INTERNATIONAL ENERGY AGENCY

Programme of Research and Development

on Wind Energy Conversion Systems

(IEA R&D WECS)

ANNUAL REPORT 1981

A report of the IEA R&D WECS Executive Committee

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FOREWORD

This report summarizes the progress during 1981 of the IEA Programme for Research and Development on Wind Energy Conversion Systems (IEA R&D WECS). It is submitted to the IEA Secretariat by the IEA R&D WECS Executive Committee and is intended to meet the requirements of Level 2 type information as set forth by the IEA Committee on Research and Development.

Louis V. Divone
Chairman

Bengt Pershagen
Secretary

IEA R&D WECS ANNUAL REPORT 1981

Executive Summary

The IEA R&D WECS program was initiated in 1977 with the objective of performing cooperative research, development and demonstration, and of exchanging information in the field of wind energy utilization. Originally, the program had four Tasks:

I Environmental and meteorological aspects of WECS

II Evaluation of numerical models for siting of WECS

III Integration of wind power into national electricity supply systems

IV Investigation of rotor stressing and smoothness of operation of large-scale WECS.

The first phase of Task III was completed in 1979 and was followed by a second phase, called Task IIIa running through 1982. Task IV was completed in 1980. A new Task V "Study of wake effects behind single turbines and in wind turbine parks" was initiated in 1980 and is scheduled for completion in 1983.

Task I was finished in 1981. The main objectives were fully realized although there was a considerable delay in completing the Task, partly due to the complex structure with eight different Sub-Tasks carried out in three different countries.

The detailed results of Task I have been published in more than 10 technical reports. The main results can be summarized as follows:

- a manual for structural safety analysis of WECS has been prepared
- co-location of biomass and wind energy farms will have marginal advantage at best
- the optimum power output from a limited array of WECS could be 9W per square meter ground area at a mutual distance of about 6 rotor diameters
- an inventory of the conditions and requirements to be placed on the siting of WECS with regard to telecommunication disturbances has been made
- the visual impact of large-scale WECS has been investigated by means of perception theory, field observations and case studies
- the accuracy of present wind forecasting methods was found to be inadequate for daily scheduling and hourly dispatching of WECS operation
- recommendations were made for defining and calculating load cases for WECS design.

Considerable progress was made during 1981 by the two study groups set up by the Executive Committee on

- Offshore siting of WECS
- Recommended practices for wind turbine testing.

The comparative study on offshore siting was completed with the main conclusion that is seems technically feasible to install a large, multi-unit WECS station offshore. Further studies are required to assess the economic viability and to develop a plan for the design and construction of a prototype offshore WECS.

The study group on Recommended practices completed a study of power performance testing of wind turbines and is continuing its efforts to define and recommend procedures for WECS costing, evaluation of fatigue, acoustics, electromagnetic interference, safety and reliability, and quality of power.

The countries participating in the IEA R&D WECS agreement are: Austria, Canada, Denmark, Germany, Ireland, Japan, the Netherlands, New Zealand, Norway, Sweden, the United Kingdom, and the United States.

Operating Agents are: Kernforschungsanlage Julich GmbH (Task IIIa), Stichting Energieonderzoek Centrum Nederland (Task V), National Swedish Board for Energy Source Development (Task I), United States Department of Energy (Task II).

1. IEA R&D WECS PROGRAM

This report reviews the progress during 1981 of the Programme of Research and Development on Wind Energy Conversion System (R&D WECS), operated under the auspices of the International Energy Agency (IEA).

IEA R&D WECS is one of two IEA projects in wind energy, the other being concerned with cooperation in the development of large-scale WECS. Both projects are in effect since 1977.

The overall objective of IEA R&D WECS is to perform cooperative research and development, and to exchange information within the framework of the Implementing Agreement. As described in Annexes I-IV to the Implementing Agreement the original programme of work had four Tasks:

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

Task II Evaluation of Models for Wind Energy Siting
Operating Agent: Department of Energy, USA

Task III Integration of Wind Power into National Electricity Supply Systems
Operating Agent: Kernforschungsanlage Julich GmbH, Germany

Task IV Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems
Operating Agent: Kernforschungsanlage Julich GmbH, Germany

The first phase of Task III was completed in 1979 and was followed by a second phase, called Task IIIa. Task IV was completed in 1980.

