International Energy Agency

Programme of Research and Development on
Wind Energy Conversion Systems

IEA R&D Wind Energy

ANNUAL REPORT 1990

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

Statens energiverk
1991:R1

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FOREWORD

This is the thirteenth Annual Report of the IEA Programme for Research and Development on Wind Energy Conversion Systems (IEA R&D WECS), reviewing the activities during 1990. The report is submitted to the Agency in accordance with the recommendations of the IEA Committee on Research and Development.

H J M Beurskens
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 Eneergy 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 twelve Tasks, seven of which have been successfully completed. Two additional Tasks are technically complete, but final reporting remains. The current 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: Central Electricity Generating Board (UK)

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

A new Annex XIII on Co-Operation in the Development of Large Wind Turbine Systems has been adopted. The Task, which will commence 1 January 1991 and continue for an initial period of three years, incorporates the activities of the IEA LS WECS Agreement which is terminated by 31 December 1990.

Tasks VIII, IX and XI are task-sharing projects, whilst Tasks XII and XIII are 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. A draft manuscript of the final report, called the Wind-Diesel Guidebook, was nearly completed during the year. The book will be published on the open market.

Eight countries are participating in Task IX Intensified Study of Wind Turbine Wake Effects. A substantial amount of experimental data was collected from operating wind turbines and windfarms and compared with predictions from theoretical models. A benchmark exercise for the evaluation of both single wakes and windfarm models has been completed. A draft final report has been submitted to the Executive Committee. It is concluded that, whilst numerical models of single wakes are now soundly based, further work is needed to better understand the interaction of wakes in a windfarm.

Task XI Base Technology Information Exchange has participants from nine countries. A main activity is the preparation and publication of Recommended Practices for Wind Turbine Testing and Evaluation. To date eight documents have been published. They are updated as experience and feedback from the users is accumulated. A second edition of Vol 1 Power Performance Testing was issued during the year, and a second edition of Vol 6 Structural Safety is being considered.

Joint Actions represent the second Subtask of Task XI. In the Joint Action on Aerodynamics the fourth symposium was arranged during the year. Proceedings from the third symposium, held in November 1989 has been published. In the Joint Action on Fatigue, an international group of experts have agreed on a reference load spectrum for wind turbine blade fatigue testing. A Joint Action on

Offshore WECS has been initiated, aiming at the exchange of experiences from the design, construction and operation of offshore wind turbines.

As a third activity within Task XI, topical expert meetings are arranged and documented. The 19th meeting took place in May 1990 on Wind Turbine Control Systems - Strategy and Problems. Proceedings of the 18th meeting on Noise Generating Mechanisms in November 1989 has been published.

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 1990 included the development of software and numerical simulation, the development, testing and installation of hardware for the modified experimental wind turbine as well as experiments for the verification of the computer models for simulating the hardware and the aerodynamic behaviour. Measurement campaigns were carried out with constant rotor speed, constant tip speed, different yaw angle, high angles of attack and tilted power.

The Executive Committee met twice during the year to review the progress of the ongoing Tasks and discuss proposals for new cooperative action. The national wind energy research programmes were presented at the meetings and progress and planning reports were exchanged.

A new Annex for Extended Wake Effect Studies is being drafted for consideration at the Spring 1991 meeting.

The Executive Committee has decided to investigate the possibility of issuing a Newsletter twice a year. The Newsletter should inform the wind energy community of IEA wind energy activities, including the status of national wind energy programmes, the progress of the Tasks as well as summary performance data and incident/accidents for large wind turbine systems.

The main issue during the year was the merger of the two Implementing Agreements. At the Fall meeting the Executive Committees of the R&D and LS Agreements unanimously agreed to terminate the LS Agreement by 31 December 1990 and to incorporate the LS activities as Annex XIII of the R&D Agreement from 1 January 1991. The decision reflects the changed environment in which the Agreements operate when most wind energy research and development is directed to large systems.

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 twelve Tasks have been initiated, nine of which have been successfully completed :

Task I — Environmental and Meteorological Aspects of Wind Energy Conversion Systems
Operating Agent : the National Swedish Board for Energy Source Development
Completed in 1981.

Task II — Evaluation of Models for Wind Energy Siting
Operating Agent : US Department of Energy - Battelle Pacific Northwest Laboratories
Completed in 1983.

Task III — Integration of Wind Power into National Electricity Supply Systems
Operating Agent : Kernforschungsanlage Jülich GmbH
Completed in 1983.

Task IV — Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems
Operating Agent : Kernforschungsanlage Jülich GmbH
Completed in 1980.

Task V — Study of Wake Effects behind Single Turbines and in Wind Turbine Parks
Operating Agent : Netherlands Energy Research Foundation
Completed in 1984.

Task VI — Study of Local Wind Flow at Potential WECS Hill Sites
Operating Agent : National Research Council of Canada
Completed in 1985.

Task VII Study of Offshore WECS
Operating Agent : UK Central Electricity Generating Board
Completed in 1988.

Task VIII Study of Decentralised Applications for Wind Energy
Operating Agent : UK National Engineering Laboratory
Technically completed in 1989.

Task IX Intensified Study of Wind Turbine Wake Effects
Operating Agent : UK Central Electricity Generating Board.
Technically 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.

Task XIII Cooperation in the Development of Large Wind Turbine Systems
Operating Agent : Solar Energy Research Institute, USA
To be completed in 1993

There are 16 Contracting Parties to the Implementing Agreement, representing 15 countries. The participation in the current Tasks is shown in Table 1. The Belgian and Swiss Contracting Parties have decided to withdraw from the Agreement, effective 31 December 1990.

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. Tasks XII and XIII are mixed cost- and task-shared.

During the year the Executive Committee of IEA LS WECS agreed to terminate the IEA LS WECS Implementing Agreement, effective 31 December 1990. Simultaneously, the IEA R&D WECS Executive Committee decided to amend the IEA R&D WECS Implementing Agreement to include LS WECS activities in its scope as of 1 January

1991 and to adopt a new Annex for Co-Operation in the Development of Large Wind Turbine Systems (see below). At the same time, ENEL of Italy and Scottish Hydro-Electric plc of the United Kingdom, being the only Contracting Parties to the LS Agreement not already Parties to the R&D Agreement, joined the IEA R&D WECS Agreement.

