<table>
<thead>
<tr>
<th>Content</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>5</td>
</tr>
<tr>
<td>Organisation</td>
<td>7</td>
</tr>
<tr>
<td>List of ForWind-Members</td>
<td>8</td>
</tr>
<tr>
<td>Former Staff Members</td>
<td>11</td>
</tr>
<tr>
<td>List of Activities</td>
<td>12</td>
</tr>
<tr>
<td>Chronicle</td>
<td>13</td>
</tr>
<tr>
<td>Research</td>
<td>14</td>
</tr>
<tr>
<td>Turbulence modelling</td>
<td>15</td>
</tr>
<tr>
<td>Offshore meteorology</td>
<td>19</td>
</tr>
<tr>
<td>Forecasting and Spatial-temporal Structure of Wind Power</td>
<td>26</td>
</tr>
<tr>
<td>Environmental Loads on Offshore Wind Energy Converters</td>
<td>32</td>
</tr>
<tr>
<td>Fatigue Assessment of Support Structures of Offshore Wind Energy Conversion Systems</td>
<td>38</td>
</tr>
<tr>
<td>Stability and early diagnosis of damages</td>
<td>42</td>
</tr>
<tr>
<td>Modelling Soil-Structure-Interaction for Offshore Wind Energy Plants</td>
<td>46</td>
</tr>
<tr>
<td>Grid Integration of Offshore Wind Energy Parks</td>
<td>51</td>
</tr>
<tr>
<td>Integrated modeling of offshore WEC</td>
<td>55</td>
</tr>
<tr>
<td>Development Projects</td>
<td>60</td>
</tr>
<tr>
<td>Further development of the wind farm program FLaP for planning, wind farm monitoring and turbine design for offshore applications</td>
<td>61</td>
</tr>
<tr>
<td>Analysis of WEC power and wind turbulence in respect to increase accuracy of energy gain prognosis</td>
<td>64</td>
</tr>
<tr>
<td>Dynamic load bearing capacity of slip resistant bolt connections in truss towers of WECs</td>
<td>65</td>
</tr>
<tr>
<td>Concrete joints between structural elements of hybrid towers for WEC subjected to fatigue loading</td>
<td>67</td>
</tr>
<tr>
<td>Usage of combined acceleration and strain sensors for early diagnosis of damages</td>
<td>69</td>
</tr>
<tr>
<td>Other</td>
<td>71</td>
</tr>
<tr>
<td>Study on regional economic effects of wind energy usage in the counties of Cuxhaven and Stade</td>
<td>72</td>
</tr>
<tr>
<td>Havarie im Windpark? Symposium on Offshore Wind Energy and Maritime Safety</td>
<td>73</td>
</tr>
<tr>
<td>Decentralised Energy Management (DEMS) Project – Improving wind power and demand forecast</td>
<td>76</td>
</tr>
<tr>
<td>Research map of wind energy in the States of Lower Saxony and Bremen</td>
<td>77</td>
</tr>
</tbody>
</table>
Participation in the EU-Project ‘Pushing Offshore Wind Energy Regions’ (POWER) 78
Development of a further education program for engineers in wind energy (WIng) 80
Participation in the EU Marie Curie Research Training Network ‘Wind Energy Assessment and Wind Engineering’ 82
Energy Management to Prevent Electrical Network Installation 85
Available Products 87
Publication List 90
Lectures at Universities 94
Diploma and Dissertations 95
Preface

The foundation stone of ForWind was laid towards the end of 2003 when proposals to finance a Research Center for Wind Energy and to create a Center of Excellence at the University of Oldenburg and University of Hannover were granted by the Ministry for Science and Culture of Lower Saxony.

The staff recruiting for the Center of Excellence was completed by February 2004 and a five-year-programme for Wind Energy Research initiated.

Due to its extensive research in the field of offshore wind energy, ForWind has become a household name in the wind energy community. Both oral presentations and poster sessions at conferences such as the European Wind Energy Conference (EWEC) in London, the German Wind Energy Conference (DEWEK) in Wilhelmshaven and at The Science of making Torque from Wind in Delft have helped to establish ForWind as a leading German research group.

In 2004 ForWind also became a member of the European Academy of Wind Energy (EAWE). The EAWE is an R&D cooperation between research institutes and universities in the wind energy field. To date, members come from Germany, Denmark, Greece and the Netherlands. The Academy was founded to formulate and execute joint R&D projects and to coordinate high quality scientific research and education on wind energy including international exchange of information and personnel on a European level.

More than 30 German and international researchers are now involved in basic research in topics such as wind fields, wind power forecasting, turbulence, offshore foundations, sea-state monitoring, fatigue analysis of support structures, interaction between construction and foundations, energy grid connections and the integrated modelling of offshore wind power plants.

Projects with different industrial partners and an intensive cooperation with the regional utility EWE AG have been initiated or are in preparation.
The Center of Excellence has undertaken studies on the *Regional Economic Effects of Wind Energy Usage*; organised a symposium on *Offshore Wind Energy and Ship Safety*; been publicly active; canvassed possible new project partners; and initiated *advanced education courses for Wind Energy Engineers*. Continuous interaction has taken place with wind energy regional partners (DEWI, DEWI-OCC, wab, fk-wind) and has lead to joint projects.

The wind energy sector in Germany is in a state of change. The rate of newly installed on-shore capacity is decreasing and the German offshore market is still in the developmental stage. A very current topic is the discussion on the technology and costs for upgrading the high-voltage electricity grid due to the need of transporting wind induced power. General discussions on *acceptance* have also significantly increased.

This is a clear sign for the need of further investigations aimed at improving offshore technologies and finding solutions for the challenges of the next generation of wind turbines.

ForWind will therefore aid in the development of sustainable technical, economical, ecological and socially acceptable solutions.

In this annual report you will find a comprehensive survey of the ForWind activities. Please do not hesitate to contact us when questions or interest in joint activities arise.

Dr. D. Heinemann  
Chairman of steering committee

Prof. Dr. P. Schaumann  
Vice-Chairman of steering committee

Dr. M. Krämer  
Managing Director
**Organisation**

ForWind represents the research activities in the field of wind energy of the universities of Oldenburg and Hannover. It is planned to create a corporate center at both universities.

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

The administrative office of ForWind is located in Oldenburg.

**Steering Committee**

The Steering Committee of ForWind consists of four heads of enlisted institutes and the Managing Director:
- Dr. Detlev Heinemann (Speaker)
- Prof. Dr. Peter Schaumann (Deputy Speaker)
- Prof. Dr. Joachim Peinke
- Prof. Dr. Werner Zielke
- Dr. Marcel Krämer (Managing Director)

**Scientific Board**

To be confirmed
# List of ForWind-Members

<table>
<thead>
<tr>
<th>Name</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr.-Ing. Khalid Abdel-Rahman</td>
<td>+49 (0) 511 762-2273</td>
<td><a href="mailto:khalid@igbe.uni-hannover.de">khalid@igbe.uni-hannover.de</a></td>
</tr>
<tr>
<td>Institute of Soil Mechanics, Foundation Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prof. Dr. Ing. Martin Achmus</td>
<td>+49 (0) 511 762-4155</td>
<td><a href="mailto:achmus@igbe.uni-hannover.de">achmus@igbe.uni-hannover.de</a></td>
</tr>
<tr>
<td>Institute of Soil Mechanics, Foundation Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Phys. Edgar Anahua</td>
<td>+49 (0) 441 798-3577</td>
<td><a href="mailto:edgar.anahua@forwind.de">edgar.anahua@forwind.de</a></td>
</tr>
<tr>
<td>Institute of Physics - working group energy and semiconductor research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Ing. Steffen Anders</td>
<td>+49 (0) 511 762-3258</td>
<td><a href="mailto:steffen.anders@baustoff.uni-hannover.de">steffen.anders@baustoff.uni-hannover.de</a></td>
</tr>
<tr>
<td>Institute of Building Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Stephan Barth</td>
<td>+49 (0) 441 798-3951</td>
<td><a href="mailto:stephan.barth@forwind.de">stephan.barth@forwind.de</a></td>
</tr>
<tr>
<td>Institute of Physics - working group hydrodynamics and wind energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jiri Beran (MSc)</td>
<td>+49 (0) 441 36116-732</td>
<td><a href="mailto:jiri.beran@forwind.de">jiri.beran@forwind.de</a></td>
</tr>
<tr>
<td>Institute of Physics - working group energy and semiconductor research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Phys. Frank Böttcher</td>
<td>+49 (0) 441 798-3007</td>
<td><a href="mailto:frank.boettcher@uni-oldenburg.de">frank.boettcher@uni-oldenburg.de</a></td>
</tr>
<tr>
<td>Institute of Physics - working group hydrodynamics and wind energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Lüder von Bremen</td>
<td>+49 (0) 441 36116-734</td>
<td><a href="mailto:lueder.vonbremen@forwind.de">lueder.vonbremen@forwind.de</a></td>
</tr>
<tr>
<td>Institute of Physics - working group energy and semiconductor research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ralf Bruns</td>
<td>+49 (0) 441 36116-733</td>
<td><a href="mailto:ralf.bruns@forwind.de">ralf.bruns@forwind.de</a></td>
</tr>
<tr>
<td>Institute of Physics - working group energy and semiconductor research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lorenzo Claveri (MSc)</td>
<td>+49 (0) 441 36116-731</td>
<td><a href="mailto:lorenzo.claveri@forwind.de">lorenzo.claveri@forwind.de</a></td>
</tr>
<tr>
<td>Institute of Physics - working group energy and semiconductor research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Ing. Wolf-Jürgen Gerasch</td>
<td>+49 (0) 511 762-2247</td>
<td><a href="mailto:wj.gerasch@isd.uni-hannover.de">wj.gerasch@isd.uni-hannover.de</a></td>
</tr>
<tr>
<td>Institute of Structural Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Phone</td>
<td>Email</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Dipl.-Ing. Joachim Göhlmann</td>
<td>+49 (0) 511 762-3358</td>
<td><a href="mailto:goehlmann@ifma.uni-hannover.de">goehlmann@ifma.uni-hannover.de</a></td>
</tr>
<tr>
<td>Univ.-Prof. Dr.-Ing. Jürgen Grünberg</td>
<td>+49 (0) 511 762-3351</td>
<td><a href="mailto:gruenberg@ifma.uni-hannover.de">gruenberg@ifma.uni-hannover.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. René Grüneberger</td>
<td>+49 (0) 441 798-3007</td>
<td><a href="mailto:rene.grueneberger@forwind.de">rene.grueneberger@forwind.de</a></td>
</tr>
<tr>
<td>Dr. Detlev Heinemann</td>
<td>+49 (0) 441 798-3543</td>
<td><a href="mailto:detlev.heinemann@forwind.de">detlev.heinemann@forwind.de</a></td>
</tr>
<tr>
<td>Dipl.-Phys. Moses Kärn</td>
<td>+49 (0) 441 36116-722</td>
<td><a href="mailto:moses.kaern@forwind.de">moses.kaern@forwind.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. Rainer Klosse</td>
<td>+49 (0) 441 36116-737</td>
<td><a href="mailto:rainer.klosse@forwind.de">rainer.klosse@forwind.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. Martin Kohlmeier</td>
<td>+49 (0) 511 762-3709</td>
<td><a href="mailto:kohlmeier@hydromech.uni-hannover.de">kohlmeier@hydromech.uni-hannover.de</a></td>
</tr>
<tr>
<td>Dr. Marcel Krämer</td>
<td>+49 (0) 441 36116-721</td>
<td><a href="mailto:marcel.kraemer@forwind.de">marcel.kraemer@forwind.de</a></td>
</tr>
<tr>
<td>Univ.-Prof. Dr.-Ing. Ludger Lohaus</td>
<td>+49 (0) 511 762-3722</td>
<td><a href="mailto:lohaus@baustoff.uni-hannover.de">lohaus@baustoff.uni-hannover.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. Frithjof Marten</td>
<td>+49 (0) 511 762-3714</td>
<td><a href="mailto:marten@stahl.uni-hannover.de">marten@stahl.uni-hannover.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. Kim Mittendorf</td>
<td>+49 (0) 511 762-4786</td>
<td><a href="mailto:mdorf@hydromech.uni-hannover.de">mdorf@hydromech.uni-hannover.de</a></td>
</tr>
<tr>
<td>Dipl.-Oec. Anneke Müller</td>
<td>+49 (0) 441 36116-723</td>
<td><a href="mailto:anneke.mueller@forwind.de">anneke.mueller@forwind.de</a></td>
</tr>
<tr>
<td>Prof. Dr.-Ing. habil. Bernd R. Oswald</td>
<td>+49 (0) 511 762-2801</td>
<td><a href="mailto:oswald@iee.uni-hannover.de">oswald@iee.uni-hannover.de</a></td>
</tr>
<tr>
<td>Name and Title</td>
<td>Contact Information</td>
<td></td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Dipl.-Ing. Ara Panosyan</td>
<td>+49 (0) 511 762-2809 <a href="mailto:panosyan@iee.uni-hannover.de">panosyan@iee.uni-hannover.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Electric Power Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prof. Dr. Joachim Peinke</td>
<td>+49 (0) 441 798-3536 <a href="mailto:joachim.peinke@forwind.de">joachim.peinke@forwind.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Physics - working group hydrodynamics and wind energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carsten Poppinga (MEng)</td>
<td>+49 (0) 441 36116-736 <a href="mailto:carsten.poppinga@forwind.de">carsten.poppinga@forwind.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Physics - working group energy and semiconductor research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Ing. Johannes Reetz</td>
<td>+49 (0) 511 762-8673 <a href="mailto:j.reetz@isd.uni-hannover.de">j.reetz@isd.uni-hannover.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Structural Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prof. Dr. - Ing. Werner Richwien</td>
<td>+49 (0) 201 183-2857 <a href="mailto:werner.richwien@uni-essen.de">werner.richwien@uni-essen.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute for Soil Mechanics, Foundation Engineering, Rock Mechanics and Tunneling, U Duisburg-Essen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prof. Dr.-Ing. habil. Raimund Rolfes</td>
<td>+49 (0) 511 762-3867 <a href="mailto:r.rolfes@isd.uni-hannover.de">r.rolfes@isd.uni-hannover.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Structural Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Ing. Jörn Runge</td>
<td>+49 (0) 511 762-4412 <a href="mailto:runge@iee.uni-hannover.de">runge@iee.uni-hannover.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Electric Power Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Ing. Tim Rutkowski</td>
<td>+49 (0) 511 762-3712 <a href="mailto:rutkowski@stahl.uni-hannover.de">rutkowski@stahl.uni-hannover.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute for steel Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prof. Dr.-Ing. Peter Schaumann</td>
<td>+49 (0) 511 762-3781 <a href="mailto:schaumann@stahl.uni-hannover.de">schaumann@stahl.uni-hannover.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute for steel Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Oec. Christoph Schwarzer</td>
<td>+49 (0) 441 36116-724 <a href="mailto:christoph.schwarzer@forwind.de">christoph.schwarzer@forwind.de</a></td>
<td></td>
</tr>
<tr>
<td>ForWind</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cand.-Kauffr. Elke Seidel</td>
<td>+49 (0) 441 36116-730 <a href="mailto:elke.seidel@forwind.de">elke.seidel@forwind.de</a></td>
<td></td>
</tr>
<tr>
<td>ForWind</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Phys. Bernhard Stoevesandt</td>
<td>+49 (0) 441 798-3577 <a href="mailto:bernhard.stoevesandt@forwind.de">bernhard.stoevesandt@forwind.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Physics - working group hydrodynamics and wind energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dipl.-Phys. Jens Tambke</td>
<td>+49 (0) 441 36116-736 <a href="mailto:jens.tambke@forwind.de">jens.tambke@forwind.de</a></td>
<td></td>
</tr>
<tr>
<td>Institute of Physics - working group energy and semiconductor research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Phone</td>
<td>Email</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Juan José Trujillo (MSc)</td>
<td>+49 (0) 441 36116-735</td>
<td><a href="mailto:juanjose.trujillo@forwind.de">juanjose.trujillo@forwind.de</a></td>
</tr>
<tr>
<td>Margret Warns</td>
<td>+49 (0) 441 36116-720</td>
<td><a href="mailto:margret.warns@forwind.de">margret.warns@forwind.de</a></td>
</tr>
<tr>
<td>Dipl.-Phys. Arne Wessel</td>
<td>+49 (0) 441 36116-735</td>
<td><a href="mailto:arne.wessel@forwind.de">arne.wessel@forwind.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. Jens Wiemann</td>
<td>+49 (0) 201 183-2853</td>
<td><a href="mailto:wiemann@hydromech.uni-hannover.de">wiemann@hydromech.uni-hannover.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. Fabian Wilke</td>
<td>+49 (0) 511 762-3367</td>
<td><a href="mailto:wilke@stahl.uni-hannover.de">wilke@stahl.uni-hannover.de</a></td>
</tr>
<tr>
<td>Dipl.-Ing. Stephan Zerbst</td>
<td>+49 (0) 511 762-4393</td>
<td><a href="mailto:s.zerbst@isd.uni-hannover">s.zerbst@isd.uni-hannover</a></td>
</tr>
<tr>
<td>Prof. Dr.-Ing. Werner Zielke</td>
<td>+49 (0) 511 762-3567</td>
<td><a href="mailto:zielke@hydromech.uni-hannover.de">zielke@hydromech.uni-hannover.de</a></td>
</tr>
</tbody>
</table>

