International Energy Agency
Programme of Research and Development on Wind Energy Conversion Systems

IEA R&D Wind Energy

ANNUAL REPORT 1989

Published by
National Energy Administration
Sweden, for the
IEA R&D WECS Executive Committee

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IEA R&D Wind Energy

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FOREWORD

This is the twelfth Annual Report of the IEA Programme for Research and Development on Wind Energy Conversion Systems (IEA R&D WECS), reviewing the activities during 1989. The report is submitted to the IEA in accordance with the recommendations of the IEA Committee on Research and Development.

Staffan Engström
Chairman of the Executive Committee

Bengt Pershagen
Secretary of the Executive Committee
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EXECUTIVE SUMMARY

The IEA Programme for Research and Development on Wind Energy Conversion Systems (IEA R&D WECS) is one of two IEA programmes on wind energy, the companion one being the Co-operation in the Development of Large-Scale Wind Energy Conversion Systems (IEA LS WECS). IEA R&D WECS has sixteen Contracting Parties from fifteen countries: Austria, Belgium, Canada, Denmark, F R Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom and United States.

The IEA R&D WECS programme has eleven Tasks, seven of which have been successfully completed. The ongoing Tasks include:

Task VIII Study of Decentralised Applications for Wind Energy
Operating Agent: National Engineering Laboratory, UK

Task IX Intensified Study of Wake Effects behind Single Turbines and in Wind Turbine Parks
Operating Agent: UK Central Electricity Generating Board

Task XI Base Technology Information Exchange
Operating Agent: Department of Fluid Mechanics, Technical University of Denmark

Task XII Universal Wind Turbine for Experiments (UNIWEX)
Operating Agent: Institute for Computer Applications, University of Stuttgart, F R Germany

Tasks VIII, IX and XI are task-sharing projects, whilst Task XII is mixed task- and cost-sharing. In the task-sharing projects the participants are committed to in-kind contributions to a joint programme, managed by the Operating Agent.

Ten countries are participating in Task VIII, which has two Subtasks: Site Assessment Techniques and Wind-Diesel Systems. Considerable progress was made over the year towards the preparation of a Guidebook on Wind-Diesel Systems, including their siting considerations. Two meetings were held during the year at which the format and strategy of preparation
as well as the preliminary draft text of the book was agreed. The final draft will be available for circulation early 1990.

Eight countries are participating in Task IX Intensified Study of Wind Turbine Wake Effects. A substantial amount of experimental data has been collected from operating wind farms and progress is reported on the development of theoretical models. Initial comparison between data and models indicates that power deficits behind two or more rows of wind turbines may be less than predicted by existing theories, although detailed comparisons have still to be reported. The Task will be concluded during 1990 with a benchmark exercise which will bring together the experimental data and theoretical techniques.

Task XI Base Technology Information Exchange has nine participants. A main activity is the preparation and publication of Recommended Practices for Wind Turbine Testing and Evaluation. To date eight documents have been published, which have received a wide circulation in the wind energy community. The documents are updated as experience and feedback from the users is accumulated. A second edition of Vol 3 Fatigue Characteristics was issued during the year, and a second edition of Vol 1 Power Performance Testing is in the final stages of preparation.

Joint Actions represent the second Subtask in Task XI. In the Joint Action on Aerodynamics a symposium was arranged during the year, including presentations on the status and prospects of new airfoil sections, calculation methods and experimental results for rotors in yaw, and three-dimensional flow through rotors, in particular at or near stall conditions. In the Joint Action on Fatigue, an international group of experts agreed on a reference load spectrum for wind turbine blade fatigue testing. The group met during the year for exchanging information on the use of the spectrum.

As a third activity within Task XI, topical expert meetings are arranged and documented. Two meetings took place during 1989: Integrating Wind Turbines into Utility Power Systems, on 11-12 April in Herndon, Virginia, USA and Noise Generating Mechanisms of Wind Turbines, on 27-28 November in Petten, the Netherlands.
Task XII Universal Wind Turbine for Experiments (UNIWEX) has seven participants from three countries. The project aims at experimental studies of aerodynamics, operational behaviour, load spectra and control strategies for various hub concepts as well as at the validation of computer codes. The main activities during 1989 were directed to the development of software and numerical simulation, and to the development, testing and installation of hardware for the modified experimental wind turbine, which was re-erected in early September. The Dutch and Swedish contributions mainly concerned preparations for the analysis of experiments in progress.

The Executive Committee met twice during the year to review the progress of the ongoing Tasks and discuss proposals for new cooperative action. Cooperation with the Commission of the European Communities Directorate General XII (CEC DG XII) was established and a representative of CEC DG XII participated in the Executive Committee meetings. Brief presentations of the national and CEC wind energy research programmes were given at the meetings and progress and planning reports were exchanged.

At the request of the IEA/CRD Working Party on Renewable Energy Technologies an evaluation of the IEA R&D WECS Agreement was undertaken by the Executive Committee and the Operating Agents. The IEA wind energy Agreements have operated successfully for nearly twelve years. During this time wind energy technology has developed considerably and an impressive expansion of the wind industry has taken place. In spite of growing commercial interests and increasing activities within other international bodies, the Executive Committee strongly recommended a continuation of the IEA programme. A number of topics suitable for joint projects were suggested.
THE IEA R&D WECS PROGRAMME

The Programme of Research and Development on Wind Energy Conversion Systems (IEA R&D WECS) was initiated in 1977. IEA R&D WECS is one of two IEA programmes in wind energy. The companion programme is the Co-operation in the Development of Large-Scale Wind Energy Conversion Systems (IEA LS WECS), which is reported separately.

The general objective of IEA R&D WECS is to undertake collaborative R&D Tasks, as defined in Annexes to the Implementing Agreement. To-date eleven Tasks have been initiated, seven of which have been successfully completed:


Task VI  Study of Local Wind Flow at Potential WECS Hill Sites  
Operating Agent : National Research Council of Canada  

Task VII  Study of Offshore WECS  
Operating Agent : UK Central Electricity Generating Board  

Task VIII  Study of Decentralised Applications for Wind Energy  
Operating Agent : UK National Engineering Laboratory  
To be completed in 1990.

Task IX  Intensified Study of Wind Turbine Wake Effects  
Operating Agent : UK Central Electricity Generating Board.  
To be completed in 1990.

Task XI  Base Technology Information Exchange  
Operating Agent : Department of Fluid Mechanics,  
Technical University of Denmark  
To be completed in 1991.

Task XII  Universal Wind Turbine for Experiments (UNIWEX)  
Operating Agent : Institute for Computer Applications,  
University of Stuttgart, F R Germany  
To be completed in 1991.

There are 16 Contracting Parties to the Implementing Agreement,  
representing 15 countries. The countrywise participation in the current  
Tasks is shown in Table 1.

In Tasks VIII, IX and XI, the participants contribute manpower and work -  
usually in their home countries - to a joint programme coordinated by the  
Operating Agent. The total level of effort is typically about 10 manyears per  
Task.
Table 1
Participation per country in the current Tasks. OA indicates country of Operating Agent.

