternatives

ForWind

Bernd R. Oswald, Anneke Müller, Marcel Krämer

Ordered by: Regierungsvertretung Oldenburg

2005

Description

During regional planning procedure for a high voltage overhead line in Lower Saxony local authorities and individuals rejected an overhead line. They demanded a soil-covered pipeline as an alternative.

The study compares overhead lines, soil-covered polyethylene sheeted cables and soil-covered gas insulated pipelines as alternatives regarding the technical and environmental aspects as well as the business-orientated point of view.

Conclusions

• In principle all three transmission alternatives are appropriate for high voltage transmission

• The overhead line is the most favourably solution from the technical and economic point of view

• A cable is a thermal bottle-neck in the 380-kV-grid. Repair works are more complex and time-consuming than on overhead lines. The cable is half as durable as an overhead line and gas insulated pipeline.

• The gas insulated pipeline has comparable electrical properties as the overhead line and similar to the cable alternative low electric losses. However repair works on gas insulated pipelines are even more complex and time-consuming (up to 20 days) than on cables.

• Investment costs (cash equivalent) for a dual system, an overhead line amount to 40 to 42 Mio. €, for the cable four times more (162 to 183 Mio. €) and ten to twelve times more (396 to 478 Mio. €) for a comparable gas insulated pipeline.

• Total expenses (cash equivalents of investment and operation expenses including losses) for a running time of 40 years for two systems mount up to 88 to 92 Mio. € (different scenarios) for overhead lines, cables are 2,2 to 2,4 times more expensive and a gas insulated pipeline 4,7 to 5,4 times more expensive than an overhead line.

• Up to now neither the soil-covered 380-kV- polyethylene sheeted cables nor the gas insulated pipelines for a length of 54 km (as planned here) exist. Both are not used for the European grid so far. There are no experiences with operating performance or actual costs.

• All of the three transmission alternatives meet the guidelines of Federal Immission Control Ordinance (Bundesimmissionsschutzverordnung (BlmschV)) for electromagnetic fields.
Further Details available at www.forwind.de/oswald-studie
7.2 Decentralized Energy Management (DEMS) Project – Wind Power and Load Forecast

ForWind
Nadja Saleck, Lüder von Bremen, Detlev Heinemann
Partners: FH Wilhelmshaven, TU Clausthal, Uni Hannover, BTC AG, EWE AG
Funded by EWE AG
2005 – 2006

Objectives
The liberalization in the German electricity and gas market and the increasing amount of renewable energy source like wind, fuel cells and PV systems leads to fundamental changes in the organization of the energy supply. The increasing decentralization of electricity and heat production requires new solution in the energy supply and management with respect to supply security and quality. The existing “top down” concept for regulation and supply needs to be revised as the “bottom up” integration of decentralized production and demand becomes more and more important and must be regarded as autark communication and information systems.

Activities
Within the framework of DEMS ForWind is responsible for wind power and demand (load) predictions. Several work packages are closed while others are still in progress as the project is likely to be extended by several components.

Correlation of peak loads by wind power production
Very high production of wind energy converters is mostly related to low pressure systems that cross the EWE region leading to high wind speeds. Obviously the peak production of individual wind parks depends on the arrival time of peak wind speeds related to the approaching synoptic system. Consequently, a certain time lag exists between peak production of several wind parks, in particular if they are lined up the storm track of the synoptic system. Figure 1 shows a time series (48h) of power production of two wind parks that are roughly 150km apart in East-West direction.

Figure 1: Time series of produced wind power of a wind park located in the far west (blue curve) of the EWE region and in the far east (green curve). Hourly values are depicted scaled with the rated power of each wind park.
A more general result is shown in Figure 2 which quantifies the time lag between peak wind power production in the entire EWE region and a wind park in the most western and eastern part of the EWE, respectively. Production data for the year 2004 was analysed and only westerly winds with wind speeds that exceed the 80% percentile have been considered. It can be seen that the peak production of the western wind parks has a lead time of about 45min while the peak production to the eastern wind park lags about 45 minutes behind the total production in the region.

Figure 2: Correlation coefficient against time lag for the wind park in the far west (black line) and far east (red line). The individual power is correlated with the power production in the entire EWE region.