**Former Staff Members**

Dr. Ulrich Focken  
Dipl.-Phys. Gunnar Harde  
Dr. Bernhard Lange  
Dr. Matthias Lange  
Dipl.-Phys. Saskia Tautz
List of Activities

**Research**
- Turbulence modeling
- Offshore-meteorology
- Forecast and spatial-time structure of wind power
- Load approaches
- Life span of settlement structures
- Stability and early diagnosis of damages
- Foundation of offshore WEC
- Grid integration of offshore-wind parks
- Integrated modeling of offshore WEC

**Development Projects**
- Windpark-Modeling for planning, operation and design of offshore-WEC
- Wind power forecast with input data from different weather models
- Analysis of WEC power and wind turbulence in respect to increase accuracy of energy gain prognosis
- Dynamic resistance of screw connections in pale pylons for WEC
- Low fatiguing connections at WEC of steel and concrete
- Usage of combined stretching strips for early diagnosis of damages

**Other**
- Study on regional ecomical effects of wind energy usage in the counties of Cuxhaven and Stade
- Symposium on offshore windenergy and ship safety
- Decentralised Energy Management (DEMS) Project – Improving wind power and demand forecast
- Research map of wind energy in the Staes of Lower Saxony and Bremen
- Participation in the EU-POWER-Project (Pushing Offshore Wind Energy Regions)
- Concept for self-improvement in wind-energy for engineers (Wing)
- Participation in the EU Marie Curie Research Training Network ‘Wind Energy Assessment and Wind Engineering’
- Energy Management to Prevent Electrical Network Installation

**Available Products**
- Wind Farm Layout Programme (FlaP)
- HanOff, WaveLoads
Chronicle

2003
September, 23rd – 27th Exhibition at HusumWind with information stand

2004
January, 20th Symposium “Steel and Offshore Windfarms”, Dillinger Hütte GTS, Dillingen → oral presentation by ForWind
March, 16th 3rd GIGAWIND-Symposium "Offshore-Windenergie Bau- und umwelttechnische Aspekte", Hannover
March, 29th Opening Event ForWind in Oldenburg
April, 19th – 21st EAWE-Conference: “The Science of making Torque from Wind”, Delft → 3 oral presentations by ForWind
May, 11th – 14th Exhibition at WindEnergy Hamburg
June, Nordic Steel Conference, Copenhagen → oral presentation by ForWind
July, 6th ForWind-Kolloquium, Oldenburg
October, 15th – 16th Energiekongress “Strom gegen den Strom”, Hamburg → oral presentation by ForWind
October, 15th – 16th Deutsche Windenergie Konferenz (DEWEK 2004), Wilhelmshaven → 10 oral presentations by ForWind → 4 poster presentations by ForWind
November, 4th VDI VDE – Fachtagung “Windkraftanlagen – Sicherheit und Zuverlässigkeit”, Darmstadt → 2 oral presentations by ForWind
November, 12th Havarie im Windpark? Symposium on Offshore Wind Energy and Maritime Safety, Oldenburg
November, 22nd – 25th 2004 European Wind Energy Conference & Exhibition, London → 3 oral presentations by ForWind → 4 poster presentations by ForWind
Research
Turbulence modelling

Institute of Physics - working group hydrodynamics and wind energy
Joachim Peinke, Stephan Barth

Description
Recent results and findings from fundamental turbulence research are conducive to the understanding of the statistics in turbulent velocity fields. These findings have been developed into powerful analyzing utilities and have been used for many different datasets coming from pure laboratory turbulence measurements to surface datasets of rough structures to seismic datasets. Together with modern insights of the structure of turbulence they shall be enlarged and adapted to applications in wind energy. Hereby the focus lies on the influence of wind field fluctuations on the power output and on the effect of small scale turbulence on components and assemblies of wind turbines. For the latter especially extreme mechanical loads and longtime dynamic fatigue are a matter of particular interest.

The results from this project should assist manufactures with constructing future generations of wind turbines with a minimum of material and a maximum of safety and reliability. In particular for applications in complex terrains and offshore this is important.

Figure 1: Schematic of fluctuations in the wind field acting on a wind turbine. Picture taken from: Robert Gasch - Windkraftanlagen - B.G. Teubner Stuttgart 1993
Approach / Activities

In the first steps we focus on the scale dependent statistics of atmospheric velocity increments (velocity differences over a certain time step $\tau$ or spatial distance $r$) measured at different on- and offshore locations and compare them to that of homogeneous, isotropic and stationary turbulence as realized in laboratory experiments. The increments are a measure to quantify and qualify temporal and spatial correlations in the wind field.

For isotropic turbulence the statistical moments of increments, the structure functions, have intensively been studied. Their functional dependence on the time scale $\tau$ is described by a variety of multifractal models. Besides the analysis of moments, probability density functions (PDFs) are often considered. They show a transition from Gaussian distributions to intermittent (heavy-tailed) ones as the scale decreases. The PDFs of atmospheric wind fields differ from those of turbulent laboratory flows where – with decreasing scale – a change of shape of the PDFs is observed. For large scales the distributions are Gaussian while for small scales they are found to be intermittent. However, the atmospheric PDFs change their shape only for the smallest scales and afterwards stay intermittent for a broad range of scales. Such a constant shape for larger and larger scales is expected only for stable distributions such as Gaussian ones or the Lévy stable laws. Although the decay of the tails indicates that distributions should approach Gaussian ones (as for isotropic turbulence) they show a rather robust exponential-like decay.

The challenge is to describe and to explain the measured fat-tailed distributions and the corresponding non-convergence to Gaussian statistics. Large increment values in the tails directly correspond to an increased probability (risk) to observe large and very large events (gusts).

Interim results / Outlook

We found that the observed intermittent form of the atmospheric wind field PDFs for all examined scales (time step $\tau$ or spatial distance $r$) is the result of mixing statistics belonging to different flow situations. These situations are characterized by different mean wind velocities. When the analysis by means of increment statistics is conditioned on periods in the measured datasets with constant mean velocity the statistics of velocity differences look pretty much the same as those of isotropic turbulence. For isotropic turbulence it is known that the PDFs can be seen as a superposition of Gaussian distributions with standard deviation $\sigma$, where the standard deviation itself is distributed in a way that the logarithm of $\sigma$ is distributed normal. We introduce a model that interprets atmospheric increment statistics as a large scale mixture of subsets of those isotropic statistics. In doing so one has to know the distribution of the mean velocities for which we assume the Weibull distribution to be the correct one. With this combined superpositions we are able to reproduce the PDFs on all scales for different wind situations. When mixing is weak the same statistics as for isotropic turbulence can be reproduced while for strong mixing robust intermittent statistics are obtained. This model should also allow a better determination of the Weibull distribution by not only trying to fit the mean wind distribution itself but also the probability density distributions on different scales.

Using properties from Markov processes we can describe the increment statistics of isotropic turbulence in a better way. Thus next steps will be the examination of the
atmospheric increment statistics by means of this more advanced method. The outgoing results shall be used to model the wind field for desired situations with the correct statistical and Markov properties. This reproduced wind field can then be used as input for the other projects to calculate the extreme mechanical loads on new components and assemblies, e.g. grounding.

Figure 2: Probability density functions of velocity differences for different time steps $\tau$ (increasing from top to bottom). The left figure shows PDFs of a dataset with several mixed mean velocities while the right figure shows the PDFs for only one mean velocity.

Publications and conference contributions
Barth, S., Böttcher, F., and Peinke J.: Wind gusts and small scale intermittency in atmospheric. Talk at the 57th Annual Meeting of the Devision of Fluid Dynamics of the APS, Seattle USA, November 2004
Offshore meteorology

Institute of Physics - Energy and Semiconductor Research Laboratory

Bernhard Lange, Arne Wessel, Saskia Tautz, Lorenzo Claveri, Jiri Beran, Juan José Trujillo, Jens Tambke, Ralf Bruns

Description

It is expected that offshore wind power will contribute substantially to the energy supply in Europe in the future. In Germany alone, the aim of the government is to install 20-25,000 MW offshore wind power by 2030, which will supply 15% of the German electricity consumption.

The wind over the sea is the energy source, which is tapped by offshore wind farm installations. But it is also the main source of loads on the wind turbines. Comprehensive knowledge about the wind conditions at offshore sites is therefore crucial for the successful development of offshore wind power. On the other hand, there has been little need to investigate the wind at locations and heights relevant for wind power utilization in the past, i.e. over coastal waters and in heights of 30-200 meters. The knowledge about the wind conditions and meteorological effects at these locations is therefore limited. Our aim is to provide the meteorological knowledge needed for the successful development of offshore wind power.

Approach / Activities

To tackle this question, the research group 'Offshore Wind Power and Wind Farm Modeling' has been established, combining the efforts of a number of research projects. It continues, but also broadens the field of expertise developed at the University of Oldenburg for a number of years.