<table>
<thead>
<tr>
<th>Country</th>
<th>Tasks</th>
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<tbody>
<tr>
<td></td>
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<td>Canada</td>
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<td>Japan</td>
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<td>Netherlands</td>
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<td>Norway</td>
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<td>United Kingdom</td>
<td>OA</td>
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<tr>
<td>United States</td>
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CURRENT TASKS

TASK VIII Decentralised Applications for Wind Energy

Over the year the Task made considerable progress towards the preparation of a Guidebook on Wind-Diesel Systems. The activities of the specialist subgroups who had been preparing material for the two Subtasks were reported on at a meeting hosted by the National Engineering Laboratory UK in April 1989. The meeting which was attended by 14 representatives of nine of the participating countries was able to agree a common format and strategy for the preparation of a single multidisciplinary book covering all aspects of Wind-Diesel systems and their siting considerations. A work programme was agreed and tasks assigned to individuals and groups to prepare specific chapters.

Difficulties caused by country representatives not being able to continue with the work due to changing priorities within their own countries continue to plague the Task as does the introduction of substitute representatives.

A meeting where the text of the handbook, drawn together by the Operating Agent and previously circulated to the Annex members, was discussed, was hosted by the Norwegian Institute for Electricity Supply A/S (EFI) in Trondheim, Norway in late August. The meeting was attended by 16 delegates representing nine of the participating countries. As a result of the meeting further refinement of the draft text was agreed as well as provision for missing content due to representative substitution by some countries. It was agreed that all material should be available to the Operating Agent in time for circulation of the final draft early in 1990 with submission to the Executive Committee in time for their Spring meeting.
### Participating Organisations

<table>
<thead>
<tr>
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<td>National Research Council</td>
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<td>Denmark</td>
<td>Risø National Laboratory</td>
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<tr>
<td>Netherlands</td>
<td>ECN Research Centre</td>
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<td>New Zealand</td>
<td>NZ Meteorological Service</td>
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<td>Norway</td>
<td>Research Institute of Electricity Supply</td>
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<tr>
<td>Spain</td>
<td>Instituto de Energias Renovables, CIEMAT</td>
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<td>Sweden</td>
<td>State Power Board</td>
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<td>Switzerland</td>
<td>Federal Office of Energy</td>
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<td>Oekozentrum Langenbruck</td>
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<td>Alpha Real AG</td>
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<td>United Kingdom</td>
<td>Rutherford Appleton Laboratory</td>
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<td>Department of Energy</td>
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<td>Solar Energy Research Institute</td>
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<td></td>
<td>University of Massachusetts</td>
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<td>Atlantic Orient Corporation</td>
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</tbody>
</table>

### Operating Agent

United Kingdom National Engineering Laboratory
TASK IX — Intensified Study of Wind Turbine Wake Effects

A technical progress meeting was held in London in June 1989 at which all the participating countries reported progress and discussed future plans.

Previous progress meetings had been concerned mainly with theoretical modelling techniques, and plans for field measurements. In contrast, the 1989 meeting was dominated by presentations of experimental data from wind farms, and discussion on the interpretation of the measurements. Substantial amounts of data have now been collected at Zeebrugge, Tøndpipe and at a US wind farm on the Castello Ranch in Altamont Pass. Data collection is also in progress at Masnød and Alta Nurra. The experimental data include measurements of turbine power, wind flow and rotor loads.

Detailed comparison with theoretical models have still to be reported, but initial assessment indicates that power deficits behind two or more rows of turbines may be less than predicted by existing theories.

Progress was also reported at the meeting in June on the development of theoretical methods. Further work has been undertaken using the UPM finite-difference model, and a number of theoretical techniques have been tested against data from the Nibe experiment. Modellers are now moving towards predictions of turbulence quantities in wind farms. Predictions are now possible of wake turbulence for single wakes using a number of theoretical models (the UK eddy-viscosity model, the TNO model and UPM finite-difference model) and predictions are also available from an empirical parameterisation due to Garrad-Hassan. Whilst it is unlikely that a proven technique for predicting turbulence in multiple wakes will become available on the time scale of this Task, data on this will be available from the experimental programme.

It is planned to bring the experimental data and theoretical techniques together during 1990 in a benchmark exercise based around Näsudden (for the evaluation of single wakes models) and Tøndpipe (for the evaluation of wind farm models). A technical review meeting will be held in June 1990 in
London at which data analysis from the wind farm measurements will be reported, together with results of the benchmark exercise. It is expected that the final report will be available around mid-1989.

Highlights of national contributions:

**Belgium**
Results are now available from Zeebrugge, indicating little reduction in power output beyond the second machine in a row. This is contrary to standard theory, and requires further investigation. More detailed comparisons with theoretical models are envisaged.

**Denmark**
Data collection is in progress at Masnedø, and the data include dynamic loads. A large amount of data has been collected at Tønderpipe, including turbulence spectra and power fluctuations. Analysis of these data is in progress.

**Italy**
Measurements have been made from the array at Alta Nurra. These data include measurements from seven operating machines spaced seven rotor diameters apart. Further measurements are planned using a row of four machines.

**The Netherlands**
Data collection at Sexbierum is awaiting recommissioning of the wind turbines. Comparisons of existing models with data from Tønderpipe and Zeebrugge are in progress.

**Spain**
Work is continuing on the development of finite-difference modelling codes. Agreement with wind tunnel data is fair, but agreement with field data from Nibe is less good. Prediction of turbulence quantities looks very promising. Work is also being undertaken on the theoretical modelling of the interaction of a wake flow with topography, in two dimensions. Wake results from the UPM code will be parameterised for use in a wind farm program, based on the Lissaman approach, and the results compared with measurements.
from Zeebrügge and Ampurdan. Comparisons will also be made with data from Tændpipe as part of the benchmark exercise.

**Sweden**
Wake measurements have been made on the turbine at Maglarp, and the measured deficits agree well with those measured earlier at Näsudden. Measurements are planned to investigate in greater detail the turbulence structure of the wake behind a single wind turbine. These measurements will complement the theoretical developments on the prediction of wake turbulence.

**United Kingdom**
Work on data analysis from the Nibe experiment has been completed, and the final report is now near to completion. The eddy-viscosity wake program has been used to make some estimates of wake turbulence, and although the results are not quantitatively precise, the technique shows promise. The empirical parameterisation of wake turbulence undertaken by Garrad-Hassan has now been reported.

**United States**
An assessment has been made of the wake effects in an array of 35 Fayette 120 kW wind turbines in Altamont Pass. This work has been reported. The initial indications are that energy losses in a large wind farm may be less than would be predicted by traditional Lissaman-type programs.