Table 1 Participation per country in the current Tasks. OA indicates country of Operating Agent.

Country	Tasks				
	VIII	IX	XI	XII	XIII
Austria					
Belgium		x			
Canada	x		x		x
Denmark	x	x	OA		x
Germany			x	OA	x
Italy		x	x		x
Japan					
Netherlands	x	x		x	x
New Zealand	x				
Norway	x		x		x
Spain	x	x	x		x
Sweden	x	x	x	x	x
Switzerland	x				
United Kingdom	OA	OA	x		x
United States	x	x			OA

TASK VIII DECENTRALISED APPLICATIONS FOR WIND ENERGY

The Task was set up in 1985 and has involved ten countries in a task-sharing arrangement, coordinated by the UK National Engineering Laboratory as Operating Agent. The overall objectives of the study were to:

- define cost effective models and techniques suitable for obtaining wind and load data necessary for planning and specifying decentralised wind energy conversion system installations; and

- apply and further develop models suitable for analysing the performance of wind-diesel systems.

Nine technical meetings were held during 1985-1989, involving 28 experts from the participating countries. At an early stage a desire was expressed to produce a work of reference which would convey to a wider engineering community the potential difficulties and stage of development of wind-diesel technology. The final report of the Task should therefore take the form of a handbook on the siting and implementation of wind-diesel systems.

A draft manuscript of the final report, called the Wind-Diesel Guide Book, was distributed to the Executive Committee Members and Task Participants in March. The manuscript was complete except for a chapter on economic issues. Writing of the remaining chapter and further editorial work are in progress to be completed in early 1991.

The authors comprise the foremost experts from the participating countries, who by discussion and information exchange have agreed upon the contents, which include:

1 Introduction
2 Wind-Diesel Options and Their Applicability
3 Consumer Demand Assessment
4 Wind Resource Assessment
5 Environmental and Other Factors
6 Design Considerations
7 Modelling Techniques
8 Installation and Operation of Wind-Diesel Systems
9 System Testing, Commissioning and Monitoring
10 Economics of Wind-Diesel Systems

The Executive Committee has agreed to have the book published on the open market. Two publishing houses have expressed willingness to publish the book, and a contract proposal has been obtained from one of them.

Participating Organisations

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

Operating Agent

United Kingdom National Engineering Laboratory

TASK IX INTENSIFIED STUDY OF WIND TURBINE WAKE EFFECTS

The Task was set up in 1985 as a follow-on from the earlier Task V study of wake and cluster effects. The study has involved eight countries in a task-sharing arrangement, coordinated by the CEGB (UK) as Operating Agent. The overall objective has been to improve the knowledge of aerodynamic interactions between wind turbines operating in windfarms.

The Task has seen the development of more reliable wake models, and the acquisition of considerable amounts of data from single turbines, pairs of interacting turbines and from full size windfarms. Four technical meetings have been held, in which data were exchanged and models compared. The experimental data and theoretical techniques were brought together in benchmark exercises based around Näsudden (for the evaluation of single wakes) and Tændpipe (for the evaluation of windfarm models).

The final technical review meeting was held 11-12 June in London at which specialists from the participating countries reported progress from measurements and modelling. Discussions took place on the single wake and Tændpipe benchmark exercises in which predictions were compared with experimental results.

The draft final report was submitted to the Executive Committee in September. The report outlines the national contributions to the Task and summarises the work completed. It then highlights the principal results and conclusions from the studies and assesses those areas where further work may be required.

It is concluded that, whereas numerical models of a single wake are now soundly based on the physics of the wake mixing process, the windfarm codes currently available are "first generation" models. For more reliable predictions of the flowfield (both mean flow and turbulence models) within a windfarm to be made, further work will

be required to better understand and quantify the physical processes taking place when wakes interact within a windfarm.

Participating Organisations

Belgium	RUCA Antwerp
Denmark	Risø National Laboratory
Italy	ENEL
The Netherlands	TNO
Spain	Universidad Politecnica de Madrid (UPM)
Sweden	University of Uppsala
United Kingdom	Central Electricity Generating Board
	ETSU for the UK Department of Energy
	Garrad-Hassan Consultants
United States	US Department of Energy

Operating Agent

United Kingdom Central Electricity Generating Board

Technical Reports and Papers

Country	Ref	Date	Title	Authors
Belgium	BM-1	7/87	The Windfarm at Zeebrügge: Instrumentation for Measument of Wake Effects	J Van Leuven D Cosaert
	BM-2	7/88	The Windfarm at Zeebrügge: Experimental Set-Up	J Van Leuven D Stevens J Van Den Poel P Vanderborght
	BM-3	7/89	Wind and Power Measurements in the Wind Farm at Zeebrügge	J Van Leuven

Denmark	D-01	5/89	Wake Interaction Measurements at the Masnedø wind farm	I Katic
	D-02	7/89	Supervising and Measuring at Tændpipe Wind Farm - Progress Report	J Højstrup I Katic P Norgard
	D-03	6/90	A Summary of Tændpipe windfarm measurements	J Højstrup P Nørgard
	D-04	6/90	Danish Windfarm Measurements: IEA Annex IX	P Sanderhoff J Højstrup
Italy	IT-01	7/88	Wind Turbulence Analysis in the Alta Nurra Wind Power Station Area	G Botta R Castagna
	IT-02	7/89	Preliminary Results of Wake Measurements at the Alta Nurra Wind Power Station	ENEL
	IT-03	6/90	Results of Wake Measurements at the Alta Nurra Wind Power Station	G Botta A Gilardi
Netherlands	NL-01	9/85	Wind Tunnel Measurements of the Wake of a Tipvane Rotor Model (Summary)	E Luken
	NL-02	8/85	Wake of a Horizontal Axis Wind Turbine Model	A M Talmon
	NL-03	1/86	Evaluation of Three Mathematical Wind Turbine Wake Models in Various Types of Flow	E Luken A M Talmon P E J Vermeulen
	NL-04	11/86	Literature Data Base on Wind Turbine Wakes and Wake Effects	E Luken
	NL-05	12/87	Comparison of Wind Tunnel and Full Scale Measurements of the Wake at the 25 m HAWT Site at ECN Petten	E Luken J W M Dekker
	NL-06	7/89	The Wind Load of Wind Turbines in Clusters - Literature Survey	E Luken