The research area was established at the beginning of 2004. The number of people working in the group has increased from 3 at the beginning of the year to 8 at the end of 2004. The research currently is focused on four highly interconnected tasks:

- Field measurement analysis
- Description of physical processes in the marine boundary layer
- Numerical meteorological modeling
- Wind farm modeling

The project 'Offshore wind power: Characterization of the marine atmospheric boundary layer', funded by the 'Land Niedersachsen' in a 'VW-Vorab' project, is the core of this research area. Additional funding has been secured from the 'Deutsche Bundesstiftung Umwelt' (DBU) for a research project and a PhD scholarship and from the EU for the Marie Curie Research Training Network WindEng (see page 82). Also the development project FLaP has been integrated in this research group (see page 87).

In 2004, work has progressed in the following research projects:

DEWI (Germany), NEG Micon (Denmark), CRES (Greece), SEAS (Denmark), ISAC (Italy) and FMI (Finland) (see page 82)

- The research project 'Evaluation of heat and momentum flux in the marine atmospheric boundary layer for offshore wind energy utilisation' (BAGO): partly funded by DBU; finished 9/2004 (final report [16])

- Development project 'Further development of the wind farm program FLaP for planning, surveillance and turbine design in offshore applications'; funded by the 'Land Niedersachsen'; (see page 87)

- Modeling of turbulence in wind farms: PhD project, funded by a DBU scholarship

- Marine boundary layer modeling for the offshore wind power generation; PhD project, partly funded within the EU RTN WindEng

- Modeling the vertical flux of momentum in the marine atmospheric boundary layer: PhD project

- Derivation of the offshore wind climatology with mesoscale models for wind power application; external PhD project in cooperation with DEWI

- Offshore wind potential with MM5: research project, partly funded within the EU RTN WindEng

- Investigation of the fetch influence on the wind speed profile in the coastal marine boundary layer due to thermal effects: internal research project in cooperation with Elsam Engineering and Risø National Laboratory

- Evaluation of the WOWC (Wind over waves coupling) model for sea surface roughness with the Rødsand measurement: MSc project in cooperation with KNMI

- Measurement of wake interactions: MSc project

- Use of GIS for the evaluation of offshore wind resource calculations: external MSc project at the University of Vechta

In most of these projects, close co-operations with national and international research institutions have been established. The close co-operations with the DEWI and the Risø National Laboratory are especially important. They resulted in several common projects and common publications. Also, close cooperation with other research groups of ForWind is maintained, resulting in common use of data, publications, teaching activities, PhD thesis, etc.

The group has contributed to the teaching activities of the Institute of Physics with a seminar on boundary layer flow together with the turbulence group. Additionally, an internal research seminar has been established, as well as an internal seminar on MM5 and an introductory course to WAsP. Members of the group participated and contributed to the DACH, EWEC, DEWEK and EGU conferences. Several proposals for future research projects have been submitted to BMU and EU.

**Interim results / Outlook**

Already in the first year, some important research results have been obtained in the area of offshore wind power meteorology and wind farm modeling. The results have been published widely, including five journal publications. In 2004, the new research task of numerical meteorological modeling of the marine boundary layer has successfully been started.
Additionally, it is planned to establish a new research task on offshore wind resource calculation methods in 2005. This is aimed at the application of the knowledge gained in the description of the physical processes and the numerical modeling.

Also, experimental work will start in connection with field measurement analysis and wind farm modeling. Focus of the experimental work will be wind tunnel studies about the flow distortion of measurement masts and studies of calibration methods for ultrasonic anemometers.

In the following, a brief description of the most important research results is given together with planned activities for the next year.

Field measurement analysis

A new wind tunnel calibration method for ultrasonic anemometers has been developed, which allows a 3-dimensional calibration with justifiable experimental effort. It has been used for the calibration of the ultrasonic anemometers of the FINO station. A data analysis program for flux measurements has been implemented and fluxes for the FINO data have been calculated [8], [12], [16], [17].

Wind tunnel calibration of ultrasonic anemometers: Left: Measurement setup in the wind tunnel of the University of Oldenburg; Right: Error in the measured vertical wind speed versus wind direction for horizontal wind speed of 10 m/s

A correction method for the influence of the measurement mast on the flow of mast mounted anemometers has been published and used for the Rødsand, Horns Rev and FINO data. The analysis of the first FINO wind profile data showed the need for an improved mast flow correction. Due to the short boom length at the FINO mast the influence of the flow distortion of the mast structure on the data is very large and can not be corrected with current model [3], [6], [13], [14].
Measured ratios of cup and sonic anemometer wind speeds at 40m height at the FINO I mast; also shown is the correction function

For the coming year, the focus of the work will be on the improvement of flux measurements and the development of a new mast flow correction method.

Description of physical processes in the marine boundary layer

The dependence of sea surface roughness on wave age has been shown to be severely spoiled by self-correlation effects [3]. The more sophisticated 'Wind over Waves Coupling model' (WOWC) from KNMI has been compared with the Rødsand data, but showed large deviations.

It was also shown that thermal effects are more important than roughness effects in the marine atmospheric boundary layer for wind speeds important for wind energy utilization. The wind speed profile at Rødsand was found to deviate systematically from the Monin-Obukhov profile [1], [2], [4], [9], [10], [11].

These studies used the measurement data from Rødsand. An initial analysis of data from the FINO measurement station suggest less influence of thermal effects over the North Sea compared to the Baltic Sea measurement Rødsand [6], [16].

A new model for the wind speed profile offshore has been developed based on the concept of inertial coupling. The model has been compared with data from the measurement station Horns Rev with promising results [13], [14], [18], [21].

For the next year, the new FINO measurement data will be used more extensively for model comparisons. Also, improved data analysis, flux measurements and correction (s. a.) are expected to give new insight in the verification of models with measurement data. The current work on the WOWC model, the inertial coupling model and the comparison of flux and profile measurements will be continued.
Bin averaged wind shear measurements between the wind speeds at 50m and 30m height versus stability parameter 10m/L for FINO I and Rødsand

Numerical meteorological modeling

The mesoscale model MM5 has been used for investigations of the wind profile in the boundary layer for different locations over land and over the sea. Different planetary boundary layer schemes implemented in MM5 have been compared [11].

First steps have been undertaken to develop a method to use the MM5 model for offshore wind resource analysis. A sensitivity study for grid resolution and nesting has been started to try to reduce computational cost for such calculations.

Considerable experience has been gained with the complex MM5 model. In 2005, the focus of the work will be on the development of a method to use MM5 for offshore wind resource calculations and on investigating the capability of MM5 to model the coastal marine boundary layer.

Wind Farm Modelling

A new model for the turbulence intensity in wind farms has been developed, which consists of two parts: A model for the turbulence intensity profile in a wake and a wake superposition model. The model has been verified with measurements from Nibe and Sexbierum with good agreement [7], [15], [19]. The turbulence model has been used in a model comparison test conducted by the 'Staatliches Umweltamt Schleswig'.

An investigation of the capability of the FLaP program for the use in wind farm monitoring has been started. Data from the wind farms Hamswehrum and Bassens are used in this study.

A new version of the wind farm modeling software FLaP has been released, which now runs in the Windows environment. The program has been sold several times mainly to international customers for educational use.

Further verification of the turbulence model with measurement data and a small experimental field study is planned for the coming year. Also, the development of a wind farm monitoring method will be finished.
Publication list

Journal papers


Conference papers


Report


MSc thesis (Diplomarbeit)


Manuscripts submitted


Manuscripts in preparation


Forecasting and Spatial-temporal Structure of Wind Power

Institute of Physics – Energy and Semiconductor Research Laboratory
Detlev Heinemann, Jens Tambke, Lüder von Bremen

Objectives
The project's overall objective is to support an effective integration of wind power into current and future electricity supply structures. To achieve this, work concentrates on two fields of research: i) Wind power forecasting techniques, its improvements and the characterization of its accuracy and ii) analysis of the influence of fluctuating power on the performance of electricity grids and its optimization.

The first phase of the project is denoted to the investigation of wind power forecasting, which will be described within this report.

Approach
Previous investigations for onshore sites showed that the two most important factors determining the accuracy of the wind power prediction are the quality of the numerical wind speed forecast commonly provided by weather services and an adequate description of the vertical wind profile in different meteorological conditions. Both investigations are subject to this project.

This investigation aims at estimating the expected performance and accuracy of wind power forecasts for offshore sites. Short-term wind power prediction systems are already in operation for onshore sites and need to be adapted for offshore applications.

As predicted wind speed is typically the main input into power prediction systems, its accuracy is highly important. Here, the predictions are provided by the Lokal-Modell (LM) of the German Weather Service (DWD). For the offshore case the special meteorological characteristics of the marine boundary layer are considered to predict the correct wind speed at the wind turbine’s hub height. In contrast to wind over land the situation offshore is different mainly due to three important effects: the non-linear wind-wave interaction leading to a variable surface roughness, the large heat capacity of the water affecting the thermal stratification, and the occurrence of internal boundary layers due to the land-sea discontinuity.

Our investigation of the offshore conditions is carried out with a focus on the later application of the results for wind power prediction. The prediction system Prevenito, which has been developed at Oldenburg University, is used for this purpose. It relies on numerical weather prediction (NWP) output to extract information about the future development of the wind field and other related meteorological variables. The NWP is spatially refined considering the local conditions of the specific site, e.g. orography and surface roughness. To calculate the wind speed at hub height the thermal stratification of the atmosphere is modeled in detail. Then the wind speed is transferred to power output by the power curve of the wind turbine where the shadowing effects within wind farms are considered. As a result Prevenito provides the predicted power output of a specific wind farm.

For a proper description of the vertical wind profile in offshore applications - in contrast to profiles over land – three important effects have to be considered: the non-
linear wind-wave interaction leading to a variable surface roughness, the large heat capacity of the water affecting the thermal stratification, and the occurrence of internal boundary layers due to the land-sea discontinuity.

Assuming that the deviations are related to the special physical processes in the marine boundary layer we present a theoretical model to derive wind profiles over the ocean which involves the inertial coupling of the Ekman layers of atmosphere and sea via a wave-boundary layer with constant shear stress. Profiles calculated with this method are compared to measured profiles.

**Activities**

The accuracy of the wind speed forecast of the NWP system “Lokal-Modell” (LM) of the German weather service (DWD) has been evaluated. The model uses measurements of 10m wind speed at several coastal sites at the German Bight and the Baltic Sea and three real offshore sites in the North Sea. The investigated period comprises a complete year (2002) with a temporal resolution of 1h and a forecast horizon of 48h. The 00 UTC forecast run of the LM has been used.

In addition, data from the meteorological mast at Horns Rev, located approximately 18 km west of Blaavands Huk at the Danish North Sea coast were used. Wind speed measurements at various heights, in particular at 62 m, for the period 10/2001 – 04/2002, were available. The LM model output provided wind speed data in three relevant heights (10m, 34m, 110m). Prediction of the 62m wind speed was calculated by interpolation of the 33m and 110m wind speeds considering a neutral logarithmic wind profile.

Horns Rev data were also used for the analysis of the offshore vertical wind profiles. Wind speed measurements in four heights (15m, 30m, 45m and 62m) for the same period 10/2001 - 04/2002 have been investigated. Corrections for flow distortion due to the mast have been applied.

**Interim Results**

**Accuracy of numerical wind speed forecasts**

Predicted and measured wind speeds are both given at 10m height. In Fig. 1 the bias of the wind speed predictions at the investigated sites are shown. For offshore sites the bias is rather small for all prediction times with a weak diurnal variation. In contrast to this, for North Sea coastal sites the bias has a large positive offset and strong diurnal variations with maximum values at approximately midnight (24 h and 48 h) and minima at noon (12 h and 36 h). Hence the actual wind speed is generally underestimated.

As an error measure the root mean square error has been used in its decomposed form which sheds some light on the origin of the forecast errors:

\[ \text{rmse}^2 = \text{bias}^2 + \text{sdbias}^2 + \text{disp}^2 \]

where bias := e, sde := \( \sigma(e) \), sdbias := \( \sigma(\text{upred}) - \sigma(\text{umeas}) \) and disp := \( \sqrt{2\sigma(\text{upred})\sigma(\text{umeas})[1 - r_{p,m}]} \) with \( r_{p,m} \) denoting the cross-correlation coefficient between the two time series and \( \sigma(\text{upred}) \) and \( \sigma(\text{umeas}) \), respectively, their standard deviations. The sdbias, i.e. the difference between the standard deviations of upred and um eas evaluating errors due to wrongly predicted variability. The sdbias together with the bias indicate amplitude errors which are typically related to site specific effects. Second, the dispersion, disp, involves the cross-correlation coefficient weighted with both standard deviations. Thus, disp accounts for the contribution of phase errors to the rmse reflecting global properties of the prediction system.
overestimated by the prediction. In particular, the change in the bias over the day indicates that the thermal stratification of the atmosphere is not accurately covered by the numerical prediction.

Fig. 1: Annual wind speed bias = upred-umeas, North Sea (left) and Baltic Sea (right). Offshore sites (emsx and deut) and coastal sites (cuxh, list, nord).