**Wind power forecasting**

The newly developed wind power forecasting model ‘Hugin’ has been adopted to the EWE region. The year 2004 was used to investigate the behavior of ‘Hugin’ using model level winds from ECMWF as input. The predictions are compared with production data of the entire EWE region. By the end of 2004 roughly 2200MW wind power capacity was installed in the EWE region.

Figure 3 shows an systematic underestimation of wind power in the afternoons and an overestimation during night times. This phenomenon inherits an increase in the RMSE forecast error in the afternoon and a drop in RMSE forecast error during night times. It is believed that these problems are triggered by changing thermal stratification of the lower atmosphere. During night times stable conditions prevail and hence strong wind sheer. Apparently, the ECMWF model overestimate the stability and has to high wind speeds during night times. In the afternoon wind speeds are underestimated leading to a negative systematic error in the wind power forecast. This may be due to overestimation of convection and turbulence resulting in too unstable thermal stratification.

The systematic error in the EWE region has the same size than in entire Germany. This means that coastal effects are not responsible for the deviation.

The RMSE forecast error increases from about 7% at day 1 to about 12% at day 3.
Figure 3: Wind power forecast error for EWE region against look-ahead time in the year 2004 computed with ‘Hugin’. The systematic error (Bias), RMSE and standard deviation of the error (sde) is shown. The error is scaled with the rated power of approximately 2200 MW.
7.3 Warning System on Deviations of predicted Wind Speeds and Adaptation of Wind Power Forecasts to near-real time Measurements (nowcasting)

ForWind

Carsten Poppinga, Lüder von Bremen, Nadja Saleck and Detlev Heinemann

Partners: Meteocontrol GmbH (Project Coordinator)

Funded by BIS (Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH) within the project, Energy Meteorology for Offshore-Wind Applications 2005 – 2006

Introduction

This project aims to generate warnings in case wind forecast errors are detected by the wind measuring network operated by the weather service provider Meteocontrol. 10m wind speed data is measured every hour and is accessible for ForWind about one hour later via ftp.

Activities

35 sites are considered in total. In order to reduce measurement errors five sites that are located less than 70km apart from each other, have been clustered. The resulting seven reference sites are compared with forecasts valid for that certain time. These forecasts had been computed one and two days ago, respectively. Additionally, an adapted (to the latest measurement) forecast was included to calculate the spread (standard deviation) of different forecast runs valid at the same time. It was shown that the forecast error (latest forecast minus measurement) is in particular large when the forecast spread was exceptional large. A large forecast spread means that the specific weather situation was hard to predict, i.e. the evolution of the weather was very uncertain.

The spread of forecasts is not only calculated for the time of the latest wind measurement but is also calculated for the future. Assuming that the correlation between forecast spread and forecast error stays invariant in time, it can be estimated to which extent the wind predictions in the future are certain or less certain. A fully operational system (Earlybird) was developed to issue warnings in several levels in case certain spreads are exceeded or will be exceeded. A user interface was developed by ForWind’s subcontractor (Energy&Meteo Systems GmbH) and was made available to the Meteocontrol.

As a bonus that was not part of the contract with Meteocontrol, ForWind included a very simple application to visualize the distribution of wind power and its sum over entire Germany together with the wind field that is interpolated from forecasts that are adapted to Meteocontrol's wind speed measurements. The interpolation is done with built-in Matlab functions. The pictures are accessible for Meteocontrol and are shown together with the current warning level of wrong wind forecasts at their end-user portal (Fig. 1).
Figure 1: Portal of Meteocontrol’s Service SaferPower to warn of wrong wind speed forecasts based on ForWind’s Earlybird system. The pictures show current production of wind power (left) and a map of wind speeds (right).
7.4 Validation of an air-sea interaction sea drag model with data from a near-shore measurement site

ForWind
Ralf Bruns, Bernhard Lange, Jens Tambke and Detlev Heinemann
Diploma Thesis by Ralf Bruns, October 2005

The impact of waves on the sea drag is investigated by a comparison of measured data and model estimates. Ultrasonic anemometer data have been taken from the Rødsand measurement mast south of the Danish island Lolland in the Baltic Sea. The data have been sampled with several quality criteria to exclude measurement errors and to make sure, that only near neutral and stationary conditions is used.