All countries will be invited to participate in the benchmark exercises which are designed to provide an assessment of the reliability of currently available wake and wind farm models, as well as to provide a common means of comparing experimental data. It is expected that results of the exercises will form a significant part of the final Task report.
Participating Organisations

Belgium
Denmark
Italy
The Netherlands
Spain
Sweden
United Kingdom

United States

RUCA Antwerp
Risø National Laboratory
ENEL
TNO
Universidad Politecnica de Madrid (UPM)
University of Uppsala
Central Electricity Generating Board
ETSU for the UK Department of Energy
Garrad-Hassan Consultants
US Department of Energy

Operating Agent
United Kingdom Central Electricity Generating Board
Technical Reports and Papers

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<td></td>
<td>BM-3</td>
<td>7/89</td>
<td>Wind and Power Measurements in the Wind Farm at Zeebrugge</td>
<td>J Van Leuven</td>
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<td>Denmark</td>
<td>D-01</td>
<td>5/89</td>
<td>Wake Interaction Measurements at the Masnede wind farm</td>
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<td></td>
<td>D-02</td>
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<td>Supervising and Measuring at Tændpipe Wind Farm - Progress Report</td>
<td>J Højstrup, I Katic, P Norgard</td>
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<td>Italy</td>
<td>IT-01</td>
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<td>Wind Turbulence Analysis in the Alta Nurra Wind Power Station Area</td>
<td>G Botta, R Castagna</td>
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<td>Preliminary Results of Wake Measurements at the Alta Nurra Wind Power Station</td>
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<td>Wind Tunnel Measurements of the Wake of a Tipvane Rotor Model (Summary)</td>
<td>E Luken</td>
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<td>Wake of a Horizontal Axis Wind Turbine Model</td>
<td>A M Talmon</td>
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<td>NL-03</td>
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<td>Evaluation of Three Mathematical Wind Turbine Wake Models in Various Types of Flow</td>
<td>E Luken, A M Talmon, P E J Vermeulen</td>
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<td>11/86</td>
<td>Literature Data Base on Wind Turbine Wakes and Wake Effects</td>
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<td>Spain</td>
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<td>Comparison of Wind Tunnel and Full Scale Measurements of the Wake at the 25 m HAWT Site at ECN Petten</td>
<td>E Luken, J W M Dekker</td>
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<td>The Wind Load of Wind Turbines in Clusters - Literature Survey</td>
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<td>Validation of Turbulence Models of Wind Turbine Wakes</td>
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<td>Wind Farms in Complex Terrain - Second Order Effects</td>
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<td>A Field Study of the Wake Behind a 2 MW Wind Turbine</td>
<td>U Högström, D N Asimakopoulos, A Smedman</td>
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<td>7/87</td>
<td>Siting Guidelines for Wind Turbine Arrays</td>
<td>D J Milborrow, J S Holt</td>
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<td>Wake Modelling and the Prediction of Turbulence Properties</td>
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<td>Fluctuating Loads on a Wind Turbine Operating in a Wake</td>
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<td>7/88</td>
<td>Near Wake Wind Tunnel Studies</td>
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<td>Wake Interaction Studies on the HWP-300 and WEG MS-1 Wind Turbine Generators on Burgar Hill</td>
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<td>The Impact of Wind Turbine Wakes on Machine Loads and Fatigue</td>
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<td>Comparison of NWAKE Model with Data from Nibe Wake Measurements Project</td>
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<td>United States</td>
<td>US-01</td>
<td>4/88</td>
<td>An Examination of Wake Effects and Power Production for a Group of Large Wind Turbines (PNL-6528)</td>
<td>D Elliott, J Buck, J Barnard</td>
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<td>10/89</td>
<td>Characterisation of Wind Turbine Wake Turbulence and Its Implication on Wind Farm Spacing</td>
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TASK XI  Base Technology Information Exchange

The objective of this Task is to promote wind turbine technology by co-operative activities and information exchange on R&D topics of common interest. There are two Subtasks:

A  Development of Recommended Practices for Wind Turbine Testing and Evaluation
B  Joint Actions

In addition, topical expert meetings are arranged as agreed by the Participants, acting in the Executive Committee.

The final Annex text was approved by the Executive Committee at the Spring 1989 meeting. The duration of the Task was extended until 31 December 1991.

In Subtask A, the second edition of Vol 3 Fatigue Characteristics was issued during the report period. A second edition of Vol 1 Power Performance Testing is in the final stages of preparation. A list of the documents published so far is shown in Table 2. The reports are available on request from the national representatives in the Executive Committee.

The preparation and updating of the documents are carried out by ad hoc groups of experts. The activities are controlled by a Standing Committee, which met twice during the year: on 6 April in Petten, the Netherlands, and on 18-19 December in Stockholm, Sweden.
Table 2  Documents in the series of Recommended Practices for Wind Turbine Testing and Evaluation

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<tr>
<th>Vol</th>
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<td>1</td>
<td>Power Performance Testing</td>
<td>1982</td>
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<td>Estimation of Cost of Energy from Wind Energy Conversion Systems</td>
<td>1983</td>
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<td>3</td>
<td>Fatigue Characteristics</td>
<td>1984</td>
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<td>Electromagnetic Interference (Preparatory Information)</td>
<td>1986</td>
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<td>6</td>
<td>Structural Safety (Preparatory Information)</td>
<td>1988</td>
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<td>7</td>
<td>Quality of Power. Single Grid-Connected WECS</td>
<td>1984</td>
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<td>8</td>
<td>Glossary of Terms</td>
<td>1987</td>
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Subtask B presently includes two activities:

- Joint Action on Aerodynamics
- Joint Action on Fatigue

In the Joint Action on Aerodynamics, a symposium was held on 16-17 November 1989 at Harwell, UK. Presentations were given on the status and prospects of new airfoil sections, calculation methods and experimental result for rotors in yaw, and three-dimensional flow through rotors, in particular at or near stall conditions.

The Harwell symposium was the third of its kind. Proceedings of the second symposium in November 1988 at Lyngby, Denmark, were published during the report period by the Department of Fluid Mechanics of the Technical University of Denmark.
In the Joint Action on Fatigue, a group of experts agreed on a reference load spectrum for wind turbine blade fatigue testing. The spectrum is known as WISPER (Wind turbine load Spectrum Reference). The group met on 31 August - 1 September at Risø, Denmark, to discuss the experience from applying the spectrum.

Two topical expert meetings were organised during the year: on Integrating Wind Turbines into Utility Power Systems, and on Noise Generating Mechanisms of Wind Turbines. Proceedings from the Rome meeting in October 1988 were published by the German Contracting Party, Kernforschungsanlage Jülich GmbH. The cumulated list of topical expert meetings arranged under the IEA Wind Energy Agreements is shown in Table 3.