Fig. 2 summarizes the forecast error according to the decomposition of the root mean square error for an offshore lightship site (“deut”). bias and stdbias are negligible and the individual dispersion dominates the rmse. The bias and the stdbias measure the systematic components of the temporarily averaged prediction error. The dispersion error (disp) describes the “phase” error of the forecast, in contrast to amplitude errors, and cannot be removed by linear corrections as the correlation is invariant under this transformation.

Fig. 2: Decomposition of RMSE at lightship “deut”.

Thus, additional linear post-processing will not improve the offshore site forecasts. The normalized rmse of the offshore sites (with respect to the annual mean) is about 20% to 30% in the first 24 hours compared to a typical onshore site with a relative rmse of about 30% to 45%.

Vertical off-shore wind profiles

Our analysis shows that the offshore profiles measured at Horns Rev deviate considerably from the expected shapes by higher wind shears. The reason for the meas-
ured deviations is not totally clear. From a physical point of view the conditions over
the sea, in particular, the wind-wave interaction leading to a different transport of
momentum compared to onshore might be an explanation for the observed devia-
tions. On the other hand, the possibility that the effects are due to failures in the mea-
surement process cannot be excluded. Hence, further investigations are necessary
to confirm our findings.

Profiles for different wind directions show for most sectors deviations from the ex-
pected logarithmic shape. The deviations are most pronounced for the sea sectors
(135° - 360°) where the profiles seem to be logarithmic up to 45m, but at 62m the
measured wind speed is on average about 0.3 m/s higher than it would be estimated
by a logarithmic extrapolation from the lower heights.

These deviations could be easily explained with a stable thermal stratification of the
boundary layer. But remarkably, this ‘bending’ to higher wind speeds at 62m height
occurs in all thermal conditions that were observed at Horns Rev: Fig. 3 shows the
normalised mean measured wind profiles from the sea sectors for the complete
range of observed potential temperature differences. The ‘bending’ even for clearly
unstable conditions cannot be explained with a logarithmic profile corrected with
Monin-Obukhov similarity theory. Besides this striking feature, the wind speed gra-
dients follow the expectations for different thermal stratifications: Unstable conditions
are related to small gradients and stable conditions to high gradients.

An alternative vertical wind profile model that is based on inertial coupling between
the Ekman layers of the atmosphere and the ocean is introduced following the basic
concept:

The geostrophic wind is regarded as the driving force of the wind field in lower layers
of the atmosphere. The momentum is transferred downwards through the Ekman
layer which is defined by a constant turbulent viscosity. Similar to the Ekman layer of
the air there is an Ekman layer of the water below the ocean’s surface. The important
point addressed here is to derive an adequate description of the coupling between
the two Ekman layers where the idea is to introduce a wave-boundary layer near the
surface. The momentum transport from the wind flow into the ocean, and hence the
wind profile, then crucially depends on the coupling relations between the three flow
layers.
The wind speed profiles according to ICWP theory are calculated such that the wind speeds at 30 m height correspond to the measured profiles at that height. In Fig. 4 the mean measured sea sector wind profile (135° - 360°) at Horns Rev and the corresponding mean of the ICWP profiles are compared. The measured wind speed at 62 m is on average larger than expected by a logarithmic extrapolation using measured wind speeds from two heights. The agreement between the ICWP and the measured profiles is rather good. Taking into account that the only information given to the ICWP model is the wind speed at 30 m, the mean wind shear is covered remarkably well. The increased wind speed at 62 m is almost captured (bias = 0.1 m/s) which is related to the non-logarithmic shape of the ICWP due to the Ekman part of the profile. The offshore WasP profile leads to a significant underestimation of the wind shear of 0.4 m/s.

The remaining differences in the profiles indicate that the parameters used in calculating the ICWPs have to be optimized. In particular, the height that marks the transition between wave-boundary layer and Ekman layer is a candidate to be adjusted. Because of the crucial influence of thermal stratification on the wind shear, the scale should become much smaller when thermal Monin-Obukhov corrections are completely integrated into the ICWP model.

![Graph showing wind speed profiles](image)

Fig. 4: Mean measured sea sector wind profile (135° - 360°) at Horns Rev compared to mean of ICWPs and average offshore WasP profile.

The introduction of an alternative way to describe the vertical wind profile over the sea seems to be promising. The new method is based on inertially coupling the Ekman layers of air and sea with a wave-boundary layer with constant shear stress in between. For wind directions with long fetches the profiles derived by this method are in good agreement with the mean measured wind shears. In general, inertially coupled wind profiles seem to be a promising approach with good potential to be further improved. Future work has to focus on describing air-sea interactions and fetch-dependent influences in order to improve both the description of wind profiles and the numerical prediction models. Most important, thermal effects have to be considered in detail.

**List of publications**


Environmental Loads on Offshore Wind Energy Converters

Institute of Fluid Mechanics and Computer Applications in Civil Engineering
Werner Zielke, Kim Mittendorf

Description
For the design of reliable and cost optimized offshore wind energy turbines an exact knowledge of the environmental loads is important. The combined consideration of the effects of wind, currents and waves is the quintessence of the project, because wind and wave loads are equally important for the design of the support structure.

The determination of loads due to waves and wind is based on meteorological and oceanographic data. On the one hand the environmental conditions have to be analysed and characterised. In the next step methods and models have to be developed with which loads on basis of the classified environmental conditions can be calculated. The goal is to develop offshore wind energy turbines using detailed knowledge of the load processes.

The results of this project will primarily serve to reduce the existing uncertainties in the design of offshore wind energy converters and will allow the design of highly optimised long term robust structures. Furthermore the developed methods will serve as modules for integrated wind turbine modelling (see research project IX).

In this report we concentrate on regular and irregular wave loads on structures consisting of arbitrarily oriented tubes (e.g. mono-piles, jackets or tripods).

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

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

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

The water particle acceleration \( \partial u \) and velocities \( u \) may be obtained from a suitable wave theory.

In case of oblique cylinders neither the method of decomposition of velocities or forces nor the drag and inertia coefficients are clear. Sarpkaya [2] showed that forces calculated by taking into account velocity and acceleration vectors acting normal on the tube agree fairly well with measurements.
**Regular Waves**

Surface gravity waves in an incompressible, homogeneous and inviscid fluid can be expressed in terms of a velocity potential $\Phi(x,z,t)$. The velocity components $u$ and $w$ are given by the spatial derivative of the potential $\Phi$.

$$u = \frac{\partial \Phi}{\partial x} \text{ and } w = \frac{\partial \Phi}{\partial z}.$$  

The field equation is the Laplace equation

$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial z^2} = 0.$$  

With following boundary conditions:

- **Bottom boundary condition (BFC),**
  
  $$w = 0 \quad \text{at } z = -h \quad \text{where } h \text{ is the water depth.}$$

- **Kinematic free surface boundary condition (KFSBC),**
  
  $$w = \frac{\partial \eta}{\partial t} + u \frac{\partial \eta}{\partial x} \quad \text{at } z = \eta(x,t) \quad \text{where } \eta \text{ is the free surface.}$$

- **Dynamic free surface boundary condition (DFSBC)**
  
  $$\frac{\partial \Phi}{\partial t} + \frac{1}{2} (u^2 + w^2) + g\eta = B \quad \text{at } z = \eta(x,t) \quad \text{where } g \text{ is the gravitational acceleration and } B \text{ is the Bernoulli constant.}$$

The coordinate system is chosen so that the positive vertical $z$-axis is pointing upwards and the $x$-axis is in line with the still water level at $z=0$. With regard to regular waves also following boundary conditions are applicable:

- **Periodic lateral boundary conditions (PLBC)**
  
  $$\Phi(x,z,t) = \Phi(x + 2\pi / k, z,t) = \Phi(x, z, t + 2\pi / \omega) \quad \text{where } k \text{ is the wave number and } \omega \text{ is the wave frequency and } \Phi \text{ the potential.}$$

- **Symmetry about the crest in x and t directions.**

The existing wave theories have different scopes where they are appropriate. The figure shows the ranges of suitability for various wave theories in dependence of relative water $(d/g/T^2)$ depth and relative wave height $(H/g/T^2)$. 
Figure 1: Ranges of suitability for various wave theories (Le Méhauté, 1976)

The water particle kinematics, surface elevations and wave loads can be computed with the software WaveLoads using following wave theories:

- Stokes First Order Theory (Airy)
- Stokes Second Order Theory
- Stokes Third Order Theory
- Stokes Fifth Order Theory
- Lagrangian formulation by Woltering
- Stream-Function Theory in Formulation by Fenton
- Fourier Wave Theory in Formulation by Dalrymple.
- Fourier Wave Theory in Formulation by Sobey.

**Irregular Waves**

The most obvious method to simulate a first order random sea is to superimpose numerous Airy waves (velocity potential $\Phi$ as well as surface elevation $\eta$) with amplitudes and frequencies determined from a variance spectrum $S(f_n)$ of water surface elevations and a random phase. Tucker [7] showed that this approach yields sea surfaces with incorrect statistical properties and suggested some slight modifications which lead to a truly Gaussian process.

$$\Phi(x, z, t) = \sum_j \Phi_j(x, z, t)$$

$$\eta(t) = \sum a_n \cos(\omega_n t + \phi_n) + b_n \cos(\omega_n t + \phi_n),$$

where the Fourier coefficients $c$ and $b_n$ are given by:
\[a_n = \sqrt{S(f_n)\Delta f} N(0,1)\]

\[b_n = \sqrt{S(f_n)\Delta f} N(0,1)\]

with \(\omega_n = 2\pi f_n\), \(S(f_n)\) variance spectrum and \(N(0,1)\) is a random normal variable with zero mean and unit variance.

This superposition implies that each component is a freely propagating wave satisfying the linear dispersion relationship. There is no interaction between the frequency components. Moreover difficulties arise in determination of water particle kinematics above the mean water lever, which is the strict upper bound of the Airy solution domain. There the hyperbolic functions quotients in the Airy theory become extreme large for high frequencies and give unrealistic velocities and accelerations. To cope with these there exist several so-called stretching methods, e.g. Wheeler [4] or Chakrabarti [5]. But the prediction of crest kinematics is still not be very accurate, because the free surface boundary conditions is not be satisfied at all.

More promising, with regard to accuracy, seem methods that seek to represent the local behaviour of an irregular wave (local approximation methods). The local Fourier approximation (LFA) introduced by Sobey [6] predicts wave kinematics from a given water surface time history at a fixed location and is an extension of the Fourier model for regular waves. For an irregular water surface profile the solution is being found in a moving time window (see Figure 2) of duration \(\tau\) (\(\tau \ll \text{wave period}\)), to best obey the boundary conditions at the given surface node \(\eta_i\).

A complete representation can be found in [6] and application and some comparisons with measurements are shown in [9]. Applied to large-scale laboratory measurements in the Large Wave Channel (GWK) of the Coastal Research Centre [8] the LFA showed a good agreement (see Figure 3).

\[\text{Figure 2: Local window of duration } \tau\]
Figure 3: Local Fourier approximation of measured data in the Large Wave Channel

References


[8]. Coastal Research Centre (FZK), Hannover, Germany, 2004, “Investigations on Wave Loadings of Cylindrical Marine Structures”, Research project sponsored by the Deutsche Forschungsgemeinschaft under No. 0u 1/4-2 (report in preparation), sparboom@fzk.uni-hannover.de.

Publication list


Fatigue Assessment of Support Structures of Offshore Wind Energy Conversion Systems

Institute for steel Construction, Hannover
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 $10^9$. Due to these special conditions the fatigue assessment is a crucial factor for both the safe and the economic design of OWECS.

Concerning the German wind farms planned in the so-called Exclusive Economic Zone of North and Baltic Sea most of the support structures will be located in regions with water depths between 20 and 50 m. For these water depths, different types of support structures are currently under discussion. A detailed description is given in [1].

So far experience with offshore wind farms is limited. Some of the structures, proposed for higher water depths, are still in a conceptual design phase and have not been applied yet. Thus a realistic forecast of fatigue behaviour and resulting lifetime requires the development of improved design concepts for the different types of support structures taking into account the special offshore conditions with its complex loading history.

Therefore the aim of the research project is to analyse the fatigue behaviour for a number of typical construction details:
1. welded joints (tripods or jacket-structures with circular hollow sections)
2. hybrid joints (grouted joints)
3. bolted joints (e.g. ring flanges with large bolts)

Within the first phase the research work was concentrated on welded and grouted joints.

**Welded Joints**

For braced structures, e.g. tripods according to Figure 1c, the fatigue strength of tubular joints is determined by local approaches (Figure 2). The concepts differ in the degree of accuracy regarding the description of damage mechanisms and in the underlying material model.

![Local Concepts](image)

**Figure 2: Local concepts for the fatigue assessment of welded joints**

The structural stress approach today is state-of-the-art in the fatigue assessment and covered by the actual offshore standards. A series of finite element calculations have been carried out, comparing the different approaches focussed on

- the extrapolation techniques
- the different S-N-curves for tubular joints
- the choice of element type and mesh size.

Research has shown that stress concentration factors (SCF) for the structural stress approach should be determined by finite element analysis with volume elements including a weld model. If shell-elements are applied without compensation for weld zone stiffening, stress extrapolation to the midline intersection of chord and brace usually leads to conservative results.