	NL-07	1988	Nibe Wake Measurements Data Analysis and Model Validation	E Luken
	NL-08	1989	Zeebrugge Windfarm Measurements - Model Validation	H van Oort
	NL-09	1989	Tændpipe Windfarm Measurements - Model Validation	H van Oort
Spain	SP-01	7/88	Validation of Turbulence Models of Wind Turbine Wakes	A Crespo J Hernandez E Luken
	SP-02	7/89	Analysis of Wind Turbine Wakes	A Crespo J Hernandez
	SP-03	7/89	Wind Farms in Complex Terrain - Second Order Effects	A Crespo J Hernandez C Andreu
	SP-04	1989	Numerical Modeling of the Flowfield in a Wind Turbine Wake	A Crespo J Hernandez
	SP-05	1990	Wind Turbine Wakes in the Atmospheric Surface Layer	J Hernandez A Crespo
Sweden	SW-01	7/87	A Field Study of the Wake Behind a 2 MW Wind Turbine	U Högström D N Asimakopoulos A Smedman
	SW-02	1990	Some Additional Data on Full Scale Wind Turbine Wakes	U Högström A-S Smedman
United Kingdom	UK-01	7/87	Siting Guidelines for Wind Turbine Arrays	D J Milborrow J S Holt
	UK-02	7/87	Wake Modelling and the Prediction of Turbulence Properties	J F Ainslee
	UK-03	7/87	Fluctuating Loads on a Wind Turbine Operating in a Wake	G J Taylor
	UK-04	7/88	Near Wake Wind Tunnel Studies	D R Green

	UK-05 7/88	Wake Interaction Studies on the HWP-300 and WEG MS-1 Wind Turbine Generators on Burgar Hill	A Scott
	UK-06 7/88	The Impact of Wind Turbine Wakes on Machine Loads and Fatigue	U Hassan G J Taylor A D Garrad
	UK-07 7/89	Comparison of NWAKE Model with Data from Nibe Wake Measurements Project	J F Ainslee
	UK-08 10/89	Characterisation of Wind Turbine Wake Turbulence and Its Implication on Wind Farm Spacing	D Quarton
	UK-09 1990	Wake Measurements on the Nibe Wind Turbines in Denmark Part 2: Data Collection and Analysis	G Taylor
	UK-10 1990	Multiple Wake Measurements and Analysis	D Smith
United States	US-01 4/88	An Examination of Wake Effects and Power Production for a Group of Large Wind Turbines (PNL-6528)	D Elliott J Buck J Barnard
	US-02 4/89	Wake Effects in a Fayette 95-115 Wind Turbine Array (SERI/STR-217-3186A)	R Simon D Matson J Fuchs

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. The Task has 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 Operating Agent is assisted by an advisory Standing Committee of technical experts. The Committee held its 12th meeting on 2-3 July in Norwich, Vermont, USA. The meeting reviewed updates of documents in the series of Recommended Practices, suggested topics for expert meetings and discussed priorities for wind energy R&D and standards.

In *Subtask A* , a second edition of Vol 1 Power Performance Testing was issued during the report period. A second edition of Vol 6 Structural Safety is being considered. A list of the published documents is shown in Table 2. The reports are available on request from the national representatives in the Executive Committee (see Appendix 2).

Subtask B currently has three activities:

- Joint Action on Aerodynamics
- Joint Action on Fatigue
- Joint Action on Offshore WECS

A fourth Joint Action on Wind-Diesel Systems is being considered as a continuation of the work in Task VIII which is technically completed.

In the Joint Action on Aerodynamics, the fourth symposium was held on 19-20 November at the ENEA Casaccia Centre in Rome, Italy.

Proceedings of the third symposium held in November 1989 at Harwell, England were published during the year.

Table 2 Documents in the series of Recommended Practices for Wind Turbine Testing and Evaluation

Vol	Title	1st Ed	2nd Ed
1	Power Performance Testing	1982	1990
2	Estimation of Cost of Energy from Wind Energy Conversion Systems	1983	
3	Fatigue Characteristics	1984	1989
4	Acoustics. Measurement of Noise Emission from Wind Turbines	1984	1988
5	Electromagnetic Interference (Preparatory Information)	1986	
6	Structural Safety (Preparatory Information)	1988	
7	Quality of Power. Single Grid-Connected WECS	1984	
8	Glossary of Terms	1987	

In the Joint Action on Fatigue, a group of experts have agreed on a reference load spectrum for wind turbine blade fatigue testing. The spectrum is known as WISPER (WInd turbine load SPEctrum Reference).

The first meeting in the Joint Action on Offshore WECS took place on 26 January in London with participation from Denmark, Germany, Italy and Sweden. It was found that interest in offshore siting is increasing. Practical experience from the operation of offshore wind turbines is accumulating from Sweden and will be available from Denmark shortly.

The 19th topical Expert Meeting was held 3-4 May in London on Wind Turbine Control Systems - Strategy and Problems. Proceedings from the 18th meeting in November 1989 in Petten, the Netherlands on Noise Generating Mechanisms for Wind Turbines were published during the year. The cumulated list of expert meetings arranged under the IEA Wind Energy Agreements is shown in Appendix 1.