Table 3
IEA Wind Energy Expert Meetings

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<td>1</td>
<td>Seminar on Structural Dynamics</td>
<td>12 Oct 78</td>
<td>Munich, Germany</td>
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<td>2</td>
<td>Control of LS WECS and Adaption of Wind Electricity to the Network</td>
<td>4 Apr 79</td>
<td>Copenhagen, Denmark</td>
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<td>3</td>
<td>Data Acquisition and Analysis for LS WECS</td>
<td>26-27 Sep 79</td>
<td>Blowing Rock, N Carolina, USA</td>
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<td>4</td>
<td>Rotor Blade Technology with Special Respect to Fatigue Design</td>
<td>21-22 Apr 80</td>
<td>Stockholm, Sweden</td>
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<td>Environmental and Safety Aspects of the Present LS WECS</td>
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<td>Reliability and Maintenance Problems of LS WECS</td>
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<td>Safety Assurance and Quality Control of LS WECS during Assembly, Erection and Acceptance Testing</td>
<td>26-27 May 82</td>
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<td>9</td>
<td>Structural Design Criteria for LS WECS</td>
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<td>Utility and Operational Experience from Major Wind Installations</td>
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<td>11</td>
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<td>Aerodynamic Calculation Methods for WECS</td>
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<td>Requirements for Safety Systems for LS WECS</td>
<td>17-18 Oct 88</td>
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<td>17</td>
<td>Integrating Wind Turbines into Utility Power Systems</td>
<td>11-12 Apr 89</td>
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<td>18</td>
<td>Noise Generating Mechanisms for Wind Turbines</td>
<td>27-28 Nov 89</td>
<td>Petten, the Netherlands</td>
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Participating Organisations

Canada  
Denmark  
Germany  
Italy  
Norway  
Netherlands  
Spain  
Sweden  
United Kingdom  
United States  

Energy, Mines and Resources  
Department of Fluid Mechanics, Technical University of Denmark  
KFA Jülich  
ENEA  
Directorate of Energy  
ECN  
IER/Ciemat  
FFA  
ETSU for the Department of Energy  
National Engineering Laboratory  
Department of Energy  

Operating Agent  
Department of Fluid Mechanics of the Technical University of Denmark  

Recommended Reports and Papers  

Recommended Practices for Wind Turbine Testing and Evaluation  
Vol 3 Fatigue Characteristics  
Published by the IEA R&D WECS Executive Committee  

Joint Action on Aerodynamics  
Proceedings of the Second Symposium on the Aerodynamics of Wind Turbines, 21-22 November 1988 at Lyngby, Denmark  
Published by the Department of Fluid Mechanics of the Technical University of Denmark  

Requirements for Safety Systems for Large Scale Wind Turbines  
Proceedings of the Expert Meeting 17-18 October 1988, Rome, Italy  
Published by the Kernforschungsanlage Jülich GmbH  

W J Stam, N J C M van der Borg  
Noise Generating Mechanisms of Wind Turbines  
An Introductory Note for the IEA Expert Meeting 27-28 November 1989, Petten, the Netherlands
**TASK XII  Universal Wind Turbine for Experiments (UNIWEX)**

UNIWEX is a computer-controlled, two-bladed experimental wind turbine of 16 m rotor diameter installed at the Ulrich Hütter Wind Test Field near Schnittingen, West Germany. The main goals of the project are the experimental study of aerodynamics, operational behaviour, load spectra and control strategies for different hub concepts, as well as the validation of computer codes.

So far, seven organisations from three countries are participating; participation of further countries is intended. In the case of Italy, the prospects are good and preparations with respect to the technical programme have been undertaken.

The Annex XII text was modified during the year in coordination with the Legal Office of IEA Paris.

Representatives of all participants met on the following occasions:
- three technical meetings (14 March, 7 April and 14-15 December)
- two Executive Committee meetings (19 April and 18 October)
- EWEC '89 (10-14 July)

The activities are described in some detail in the corresponding publications, listed in the references. As a consequence of the technical meetings, the work plan was updated with respect to priorities in the technical topics and the time schedule. The project was presented at the two EC meetings, at the IEA Headquarters in Paris (24 May) and at the EWEC '89 Conference.

The main technical activities in 1989 are listed below:

**At ICA/University of Stuttgart**
1. Software Development and Numerical Simulation
   - Discussions of an improved modelling of the induced wind velocity
   - Software development
     * Description of the wind field for upwind rotors
   - Software applications
     * Calculation for instationary gusts
     * Investigation of the influence of generator stiffness
* Re-analysis of the rotor blade
  - Modelling of the modified UNIWEX wind turbine
  * Adaption of the numerical models for tower, drive train and rotor blade
- Graphic post-processing
  * Development of new tools
  * Computer animation for eigenmodes of the UNIWEX turbine and the rotor blade
- Compilation of the wind turbine data for the other participants

2 Hardware Development, Tests and Measurement System
- Hydraulic system
  * Completely new system for the hub hydraulics due to new drive train
  * Overhaul with respect to increased safety and user comfort
  * Passive safety device to avoid loss of the hydraulic generator moment replacing an active device
- Electronic system and real-time software
  * Adaption of the hub electronics to the new computer system on the ground
  * New control and data retrieval system, also due to active yaw option
  * Adaption of the software to the new ground computer software
  * New menu-oriented operations control/graphic display system
- Tower system
  * Implementation of the option for controlled active yawing
  * Overhaul of the tower on the occasion of re-installing the nacelle
  * Improvement of erection/fold down procedure
- Rotor system
  * New spinner due to changed pitch kinematic (upwind operation) and in order to simplify maintenance and weather protection
  * Both friction and play in the pitch bearings were reduced
- Wind measurements
  * A new cup anemometer was manufactured and installed
  * A new beam for wind measurement devices was constructed
- Re-erection of the wind turbine on 7 September 1989
  * Trial runs and re-commissioning
At FFA, Sweden
1 Theoretical Part - GAROS Analysis Program
- Introduction of induced velocity in the rotor plane for calculation of aerodynamic forces in the time response analysis
2 Measurement Programme
- Because of the delay in the instrumentation and erection of the UNIWEX machine, no data analysis has been done in this area.

At ECN, the Netherlands
1 Finalization and signing of contracts between the Dutch participants and acquisition of funding from the Management Agency for Energy Research (NOVEM)
2 Preparation and discussion of measurement campaigns and their influence on the work programme, both between ECN, DUT, SPE and with the international partners
3 Discussion of the technical data of UNIWEX in order to establish the input data for the Dutch simulation codes PHATAS II (ECN), FLEXLAST (SPE) and DUWECS (DUT)
4 Preliminary calculations with PHATAS II, using the input data from ICA Stuttgart.

Participating Organisations

Germany
- Kernforschungsanlage Jülich GmbH (KFA)
- Institute for Computer Applications (ICA), University of Stuttgart

Netherlands
- Netherlands Energy Research Foundation (ECN)
- Delft University of Technology (DUT)
- Stork Product Engineering (SPE)

Sweden
- National Energy Administration Sweden (STEV)
- The Aeronautical Research Institute of Sweden (FFA)

Operating Agent

Institute for Computer Applications, Stuttgart
Technical Reports and Papers

1. Handouts for the technical meetings, dated 89-03-14
3. K. A. Braun, M. Müller: Status Report on UNIWEX presented at the 23rd IEA R&D WECS EC meeting, 19 April 1989, Antwerpen
5. K. A. Braun, A. Finkel: Numerical Aeroelastic Simulation of the Two-Bladed Test Wind Turbine UNIWEX, EWEC '89, Glasgow, UK, 10-13 July 1989
6. M. Müller: Experimental Investigation with the Universal Test Wind Turbine UNIWEX, EWEC '89, Glasgow, UK, 10-13 July 1989
7. Progress Report on Task XII given at the 24th IEA R&D WECS EC meeting, 18 October 1989, Wilhelmshaven, Germany
8. H. Snel: Purpose of the Dutch Participation in the UNIWEX Project, Presentation at the 24th IEA R&D WECS EC meeting, 18 October 1989, Wilhelmshaven, Germany
PROPOSED NEW ACTION

Systems Interaction

After the Herndon expert meeting on Integrating Wind Turbines into Utility Power Systems, the proposed draft Annex was restructured by the US Contracting Party, taking a new, case study approach. A detailed work plan will be prepared after the Spring 1990 EC meeting. The study will be complementary to the planned second phase of the CEC penetration study.