The validity of parametric equations for the determination of stress concentration factors have been examined, also with regard to special structural details like haunched tubular members, which are proposed in some designs. It could be shown that simplified approaches, using parametric equations and influence functions to determine stress concentration effects at the welds, should be used with caution, especially with respect to the multiaxial loading effects. Nevertheless the simplified methods are a powerful tool in the early design stage. Based on a number of calculations of simple tubular joints, a new dimensionless parameter has been defined. It considers the dif-
ferent boundary conditions at the brace ends and can be used as an add-on to the existing parametric equations. The developed correction functions allow a conversion, e.g. of results with small test specimens, into the realistic undisturbed stress distributions of the in-situ structure. Its applicability to tripods joints has been proven.

As the boundary conditions of local finite elements models have a great impact on the results, the top and bottom nodes of the tripod structures have been analysed in detail. Especially for the top tripod node, coupled beam-volume-models had to be developed as the joints itself are directly loaded.

Although not part of the actual offshore standards, sophisticated concepts like the notch stress approach better reflects the parameters having impact on the fatigue strength. On the other hand scale effects lead to high numerical efforts, as the notches of the weld toes are assumed to have radiuses of only 1 mm while the overall dimensions are much higher (steel plates with a thickness up to 100 mm and tube diameters up to 6000 mm are expected). Analysis procedures have been developed to get a reduced computing time, including sub-modelling techniques and multipoint constraint (MPC) contact, which provides a way to connect parts in assemblies without requiring the parts to share nodes.

Case studies have shown that the notch stress approach can be successfully applied to tubular joints [2]. Some of the differences between test results and fatigue strength predictions with the structural stress approach have been explained with this approach.

If welds of tubular joints are treated after the welding process to increase their fatigue strength, the danger of fatigue failure starting at the weld root can be governing. So far calculations for typical tripod geometries have been done leading to a preliminary design concept. This concept will be evaluated further, as this problem usually is not covered by the offshore standards and yet structural stress approaches not have been validated sufficiently.

Further work will be done regarding the possible application of cast iron nodes in typical tripod structures.

**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, needed to transfer forces from one steel member into the other. Grouted joints have been developed for braced structures of oil and gas platforms, mainly exposed to axial loads. The application for OWECS requires that bending moments have to be transferred additionally. Although grouted joints already have been used for monopile structures in offshore wind farms, experience is missing concerning bearing capacity and fatigue strength of this structural detail.
Nonlinear effects involving the two different materials can hardly be evaluated using only numerical methods. Further knowledge has to be gained by large scale model test (Figure 3). For this reason a test setup has been developed. Numerical models have been improved concentrating on the simulation of the structural steel parts. Besides realisation of the tests, more work has to be spent in the prediction of fatigue damage mechanisms of the grout material. Research in this sector will benefit from the research results of the ForWind development project V, where damage prediction of concrete structural details under dynamic loading are examined.

Publications


Stability and early diagnosis of damages

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

The windpower has been reached an outstanding importance within the renewable energy sources. This branche is new and progressive. With development of this field new problems are arised which will be to solved. In view of the future of this young branche it makes sense to research.

**Situation and problems**

Offshore windenergy plants are difficult to available and reachable. Therefore it is essential to minimise costs of maintenance and repair in order to use offshore-windenergy-plants profitable. So an optimised concept of condition-related plant maintenance is required to detect damages at an early stage. Thus consequential damages can avoided and lifetime of offshore windenergy plants can increased.

The structures of offshore windenergy plants are subjected to extensive dynamic loads of wind and waves. This loads appear with very high cyclenumbers over the lifetime. This cyclenumbers may be greater than in aeronautical applications. In contrast support structures of offshore windenergy plants have regions with risks of fatigue. There are welded joints, screwed joints and hybrid connections between different materials. In particular regions like splash zone or scour generation zone are to surveyed.

That applies to rotorblades too. Furthermore specific material properties of gfk- and cfk-structures are to taken into account.

**Aims**

From this it follows the aim, to control condition of structures telemonitoring with a condition monitoring system (CMS) and to apply condition-related plant maintenance.

As results lightly modifications will be detected at an early stage, the place of damage will be localised and the degree of damage will be quantified.

The CMS should have been the following properties: Funktion have to ensure in lab and in-situ, also after modifications at structure. Robustness should resist the rough offshore-conditions. To avoidance of liability CMS should have been as easy as possible.

**Approach**

The approach traced to attain the aims bases on the connection, damages on elastomechanical structures involves the dynamical behavior of these structures. For instance decrease of cross section modifies stiffness, thus modifies eigenfrequencies. Here modal values are measured and hence informations about structure are driven inverse.

Besides a mathematical model of the structure is set up. The model reproduces dynamical properties of structure which is being monitored. To regard risky regions of structure associated parts of modelmatrices are parametrised.
There are several procedures of experimental modal analysis to receive modal values of structure. Here we measure eigenfrequencies of structures from ambient vibration. Measuring data are transformed, transferred and saved.

With measured data parameter of current structure can determined on parametrised model. Parameter reproduces current condition of structure of offshore-windenergy-plant which is regarded.

The diagnostic statements from this parameters are the fact, the location and the degree of damage.

**Figure 1: Damage detection on offshore-windenergy-plants**

**Activities**

For performance of theoretical approach some tasks and activities are needed to manage as follows:

**Validation of method**

In order to validate the method studies of parameters and sensitivity analysis are to made. Among other things measuring errors have to take into account.

Furthermore simulations on finite-element-method-models for several structures will be to execute.

Also several models will be to made. This models should have the ability of subject reversible and irreversible damages. Additional model-tests on real structures are performed, which are not necessarily wind-energy-plants.
**Optimisation**

Than the running CMS can optimise with regard to several properties as follows. There are for instance the minimisation of numbers of sensors to increase the rate and simpleness. Also application of appropriate programs, rewrite of sequences into another computer languages and a useful formulation of sequences can ensure short calculating time and stability.

**Results**

At the time the method is working faithful in simulations at easy models. Benefits appear which have importance for condition monitoring on offshore-energy-plants. Under other things structures are not to excited. So expensive installations are not needed to apply. Also complexity for sensors and associated complexity for transforming, transmitting and saving keeps small because only eigenfrequencies are needed.

For instance lightly damages on a model of monopile-structure involves minor modifications of eigenfrequencies and are detected by method (Fig.2). In simulation damages which are subjected on second part of structure and parameters are determined from firstly three eigenfrequencies.

<table>
<thead>
<tr>
<th>Damage</th>
<th>undamaged</th>
<th>2,50%</th>
<th>5%</th>
<th>10%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenfrequencies</td>
<td>0,34500</td>
<td>0,34498</td>
<td>0,34496</td>
<td>0,34491</td>
<td>0,34479</td>
</tr>
<tr>
<td>in Hz</td>
<td>2,05320</td>
<td>2,05260</td>
<td>2,05200</td>
<td>2,05060</td>
<td>2,04740</td>
</tr>
<tr>
<td>Parameter a1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>a2</td>
<td>1</td>
<td>0,975</td>
<td>0,951</td>
<td>0,900</td>
<td>0,800</td>
</tr>
<tr>
<td>a3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Figure 2: Eigenfrequencies and parameters at several degrees of damage*

**Outlook**

Both the extension of method for larger models, other structures, further fields of application, and application on testplants and real offshore-structures are perspectives.

Previous period shows confident results with approach which is traced. The problems resulting from aims are solvable. They will discussed in the following periods. The main aim keeps the application of the CMS on offshore-windenergy-plants.
Sources
Modelling Soil-Structure-Interaction for Offshore Wind Energy Plants

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

Martin Achmus, Khalid Abdel-Rahman

**Project description**

Offshore wind farms promise to become an important source of energy in the near future. But, at the time being, only artificial competitiveness is reached in Germany by a law forcing energy suppliers to buy wind current at a fixed price. Thus, economic construction and design methods are indispensable to make offshore wind energy really competitive.

A significant portion of the total costs for Offshore Wind Energy Converters (OWECs) in relatively deep water (20 to 50 m) comes from the foundation structure. For this reason, the optimization of the foundation structures is of great importance. The level of safety should be as low as possible for economical reasons. This of course implies reliable calculation approaches for the (long-term) behaviour of OWECs under the complex static, cyclic and dynamic loading by wind and waves.

Object of this project is the development of numerical simulation models for OWEC foundation structures in order to describe and to study the behaviour of such structures and hence to be able to optimize the design.

**Approach of research**

In the numerical modelling of the behaviour of foundation structures for Offshore Wind Energy Converters (OWEC) static, quasi-static cyclic as well as dynamic loads are to be considered. In this regard, a strong relation to the project IV (loading approaches) exists.

Firstly, models for different foundation structures shall be developed and the behaviour under static loads shall be investigated. Models for monopile, gravity and tripod foundations will be established. Based on these models, in subsequent steps extensions for cyclic and at last also for dynamic loads shall be developed. Finally, the results shall be used for the identification and validation of simplified design models, which can be implemented as software modules in an integral modelling approach. The working steps foreseen for the 5 year-duration of the whole project are shown in Fig. 1.
In the first year of the project the work was concentrated on monopile foundations, which are thought to have the best potential for safe and economic OWEC foundations. Firstly, monotonic loading was considered. The results obtained so far are summarized in the following. Models for gravity and tripod foundations have been established as well, but parametric studies have not yet been carried out.

In current offshore practice, horizontally loaded piles are designed using a special subgrade method, indicated in a guideline of the American Petroleum Institute (API). But, this procedure is only proved suitable for piles with diameters up to approx. 2 m. Therefore the behaviour of monopiles with larger diameters is examined using a three-dimensional finite element model.

Soil and pile are modelled with 8-nodes continuum elements. The interaction behaviour between pile and soil is simulated using contact elements between both of them. The numerical modelling is done stepwise. First the initial stress field is generated in the model, then the installation of the monopile is modelled by replacing the soil elements located in the pile position with the pile elements and then activating the contact conditions between both of them. Finally the loading conditions in the horizontal as well as in the vertical direction are applied on the pile head. The monopile elements were extended above the ground surface in order to combine different cases of loading (horizontal force and bending moment at seabed level).

The computations take place using the program system ABAQUS on a large computer workstation with parallel processor technology. This computer enhances the computation efficiency and minimizes the time effort required for a parametric study.

Numerical models of monopiles with different diameters, embedded lengths and wall thicknesses have been developed. In Fig. 2 some results (horizontal displacements and mobilized earth pressures) obtained for a monopile embedded in homogeneous sand are given as an example.
Figure 2: Horizontal displacement (left) and mobilised passive earth pressure (right) for a monopile D=7.5 m, L = 30 m in dense sand, H = 8 MN, M = 240 MN.

The most important aspect of the numerical model is the material law used for the soil. A substantial soil feature to be considered here is the stress-dependent stiffness of soil. First, linear elastic and also a hypoplastic approach was investigated (Achmus & Abdel-Rahman 2004). Finally, a suitable material law was chosen which can be applied to non-cohesive as well as cohesive soils. This law is based on an elasto-plastic material model with Mohr-Coulomb flow conditions. The stiffness is dependent on the mean stress level in a soil element, which is changing during the step-wise increase of the loading. This model was implemented in the ABAQUS program. Calculation results for piles with small diameters show via a comparison with the API method results that this numerical approach gives reasonable results.

For the design of OWEC’s with respect to serviceability the displacement and the rotation of the foundation structure under design load are important. By parametric studies force-displacement and force-rotation curves for different geometric and soil conditions were derived. As an example, curves for a monopile D = 7.5 m, L = 30 m embedded in dense sand are given. For a given combination of horizontal force and bending moment the respective displacements can be obtained from the diagram. Such curves can be used for the preliminary design of monopile foundations.

Results of these parametric studies will be published in 2005 (Abdel-Rahman & Achmus 2005, Achmus et al. 2005).
Concerning monotonic static loading, the next steps in the research will be the expansion of the parametric studies on general soil conditions (consideration of layered subsoil) and also the consideration of tripod foundations.

Additionally, research will be concentrated on the behaviour of foundation structures under cyclic loading. Basics concerning the choice of suitable approaches for the simulation of the behaviour under cyclic loading have been worked out during the first year. The choice and implementation of suitable material laws as well as the identification of typical loading conditions will be subject of the coming research works.

Beside the numerical and analytical approaches used in this project, small-scale model tests on monopiles under cyclic loading will be carried out at the Institute of Soil Mechanics, Foundation Engineering and Waterpower Engineering. Preinvestigations have already been executed. By these tests, a validation of theoretical approaches shall be carried out.
Publications list


Grid Integration of Offshore Wind Energy Parks

Institute of Electric Power Systems, Hannover
Bernd R. Oswald, Jörn Runge

Situation and Motivation
By the end of 2004 about 16000 wind energy turbines with a total power of around 16000 MW were installed exclusively onshore in Germany. However, the further increase in wind power generation in the next years is fully concentrated on offshore wind parks in the North and the Baltic seas. The starting signal for accessing the offshore field has been given with the recently approved pilot phase of the Borkum West wind park project, which is 45 km away from the coast at 30 m water depth.