The friction velocity or the drag coefficient has been calculated with the eddy covariance method. A tilt of the measurement instrument has been found and corrected for with the planar fit tilt correction method. On top of this a comparison of the planar fit with the so called double rotation method has been performed.

Despite the theoretical advantage of the planar fit method, no advantage has been detected. Comparing linear detrending and block averaging calculation of the variances, linear detrending shows an advantage for obvious wind speed and/or wind direction changes, while for the rest of the data the results are inconsistent.

A small wind speed dependence has been found with smaller measured than modelled drag coefficients at larger wind speed. The main reason is, that measured and modelled Donelan wave spectra differ mainly in magnitude of the spectral peak and a systematically larger modelled than measured significant wave height.

Seasonal dependencies have been found to be responsible for some scatter. There are mean dependencies on the differences between water and air temperature or on the vertical heat flux. An additional small increase of the scatter has been found dependent on the anemometer height.

The general dependency of the measured friction velocity on wave parameters has been found only allusively in the much larger scatter because of different reasons. The fetch dependence of the modelled friction velocity as consequence of fetch dependent Donelan spectrum has not been detected in larger scatter of the measured values, but can not be excluded either.

Comparing the Charnock relation with a wind speed dependent Charnock parameter the only theoretical advantage of the model seems to be a little modification of the results in dependence of the wave parameters. But this impact is very small for the model and hardly recognizable in the large scatter of the measured data.

The advantage of the model is the direct coupling of wind and waves, which is based on physics and which gives a direct result for the sea drag without extra modelling the Charnock parameter. The results for the complicated Rødsand sites show no advantage compared to the Charnock relation (Fig. 1). For the near shore Rødsand site this study reveals, that the current wind speed and sea state parameters alone are not sufficient for an adequate modelling of the sea drag.
Figure 1: Modelled (solid triangles) and measured (open triangles) friction velocity $u^*$ against the measured 10m wind speed (corrected to neutral conditions). The red curve shows the modelled friction velocity $u^*$ with the Charnock relation for $c_d$. A Charnock parameter of $a_{Ch}=0.011$ was used.
7.5 ANEMOS - Development of a Next Generation Wind Resource Forecasting System for the Large-Scale Integration of Onshore and Offshore Wind Farms

ForWind
Jens Tambke, Carsten Popenge, Lüder von Bremen and Detlev Heinemann
Type: EU Project (FP 5), Research Action
Partners: 4 Universities, 9 Research Labs, 1 public institution, 8 industry
Duration: 1 October 2002 - 30 September 2006

Introduction
ANEMOS aims to develop accurate models that outperform considerably actual state-of-the-art, for onshore and offshore wind resource forecasting (statistical and physical). Emphasis is given on integrating high-resolution meteorological forecasts.

Activities
For the offshore case, marine meteorology will be considered as well as information by satellite-radar images. An integrated software, ANEMOS, will be developed to host the various models. This system will be installed by several utilities for on-line operation at onshore and offshore wind farms for local/regional/national wind prediction. The applications are characterised by different terrains and climates, on-/near-/off-shore farms, interconnected or island grids. The on-line operation by the utilities will permit to validate the models and to analyse how predictions can contribute to a competitive integration of wind energy in the developing liberalised electricity market.
7.6 POW’WOW - Prediction Of Waves, Wakes and Offshore Wind

ForWind

Lüder von Bremen, Abha Sood, Jens Tambke

Type: EU Project (FP 6), Coordination Action

Partners: 3 Universities, 8 Research Labs, 1 industry

Duration: 1 October 2005 - 30 September 2008

Introduction

Currently, a good number of research projects is underway on the European and national level in the fields of short-term forecasting of wind power, offshore wind and wave resource prediction, and offshore wakes in large wind farms. The purpose of this Action is to co-ordinate the activities in these related fields, to spread the knowledge gained from these projects among the partners and colleagues, and to start the work on some roadmaps for the future. Therefore, the leaders of research projects are assuming the function of a multiplier towards the larger research and user community. Additionally, in the fields of short-term forecasting and offshore energy resource, Expert Groups will be formed to act as the central focus point for external stakeholders (e.g. the EU commission). The liaison with other groups will also include groups outside of Europe.