Participating Organisations

Canada	Department of Energy, Mines and Resources
Denmark	Department of Fluid Mechanics, Technical University of Denmark
Germany	KFA Jülich
Italy	ENEA
Norway	Directorate of Energy
Netherlands	ECN
Spain	IER/CIEMAT
Sweden	FFA
United Kingdom	ETSU for the Department of Energy National Engineering Laboratory
United States	Department of Energy

Operating Agent

Department of Fluid Mechanics of the Technical University of Denmark

Technical Reports and Papers

Recommended Practices for Wind Turbine Testing and Evaluation
Vol 1 (2nd Edition) Power Performance Testing.
Published by the IEA R&D WECS Executive Committee

Proceedings of the Third Symposium on the Aerodynamics of Wind Turbines, held 16-17 November 1989 in Harwell, England.
Published by the Energy Technology Support Unit, UK

Noise Generating Mechanisms for Wind Turbines
Proceedings of the 18th Expert Meeting held 27-28 November 1989 in Petten, the Netherlands.
Published by the Research Centre Jülich GmbH, Germany

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 Schnittlingen, Germany (see Figures 1 and 2). 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:

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 (NE)
	The Aeronautical Research Institute of Sweden (FFA)

Operating Agent

Institute for Computer Applications (ICA), University of Stuttgart

Representatives of the participants met on the following occasions:

- four technical meetings (2 April, 11-12 July, 7 September in Stuttgart and on the testfield, 31 July in Bromma)
- a measurement campaign (19-24 November on the testfield)
- an Executive Committee meeting (5 September in Santiago de Compostela)
- ECWEC '90 (10-14 September in Madrid)

As a consequence of the technical meetings, the work plan was updated with respect to priorities in the technical topics and the time schedule. Progress reports were given at the two EC meetings. At the Fall meeting the time schedule was extended from 1 April to 31 December 1991.

The main technical activities in 1989 are listed below:

At ICA/University of Stuttgart

1 Software Development and Numerical Simulation

- Simulation software
  - Software development
    * Studies of unsteady aeroelastic effects of horizontal-axis wind turbines using the program system ARLIS with a new implemented vortex ringmodel (see Figure 3)
    * Description of the windfield for upwind rotors using the potential flow around a plane half-body and around an infinite cylinder
    * Installation and tests of ARLIS on the work station STELLAR
  - Software applications
    * Applications of the aeroelastic program system ARLIS to one-, two- and thre-bladed horizontal-axis wind turbines
- Modelling of the modified UNIWEX wind turbine
  - Re-analysis of the finite element model of the nacelle (new cardan shaft and new suppots of the gearbox and the generator, see Figures 3 and 5)
  - Structural re-modelling of the rotor blade using the shell-beam conversion package ATACYT and the new measured rotor blade geometry
  - Re-analysis of the whole UNIWEX wind turbine with the finite element method
- Identification of the simulation model by comparison with measurements
  - Eigenfrequencies of the rotorblade
  - Eigenfrequencies of the whole wind turbine
  - comparison of c_p– lambda – curves calculated by different institutions
- Post-processing and animation
  - Development of new plot software for evaluation of results

- Implementation of newly developed processors in the FE-package ASKA for displaying of steady state and transient response results (see Figure 6)
- Development of special graphic software for computer animation on IRIS and STELLAR work stations
- Computer animation of eigen modes, steady state and transient response behaviour for beam, shell and volume structures

• Compilation of wind turbine data for the other participants

2 Development of hard- and software for testing purposes

• Implementation of a system for the control of the rotot speed by "generator" torque, the option for the control by blade pitch being maintained
• Construction of a mobile telescope meteorological mast for wind measurements at hub height
• Improvement of all control algorithms, including the simulation of the flexible hub (free flapping and teetered hub)
• Development of the complete software for for the processing and post-processing of the measured data
  - Working-up of the measured raw data to bulk data
  - Display of raw and worked-up data
  - Interactive frequency analysis
  - Interactive selection, display and output of specific values and mean values
  - Elaboration of c_p–lambda curves with different methods
  - Plotting and display possibilities for all post-processing results (see Figure 7)

3 Experiments

• Comprehensive calibration of all sensors
• Measurements of geometry and eigenfrequencies, partly under direct assistance of the other participants
• Runs for the verification of the computer models for the simulation of the hardware and the aerodynamic behaviour
• Runs with constant rotor speed controlled by
  - blade pitch
  - "generator" torque

- Runs with constant tip speed
- Runs with different yaw angle (relative to the wind direction) and constant yaw rates. The results are used for investigations of power control by yawing strategies.
- Runs at high angles of attack
- Runs with tilted power

As most of these experiments have been undertaken upon the wishes of the Dutch and Swedish partners, the respective measurement recordings have been worked-up and distributed among these participants.

At ECN, the Netherlands

1 Analysis of measurements

With the results of measurements of the UNIWEX now coming in, analysis of the mesurement signals was taken up by the Dutch participants. Some anomalies were detected and discussed at a technical meeting with the Operating Agent. Most have now been explained or, in some cases, given rise to adjustments in the measurements, the sensors. A discrepancy between the plane blade moments and the axial torque signals is still of some concern. number of measurements were performed with the explicit aim of system identification, for the Delft University of Technology.

2 Calibration

In order to obtain a better idea of system geometry, eigenfrequencies and expected error ranges, an extensive programme of calibration tests was conducted together with the Operating Agent in the week of 19-24 November. Part of the measurements must still be interpreted. One important discovery was a slight unbalance in the blades, which explains some of the measured phenomena.

3 Numerical simulation

A number of calculations were done with the system identification methods used by the DUT. The blade moment signals measured by the load cells seem to indicate that a system of relatively high order is needed for a good simulation. At ECN and SPE the simulation software was readied for the inclusion of the results of a wind

generator. This will give a muchmore realistic behaviour of the excitations with frequency of nP (1P being the rotational frecuency), due to the "vortex licing" effect.

At FFA, Sweden

1 Analysis of measurements

Three magnetic tapes with measurements have been received containing data from runs with constant rpm, according ti request made ealier by the Swedish participant. The evaluation of the data and the interpretation of the results are not yet finished.

2 Studies of control strategies

During a meeting at the test field on 7 September the possibilities of studies of control strategies were discussed. It was found that the present hardware for UNIWEX is not suitable for an extension of the original work plan in this direction, i e for research on on control strategies involving for example variable rotor speed coupled with yawing or stalling.

3 Numerical simulation

The planned modelling of the modified UNIWEX turbine has not yet started. The numerical simulation program GAROS has nonetheless been updated and used during the year for stability studies on other wind turbines. Hence the capability of the software has been increased, allowing for a more sophisticated analysis of the UNIWEX turbine. An agreement on a joint paper to be presented at the wind energy conference in Amsterdam 1991 has been made. The paper concerns the numerical simulation of the UNIWEX turbine in two diferent computer codes, ARLIS and GAROS, and a comparison of the differences in the theoretical background for the codes.