The installation of large offshore wind farm, with 5 MW class generators and a total power in the order of present large conventional power plants, introduces new challenges not only to civil engineers, but also to electric power suppliers and grid operators.

On the one hand, appropriate measures for the extension and reinforcement of the power transmission system should be taken on time. This is necessary, due to the substantial power of the offshore wind parks to be transmitted to the load centres, which lie inland several hundred km away from the coast. On the other hand, the portion of fluctuating and difficultly forecastable wind power in the total power of the grid increases with the realization of the offshore projects. Thus, operational demands for meeting the system frequency and voltage stability rise considerably. When the issue of transmission system extension and reinforcement is discussed, it should be also taken into consideration that licensing procedures, for overhead lines in particular, are very lengthy and could fail to win approval. It is therefore necessary to also evaluate the non conventional alternatives (High-Voltage Cable or Direct-Current Transmission) and the roll they can play.

Approach and activities
The issue of system stability, just as that of system extension, must be clarified prior to erecting additional offshore wind energy parks. This would be achieved through system simulations. Consequently, models for synchronous generators with full-bridge converters and doubly-fed induction machines, which are installed in wind energy parks, are to be developed for various objectives of analysis. Furthermore, submarine cables and the high-voltage network should be incorporated into the corresponding analysis by additional transmission lines. Moreover, adequate models should correspondingly be developed for non conventional transmission lines. An overview of the model structure is illustrated in Fig. 1.

The wind velocity represents the input variable for the model. It has a stochastic character and is simulated by the superposition of a forecastable fixed component and a random component. The model for the wind excitation is being developed in cooperation with the University of Oldenburg. Based on the behaviour of the wind velocity, the driving power for the generators can be determined through known aerodynamic relationships. The generators and transmission lines models must be adjusted in accordance with the purpose of analysis. For the task of investigating
power flow problems, the steady state generator model supplying active and reactive power depending on the reference value of the controller is sufficient.

Investigating the control response and stability, call for dynamic models for the generators with their control hardware including the converters. However, transmission components and the grid can be further represented by steady state models. For decoupling active and reactive power, a controller model in stator voltage frame oriented coordinate system is introduced. To investigate the stresses experienced by the equipments due to short circuits and switching operations, transient models of generators, transmission lines and network must be utilized. These models are very complex, due to their model order and high time resolution demand. Subsequently, it is essential to optimize the models with regard to their accuracy and complexity.

Figure 1: Model structure: 1) Wind/Aerodynamic; 2) Generator; 3) Control; 4) Transmission; 5) Grid

Results and future work

Based on the methods described in Part 2, the steady state, dynamic and transient models of the doubly-fed induction machine including the controller have been developed and tested on selected examples first.

A model for the High Voltage Direct Current (HVDC) transmission was derived to be included into the static network calculation.

Fig. 2 shows the movement of the operating point during the starting process of a wind generator at constant wind velocity, which is calculated with the dynamic model. At first, the Generator runs with deactivated control into the operating point I (magenta line represents the mechanical power and the solid red line the electrical power). Subsequently, the control is activated (the dashed red line is the control-characteristics line). This leads to the transition from point I to point II (the green line represents the mechanical power and the black line the electrical power), where maximum efficiency is guaranteed.

In Fig. 3, the momentaneous value characteristics of current (a, b), the mechanical and the electric power (c) and the rotor speed (d) during the starting, the control initialisation and a three phase short circuit near the generator, calculated with the transient model, are illustrated.
Future work will be concentrated on:

- Modelling of wind energy generators with synchronous generators and completion and verification of the already developed models,
- Simulation of entire wind energy parks with multitude of generators,
- Development of aggregated models for the clusters of a wind energy park or for an entire wind energy park,
- Simulation of system operations and faults.

**Figure 2:** Trajectories in the $P$ - $n$ - frame computed with the dynamic model
Figure 3: Time functions of stator current (a, b), mechanical and electrical power (c) and rotor speed (d) computed with the transient model

\[ t = 0 \text{s}: \text{switch on}; \quad t = 5 \text{s}: \text{control initiation}; \quad t = 10 \text{s}: 3\text{-phase short circuit} \]

References

Runge, J.; Oswald, B.: Modelling of a controlled doubly fed induction machine for the use in offshore wind power plants. UPEC (Universities Power Engineering Conference) 2004, Bristol, UK, Sep. 06 - Sep. 08, pp. 1155 – 1159

Panosyan, A.; Oswald, B.: Modified Newton-Raphson load flow analysis for integrated AC/DC power systems. UPEC (Universities Power Engineering Conference) 2004, Bristol, UK, Sep. 06 - Sep. 08, pp. 1186 – 1189

Oswald, B.: Fault simulations in power systems using a unified matrix method. UPEC (Universities Power Engineering Conference) 2004, Bristol, UK, Sep. 06 - Sep. 08, pp. 1223 – 1227

Oswald, B.: Grid Integration Of Large Off-Shore Wind Farms. WWEC (World Wind Energy Conference) 2004, Beijing, China, Oct. 31 - Nov. 04
Integrated modeling of offshore WEC

Institute of Fluid Mechanics and Computer Applications in Civil Engineering, Hannover
Institute of Physics - working group hydrodynamics and wind energy, Oldenburg
Werner Zielke, Martin Kohlmeier, Abderrahmane Habbar, Bernhard Stoevesandt

Motivation
The aim of the research project IX is to meet the demand of an integral simulation of offshore wind energy turbines.

The achievement of this goal 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 subsystems. Thus, the models used by the participating research teams and research departments are normally 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 integral 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.
- Data formats are not homogenous.
- 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 considered:

1. Data exchange facility: Meta data base MetaWind.
2. Development of an integral model for the coupling of simulation programs used or developed by the research teams.

Most important aspects of the integral model are the realization of model interactions or couplings, using different strategies summarized in Table 1. Consequently, the development of an integral model will be done stepwise in the following way: (1) no coupling in independent models; (2) iterative coupling with direct or indirect exchange of input and output data; (3) fully and direct coupling in simplified models.
Table 1. Overview of integrated modeling strategies.

<table>
<thead>
<tr>
<th>Coupling strategy</th>
<th>Realization in the integral model</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Simulation without any coupling</td>
<td>Operation of a single model without any coupling</td>
</tr>
<tr>
<td>(2) Simulation with iterative coupling</td>
<td>Operation of multiple models with internal or external data exchange</td>
</tr>
<tr>
<td>(3) Simulation with direct coupling within a coupled model</td>
<td>Operation of multiple uncoupled or coupled models with or without data exchange.</td>
</tr>
<tr>
<td>developed for strongly interacting sub problems</td>
<td></td>
</tr>
</tbody>
</table>

**Meta data base: MetaWind**

According to the above mentioned strategy the integral model has to be build up successively. 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’ is developed and accessible via the link www.metawind.uni-hannover.de.

The structure of the MetaWind system is depicted in Figure 1. It consists of a central server of meta information. The local perl-program is dynamically generating the requested html pages. They are providing access to the data supplied by the research teams. At the same time a user or user group management is controlling the access authorization. The administration is done via input masks provided by the system and shown in an html browser. Thus, a non-local administration is possible.

![Figure 1: Decentral data base MetaWind.](image-url)
The data stored on the central server system are restricted to meta information: e.g. the data supplier, standard information on the specific data or the data type itself. The raw data are stored on decentralized server systems.

The data can be accessed via html browsers by accessing the project tree or using the incorporated search engine. Finally, the data can be visualized, downloaded or converted in other formats.

In order to reduce the effort of importing data into the system, upload of raw data is possible. It is processed by predefined file mask. Thus, data can be transferred into a standard format for direct online visualization by Java applets in two or three dimensions.

**Integral model**

As already mentioned above, different kinds of programs and data packages have to be combined within the integral model. It has to provide the link between several different models and types of input or output data.

**Model realization**

The starting point of the research project is depicted in Figure 2a: the data prepared for one model is processed without any linkage to other models.

With the developed meta data base MetaWind the processed data can now be made accessible or visualized by other research teams. Moreover, interfaces to other data formats or simulation tools can be developed within the ForWind research group and provided via MetaWind (Figure 2b).

![Figure 2: Stand-alone model (a) with access to the MetaWind system (b).](image)

**Model Datatypes**

As a general data format to be introduced in the general model XML has been chosen. XML is a meta-language for data exchange. The advantage of using XML lies in the flexibility and the machine accessibility of XML. To make XML usable a general schema has to be chosen or developed. It seemed reasonable to adopt the XMLDepri schema developed by „Overspeed GmbH“ and ISET. Nevertheless the XMLDepri does not fulfill all the needs of data exchange for ForWind yet. For further applica-
tions the schema is being extended. This involves especially the implementation of binary data and a user specific protection of the data.

Over all the requirements of the data-format have been laid out by now. The further implementation into „MetaWind“ is in progress.

**Model development strategy**

The interaction of physical processes, resulting loads, structures and the most important coupling effects arising during the simulation of an offshore wind energy turbine is depicted in Figure 3.

The aim of the integral model is to resolve these interactions within a program that 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

---

**Figure 3: Components of the integral model: processes, loads and sub systems.**

According to these demands, a concept for an integral model approach has been developed. A sketch of this integral model concept is depicted in Figure 4. The program will be build up in an object oriented language (C++) using an application development framework (Qt) for a GUI based cross-platform application with graphical visualization.
Integration of the Windmodels

For the intergarted model projects I-III contribute different wind data on different time scales. The partial project in the greatest need of precise wind data, would be the one concerned with the rotor- and airfoil-development. This has – so far – not been part of any research project of ForWind. Therefore steps have been taken to close the gap between the wind and the rest of the constructive work done by ForWind: In cooperation with the DLR in Göttingen and Enercon the development of a aerodynamic model for turbulent flow on rotor blades is to be part of the Oldenburg part of the project. This is to be supported by computational fluid dynamics simulations and measurements. For this reason the Helmholtz summerschool of computational fluid dynamics in Potsdam has been attended. Also a cooperation with the Institut für Flugzeugbau at the University of Stuttgart has been taken into account for the integration of the rotor and controlling system.

Summary and outlook

With the realization of the MetaWind system a platform for data exchange, data conversion, communication and data management has been established. Further developments within the MetaWind system aim towards the improvement of data conversion tools and the enabling of the communication between the integrated model and the meta data base.

The development of a concept for an integral model has been initiated. Thus, the configuration of a platform for the integration of sub models can be considered as the next step.

References

Development Projects
Further development of the wind farm program FLaP for planning, wind farm monitoring and turbine design for offshore applications

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

Description
Large wind farms, especially offshore, will have to be equipped with wind farm monitoring tools, which compare online the delivered power of each turbine with an expected or modeled value. For the design of multi-megawatt turbines for large offshore wind farms, the loads on the turbine are largely determined by the turbulence in wake situations. Very simple models for this are commonly used and better models are needed.

The aims of the project are to improve the modeling of turbulence in wind farms and use this improved model capability for improvement in wind farm monitoring and turbine design. The focus is on the application for offshore wind farms, where the turbulence increase due to wind farm effects is especially large.

Approach / Activities
This aims have been defined as a development project together with two commercial companies as partners. These are Overspeed GmbH & Co KG and General Electric Wind Energy. The project has started 1.9.2004 and has a planned duration of 12 months. The work is structured in four subprojects:

- Subproject I: Modeling of the 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 / Outlook
In the following, a brief description of the most important results is given.

Subproject I: Modeling of the turbulence intensity
A new model for the turbulence intensity in wind farms has been developed, which consists of two parts: A model for the turbulence intensity profile in a wake and a wake superposition model. The model has been verified with measurements from Nibe and Sexbierum with good agreement [1],[2],[3].
Subproject II: Modeling of fatigue loads

The parameters needed for load calculations of large wind turbines inside a wind farm have to be calculated with the turbulence model. Based on these parameters, load calculations for wake and free stream situations are performed. The start of the cooperation with GE Wind Energy is delayed because of change of personnel and restructuring at GE Wind Energy.

Status: not started, delayed

Subproject III: Use for wind farm monitoring

The wind farm model FLaP has to be extended to allow the time domain calculation of wind farm effects for each individual turbine of a wind farm in a time series. With this model, the capability of the FLaP program for the use in wind farm monitoring has to be investigated. Data from the wind farms Hamswehrum and Bassens are used in this study.

Status: ongoing

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.

**Status:** finished

**Publication list**


Analysis of WEC power and wind turbulence in respect to increase accuracy of energy gain prognosis

Institute of physics - working group hydrodynamics and wind energy, Oldenburg
Stephan Barth, René Grüneberger
Partner: Enercon GmbH, Aurich; EWO Energietechnologie GmbH, Lichtenau
2003 - 2005

Description
In complex terrains the estimation of wind turbine energy output sometimes shows large uncertainty. But for an optimal integration into the electrical power grid an accurate output assessment is indispensable.

Thus one goal of this project is to describe the connection between the turbulent wind field and the wind turbine power output in complex terrains and to develop a more advanced model of the power curve. This new model can then be used to optimize wind park management.