Activities

To facilitate the spread of knowledge, a number of workshops is planned, being smaller and more focused on their topics than the usual conferences. In order to include more researchers from the new and accession states, they can get travel grants paid from the project.

One issue hampering the progress in our fields is the difficulty of getting access to good data. In most cases, data on offshore wind or power is strictly confidential, and also data on onshore wind power, especially in conjunction with numerical weather predictions, is not easy to come by. One example of a good testing procedure comes from the Anemos project, where in all 6 test cases were defined, to be run by all involved institutes. This idea is taken to the next level with the set-up of two Virtual Laboratories, one for offshore wake modelling, the other one for short-term forecasting.

Outlook

In the end, this Coordination Action will also support preparation of next actions such as a Network of Excellence or an Integrated Project, connecting many additional partners within the European Research Area.
7.7 WindEng: “WIND ENERGY ASSESSMENT AND WIND ENGINEERING”

ForWind
Barbara Jimenez, Jiri Beran, Lorenzo Claveri, Tim de Paus, Lüder von Bremen, Abha Sood

Type: EU Project (FP 5), Training Network
Partners: Universities, Research Labs, industry
Duration: 1 September 2002 – 31 December 2005

Objectives:
The aim of the network is to bring together young and experienced researchers to work jointly to improve wind resources assessment methodologies and to define the basis for the design of wind turbines and wind farms in different environments.

The spin-off of this NETWORK will be increased knowledge of the following subjects:
To define reliable values for turbulence descriptors to be used in modelling the turbulent wind fields in homogeneous and complex terrain as well as offshore, in order to offer guidelines for wind turbine design.
To improve existing methods used for modelling European wind climates from the cold Scandinavian to the warm Mediterranean regions, in order to offer reliable tools for manufacturers or developers to calculate the energy production of wind farms in complex terrain and offshore.

The main subject areas are related to different situations in which wind turbines are erected.
7.8 Research map of wind energy in the States of Lower Saxony and Bremen

ForWind

Andreas Kähler, Marcel Krämer, Elke Seidel, Alexander Nobbe

Partner: Forschungs- und Koordinierungsstelle Windenergie (fk-wind), Bremerhaven

Funded by: Ministry of Science and Culture

2004 – 2005

Description

The basis for the making of a map concerning the wind power research in Bremen and Lower Saxony (Forschungslandkarte Windenergie Bremen-Niedersachsen) was a decision of a meeting of the federal state government of Lower Saxony and the senate of the Free Hanseatic City of Bremen on November 11th, 2003. Between the Federal States Bremen and Lower Saxony a cooperation was agreed upon to develop and use the economical, ecological and scientific potentials of on- and offshore wind power.

The motivation to develop a combined research map for wind power comprises the compilation and presentation of research and development facilities, featuring professional competence to work on wind power specific problems or already work on ongoing projects. Based on the results, statements shall be made concerning existing know-how or alternatively know-how still to be extended, deficits in the R&D sector and potential regional and national overlaps.

Results

The findings of the survey delivered in both Federal States insight into the multi disciplinary diversity of existing professional competence, either already being used for wind power research or ready to be applied to it. Main research and further important expertise could be detected. Furthermore the interviewed institutions directly listed different (topics of) needs for research. The collected data still showed deficits which can be covered by using synergetic expert knowledge and by the work on research projects.

The database of the research map has to be constantly updated by ForWind and fk-wind in collaboration with the listed institutions. This implies next to contacting the listed institutions to review their presentation also an enlargement of the present database with new research and development establishments.

It is now possible to get an own impression of the research activities in the field of wind energy by visiting the homepage:
www.forschungslandkarte-windenergie.de
7.9 Partner of the EU-Project ‘Pushing Offshore Wind Energy Regions’ (POWER)

ForWind
Moses Kärn
2004 – 2007

Description

POWER is a project in the EU-Interreg III B Programme North Sea Region financed through the European Regional Development Fund (ERDF).