Technical Data of the UNIWEX - test wind turbine:

Rotor:

Number of blades	2
Diameter	16 m
Speed	variable (rated 70 r.p.m.)
Tip speed ratio	12 (rated)
Hub type	variable (fully articulated)

Blade:

Length	7.80 m
Chord length	0.15 m ... 0.70 m
Airfoils	FX 77-W-343
	FX 77-W-270
	FX 77-W-151 A
Material	Composites
Mass	106 kg netto
	137 kg with ballast
	in 22 chambers

Tower:

Type	supported steel tube, yawing
Hub height	15 m
Diameter	0.82 m
Foundation	I-Steel-rig, ballast

Generator, Gear:

Hydraulic motor-generator	45 kW
Planetary step up gear	1:40

Control:
(by means of computer controlled servo hydraulics)

Blade pitch
Generator torque
Rotor yawing

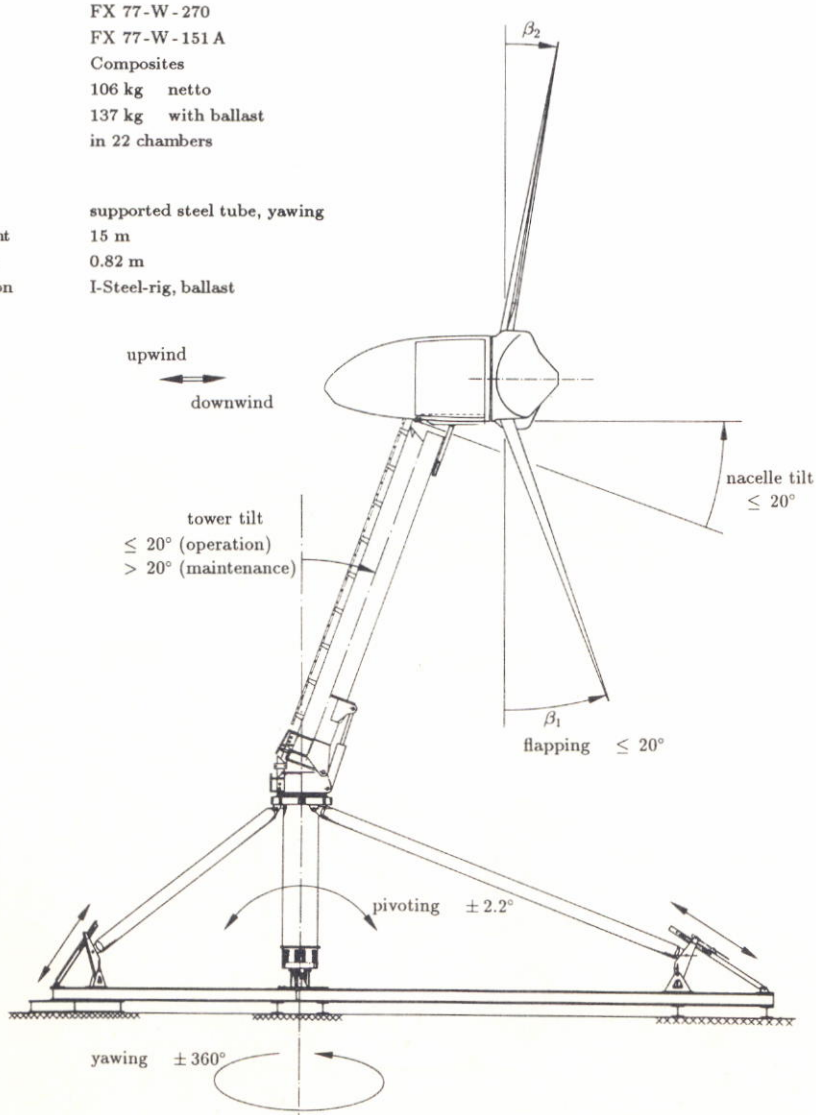


Figure 1: General view, characteristics and technical data of the UNIWEX wind turbine

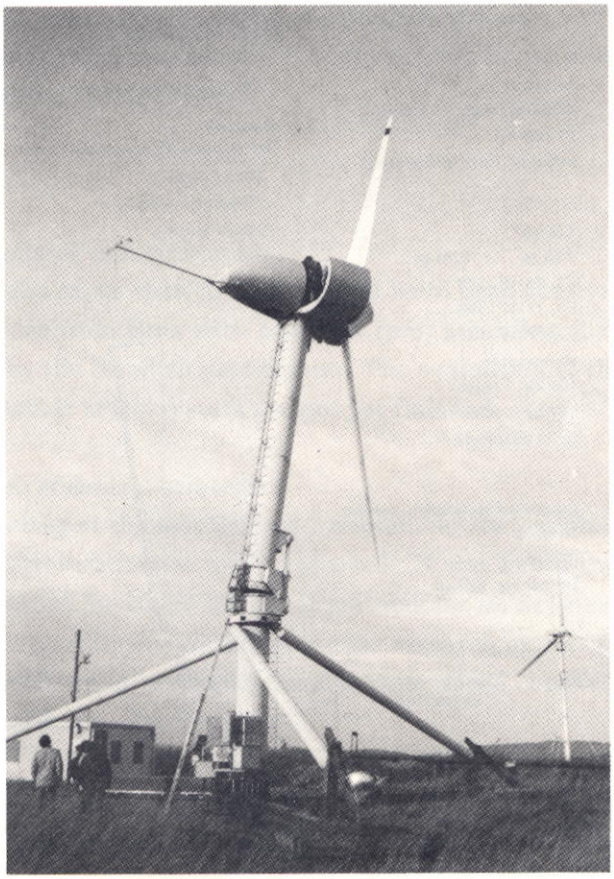


Figure 2: UNIWEX wind turbine in operating position with opened installation platform