An other goal is the comparison between different types of anemometers in realistic wind field conditions in contrast to pure laminar wind tunnel calibrations.

Approach / Activities
To develop a new model of a multidimensional power curve (meteorological and location related) the turbulent wind field has to be recorded. To do so a mast of 100m height, equipped with several ultrasonic and cup anemometers as well as wind vanes and temperature probes has been installed besides a wind turbine in a wind park. The measurement instruments are located in different heights in order to cover the whole wind profile. The three-dimensional velocity data as well as the electric power output are acquired with high temporal resolution.

First datasets have been acquired and checked for consistence. In doing so several dropouts have been found. Those dropouts were caused by technical problems and some failures of the data acquisition hardware. That liable hardware in the setup has been replaced. Current activities concentrate on the implementation of a new protection system for the data acquisition hardware as well as a remote diagnostic system.

Interim results / Outlook
Due to the technical problems there are no preliminary results so far. We expect to receive the fist complete datasets in the beginning of 2005 and to proceed with the program described above.
Dynamic load bearing capacity of slip resistant bolt connections in truss towers of WECs

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

Description
Pre stressed slip resistant bolt connections are used in truss towers for WECs (Fig. 1). The load bearing capacity of these connections may vary due to the fact that loads are not static but dynamic. The design value for the resistant of the connection is:

\[ F_{S,Rd} = 0.9 \cdot \mu \cdot \frac{\gamma_{M3}}{\gamma} \cdot F_v \]

Dynamic preloads lower than the connections resistance can lead to two effects:
- The bolts preload \( F_v \) decreases due to settlement effects, which results in a lower connection resistance,
- The friction factor \( \mu \) increases, which leads to higher load bearing capacity.

The investigations goal is to examine these two effects by testing and FE-Simulations and finding options for an improved assembly.

Activities
To reduce the lost of bolt-preload a spring washer was designed and tested (Fig. 2).

Due to the spring washer’s flexibility, effects of inevitable settlement are reduced. A testing program has been set up to investigate different influence factors on the structural behaviour which includes:
- Different layer thicknesses of the plates zinc coating
- Different layer thicknesses of the plates paint coating
• Effect of dynamic preloading on the friction factor \( \mu \)
• Alternative connection devices

**Results / Outlook**

FE-Simulations of the connection show that even under low sheer forces displacements between the bolted plates occurs, which could lead to improvement of the sticking friction after dynamic preloads. This fact and the positive effect of the spring washer are to be checked by the projected experiments.

**Publications list**


Concrete joints between structural elements of hybrid towers for WEC subjected to fatigue loading

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

Description
The concrete joints of hybrid towers for WEC are stressed by highly concentrated loads. These loads have to be transferred from the steel adapter across the concrete joint into the concrete tower. A fatigue damage process is initiated by high cycle dynamic loads causing stiffness degradation. The aim of this project is the development of a damage model to describe the non-linear fatigue process in concrete.

Activities
Mechanical analysis of the concrete joints are performed as well as experimental testing. Furthermore, measurements started at a concrete tower for a 5 MW WEC to observe the fatigue process under real conditions. The test results will be used for validating numerical models.

Results / Outlook
Several models describing the fatigue behavior of concrete have been proved, and a damage model for constant amplitude loading, based on fracture energy, has been modified for two-stage fatigue loading. First numerical results are in good conformity with test results from literature. Therefore, the damage approach will be developed further in order to include multi-stage loading. This model will be applied to perform fatigue design for concrete joints of hybrid towers.
Publications list


Usage of combined acceleration and strain sensors for early diagnosis of damages

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

Description
Extreme conditions in offshore wind farm sites require a functional system for structural monitoring of the whole construction. However, it will not be possible to reach these farms at any time and it may be necessary due to possible bad weather conditions to demand a system for detection of structural damages without the need of being offshore.

The “Proportionality Of Dynamic Load And Dynamic Velocity” will be investigated as the main method for the detection of structural damages. Therefore, special tower-models (scale 1:25) were built to examine the possibilities of diagnosis by using combined acceleration sensors and strain gages observing the dynamic behavior of the models. Measuring at important positions of the tower structure we hope to reveal a new way of monitoring and damage detection.

Approach / Activities
In order to assess the quality of the results of this particular theory another two methods are used, “Comparing Modal Analysis” and “Subspace-Method”. Both methods compare the undamaged and damaged state of the system. By using “Comparing Modal Analysis” the difference of eigenfrequencies is evaluated. “Subspace-Method” detects the difference of dynamic-influence-lines as a tool for at least localizing the damage. The function of proportionality of dynamic load and dynamic velocity is briefly explained - a change of the dynamic load measured by strain gages means also a change of dynamic velocity which can be derived from the acceleration sensor signals by simple integration.

For best estimation of the measured signals, it is important to select the structures locations of highest amplitudes referring the first few bending-eigenforms of the structure. The combination of these two kinds of signals offers a more rapid detection of changes within the structure.

Investigating the models dynamic behavior, several measurement-runs have been taken until now. Damages were simulated by adding masses of little weight along the tower-pipe at different heights. Later on intense cracks were installed. The signal data was recorded and post-processed.
Interim Results / Outlook

Using the “Comparing Modal Analysis” revealed that this will not be suitable for damage detection. The criterion “Eigenfrequency” is not sensitive enough to make a fundamental statement. When using the “Subspace-Method” things look different. FE-simulation as well as model-simulation produced results which proved that this method is suitable detecting and also locating damages fairly good indeed.

The most important thing to realize when applying this method is its dependence on the number of installed sensors. The more sensors installed the more precise the results you will get.

Further tests will be made to optimize the number of sensors required as an important cost criterion for future application of structural damage diagnosis to offshore wind farms.

At present, measurements are run considering the “Proportionality Of Dynamic Load And Dynamic Velocity” as stated above.

Sources


Other
Study on regional economic effects of wind energy usage in the counties of Cuxhaven and Stade

ForWind
Marcel Krämer, Elke Seidel
Ordered by: Bundesverband Windenergie (BWE), Osnabrück
2004

Wind energy use in Germany has seen an impressive growth over the last years. The reason for his was the encouraging legislation, esp. the Renewable Energy Act (EEG). Over 16,000 Wind energy Converters (WEC) are installed with a capacity of more than 16,000 Megawatts.

Although in general acceptance of Renewable Energies (RE) is high, recently there is growing opposition to further installation of WEC. This opposition is often based in the affected region. Inhabitants there believe, they would not have any advantages of installed WEC. To investigate the economic effects of wind energy use in regions, the German Wind Energy Association (BWE) assigned ForWind to create a study.

The results are surprisingly positive: Although only few projects could be analysed, a reasonable sum of moneys in the planning and erecting period as well as during operation is going to regional companies and service providers. In the explored states of Stade and Cuxhaven over 140 Mill. EUR (without costs of WEC) are initiated by wind energy use.

The regional income by feed-in tariff is more than 100 Mill. EUR (of course not all of this goes to the regional companies, but a mentionable part, which can not be amounted exactly).

So wind energy usage secures employment in the region which has effect also to encourage younger people to stay in this region.

The study shows that it is a profit for the region to promote wind energy because there are effects of:

- orders for regional companies in the field of service, foundation
- employment
- taxes
- perspectives for young professionals

The more the region supports the wind energy by legislation or developing general economic conditions (establishing of service companies) the more the profit of the region will be.
Havarie im Windpark?
Symposium on Offshore Wind Energy and Maritime Safety
ForWind
Moses Kärn, Marcel Krämer, Margret Warns, Elke Seidel
2004

Description
On November 12th, 2004 ForWind held the international symposium “Havarie im Windpark?” focusing on issues of maritime safety rising from the planned offshore wind farms.

In the North and Baltic seas offshore wind farms (OWF) with power outputs up to 1.5 GW are planned. They will be comprised of wind energy converters (WEC) of up to 5 MW each and the farms will extend regions of more than 1.5 sqkm. So, offshore wind farms are hard obstacles for sea traffic. But although German offshore sites fit the required safety standards and are approved by the Bundesamt für Seeschifffahrt und Hydrographie (BSH) there is still an ongoing discussion whether and to what extend OWFs pose problems for sea traffic and how high the risks are for accidents with disabled ships possibly leading to environmental damage.

Approach
ForWind investigated the questions related to offshore wind energy and maritime safety at the symposium within three focal themes:

- analysis of the risk potential,
- assessment of risks and damages,
- concepts of avoiding accidents and minimising risks.

12 experts from Germany, Denmark and the Netherlands explored these topics in four sessions. In the concluding plenary discussion the audience had the opportunity to discuss the presented issues of risk potential, the methods of their assessment, and concepts of avoiding accidents and minimizing risks with representatives from politics, associations and business.

Nautical traffic regulations and approval procedures for offshore wind farms
Martin Köhn, Mariko.Ris - Maritimes Kompetenzzentrum, Elsfleth
Offshore-Windparks -- eine nautische Herausforderung?

Bernhard Litmeyer, Wasser- und Schifffahrtsdirektion Nordwest (WSD NW), Aurich
Sicherheitskonzept Deutsche Küste

Christian Dahlke, Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg
Genehmigungsverfahren und sicherheitsrelevante Anforderungen an Offshore-Windparks

Risk potential and risk analysis (I)
Thomas Haukje, MARSH GmbH, Hamburg
Anforderungen der Assekuranz
Wolf-Dieter Leibrandt, GAUSS mbH, Bremen
*Risikoabschätzung von Offshore Windenergieprojekten in der deutschen Nordsee*

Dr.-Ing. Daniel Povel, Germanischer Lloyd AG, Hamburg
*Betrachtung von Maßnahmen zur Reduzierung des Kollisionsrisikos*

**Risk potential and risk analysis (II): international perspective**

Dr. Claus Fridtjof Christensen, DNV Global Wind Energy, Roskilde (DK)
*Important parameters in navigational risk analysis and a comparison of the German, Danish and English authorities' requirements*

Henk den Boon, E-Connection Project BV, Bunnik (NL)
*Reduction of ship collision risks for offshore wind farms in 20-25 m deep seawater (EU-Project SAFESHIP)*

Mikkel Gardner Andersen, DNV Global Wind Energy
*Using Bayesian networks to model ship collisions against offshore wind farms*

**Environmental dangers and risk prevention strategies**

Dr. Ulrich Kremser, Umweltbundesamt (UBA), Berlin
*Zur möglichen Kollision Schiff – Windpark und der Vermeidung bzw. Minimierung von Umweltfolgen*

Prof. Dr. Kai Wirtz, GKSS, Geesthacht / ICBM, Uni. Oldenburg
*Entscheidungshilfesysteme zur Folgenabschätzung von Öl- und Schadstoffunfällen an Offshore-WEA*

Leszek T. Szymanski, Havariekommando, Cuxhaven
*Maritime Notfallvorsorge - Organisation und Aufgaben des Havariekommandos*

**Panel discussion**

Christian Dahlke, BSH, Hamburg

Uwe Johannsen, WWF Deutschland, Bremen

Reinhard Kaib, Stadt Borkum

Dr. Ulrich Kremser, Umweltbundesamt, Berlin

Udo Paschedag, Bundesumweltministerium, Berlin

Ubbo de Witt, Projekt GmbH und Projekt Ökovest GmbH, Oldenburg

Presentaion: Hans-Jürgen Schmidt, NDR, Oldenburg

**Interim Results**

ForWinds symposium was the first event to bring together leading experts in the field of offshore wind energy and maritime safety, and to open the discussion to a broader public. So far, discussions in that field have been scattered among small expert groups. With 16 international experts and 130 participants from various institutions, companies and authorities the symposium was a big success not expected by the organizers. This was also reflected in the feedback by the participants who gave ForWind overall best marks for the concept and the organization. The symposium
brought ForWind into broad public attention. Press coverage of the event was nation-wide in print media, radio and internet portals, e.g. Nordwest-Zeitung, Wirtschaftsecho, Deutschlandfunk, Verivox.de.

**Publication**
A detailed documentation of the symposium is forthcoming Spring 2005.
Decentralised Energy Management (DEMS) Project – Improving wind power and demand forecast

ForWind
Rainer Klosse, Marcel Krämer, Lüder von Bremen, Carsten Poppinga, Jens Tambke
Ordered by: EWE AG, Oldenburg
2004 – 2006

For the electrical energy market, day-ahead consumer load profile forecasts are needed. In this case the focussed consumer load is the difference between the overall load in the electrical network and the big industry consumers reduced by the renewable energy feed-in.

The energy consumption has a daily, weekly and seasonal characteristic. Additionally the weather has an influence of a mainly by private households penetrated consumer area. Meteorology values often have a higher relevance at times of high prices. From historical data, it is possible to estimate a load profile for the next days. Usually long year experiences of employers of the utilities are used. They often are supported by mathematic, numerical forecast tools. But the commercial forecast tools do not use the weather data in a sufficient way. High errors are occurring during critical time steps. On the other hand more automation is necessary out of increasing numbers of forecasts for decreasing extensions of areas to get a more accurate grid control.

In this work, values of weather prediction are included in the power consumption forecast. Different mathematic models like multi regression analyses, autocorrelation models, fuzzy logic and artificial neuronal networks were used.