During 1980 a new Task was initiated:

Task V Study of Wake Effects behind Single Turbines and in Wind Turbine Parks.
Operating Agent: Stichting Energieonderzoek Centrum Nederland

Another Task was approved by the IEA R&D WECS Executive Committee in 1981. At the end of 1981 it was in the process of being established as an Annex to the Implementing Agreement:

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

The participation in the current Tasks is as follows:

Country	Task I,	Task II,	Task IIIa,	Task V
Austria	x			
Canada	x	x		x
Denmark	x			x
Germany	x	x	x	
Ireland	x			
Japan	x	x	x	x
Netherlands	x		x	x
New Zealand	x			
Norway	x	x		
Sweden	x	x	x	x
United Kingdom		x		x
United States	x	x	x	x

Tasks I and IIIa are commonly funded, which means that the costs are shared by the contracting parties in pre-determined proportions Task II is a task-sharing project where each participant carries his own costs. Task V is a mixed cost- and task-sharing project.

In addition to the Tasks, the Executive Committee initiated special studies on:

- Offshore Siting of WECS

- Recommended Practices for Wind Turbine Testing

The special studies are being performed by ad hoc study groups established by and reporting to the Executive Committee.

In the following the progress during 1981 of the Tasks and the special studies are briefly described.

2. TASK I. ENVIRONMENTAL AND METEOROLOGICAL ASPECTS OF WIND ENERGY CONVERSION SYSTEMS

This Task is divided in eight Sub-Tasks, carried out in three different countries, acting as Responsible Participants, as follows:

Sub-Task	Title	Responsible Participant
A 1	Study of WECS farm area and WECS safety limit requirements	Sweden
A 2	Study of combined wind-biomass energy systems	Ireland
A 3	Study of wind wake effects	Netherlands
A 4	Study of the impacts of large-scale WECS on the performance of electro-magnetic wave systems	Netherlands
A 5	Study of aesthetic factors and visual effects of large-scale WECS	Sweden
A 6	Reporting	Sweden
B 1	Investigation of the uncertainty in wind forecasting for wind power networks	Sweden
C 1	Load case recommendations	Sweden

Sub-Task A 4 was completed in 1979 and A 2, A 5, B 1 and C 1 in 1980. The main results were summarized in previous Annual Reports and are not repeated here.

The remaining Sub-Tasks A 1, A 4 and A 6 were finished during 1981. The main achievements are reported below.

2.1 Sub-Task A 1. Study of WECS farm area and WECS safety limit requirements

A manual for structural safety analysis of WECS was prepared, including data on material strengths, identification of failure possibilities, critical loads and load combinations. The principles of reliability analysis, as applicable to WECS, were reviewed, and the function of safety systems to prevent structural failure and mitigate possible hazards discussed. The throw-length of a separating turbine blade or blade fragment was calculated as a basis for assessing the probability that a person would be hit by the separating object.

The final report of the Sub-Task was published in February 1981 as a company report from the performing organization, the Aeronautical Research Institute (FFA), Stockholm:

EGGWERTZ S, CARLSSON I, GUSTAFSSON A, LINDE M, LUNDEMO C, MONTGOMERIE B, THOR S-E
Safety of wind energy conversion systems with horizontal axis
FFA Technical Report HU-2229

2.2 Sub-Task A 4. Study of the impacts of large-scale WECS on the performance of electromagnetic wave systems

A study was made to assess the possible effects of large-scale WECS and the restrictions to be placed on their location with respect to the telecommunication systems applied in the Netherlands. It was found, for example, that a WECS cannot be installed within an area bounded by a distance of 100 m from the centerline of a fixed service link, and that the minimum distance between a WECS and the transmitting antenna of a broadcasting service has to be 6 kilometers. In the second phase of the study, calculations were made of the electromagnetic scattering from cylinders, simulating horizontal axis WECS. Some conclusions were drawn as to the possibilities of reducing the scattering.