Offshore Studies

Offshore WECS wind turbines are now being installed in Denmark and Sweden, and projects have been proposed in the Netherlands and the United Kingdom. A meeting will be arranged by the UK EC Member to explore the possibility of intensified information exchange between countries who are actively planning offshore Wecs installations. Interest in participation has been expressed by EC Members from Denmark, Germany, Italy, the Netherlands and Sweden.
ACTIVITIES OF THE EXECUTIVE COMMITTEE

The 23rd meeting of the Executive Committee took place on 19 April 1989 at the Rijksuniversitair Centrum Antwerpen, Belgium. The 24th meeting was held on 18 October 1989 at the Jade Windpark, Wilhelmshaven, F R Germany. At the meetings the EC reviewed the progress of the ongoing Tasks and discussed proposals for future work.

Mr S Engström (Sweden) and Mr J Beurskens (the Netherlands) served as Chairman and Vice Chairman during the year. At the fall meeting Mr J Beurskens and Mr P Surman (UK) were elected Chairman and Vice Chairman for 1990.

Some changes in membership were announced during the year. An updated list of EC Members and Alternate Members is attached as Appendix 1.

A Conformed Copy of the Implementing Agreement including Annexes, taking into account changes and amendments since the original version of 1977, is being prepared by the IEA Secretariat.

Cooperation between the IEA R&D WECS and the Commission of European Communities Directorate General XII (CEC DG XII) was established during the year. A representative of CEC DG XII participated in the EC meetings and technical reports were exchanged.

As agreed by the EC at its fall meeting 1988, brief reviews of the national and CEC wind energy R&D programmes were presented at the EC meetings. Each member country will report once a year in the future.

At the request of the IEA/CRD Working Party on Renewable Energy Technologies, a self-evaluation of the IEA R&D WECS activities was undertaken by the Executive Committee and the Operating Agents of the various Tasks. The findings and recommendations are summarised as follows:
Wind energy technology has developed considerably over the past decade and an impressive expansion of the wind industry has taken place in the lead countries.

By the end of 1988 about 1800 MW of wind system capacity was installed in about 20,000 units, mainly in California.

Current-day wind turbines can compete with other electricity generating systems under favourable conditions.

Prospects of further cost reductions and the large wind resource potential make wind energy the most promising of the renewable technologies in the near term.

Many countries have substantial national programmes for basic research and advanced components development for intermediate to large (megawatt-sized) wind turbines.

The IEA wind energy Agreements have operated successfully for nearly twelve years. Seven Tasks have been completed and four Tasks are currently ongoing.

In spite of growing commercial interests and increasing activities within other international bodies, there is a strong need for continued IEA cooperation.

The evaluation was presented by the EC Chairman at the Spring meeting 1989 of the IEA/CRD Working Party on Renewable Energy Technologies.

Report by the Executive Committee
April 1989

A list of selected reports and publications produced within the IEA R&D WECS Agreement from the above report is found in Appendix 2.
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CUMULATED LIST OF SELECTED TECHNICAL REPORTS AND PAPERS PRODUCED WITHIN IEA R&D WECS

General


A Strategic Review
IEA R&D WECS Executive Committee, September 1987


Annex I Environmental and Meteorological Aspects on Wind Energy Conversion Systems


Ouderling J M G A, J T A Neessen; An Inventory of Conditions and Requirements for the Installation of Large-Scale Windmill Networks with Respect to Their Impact on Telecommunications Networks, PTT Report 454 TM, Leidschendam, 1979


Bodin S, U Fredriksson; Uncertainty in Wind Forecasting for Wind Power Networks, SMHI Report RMK 25, Norrköping, 1981


Törnkvist G; Design Recommendations for Wind Energy Converters with Horizontal Axis, Saab-Scania Report FKL-V-80.11, Linköping, 1980

Törnkvist G; Design Recommendations for Wind Energy Converters with Vertical Axis, Saab-Scania Report FKL-V-80.12, Linköping, 1980


Annex II Evaluation of Wind Models for Wind Energy Siting

Pennell W T; An Evaluation of the Role of Numerical Wind Field Models in Wind Turbine Siting, Report PNL-SA-11129, Battelle Pacific Northwest Laboratory, 1983

Annex III and IIIa Integration of Wind Power into National Electricity Supply Systems


Dub W, H Pape; Integration of Wind Power into the Grid of the Netherlands - An Economic Assessment, 1981

Dub W, H Pape; Integration of Wind Power into the Swedish Grid - An Economic Assessment, 1981

Dub W, H Pape; Integration of Wind Power into National Electricity Supply Systems, Final Report of Task IIIa, University of Regensburg, 1982

Annex IV Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems

Reports published by the University of Stuttgart 1978-1980:

Wortmann F X; Tragflügelprofile für Windturbinen
Argyris J H, K A Braun; Lastwechselzahlen und Materialwerte für die Auslegung einer Windturbine speziellen Naben-Konstruktion

Argyris J H, K A Braun, B Kirchgässner; Statische Untersuchung von Rotorblättern unter Eigengewicht und im stationären Betrieb

Walter G A; The Influence of Airfoil Properties on the Flapping Motion and Rotor Forces of Two-Bladed Wind Turbines with Flapping Hinges and Flap-Pitch Coupling under Gust Loading

Mickeler S; An Analytical Investigation Relating to Two-Blade Wind Turbines with Flapping Hinges and Flap-Pitch Coupling at Mains-Driven Operation

Mayer M; One-Blade Turbine with Torsionally Compliant and Partially Hinged Balancing Mass

Wortmann F X; A Gust Generator for Wind Turbines

Argyris J H, K A Braun, B Kirchgässner; Dynamic Analysis of a Rotor Blade with Flap and Lag Freedom and Flap-Pitch Coupling

Argyris J H, B Kirchgässner; Stability and Response to Gravity of the Flap-Lag Motion for Rigid Rotor Blade with Flap-Pitch Coupling

Argyris J H, K A Braun; Static and Dynamic Investigations of Different Towers for Wind Turbines

Argyris J H, K A Braun, B Kirchgässner, R Walther; Static and Dynamic Investigations for the Model of a Wind Rotor

Argyris J H, W Aicher, F Karl, W Kümmerle, M Müller; Rotor Model for the Verification of Computational Models

Annex V Study of Wake Effects behind Single Turbines and in Wind Turbine Parks

Vermeulen P E J; A Wind Tunnel Study of the Wake of a Horizontal Axis Wind Turbine, MT-TNO Report 78-096/4, September 1978

Milborrow D L; Model Tests of Windmill Clusters - Philosophy and Preliminary Results, CERL Memorandum LM/ENG/318, 1978


Vermeulen P E J; Studies of the Wake Structure of Model Wind Turbine Generators, MT-TNO Reprt 79-012904
Milborrow D J; Wind Tunnel Measurements on Wind Turbine science, London, 1979