POWER creates a North Sea competence network for offshore wind energy. POWER unites North Sea regions with an interest in supporting and realising the economic and technological potentials of offshore wind energy. The project assesses environmental and planning as well as acceptance issues of offshore wind farms, supports the development of a reliable supply chain for the sector, and elaborates skills development measures. 37 organisations take part, with representatives from Germany, the UK, Denmark, the Netherlands and Belgium. Transnational cooperation between these regions is creating a North Sea competence network for offshore wind energy.

POWER has an overall budget of about 3,5 million Euro. The exact duration is from July 01, 2004 to June 30, 2007. Altogether 24 partners participate in the project. It is managed by the Bremerhaven Gesellschaft für Investitionsförderung und Stadtentwicklung mbH (BIS) on behalf of the Bremen Senator für Bau, Umwelt und Verkehr. Additionally, the coastal regions are represented by the transnational partners: Suffolk County Council (UK), Kop en Munt (NL), EU Vest (DK) and Port of Ostend (B).

POWER activities are divided into four subprojects (‘work packages’):

WP 1: Planning and Participation: The planning and participation workstream intends to improve the integration of the different planning systems in the Member States bordering the North Sea. Its aim is to give insight in possible improvements in the decision-making and implementation process for offshore wind farms (OWF), and to harmonize planning and information strategies.

WP 2: Economic Support / Supply Chain: Supply chain analysis will be conducted, and available facilities in the North Sea Offshore Wind Regions will be mapped.

WP 3 Education: The objective of this part of the POWER project is to establish the needs of the offshore wind sector for specialists and skilled workers for the complete supply chain, in order to develop qualification and further training courses.

WP 4 Dissemination: The last Work Package focuses on the dissemination of gathered knowledge both between the project partners and beyond, by means of mailing actions, a website, a newsletter and a travelling or simultaneous exhibition in all par-
Participating regions. Finally, the setting up of a new Offshore Wind Energy Information Centre in will be supported.

**Approach / Activities**

ForWind is formally the associated partner to the junior research group IMPULSE at the Institute for Chemistry and Biology of the Marine Environment (ICBM) at the University of Oldenburg. As such we have moved in their position in work package 3.

**Partners involved in WP 3**

- University of Applied Sciences Bremen, DE
- University of Applied Science Bremerhaven, DE
- ForWind – Center for Wind Energy Research, University of Oldenburg, DE
- Bremerhaven Labour Ltd., DE
- The Senator for Labour, Women, Health, Youth and Social Affairs, Free State of Bremen, DE
- Delft University of Technology, NL
- Energy Research Centre Netherlands (ECN), Petten, NL
- Hogeschool InHolland, Alkmaar, NL
- ROC Kop van Noord Holland, Den Helder, NL
- New and Renewable Energy Centre, Blyth, UK
- Offshore Center Denmark (OCD), Esbjerg, DK

**Main outputs of WP 3**

- Overview of basic necessities and requirements
- Vocational training
- Summer school and MBA/BBA Education
- Dissemination / transnational answers

ForWind is basically involved in the development of a summer school and MBA/BBA curriculum and the organization of summerschools. As part of the workpage team ForWind is also contributing to the other outputs.

**Results and next steps**

An internal information exchange programme has been organized in 2005 for the whole project. A summer school for 2006 is currently in the planning phase. It is scheduled for mid September.

**Link**

www.offshore-power.net
Introduction

In dependence to the vigorous growth of the wind power sector the requirements on their employees increase. Encouragement and fervour were the most important criteria at the beginning of wind power evolution. Nowadays, comprehensive expert skills and technical knowledge as well as systematic understanding are fundamental for a sustainable success.

The future of the wind power energy comes along with numerous challenges like repowering, projects linked throughout the world and offshore wind power projects. From professionals that requires a fundamental understanding for almost every concern around wind energy projects.

It includes complying with commercial, technical and legal formalities as well as the planning processes and contact with media.

It is necessary to possess an extensive knowledge in order to maintain an overview about this complex environment and to determine the strategy of the company and projects. Consequently, know-how about the essential tools and methods as well as a detailed practical experience in project management, conduct of negotiations and project presentation are indispensable.

The methods

The advanced training programme - Wind power technique and management - will be realised and supported by numerous actors:

- The management, consisting of representatives of ForWind, Windenergieagentur Bremen e.V. (WAB), fk-Wind, Stiftungslehrstuhl Windenergie (SWE) of the University of Stuttgart and Overspeed GmbH & CoKG, has developed the innovative concept for this study, based on an educational demand analysis.