The results were published in two reports from the performing organization, the Dr Neher Laboratorium of the Dutch PTT:

OUDERLING JMGA, NEESEN JTA
An inventory of conditions and requirements for the installation of large-scale windmill networks with respect to their impact on telecommunication networks PTT Report 454 TM

NEESEN JTA, OUDERLING JMGA
Calculations on the scattering properties of wind energy conversion systems PTT Report 475 TM

2.3 Sub-Task A 6. Reporting

The final report for the whole of Task I was published in November 1981 by the Operating Agent, the National Swedish Board for Energy Source Development:

PERSHAGEN B (Ed.)
Environmental and meteorological aspects of wind energy conversion systems
NE 1981:25

It was concluded that the main objectives of Task I had been fully realized, although there was a substantial delay in completing the project.

3. TASK II. EVALUATION OF WIND MODELS FOR WECS SITING

The objectives of this Task are to verify selected atmospheric boundary layer numerical models by comparison with each other and with observed data, and to evaluate the usefulness of such models for wind turbine siting.

The verification program is divided into three sub-tasks:

- Preparation of a detailed verification plan.
- Model verification carried out by the various participants.
- Reporting the final results.

The first sub-task was completed in 1979. Three data sets were chosen from the island of Oahu and the state of Nevada in the USA and the island of Gotland in the Baltic. Five numerical models are included:

- a simple mass-consistent wind interpolation code, the NOABL code developed by Science Applications, Inc., USA
- a one-level, primitive equation model, SAM, developed by the Atmospheric Environment Service of Canada
- a multi-level, time-dependent, hydrostatic model (the University of Virginia mesoscale model)
- a multi-level, time-dependent, non-hydrostatic model (the Tapp and White model of the UK Meteorological Office)
- a multilevel, time-dependent, hydrostatic model, SIGMENT, developed by Science Applications, Inc.

Difficulties were experienced in getting the more complicated models underway. In a meeting in August 1981, which was meant to be final, some models had not yet been applied to all verification periods. A qualitative examination of the model results obtained so far was not very encouraging. In most cases the models did not seem capable of accurately simulating the observed wind fields.

The original time schedule called for completion of the Task in December 1981. Due to the unexpected difficulties a more realistic final date is July 1982.

4. TASK IIIa. INTEGRATION OF WIND POWER INTO NATIONAL ELECTRICITY SUPPLY SYSTEMS

Task IIIa is a continuation of Task III, in which a computer model was developed for analyzing the technical and economical possibilities of integrating large-scale WECS into national electricity networks. The model was applied to the case of Germany. The results were published in a book:

JARASS L, HOFFMANN L, JARASS A, OBERMAIR G
Windenergie
Eine systemanalytische Bewertung des technischen und wirtschaftlichen Potentials fur die Stromerzeugung der Bundesrepublik Deutschland
Springer Verlag, 1980.
(Also available in English)

In Task IIIa the analysis is carried out for Japan, the Netherlands, Sweden and the USA the following main steps are carried out for each country:

- Acquisition of meteorological data, load data and cost data
- Analysis of wind data
- Estimation of WECS power output
- Integration of wind power into the electricity system
    - o Control of wind power output fluctuation
    - o Capacity savings
    - o Present worth break-even costs
- Cost-benefit aspects of wind turbines.

In January 1981 a two-day expert meeting was held. The meeting addressed mainly the problems related to the integration of wind power into the grid. Proceedings from the meeting were published by the Operating Agent, the Projektleitung Energieforschung, Kernforschungsanlage Julich.

The status of work by the end of 1981 may be summarized as follows:

- Japan: Data acquisition, data processing and all calculations have been completed.

- Netherlands: The report has been submitted.

- Sweden: The report has been submitted.

- USA: Data acquisition, data processing and all calculations have been completed.

During 1981 the following reports were published:

1981 Meeting of Experts of Annex III and IIIa -
Integration of Wind Power into National Supply Systems
Spez. Ber. Nr 108
Kernforschungsanlage Julich, April 1981

DUB W, PAPE H
Integration of Wind Power into the Grid of the Netherlands -
An Economic Assessment

DUB W, PAPE H
Integration of Wind Power into the Swedish Grid -
An Economic Assessment

Task IIIa is scheduled for completion by Spring 1982.

5. TASK V. STUDY OF WAKE EFFECTS BEHIND SINGLE TURBINES AND IN WIND TURBINE PARKS

This Task was initiated in 1980 with the Stichting Energieonderzoek Centrum Nederland as Operating Agent. The objective is to produce estimates of the performance of arrays of wind turbine generators, including:

- power output efficiency as a function of spacing, disposition and number of machines and machine types

- generated turbulence levels and associated dynamic effects.