Builtjes P J H, DJ Milborrow; Modelling of Wind Turbine Arrays, August 1980


Builtjes P J H, D J Milborrow; Modelling of Wind Turbine Arrays; Proc. Third Int. Symp. on Wind Energy Systems, Copenhagen, August 1980

Milborrow D J, J F Ainslee; Calculation of the Flow Patterns and 2nd BWEA Wind Energy Workshop, Cranfield, Multi-science, London, 1980

Milborrow D J; The Performance of Arrays of Wind Turbines, J. Ind. Aerodynamics 5 (1980) 403


Vermeulen P E J, R C Heijke; Measurements of the Drag Coefficient of the CERL Wind Turbine Simulator, MT-TNO Report 81-02840


Vermeulen P E J; Definition of the Turbulence Concept in Relation to Wind Turbine Design, MT-TNO Report 81-09061, July 1981

Ainslee J F; Computer Modelling of Clusters of Wind Turbines, CERL Note RD/LN 187/80 1981

Ainslee J F; Computer Modelling of Wake Effects in Clusters of Wind Turbines, CERL Memorandum LM/PHYS/229, 1981


Vermeulen P E J; Turbulence Measurements in Simulated Wind Turbine Clusters, MT-TNO Report 82-03003, February 1982


Alfredsson P H; A Comparison between Predicted and Measured Data from Wind Turbine wakes, Wind Engineering 6 (1982) No.3 p 149

Ainslee J F; Comparison of Wake Models for Computing Interactive Effects between Wind Turbines, CERL Note TPRD/L/2302/N82, 1982

Milborrow D J; Wakes and Clusters of Wind Turbines - Research Progress and Future Trends, CERL Note TPRD/L/2204/N81, 1982


Ainslee J F; Development of an Eddy Viscosity Model of a Wind Turbine Wake, CERL Memorandum TPRD/L/AP/0081/M83, 1983

Milborrow D J, J N Ross; The Influence of Turbulence and Rotor Thrust on Wind Turbine Wake Characteristics, CERL Memorandum TPRD/L/AP/0098/M83, 1983

Milborrow D J; Preliminary Theoretical Estimates of Interactions between the Nibe Wind Turbines, CERL Memorandum TPRD/L/AP/0115/M83, 1983

Taylor G J; Wake Structure of a 17 m Diameter Horizontal Axis Wind Turbine, CERL Memorandum TPRD/L/2554/M83, 1983

**Annex VI Study of Local Wind Flow at Potential WECS Hill Sites**


Walmsley J L, J R Salmon; A Boundary-Layer Model for Wind Flow over Hills: Comparison of Model Results with Askervein '83 Data, Paper A14, European Wind Energy Conf., Hamburg 22-26 October 1984


Teunissen H W, M E Shokr; The Askervein Hill Project: Wind Tunnel Simulation (Smooth Model) at Length Scale 1:1200, Research Report MSRB-85-1, Atmospheric Environment Service, Toronto,Canada, April 1985

Taylor P A, J L Walmsley, J R Salmon; Guidelines and Models for Estimating Wind Speeds at WECS Sites in Complex Terrain, Proc. INTERSOL '85, Montreal, Canada, June 1985


Teunissen H W, M E Shokr; Wind-Tunnel/ Full-Scale Comparisons of Boundary-Layer Flow over Askervein Hill, Scotland, Proc. Asia Pacific Symp. on Wind Engineering, Roorkee, India, December 7-8, 1985

Annex VII Study of Offshore WECS

General Documents

Offshore Wind Power in Denmark, DEFU Report EV-83-01E, DEFU, Lyngby, Denmark, 1983

Burton A L (Ed.); Report on Offshore Wind Energy Assessment Phase IIIB. Volume 1, Executive Summary, Taylor Woodrow Report 014/OW/102, ETSU, Harwell

A Study into the Use of Vertical Axis Wind Turbines in Offshore Locations, Vol. 1 and 2, MacAlpine London, ETSU Harwell

Oscar D S, P L Paez; Analysis of Wind Turbines on Offshore Support Structures Excited by Random Wind and Waves, Sandia Report SAND87-1689, Sandia Labs, Albuquerque, New Mexico, U.S.A.


Data Collection and Compilation


Palutikov J P, T D Davies, P M Kelly; The Variability of the Wind Field over the British Isle: Implications for Wind Power Production, University of East Anglia, Norwich, CEGB, London, April 1985


Wills J A B; Summary Results from West Sole, NMI, Feltham, ETSU, Harwell

Kvick T; Summary of the Swedish Activities in the Meteorological Programme, SMHI, Norrköping, September 1983

Kvick T; A Case Study of a Boundary-Layer Wind Regime in Stably Stratified Air over the Baltic Sea, SMHI, Norrköping, October 1983
Kvick T, H Andersson; Wind Speed Statistics Measured at Swedish Lighthouses (Summary), SMHI Report 1984:14, SMHI, Norrköping, May 1984

Kvick T, S Salomonsson; Sodar-Based Wind Speed Measurements Made at a Very Small Island (Summary), SMHI Report 1984:15, SMHI, Norrköping, June 1984

Kvick T, E Olsson, U Fredriksson, H Tärnevik; Numerical Simulations of the Wind Energy Conditions along the Swedish Coast (Summary), SMHI Report 1984:19, SMHI, Norrköping, June 1984

Høstrup J; Summary of Risø Work at Six Different Locations, Risø Nat. Lab., July 1984

Høstrup J; Sprogø Data !977-84, Prepared for Annex VII, Risø Nat Lab, July 1984

Eckman R M, J Høstrup; Some Measurements of Lateral Coherence in Neutral Conditions, Risø Nat Lab, October 1985

**Conceptual Design of an OWECS Power Station**

Iperen J van; Conceptual Design of an OWEDS Power Station: Comparative Study Phase I Definition of the Scale and Operational Layout of an Offshore Power Station, Report P788/C.1.1, Hydronamic BV, Sliedrecht, February 1984


Otway F O J; Offshore Wind Energy: Comparison of British, Swedish and Danish Studies, Report GDCD/PE-B/SS/97, CEGB, GDCD, Barnwood, January 1986


Hardell R, L Fritz; Access to Offshore Wind Power Stations in Connection with Monthly Inspection, AIB, Stockholm, November 1983

Hardell R; Wind Power Stations Off the Swedish Coast: Some Proposed Locations, AIB, Stockholm, October 1984

Hardell R; Wind Power Plants Off the Swedish Coast: Estimates of Generation Costs, AIB, Stockholm, December 1984
Hardell R, R Werner; AIB Offshore Wind Power: Study of the Construction of Offshore Wind Power of the Näsudden Type, AIB, Stockholm, December 1984

WTS-5 Offshore Wind Turbine System: Engineering Study Carried Out by Götaverken-Arendal AB, Götaverken, Gothenburg, August 1984

Development of Design Specifications

Hardell R; Technical Specification of OWECS Prototype, 3K Engineering, Stockholm, September 1986

Hardell R; Objectives for an Offshore Prototype Wind Turbine, 3K Engineering, Stockholm, November 1986