- The development and realisation of the advanced training programme - Wind power technique and management - were enabled by “Regionale Arbeitsgemeinschaft Bremen (RAG)”, “Regionale Innovationsstrategie (RIS)” and the city council of Oldenburg.

- A number of experts coming out of the economy and the “scene” have founded an advisory committee for sponsoring, ensuring practice oriented learning and in content advice.

- Well-known abstractors out of companies and the sciences provide access to the latest know-how of the sector
Management representatives from ForWind, FkWind, Stiftungslehrstuhl Windenergie at the University of Stuttgart and Overspeed GmbH&Co.KG developed an innovative concept.

The complexness of wind power projects will be taken into account to the contents, the alignment at the participants with different qualifications and the emphasis on project work within the curriculum. Part-time studies with phases of self organised studying and seminars will alternate to achieve high flexibility on time. The advanced training programme -Wind power technique and management- is tended to employees of the wind power sector as well as to interested people who wants to enter it.

The contents of the studies are as follows:

- natural science/technique
- management
- planning
- legal bases
The duration of the programme is approximately ten months. A certificate will be handed out by the University of Oldenburg after passing the examination.

1. start-up seminar
   Overview
   Basic terms
   Field trips
   Project management
   Discussions with experts

2. Potential of wind
3. Planning and erection
4. Rotor and power train
5. Law
6. Generator controlling and steering
7. Funding
8. Tower, foundation, load assumption
9. Operating and monitoring
10. Wind farms
11. Network connection – offshore
12. Final seminar

Basics and Organisation
Technique
Planning, Law and Efficiency

Prospects:
The pilot study programme commences in August 2006. The first class is expected to finish the course in June 2007. As from the second year the course is proposed to pay for itself.
It is planned to implement a continual improvement into the programme. Therefore, all provided contents and applied methods will be evaluated by course participants, lecturers and the advisory committee.

The possibility of internationalisation by teaching seminars in English as well as offering national and international accredited degrees (MA) is presently being investigated. Furthermore, an enhancement towards offshore wind power is also at work.

Link

www.wind-studium.de
8 Available Products

8.1 Wind Farm Layout Programme (FLaP)

Contact: Arne Wessel
arne.wessel@forwind.de

The Farm Layout Program (FLaP) is a software product for optimisation and design of wind farm layouts.

The functionality of the software includes the calculation of the efficiency losses caused by shadowing effects inside the wind farm, the optimisation of the farm layout towards higher efficiencies and the calculation of the immission of noise by the wind energy plants. Based on the description of the characteristics of wind energy plants and the meteorological conditions annual revenues are prognosed and charts for acoustical immissions are calculated.

FLaP runs at Windows NT computers in native mode, which has therefore no limits in the dimension of the wind farm. The program allows menu-driven handling via graphical user interface or command line processing for operational mode.

As interchange formats for the farm layout, FLaP could export DXF (AutoCad, AutoSketch) and HPGL.

FLaP calculates the efficiency and power output of the whole wind farm and the single wind turbines, based on the annual wind statistic and the power curves of the wind turbines as input parameters. The shading effects of the wind farm are taken into account by the model of Jensen (Risø-model), which uses a simple model for the wind speed in the wake of a wind turbine. The actual beta version includes the more sophisticated wake model from Ainslie, which assumes a Gaussian wind speed profile in the wake of the wind turbine.

The sound immission could be estimated at defined point or illustrated as iso-lines of the sound level. The calculation of the sound level is determined according to VDI 2714.

The optimisation modul uses an evolutionary algorithm to optimise the wind farm layout towards higher farm efficiency. Therefore it rearranges the position of the wind turbines inside a defined area.

FLaP was developed in the Energy Meteorology Research Group in the Institute of Physics at the University of Oldenburg and has now been in use in research facilities and engineering companies for seven years. In the last two years it was constantly enhanced with the actual scientific results.
8.2 HanOff

Contact: Frithjof Marten
marten@stahl.uni-hannover.de

This Software makes it possible to calculate hydrodynamic transparent structures with respect to sea loads – static as well as dynamic. The response is determined by the commercial FE programme ANSYS®. The wave loads are worked out for the calculations by using linear and non-linear wave theories for calm or wild sea - depending on the boundaries. Beside the internal load calculating module a prepared I/O-System makes the usage of results of other wave load calculating programmes (e.g. WaveLoads). Within the post processing damage calculations can be made in time or frequency space. The life-span of tube node fittings is calculated full-automatically by the concept of structural span.