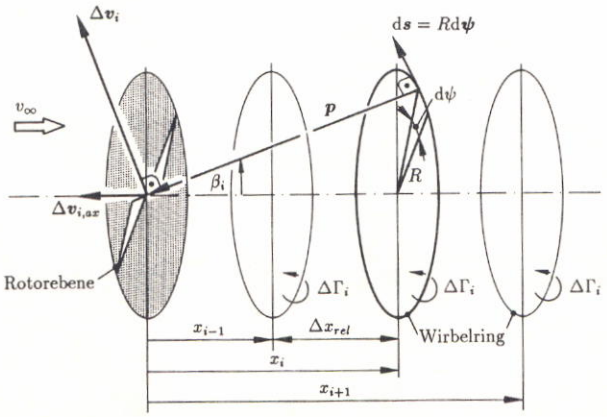


Figure 3: New implemented vortex ring model for analysis of unsteady aeroelastic effects

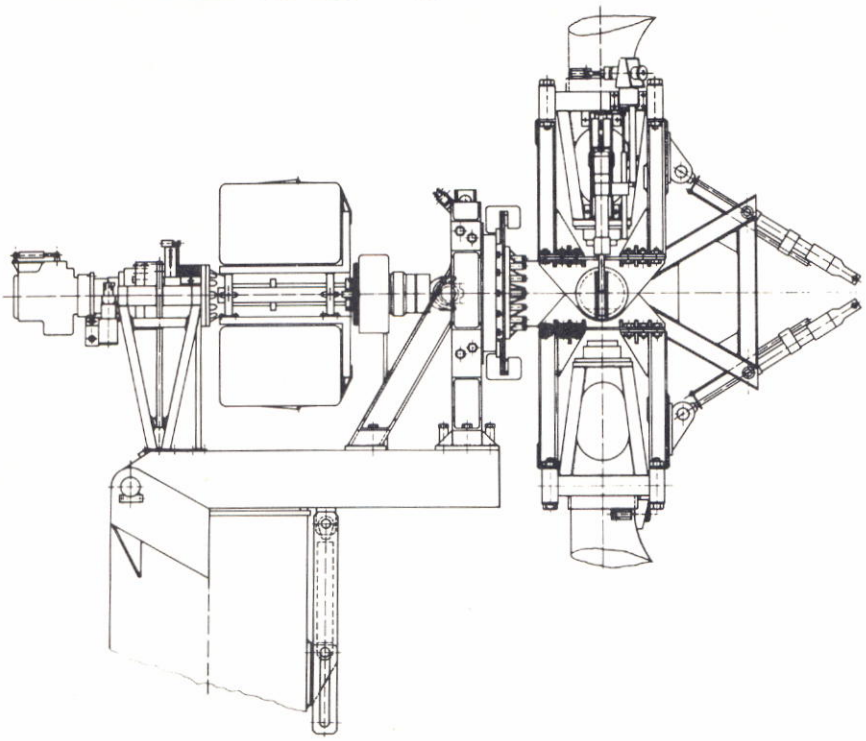


Figure 4: General view of the UNIWEX-nacelle

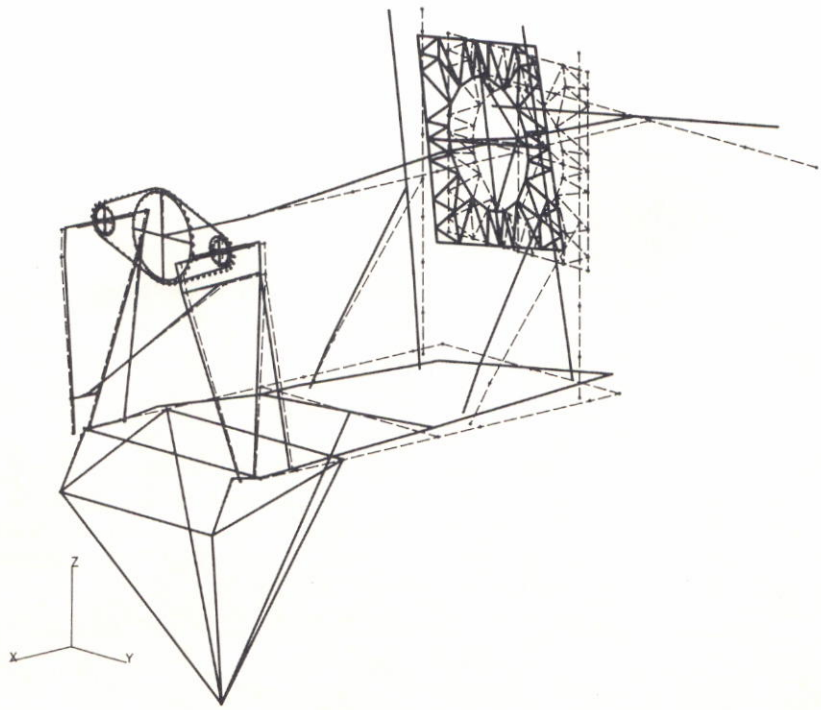


Figure 5: 1. eigenmode of the UNIWEX-nacelle with stiff horizontal rotor ($f_1 = 4.53\,\mathrm{Hz}$)