Annex VIII Decentralized Applications for Wind Energy

Hulle F van; Site Assessment Models: Interim Report, Petten, the Netherlands, May 1987


Horbathy R; Influence of Turbulence on the Energy Output of WECS, Oekozentrum Langenbruck, Switzerland, 1987

Manwell J F, J G McGowan; Errors and Uncertainty Analysis for Wind/Diesel Experimental Projects, University of Massachusetts, USA, 1987

Infield D; IEA Validation Exercise Using ECN Wind/Diesel Data - Report on Validation of RAL Statistical Modelling Techniques, Rutherford Appleton Laboratory, Chilton, UK, 1987

Greisen H; Trial Validation of Calculation Programs for AWDS, Risø National Laboratory, Roskilde, Denmark, 1987

Uhlen K; IEA Wind/Diesel Model Validation Exercise, EFI, Trondheim, Norway, 1987

Annex IX Intensified Study of Wind Turbine Wake Effects

Van Leuven J, D Cosaert; The Wind Farm at Zeebrugge: Instrumentation for Measurement of Wake Effects, BM-01, July 1987

Van Leuven J, D Stevens, R Van Den Poel, P Vanderborght; The Belgian Wind Farm at Zeebrugge: Experimental Set-Up, BM-02, July 1988

Van Leuven J, D Stevens; Wind and Power Measurements in the Wind Farm at Zeebrugge, BM-03, July 1989
Katic I; Wake Interaction Measurements on the Masnedø Wind Farm, D-01, May 1989

Højstrup J, I Katic, P Nørgard; Supervising and Measuring at Tøndpipe Wind Farm - Progress Report, D-02, July 1989

Botta G, R Castagna; Wind Turbulence Analysis in the Alta Nurra Wind Power Station Area, IT-01, July 1988

ENEL; Preliminary Results of Wake Measurements at the AltaNurra Wind Power Station, IT-02, July 1989

Luken E; Wind Tunnel Measurements of the Wake of a Tipvane Rotor Model (Summary), NL-01, July 1985

Talmon A M; Wake of a Horizontal Axis Wind Turbine Model, NL-02, August 1985

Luken E, A M Talmon, P E J Vermeulen; Evaluation of Three Mathematical Wind Turbine Wake Models in Various Types of Flow, NL-03, January 1986

Luken E; Literature Data-Base on Wind Turbine wakes and Wake Effects, NL-04, November 1986

Luken E, J W M Dekker; Comparison of Wind Tunnel and Full-Scale Measurements of the Wake at the 25 m HAWT Site at ECN Petten, NL-05, December 1987

Luken E; The Wind Load of Wind Turbines in Clusters, NL-06, July 1989

Crespo A, J Hernandez, E Luken, Validation of Turbulence Models of Wind Turbine Wakes, SP-01, July 1988

Crespo A, J Hernandez; Analysis of Wind Turbine Wakes, SP-02, July 1989

Crespo A, J Hernandez, C Andreu; Wind Farms in Complex Terrain - Second Order Effects, SP-03, July 1989

Högström U, D N Asimakopoulos, A Smedman; A Field Study of the Wake behind a 2 MW Wind Turbine, SW-01, July 1987

Elliott D, J Buck, J Barnard; An Examination of Wake Effects and Power Production for a group of Large Wind Turbines, PNL-6528, US-01, April 1988


Milborrow D J, J S Holt; Siting Guidelines for Wind Turbine Arrays, UK-01, July 1987
Ainslie J F; Wake Modelling and the prediction of Turbulence Properties, UK-02, July 1987

Taylor G J; Fluctuating Loads on a Wind Turbine Operating in a Wake, UK-03, July 1987

Green D R; Near Wake Wind Tunnel Studies, UK-04, July 1988

Scott A; Wake Interaction Studies on the HWP-300 and WEG MS-1 Wind Turbine Generators on Burgar Hill, Orkney, UK-05, July 1988

Hassan U, G J Taylor, A D Garrad; The Impact of Wind Turbine Wakes on Machine Load and Fatigue, UK-06, July 1988

Ainslee J F; Comparison of NWAKE Model with Data from Nibe Wake Measurement Project, UK-07, July 1989

Quarton D; Characterisation of Wind Turbine Wake Turbulence and Its Implications on Wind Farm Spacing (Wake Turbulence Characterisation), UK-08, October 1989

Annex XI Base Technology Information Exchange

Proceedings of the Second Symposium on the Aerodynamics of Wind Turbines, 21-22 November 1988 at Lyngby, Denmark

Proceedings of the Expert Meeting on Requirements for Safety Systems for Large Scale Wind Turbines, 17-18 October 1988, Rome, Italy

Stam W J, N J C M van der Borg; Noise Generating Mechanisms of Wind Turbines, An Introductory Note for the IEA Expert Meeting 27-28 November 1989, Petten, the Netherlands

Recommended Practices for Wind Turbine Testing and Evaluation


Frandsen S, A R Trenka, B Maribo Pedersen (Eds); Vol 1 Power Performance Testing, 1982

Nitteberg J (Ed); Vol 2 Estimation of Energy Costs from Wind Energy Conversion Systems, 1983


Ljunggren S, A Gustafsson, A R Trenka (Eds); Vol 4 Acoustics. Measurement of Noise Emission from WECS, 1984
Ballard L J, R H Swansborough (Eds); Vol 7 Quality of Power. Single Grid-Connected WECS, 1984


Chignell R J (Ed); Vol 5 Electromagnetic Interference, 1986

Elliot G (Ed); Vol 8 Glossary of Terms, 1987


Beurskens J (Ed); Vol 6 Structural Safety. Review of Standards and Codes of Practice, 1988

Annex XII Universal Wind Turbine for Experiments (UNIWEX)

Hopf A; Auslegung eines Rotorblattes für eine Windturbine mit Hilfe der Methode der finiten Elemente, Studienarbeit, ICA, Stuttgart, 1989

Müller M; Eine rechnergesteuerte Windturbine zur Simulation und Überprüfung von Konstruktionskonzepten. 12. GESA-Symposium, Veitshöchheim, 11-12 May 1989

Braun K A, A Finkel; Numerical Aeroelastic Simulation of the Two-Bladed Test Wind Turbine UNIWEX, EWEC '89, Glasgow, UK, 10-13 July 1989

Müller M; Experimental Investigation with the Universal Test Wind Turbine UNIWEX, EWEC '89, Glasgow, UK, 10-13 July 1989