8.3 WaveLoads

Contact: Kim Mittendorf
mdorf@hydromech.uni-hannover.de

The software WaveLoads is developed for calculating wave induced loading on hydrodynamic transparent structures (e.g. jacket structures).

The usage of our software is free of charge, only a licence agreement has to be signed.

Do not hesitate to contact us for further or detailed information.
8.4 Hugin

Contact: Dr. Lüder von Bremen
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Description:
Wind Power Forecasts for Germany or subregions of Germany. The new model ‘Hugin’ is based on a new and simpler approach of physical wind power model forecasting. There are three key difference compared to standard physical models: i) the selection of representative reference sites is not longer necessary as regular fields (0.5° x 0.5°) of wind speed and temperature became available. Furthermore ii) wind fields other than the surface 10m wind speed are ready for use, what avoids the extrapolation of wind speeds to hub height taking thermal stratification into account. As a third difference the manufacturer’s power curves are not used any longer as a parameterization was found to describe the power curve of a specific WEC by its maximum power.

The model is ready to digest with wind fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) that are given at the following heights over ground 30m, 61m, 100m, 130m. Operational forecast data is expected to be delivered by Meteocontrol.

The model works for entire Germany, but can also be restricted to subregions only. The graphical interface is optional.

Figure 1: Example of visualization of wind power forecast for Germany calculated with ‘Hugin’. The forecast is issued 7 July 2004, 00UTC and is valid for 8 July 2004, 00UTC. The given bars represent the power within a 0.4° x 0.4° grid box.
9 Publication List

9.1 Conference contributions


Anahua, E., Peinke J.: Analysis of the Atmospheric effects on the WECS power characteristics. The European Academy for Wind Energy (EAWE), Kassel März 2005 (oral presentation).


Europe” of the European Academy of Wind Energy (EAWE), University of Athens, 22./23.09.2005.


Oswald, B.R.: Offshore-Windparks - Eine Herausforderung für die Hochspannungssübertragungstechnik, Colloquium dedicated to the memory of Prof. Dr.-Ing. Fritz Obenaus, 08.10.2004, Dresden.


Schaumann, P., Wilke, F.: Current Developments of Support Structures in Offshore Environment. ICASS ’05; Advances in Steel Structures; Shanghai, China; 06/2005.


### 9.2 Articles


Anahua, E., Barth, S., Peinke J.: Characterisation of the Power Curve for Wind Turbines by Stochastic Modelling. Wind Energy - J. Peinke, P. Schaumann, S. Barth (Eds.) (Springer), accepted for publication.


Klosse, R.: Biogas macht Wind wirtschaftlicher - Die Speicherdimensionierung eines virtuellen Kraftwerkes aus Biogas- und Windenergieanlagen beeinflusst dessen Rentabilität. Erneuerbare Energien Ausgabe 2, 02/05.


Oswald, B.R.: Vom Winde verweht, article in Universität Hannover-EXTERN, April 2005, Hannover.


9.3 Other Publications


10 Lectures at Universities

Barth, S., Peinke, J.: Wind Energy, Vorlesung Wintersemester 05/06.


Barth, S., von Bremen, L.: Windenergie, Seminar, Oldenburg / Institut für Physik; Sommersemester 05.


Heinemann, D.: Energy Meteorology, Vorlesung Wintersemester 05/06.

Heinemann, D.: Energy Systems I, Vorlesung Wintersemester 05/06.

Heinemann, D.: Erneuerbare Energien, Projektorientiertes Praktikum, Wintersemester 05/06.


Schaumann, P.: Stabilität im Stahlbau (Vorlesung). Universität Hannover, Institut für Stahlbau, Sommersemester 05.


11 PhD theses


12 Diplom theses / Bachelor / Master


13 Annex

13.1 List of ForWind-Staff Members

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