The different models have their own characteristic. The fuzzy logic often has good results, but sometimes big deviations. The artificial neuronal networks can also handle non linear dependencies, but the accuracy does not fulfil the requirements. With multi regression analyses or autocorrelation models it is possible to follow the physical subjection.

It has been shown that the mathematic models are able to support the power consumption forecast to increase the accuracy. Knowledge of the meteorological dependency improves the prediction in general.
Research map of wind energy in the States of Lower Saxony and Bremen

ForWind

Andreas Kähler, Marcel Krämer, Elke Seidel

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

Funded by: Ministry of Science and Culture

2004 – 2005

On initiative of the working group „wind energy“ of Bremen and Lower Saxony it has been decided to investigate all research activities in the field of wind energy in the two states. Together with fk-wind at Bremerhaven, a questionary was developed to find out the activities of the scientific institutes. Goal of the project is to present all activities to the public, esp. companies, where they can find partners in research.

Results will be presented in summer 2005. All informations will be available at:

www.forschungslandkarte-windenergie.de
Participation in the EU-Project ‘Pushing Offshore Wind Energy Regions’ (POWER)

ForWind
Moses Kärn
2004 – 2007

Description
POWER is one of the projects in the EU-Interreg III B Programme North Sea Region financed through the European Regional Development Fund (ERDF).

POWER aims to boost the development of off-shore wind energy in the participating coastal regions. It will focus on improved planning, participation and decision-making processes regarding offshore wind farms; supporting the establishment of off-shore wind energy industries and positioning the North Sea Region as a global hot spot for off-shore wind energy; and providing education and training courses to fulfil the need of the off-shore wind energy sector for specialist knowledge and a skilled workforce.

POWER has an overall budget of about 3,5 million Euro. The exact duration is from July 01, 2004 to June 30, 2007. Alltogether 24 partners participate in the project. It is managed by the Bremerhavener 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 Oostend (B).

ForWind is 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.

Approach / Activities
POWER activities are divided into four subprojects (‘work packages’):
WP 1: Planning and Participation
WP 2: Economic Support / Supply Chain
WP 3: Education
WP 4: Dissemination

Extensive research will be conducted into the opportunities and difficulties for making use of offshore wind energy. Public stakeholders will be intensively involved in the process. A pilot Decision Support System will be developed, which will include environmental, societal and utilisation issues. Guidance on the significance of environmental impacts will result from this first Work Package as well.

In a second Work Package, a supply chain analysis will be conducted, and available facilities in the North Sea Offshore Wind Regions will be mapped.

A third Work Package covers the support of training providers in the North Sea Region and the development of standards and certificates for offshore wind energy
courses or modules. Appropriate methods and didactics will be provided in co-operation with offshore wind energy companies. Several summer schools on offshore wind energy will be held for both interested student and graduate engineers and companies. The curricula and evaluations of these will be published.

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 participating regions. Finally, the setting up of a new Offshore Wind Energy Information Centre in Oostend (Flanders) will be supported.

ForWind is engaged in WP 3 and WP 4 in close cooperation with the junior research group IMPULSE at the ICBM to develop summer schools and course modules.
Development of a further education program for engineers in wind energy (WIng)

ForWind
Moses Kärn, Christoph Schwarzer
Partners: Windenergie-Agentur Bremerhaven/Bremen e.V. (WAB), City of Oldenburg
Funded by: Regionale Arbeitsgemeinschaft Bremen-Niedersachsen (RAG), Regionale Innovationsstrategie Weser-Ems (RIS)
2004 – 2006

Description
The aim of the project is to develop a further education course for engineers in wind energy, and those who come from classical engineering disciplines and want to get into the field of wind energy. The curriculum will be designed according to the needs of industry and employees regarding content, didactical concept and workload. It will comprise home learning as well as workshops. The acceptance of blended learning will be evaluated and e-learning modules will be developed accordingly. A high ranking certificate should be issued.

The project is lead by ForWind in cooperation with the Windenergie-Agentur Bremerhaven/Bremen e.V. (WAB) and the City of Oldenburg. It is financed by the Regionale Arbeitsgemeinschaft Bremen Niedersachsen (RAG) and the Regionale Innovationsstrategie Weser-Ems.

Approach/Activities
The project is divided into the development-phase, pilot-phase and controlled operation. Funding as yet is available for the development-phase which is planned to take one year. The continuation of the project with the following phases depends on the successful raising of further funding.

The development-phase is divided into the following tasks:

1. Determination of requirements
   Industry and possible participants will be asked for their needs and interests through means of interviews and workshops.

2. Development of the curriculum
   Based on the requirements the didactical concept and curriculum will be developed in cooperation with leading experts in the field.

3. Preparation and design of the course material
   Reading material and the online platform will be produced according to the didactical concept.

4. Quality assurance
   Tools for evaluation and quality control will be developed to be able to improve the offered training continuously.

5. Development of a business model and the certificate
   In order to secure the future operation and in order to guarantee a high ranking certificate close cooperation with universities, wind energy associations and chambers of commerce is aimed at.
6. **Marketing**

A concept and tools for marketing of the educational program will be developed beginning in the first phase.

**Interim results / Outlook**

For the project a new staff member, Mr. Christoph Schwarzer, has been successfully employed for the period of one year starting in mid March 2005. The realization of the project will start then, and the development-phase should be completed by March 2006.
Participation in the EU Marie Curie Research Training Network

'Wind Energy Assessment and Wind Engineering'

Institute of Physics - Energy and Semiconductor Research Laboratory
Bernhard Lange, Lorenzo Claveri, Jiri Beran
2003 - 2005

Description
The aim of the network is to bring together young and experienced researchers to work jointly to define the basis for the design of wind turbines and wind farms in different environments.

The network focus on the important objectives in the exploitation of wind energy: to identify how much energy is available, how to design wind farms and the most appropriate wind turbines available for the location and finally to evaluate the time variation of wind energy.

The aim of the University of Oldenburg in this network is to investigate the usability of mesoscale meteorological modeling for wind energy utilization. A focus is laid on the use for offshore conditions.

Approach / Activities
Five research areas are covered in the project:

1. Atmospheric turbulence
2. Wind energy assessment in complex terrain
3. Wind modeling in complex terrain
4. Offshore wind engineering
5. Power forecast

ForWind contributes to areas 2, 3 and 4. Mesoscale meteorological modeling is used for the applications wind energy assessment, wind modeling and offshore wind engineering. The mesoscale model MM5 is used and compared with measurement data from different measurement locations on land and over the sea.

The duration of the project is from 1.9.2002 to 31.12.2005. ForWind started in the project at 1.7.2004. Partners in the network are:

1. Risoe National Laboratory (coordinator) (Denmark)
2. University of Oldenburg (Germany)
3. Deutshes Windenergie-Institut GmbH (Germany)
4. NEG-Micon A/S (Denmark)
5. Centre for Renewable Energy Sources (Greece)
6. SEAS Distribution A.m.b.A. (Denmark)
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 projects 'Marine boundary layer modeling for the offshore wind power generation' and 'Derivation of the offshore wind climatology with mesoscale models for wind power application'.

**Interim results / outlook**

Considerable experience has been gained with the complex MM5 model. The performance of different planetary boundary layer schemes implemented in MM5 has been investigated by comparison of modeled and measured time series of wind profiles for number of locations on land and over the sea. The PBL-schemes Blackadar, ETA and MRF have been used [1].

First steps have been undertaken to develop a method to use the MM5 model for offshore wind resource analysis. A sensitivity study for grid resolution and nesting has been started to reduce computational cost for such calculations.

The first results are very promising and in 2005, a focus of the work will be on the development of a method to use MM5 for offshore wind resource calculations. Additionally, the capability of MM5 to model the coastal marine boundary layer will be investigated.
Publication list
Manuscripts in preparation
Energy Management to Prevent Electrical Network Installation

ForWind
Rainer Klosse
2003 – 2004

Summary
After growing numbers of wind energy installations in the previous years a high quota of biogas power systems is expected to contact at limited medium voltage lines. In a case study a medium voltage system including one wind energy converter with fluctuating power production and two adjustable biogas systems were operated by decentralised energy management. The required grid capacity was calculated. Variation of biogas storage time horizon and the number of including households shows their demand compensation effect.

Benefits of a decentralised energy management
In some regions of Germany where there is more then 30% fluctuating electrical energy production by wind energy and an additional 10% by biogas will be expected to be installed until 2010. Often they are connected by medium voltage lines together with rurally characterised household consumers. A new high demand of the electrical lines will be the consequence during times of high wind speeds and low energy consumption. By using a probabilistic load flow calculation it is investigates whether it is necessary to increase the capacity of the grid, as it was done mostly in the past, or whether it is possible to use decentralised energy management controls like a virtual power plant to store biogas for a short while and inject the electrical energy at a more opportune time. The time scales of energy storing which have relevant effects on saving infrastructure costs are estimated. Overload situations were counted and the necessary energy storage capacities to reduce power peaks were calculated.

For a case study a typical medium voltage grid was simulated. Time series of measured 15 minutes mean active power from the year 2003 of one wind turbine and two biogas converters have been added. At the same virtual grid the number of representative mean household profiles has been varied.

Different types of system simulations were use to estimate the storage volume and the type of storage control. The target was, to find out the general potential of decentralised energy control. To find out there expected costs for additional storage volume and there practicability in the praxis.

Retrospective to 2003 there was no need to lay out the electrical power line to the sum of all rated powers of generators. The “decentralised energy management” observe the network limits. Under these conditions the biogas systems can be installed with no more expensive grid installations.

Only a part of surplus biogas can be store rentable to prevent overload situations. Different feeding tariffs for the renewable energies have been taken in to account. More considered households reduce annual cost but extend the amortization time.
Additional tasks for the biogas storage improve there rentability. Links to wind power and load power prediction improve the practicably.

A part of this results were published at the German Wind Energy Conference DEWEK’04 “Overload Control by using decentralised Energy Management with access to adjustable Biogas Generation to compensate fluctuating Wind Energy Production” and at the European Wind Energy Conference & Exhibition EWEC’04 “Potential of energy management considering fluctuating wind energy, household consumers and adjustable biogas generation”
Available Products

*Wind Farm Layout Programme (FLaP)*

Contact: Arne Wessel
arine.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.
Figure 1: FLaP screenshot: Here the position of wind turbines (sexangles), the acoustic noise isobars with the specification of the sound level in dB (A) as well as the border for the optimisation algorithm (triangle) with lanes, are displayed. The „X“ indicates the platforms of acoustic measurement.
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-automaticly by the concept of structural span.

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.
Publication List


Barth, S., Böttcher, F., and Peinke J.: Wind gusts and small scale intermittency in atmospheric. Talk at the 57th Annual Meeting of the Devison of Fluid Dynamics of the APS, Seattle USA, November 2004


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.: Fault simulations in power systems using a unified matrix method. UPEC (Universities Power Engineering Conference) 2004, Bristol, UK, Sep. 06 - Sep. 08, pp. 1223 – 1227

Oswald, B.: Grid Integration Of Large Off-Shore Wind Farms. WWEC (World Wind Energy Conference) 2004, Beijing, China, Oct. 31 - Nov. 04

Panosyan, A.; Oswald, B.: Modified Newton-Raphson load flow analysis for integrated AC/DC power systems. UPEC (Universities Power Engineering Conference) 2004, Bristol, UK, Sep. 06 - Sep. 08, pp. 1186 – 1189


Runge, J.; Oswald, B.: Modelling of a controlled doubly fed induction machine for the use in offshore wind power plants. UPEC (Universities Power Engineering Conference) 2004, Bristol, UK, Sep. 06 - Sep. 08, pp. 1155 – 1159

Santjer, F., Klosse, R.: Spread of Electrical Harmonic Current Distortion. European Wind Energy Conference & Exhibition, Madrid, Spain, 06/03


Lectures at Universities

Barth, Stephan & Lange, Bernhard; Strömung in der atmosphärischen Grenzschicht; Oldenburg / Institut für Physik; 2004-2005

Grüneberger, René und Hölling, Michael: Hochauflösende Turbulenzmesstechnik (Fortgeschrittenen-Praktikum). Carl von Ossietzky Universität Oldenburg, Institut für Physik, Wintersemester 2004/05

Klosse, R.: Decentralised Energy Management considering Fluctuating Wind Energy and Adjustable Biogas Generation PPRE Alumni Summer School, Oldenburg 08/04


Diploma and Dissertations

Barth, Stephan: *Entwicklung eines hochauflösenden Geschwindigkeitssensors*. Carl von Ossietzky Universität Oldenburg, Institut für Physik, 2004

Jüngel, Nikolas: *Schadenserkennung an Offshore-Strukturen*, Curt-Risch-Institut, 2004

Lagemann, Christof: Schadensfrüherkennung bei Offshore-Windenergieanlagen, Curt-Risch-Institut, 2004

Mottaghian-Milani, Daniel: Berechnung des Schwingungsverhaltens einer Onshore-Windenergieanlage, Curt-Risch-Institut, 2004


Siefert, Malte: *Analyse der kleinskaligen Turbulenz mittels multivariater Markovprozesse*. Carl von Ossietzky Universität Oldenburg, Institut für Physik, 2004