Work is performed jointly in the Netherlands and the United Kingdom in three major areas:

a. Measurements of individual wake structure and decay.

b. Measurements of machine performance in velocity fields of the type that may be encountered in a wake.

c. Theoretical and experimental modeling of machine cluster performance by combining information on individual wakes with knowledge of machine performance in wake-type flows.

During 1981 the following progress was made in these areas:

Individual wake structure

Wind tunnel studies

- Wake measurements were made behind a 3 m diameter horizontal axis rotor at a distance of one diameter

- The University College London has measured the wake decay of a 36 cm rotor which was earlier used in the Dutch program.

Full-scale studies

- The wake generated by a 17 m horizontal axis machine has been measured. Integration of the velocity profile has yielded thrust and power coefficients consistent with expected values. Analysis of the data is continuing.

Machine performance in a wake

- A mini array of 3 machines (6 m diam) plus 4 simulators is constructed at P.I. Engineering, U.K. Meteorological measurements have been made and the site wind profiles determined. Wake measurements will commence shortly. Information on machine performance will be derived from these measurements at Alresford.

Cluster performance

Wind tunnel studies

- Analysis of data from the comprehensive program at Central Electricity Research Laboratories is proceeding. Three thrust coefficients and four spacings (5, 7, 10 and 14 diameters) were used. Use of the turntable enabled data to be derived at 5^{o} intervals.

  Detailed measurements of the wake characteristics of the CERL simulators have been made using a laser doppler anemometer.

- Detailed turbulence measurements have been made by TNO in their simulated wind turbine clusters. For this study, use was made of a multi-element hot wire probe which gives data on the turbulence distribution over the rotor disc. This data acquisition technique is based on a study on turbulence effects of wind turbines.

Theoretical studies

Both CERL and TNO have developed computer models which predict the power output of individual turbines within an arbitrary cluster configuration.

Meetings

A technical meeting was held at CERL, Leatherhead on February 2-3, 1981. The purpose of the meeting was to review the status of work and to discuss possible extensions to Annex V.

The meeting was attended by specialists from Denmark, Ireland, the Netherlands, Sweden, the U.K. and the USA. CERL prepared a report containing most of the CERL contributions to the meeting.

Reports

The following technical reports were published during 1981:

VERMEULEN PEJ
Report of the IEA Technical Meeting on Wakes and Clusters, held at Leatherhead, February 2-3, 1981.
MT-TNO 81-04676

CLAYTON B R, FILBY P
Wind turbine wake studies
Proc. Third BWEA Wind Energy Conference, April 9-10, 1981

TAYLOR G J, TURNER J D, FORDHAM J
Preliminary performance measurements on the 5 m horizontal axis wind turbine at University College, Swansea.
IEA Annex V Technical Meeting, Leatherhead
February 2-3, 1981

MILBORROW D J
Measurement and interpretation of wind turbine wake data
Proc. Third BWEA Conference
April 9-10, 1981

ROSS J N, AINSLIE J F
Wake measurements in clusters of model wind turbines
using Laser Doppler Anemometry
Proc. Third BWEA conference
April 9-10, 1981

VERMEULEN PEJ, HEIJKE RC
Measurements of the drag coefficient of the CERL
Wind turbine simulator
MT-TNO Report 81-02840

AINSLEE J F
Computer modeling of wake effects in clusters of wind turbines
IEA Amex V Technical Meeting, Leatherhead
February 2-3, 1981

VERMEULEN PEJ, BUILTJES PJH, VIJGE JBA
Mathematical modeling of wake interaction in wind turbine arrays
MT-TNO Report 81-01473

VERMEULEN PEJ
Definition of turbulence concept in relation to wind turbine design
MT-TNO Report 81-09061

6. STUDY OF LOCAL WIND FLOW AT POTENTIAL WECS HILL SITES

Planning activities have been performed for a prospective new Task with the purpose of carrying out a major cooperative field experiment to measure in detail the spatial characteristics of mean wind and turbulence over a typical WECS hill site. The results would be compared with mathematical and physical (wind tunnel) models in order to assess the faithfulness with which such models can predict the actual flow.