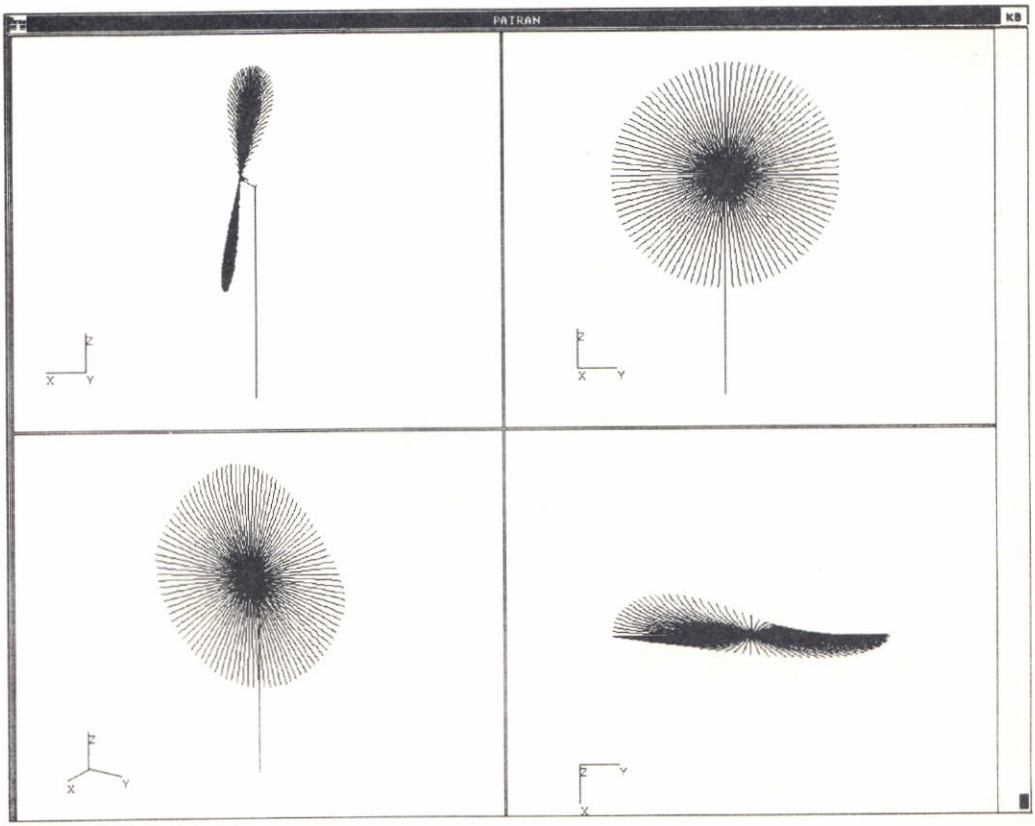
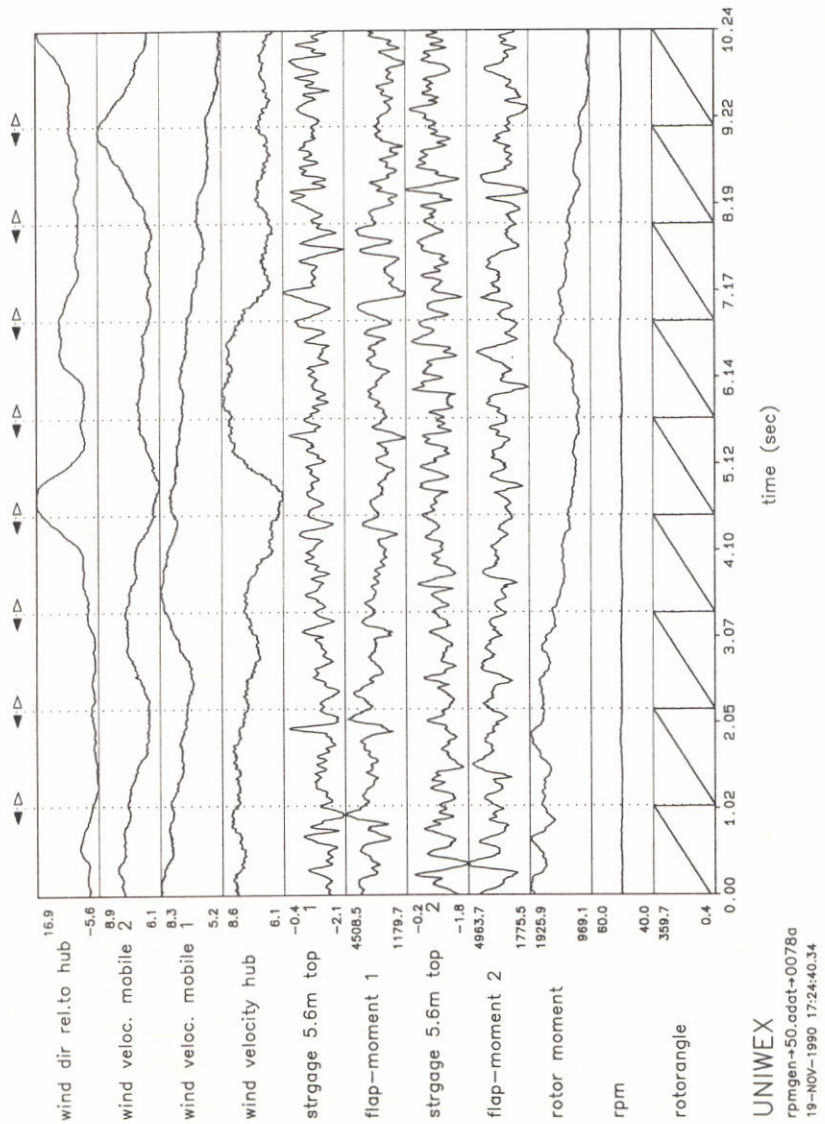


Figure 6: Computer animation and displaying of steady state and transient response results



This plot shows results of a run with fixed hub and rotor speed control by rotor torque. The mobile anemometers were placed 19 m upwind the rotor plane with a lateral distance of 3.5 m and the anemometer on the hub at 7.5 m upwind the rotor plane. It can easily be seen, that it is important for a good interpretation of the measurement data to have more than one anemometer. The plot shows that the load peaks in flap direction (mainly coming from the tower shadow) increase with the rotor power (rotor moment).

Figure 7: Plot of measuring results

TASK XIII COOPERATION IN THE DEVELOPMENT OF LARGE-SCALE WIND TURBINE SYSTEMS

At the fall meeting the Executive Committee adopted a new Annex XIII, effective 1 January 1991. The Annex incorporates the activities of the LS WECS Implementing Agreement which will be discontinued as of 31 December 1990 by decision of the LS WECS Executive Committee. The Annex will be in force for an initial period of three years.

The objective of the Task is to further the development of Large Wind Turbine Systems (LWTS) by means of cooperative action and exchange of information on the planning and execution of national LWTS research, development and demonstration programmes. An LWTS is defined as a megawatt-sized wind turbine or windfarm.

The Task will involve ten countries in a cost-shared arrangement, coordinated by the Solar Energy Research Institute (USA). Information systems will be established for the exchange of information on LWTS design, testing, performance and incidents/accidents. Annual reports of LWTS activities in the participating countries will be prepared.