Braun K A, A Finkel; Compilation of Data for the UNIWEX Wind Turbine, Stuttgart, November 1989
<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Author(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985:R1</td>
<td>IEA Forestry Energy Project, A study of Biomass Liquefaction test Facility</td>
<td></td>
</tr>
<tr>
<td>1985:R4</td>
<td>Demand for Commercial Energy in Developing Countries, Phil O'Keefe, Beifer Institute</td>
<td></td>
</tr>
<tr>
<td>1985:R5</td>
<td>Kommunal energiplanering Fem uppsatser</td>
<td></td>
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<td>1986:R2</td>
<td>LÅGA OLJEPRISER? Effekter på svensk energiförsörjning</td>
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<tr>
<td>1986:R3</td>
<td>ELMARKNADEN 1985 - En vändpunkt?</td>
<td></td>
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<tr>
<td>1986:R4</td>
<td>Förutsättningar för minskning av svavelhalten i oljeprodukter i Sverige Underlagsmaterial till statens energiverks utredning om svavelhalten i oljeprodukter Nils Elam, Atrax Energi AB</td>
<td></td>
</tr>
<tr>
<td>1986:R5</td>
<td>Reduction of sulphur content in gasoil and heavy fuel oil Background material for the National Energy Administration's study of the sulphur content in oil products Prepared for the National Energy Administration by Purvin &amp; Gertz, Inc.</td>
<td></td>
</tr>
<tr>
<td>1986:R6</td>
<td>Avsvavling av petroleumprodukter Tekn. lic. Arne Bergholm Framställninga av lågsvavliga eldmingsoljor Sveriges tekniska attachéer, Washington Underlagsmaterial till statens energiverks utredning om svavelhalten i oljeprodukter</td>
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<td>Nedsättning av energiskatterna inom industrin</td>
<td></td>
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<tr>
<td>1986:R10</td>
<td>IEA District Heating. Cost Analysis of District Heating Networks</td>
<td></td>
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<tr>
<td>Year:R1</td>
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<td>Elförbrukning föruppvärmning övrigsektorn</td>
<td>Eje Sandberg, Rolf Westerlund, K-konsult</td>
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<tr>
<td>1986:R12</td>
<td>Efter Tjernobyl Ny elproduktion vid forcerad kärnkraftavveckling</td>
<td>PFBC</td>
</tr>
<tr>
<td>1986:R13</td>
<td>Efter Tjernobyl Förgasning av inhemska bränslen för elproduktion</td>
<td>Jan Fors, Leif Magnusson, Teknikgruppen AB</td>
</tr>
<tr>
<td>1986:R14</td>
<td>Efter Tjernobyl Forsöjningsmöjligheter för extremt lågsvavlig</td>
<td></td>
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<td>1986:R15</td>
<td>Efter Tjernobyl Naturgasen - ett alternativ</td>
<td>Swedegas AB</td>
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<td>1986:R16</td>
<td>Efter Tjernobyl Ut ur återvändsgränderna</td>
<td>Olof Eriksson, Arne Mogren</td>
</tr>
<tr>
<td>1986:R18</td>
<td>Efter Tjernobyl Katastrofrisker i energisystemet</td>
<td>Lars Kristoferson, Björn Kjellström, Per Johan Svenningsson</td>
</tr>
<tr>
<td>1986:R19</td>
<td>Efter Tjernobyl Energimarknader och prisrelationer</td>
<td>Per Anders Bergendahl</td>
</tr>
<tr>
<td>1986:R20</td>
<td>Efter Tjernobyl Industrins elanvändning</td>
<td>AF-Energikonsult, Stockholm</td>
</tr>
<tr>
<td>1986:R21</td>
<td>Efter Tjernobyl Analys av skogssektorn vid förändrade energipriser</td>
<td>Göran Lönnler, Sten Nilsson, Hans-Olof Nordvall</td>
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<td>1986:R22</td>
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<td>1986:R23</td>
<td>Efter Tjernobyl Arbetsmiljö vid utvinning, beredning och transport av vissa bränslen för kraft- och värmecentraler</td>
<td>Yngve Hagerman</td>
</tr>
<tr>
<td>1987:R1</td>
<td>IEA Bioenergy Annual Report 1986</td>
<td></td>
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<tr>
<td>1987:R3</td>
<td>Värmepumpar Aktuella förändringar och framtidsutsikter</td>
<td></td>
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<tr>
<td>1987:R4</td>
<td>IEA District Heating Temperature levels in district and local heating systems in Sweden</td>
<td></td>
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<tr>
<td>1987:R5</td>
<td>El- och värme produktion med naturgas</td>
<td></td>
</tr>
<tr>
<td>1987:R6</td>
<td>IEA District Heating Technical and economic assessment of new distribution technology</td>
<td></td>
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<tr>
<td>1988:R1</td>
<td>IEA Bioenergy Annual Report 1987</td>
<td></td>
</tr>
<tr>
<td>1988:R3</td>
<td>IEA Large-Scale Wind Energy Annual Report 1987</td>
<td></td>
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<tr>
<td>1988:R4</td>
<td>Moms på energi Konsekvenser för svensk ekonomi och industri</td>
<td></td>
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<tr>
<td>1988:R5</td>
<td>Förändrad energibeskattning Tre rapporter</td>
<td></td>
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<tr>
<td>1988:R6</td>
<td>Import av trädbränslen till Sverige Potential på kort och lång sikt</td>
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<tr>
<td>1988:R7</td>
<td>Oljeberoende Och allokeringspolitik</td>
<td></td>
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<tr>
<td>1988:R8</td>
<td>Effekter på hushållens konsumtionsstandard av förändrad beskattning av energi Effekter baserade på förslag om övergång till momsbeskattning av energi</td>
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<td>1988:R12</td>
<td>IEA District Heating Small Heat Meters</td>
<td></td>
</tr>
<tr>
<td>1988:R13</td>
<td>IEA District Heating State-of-the-art review of coal combustors for small district heating plants</td>
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<tr>
<td>1988:R14</td>
<td>Utvärdering av det svenska oljeprospekteringsstödet</td>
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<td>1988:R15</td>
<td>Elmarknadsrapport 1988</td>
<td></td>
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<tr>
<td>1989:R2</td>
<td>Energi ur industriavfall En fallstudie över hinder och drivkrafter</td>
<td></td>
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<tr>
<td>1989:R4</td>
<td>IEA Large-Scale Wind Energy Annual Report 1988</td>
<td></td>
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<tr>
<td>1989:R5</td>
<td>Petroleumbränslen Kvalitetsutveckling från 1980 och framåt</td>
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<td>1989:R6</td>
<td>Koldioxid från fossil förbränning Möjligheter att reducera och deponera koldioxiden</td>
<td></td>
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<tr>
<td>1989:R7</td>
<td>Värmeproduktion med gasol Föreskrifter och säkerhetsfrågor Teknik, Ekonomi, Miljökonsekvenser</td>
<td></td>
</tr>
<tr>
<td>1989:R8</td>
<td>Naturgasmarknaden i Västeuropa Historisk bakgrund och framtidsbedömningar</td>
<td></td>
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<tr>
<td>1989:R9</td>
<td>Ett miljöanpassat energisystem Bilder av energipolitikens framtida omvärld</td>
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<td>1989:R10</td>
<td>Ett miljöanpassat energisystem Styrmedel för minskning av CO2 under svensk kontroll</td>
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<td>1989:R11</td>
<td>Ett miljöanpassat energisystem Miljöscenarier för torvanvändning fram till år 2015</td>
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lång sikt

1989:R27 Ett miljöanpassat energisystem
Rökgaskondensering

1990:R1 IEA R&W Wind Report
Annual Report 1989
1990:R2  IEA Large-Scale Wind Energy
         Annual Report 1989

1990:R3  IEA Bioenergy
         Annual Report 1989