The National Research Council of Canada would act as Operating Agent for the Task. Denmark, Germany, New Zealand and the United Kingdom have expressed interest in participation. Hills in the Outer Hebrides have been provisionally selected as sites for the experiment. A draft Annex has been prepared.

7. OFF-SHORE SITING OF WECS

Noting that initial feasibility studies for offshore siting of large-scale WECS had been carried out in the Netherlands, Sweden, the United Kingdom and the United States, the Executive Committee initiated in 1980 a study project with the following objectives:

- to compare and evaluate the existing studies
- to specify areas for which there is agreement that no further work is necessary
- to identify areas requiring further investigations
- to propose tasks for collaborative efforts.

The study was performed on a task-sharing basis among the above-mentioned countries, each being responsible for reviewing a certain technical area and with Sweden as coordinator. The group presented a two-part report to the Executive Committee in September 1981:

Offshore Siting of WECS
Part 1: Comparison of four national feasibility studies
Part 2: Proposals for future work.

(Distribution of Part 1 is restricted to members of the countries participating in the study).

Only horizontal-axis wind turbines on bottom-mounted platforms were considered in the comparative study. The main conclusion was that it seems technically feasible to install a large, multi-unit WECS station offshore. The basic features of such a station should be:

- a cluster of 50-200 integrated wind turbines

- with rotor diameters of 50-110 meters

- on individual fixed support structures

- in water depths of 10-45 meters.

Areas requiring further study include:

- assessment of the economic viability, in particular the influence on total costs of the fabrication and installation of support structures and of marine operation and maintenance

- development of a realistic plan providing a sound basis for judgement of the potential of offshore WECS and for further action step by step.

A plan for further action should include design and construction of a prototype offshore WECS and a parallell program of research and development activities.

The recommendations of the ad hoc study group were discussed by the Executive Committee at its meeting in October 1981. Considerable interest was shown in the possibility of an international cooperative program. It was agreed to let the ad hoc group work out a detailed proposal for consideration by the Executive Committee in the spring of 1982.

8. RECOMMENDED PRACTICES FOR WIND TURBINE TESTING

Evaluation of the performance of a wind turbine includes a number of aspects, such as energy production, quality of power, reliability, safety, generating costs and environmental impact. In order to verify the characteristics of a WECS some test procedure is used in each of these areas. It is important to have internationally accepted test procedures so that performance data can be meaningfully compared.

The Executive Committee organized in 1980 an expert group for the study of recommended practices for wind turbine testing. Initially, the group studied procedures for determining the "power curve" (power output vs wind speed) for a wind turbine. The results were published in a report:

TRENKA A R, MARIBO PEDERSEN B, FRANDSEN S (Ed.)
Recommended practices for wind turbine testing
1. Power performance testing
Risö National Laboratory, 1981.

The expert group continues its efforts to define recommended procedures in the following areas:

- cost of energy from WECS
- fatigue evaluation
- acoustics
- electromagnetic interference
- safety and reliability
- quality of power

During 1981 the group had three meetings

February 19-20 at Geilo
May 13-14 in Stockholm
September 7- 8 at Petten

The group aims at finalizing all tasks before January 1983.

9. ACTIVITIES OF THE EXECUTIVE COMMITTEE

The Executive Committee held its seventh meeting on May 11 and 12, 1981 at the Institute for Energy Technology in Kjeller, Norway. At this meeting Mr Divone (USA) and Mr Sens (the Netherlands) were re-elected Chairman and Vice-Chairman for 1981. The eighth meeting was held on October 8, 1981 in Washington D.C. in connection with the Fifth Biennal Wind Energy Conference and Workshop sponsored by the Division of Wind Energy Systems, U.S. Department of Energy.

The technical and financial status of the Tasks and the progress of the study group were reviewed at the EC meetings and the appropriate decisions taken. Proposals for new Tasks were discussed, including

- local wind flow measurements (Canada)
- study of wake and cluster effects on the pair of wind turbines at Nibe (U.K.)
- wind energy integration studies in the second to minute time scale (Germany).

The Chairman initiated a discussion of possible future themes for the IEA R&D WECS agreement. Three areas were identified as particularly interesting:

- Decentralized uses of wind power
- Stability of turbines and arrays
- Offshore siting of WECS

Memos were drafted on each subject by members of the Executive Committee as background for continued discussion.