Participants

Canada	Department of Energy, Mines and Resources
Denmark	Ministry of Energy
Germany	Forschungszentrum Jülich GmbH
Italy	Ente Nazionale per l'Energia Elettrica
Netherlands	Stichting Energieonderzoek Nederland
Norway	Directorate of Energy
Spain	Instituto de Energias Renovables
Sweden	National Energy Administration
United Kingdom	Scottish Hydro-Electric plc
United States	Department of Energy

Operating Agent

Solar Energy Research Institute (USA)

PROPOSED NEW ACTION

Systems Interaction

In view of the CEC grid integration study and existing bilateral agreements, the proposal for an IEA study has been withdrawn.

Extended Wake Effects Study

The Participants of Task IX, which is being finally reported (see above), have recommended that further work be considered in the following areas:

- Local flow effects and atmospheric stability
- Overlapping wakes and rules for superposition
- Prediction of turbulence within windfarms
- Windfarm performance in hilly terrain
- Wake-induced blade loads and rotor fatigue within windfarms.

The UK Contracting Party will draft an Annex for consideration at the Spring 1991 meeting of the Executive Committee.

Effect of Environment on Wind Turbine Safety and Performance

A proposal was introduced by the German Contracting Party for a cooperative study of the effects of icing conditions on wind turbines. A workshop will be arranged on the generalised subject of environmental effects on wind turbine safety and performance.

Wind Energy Newsletter

At the Fall meeting the Executive Committee decided to investigate the possibility of issuing a Newsletter twice a year. The Newsletter should inform the wind energy community of IEA wind energy activities, including the status of national wind energy programmes, Task progress reports, summary LWTS performance data and incident/accident reports, calendar of meetings and lists of technical reports and publications. A test issue will be prepared for consideration at the Spring 1991 meeting of the Executive Committee.

THE EXECUTIVE COMMITTEE

The 25th meeting of the Executive Committee took place on 19 April 1990 at the Sin-Osaka City Plaza Hotel, Osaka, Japan. The 26th meeting was held on 5 September 1990 at the Hotel De Los Reyes Catolicos, Santiago de Compostela, Spain. At the meetings the EC reviewed the progress of the ongoing Tasks and discussed proposals for future work.

Mr H J M Beurskens (the Netherlands) and Dr P Surman (UK) served as Chairman and Vice Chairman during the year. At the Fall meeting Mr Beurskens and Dr Surman were re-elected Chairman and Vice Chairman for 1991.

Some changes in membership were announced during the year. An updated list of EC Members and Alternate Members is attached as Appendix 2.

Following the completion of Tasks VIII and IX, the Swiss and Belgian Contracting Parties are withdrawing from the Implemeting Agreement, effective 31 December 1990. In consequence of the merger of the R&D and LS Agreements, ENEL of Italy and Scottish Hydro-Electric plc are entering the R&D Agreement as of 1 January 1991.

At the Fall meeting the Executive Committees of the R&D and LS Agreements unanimously adopted a Resolution to the effect that the LS Agreement is terminated by 31 December 1990, that the LS activities are incorporated as Annex XIII of the R&D Agreement as of 1 January 1991.

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

IEA Wind Energy Expert Meetings

No	Title	Date	Venue
1	Seminar on Structural Dynamics	12 Oct 7	Munich, Germany
2	Control of LS WECS and Adaption of Wind Electricity to the Network	4 Apr 79	Copenhagen, Denmark
3	Data Acquisition and Analysis for LS WECS	26-27 Sep 79	Blowing Rock, N Carolina, USA
4	Rotor Blade Technology with Special Respect to Fatigue Design	21-22 Apr 80	Stockholm, Sweden
5	Environmental and Safety Aspects of the Present LS WECS	25-26 Sep 80	Munich, Germany
6	Reliability and Maintenance Problems of LS WECS	29-30 Apr 81	Aalborg, Denmark
7	Costing of Wind Turbines	18-19 Nov 81	Copenhagen, Denmark
8	Safety Assurance and Quality Control of LS WECS during Assembly, Erection and Acceptance Testing	26-27 May 82	Stockholm, Sweden
9	Structural Design Criteria for LS WECS	7-8 March 83	Greenford, UK
10	Utility and Operational Experience from Major Wind Installations	12-14 Oct 83	Palo Alto, California
11	General Environmental Aspects	7-9 May 84	Munich, Germany
12	Aerodynamic Calculation Methods for WECS	29-30 Oct 84	Copenhagen, Denmark
13	Economic Aspects of Wind Turbines	30-31 May 85	Petten, the Netherlands
14	Modelling of Atmospheric Turbulence for Use in WECS Rotor Loading Calculations	4-5 Dec 85	Stockholm, Sweden
15	General Planning and Environmental Issues of LS WECS Installations	2 Dec 87	Hamburg, Germany

IEA Wind Energy Expert Meetings (continued)

No	Title	Date	Venue
16	Requirements for Safety Systems for LS WECS	17-18 Oct 88	Rome, Italy
17	Integrating Wind Turbines into Utility Power Systems	11-12 Apr 89	Herndon, Virginia USA
18	Noise Generating Mechanisms for Wind Turbines	27-28 Nov 89	Petten, the Netherlands
19	Wind Turbine Control Systems - Strategy and Problems	3-4 May 1990	London, England

IEA R&D WECS EXECUTIVE COMMITTEE ADDRESS LIST

(M = Member, A = Alternate Member)

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A study of Biomass Liquefaction test Facility

1985:R2 **IEA Forestry Energy**
Annual Report 1984

1985:R3 **IEA Peat Production and Utiliazation Project**
Annual Report 1984

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Phil O'Keefe, Beifer Institute

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Nils Elam, Atrax Energi AB

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Background material for the National Energy Administration's study of the sulphur content in oil products.
Prepared for the National Energy Administration by Purvin & Gertz, Inc.

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Tekn. lic. Arne Bergholm.
Framställning av lågsvavliga eldningsoljor.
Sveriges Tekniska Attachéer, Washington.
Underlagsmaterial till Statens energiverks utredning om svavelhalten i oljeprodukter.

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