IEA Wind Energy Annual Report 1991

NUTEK

Swedish National Board for Industrial and Technical Development

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WKA II at Kaiser-Wilhelm-Koog, Germany
Rated power 1,2 MW

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Foreword

This is the fourteenth Annual Report of the IEA collaboration in wind energy, reviewing the activities during 1991. It is also the first report under the amended R&D Implementing Agreement, as of 1 January 1991, for Co-operation in the Research and Development of Wind Turbine Systems (IEA R&D Wind). The amended R&D Agreement incorporates the activities of the previous Large-Scale WECS Agreement which was discontinued by 31 December 1990.

The report is published by Nutek, the Swedish Contracting Party to the Agreement, on behalf of the IEA R&D Wind Executive Committee. It is edited by B Pershagen with contributions from D F Ancona (USA), F Avia (Spain), K A Braun (Germany), P W Carlin (USA), H G Douma (the Netherlands), P Nielsen (Denmark), E Sesto (Italy), W G Stevenson (UK) and R Windheim (Germany).

Petten and Nyköping in January 1992

H J M Beurskens	B Pershagen
Chairman of the	Secretary of the
Executive Committee	Executive Committee

Contents

Executive Summary

The report reviews the progress during 1991 in the Agreement for Co-operation in the Research and Development of Wind Turbine Systems (IEA R&D Wind), operated under the auspices of the International Energy Agency (IEA).

IEA R&D Wind is an agreement for carrying out joint research, development and demonstration projects. Since 1 January 1991, the activity also includes the exchange of information on the planning and execution of national programmes for the design, construction, operation and evaluation of large-scale wind turbines with a rated power of approximately 1 MW or more.

IEA R&D Wind has 16 signatories from Austria, Canada, Denmark, Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, the United Kingdom and the United States.

Wind energy continues to stand out as one of the most promising new renewable energy source in the near term. Significant progress was made during the year in the member countries. The number of wind turbines increased to about 21 000, corresponding to about 2200 MW of rated power. The performance of wind systems continues to improve as the technology matures.

Most of the installed capacity is in the form of arrays or clusters of small and medium size units, known as windfarms. About 1600 MW of windfarm capacity is found in California, USA. Megawatt size windfarms are in operation or under construction also in Canada, Denmark, Germany, Italy, the Netherlands, Norway, Spain, Sweden and the United Kingdom. The first offshore windfarm of 11x450 kW units started operation in mid-1991 near Vindeby, Denmark.

Today's utility-interconnected wind systems in the USA are reported to produce electricity at costs of 0,06 to 0,10 USD/kWh. These costs are nearly one third those of ten years ago. Corresponding average costs for a sample of eight operating windfarms in Denmark are equivalent to 0,07 USD/kWh, including 0,01 USD/kWh for operation and maintenance. Investment costs for the Danish windfarms were equivalent to 1250 USD/kW, of which about 2/3 was wind turbine costs.

The average unit size in today's windfarms is about 100 kW. The rating of new machines is increasing and was, on the average, 160 -180 kW during 1990 - 1991. Commercial wind turbines rated at 400 - 450 kW were delivered during the year. The trend toward larger sizes is partly explained by the better land area utilization of the larger machines.

a computerized information system containing design and performance data as well as incident/accident reports and national programme funding summaries.

Much of the information exchange takes place at the Executive Committee meetings twice a year when the national wind energy activities are reviewed with emphasis on large-scale systems. The highlights are summarized in the Wind Energy Newsletter, of which the first issue was published during the year.

The world's largest vertical-axis wind turbine, the 4 MW EOLE, erected at Cap Chat, Quebec, *Canada*, has been operating in automatic mode since March 1988 and generated more than 8600 MWh during more than 13 000 hours. A blade crack was observed in May 1991. After repair the turbine went back into operation at the end of June. Two large windfarms of medium-sized machines are under construction in Alberta.

As of 31 December 1991, the total capacity of grid-connected wind turbines in *Denmark* was 410 MW in 3230 units (up 791). The first 100 MW utility programme will be fully implemented by the end of 1992. It is expected that another 100 MW will be installed before the end of 1993. The annual power generation was 730 000 MWh, corresponding to 2,3 % of the Danish electricity consumption. Denmark has nine large wind turbines in operation, all of the three-bladed horizontal-axis type: a 2 MW unit at Tvind, two 630 kW units at Nibe, five 750 kW units at Masnedø and a 2 MW unit at Tjæreborg. A 1 MW advanced turbine is being designed for installation at Avedøre in 1993.

In *Germany*, the totally installed wind power approached 100 MW at the end of the year, about a third of which in the framework of the 250 MW Wind programme. Five large-scale wind turbines are in operation, including three 640 kW single-bladed Monopteros machines, the three-bladed 1,2 MW WKA 60 on Heligoland and the advanced WKA 60 at Kaiser-Wilhelm-Koog, which was put into operation during the year. The 2 MW Aeolus II and the 750 kW HSW turbines are in advanced stages of construction and will be installed next year.

In *Italy*, the two state-owned organisations ENEA and ENEL together with Italian wind turbine manufacturers are engaged in a national wind energy programme aiming at 300 to 600 MW of wind power by the year 2000. Three machine prototypes have been developed: a medium-scale MEDIT (225 kW) and M30 (200 kW) in operation at the Alta Nurra test site in Sardinia, and the large-scale 1,5 MW GAMMA 60 to be installed at Alta Nurra in 1992. ENEL is constructing two 10 MW windfarms in Sardinia and the Apennines. Series fabrication of MEDIT 320 and M30 for the windfarms is going on. ENEA is promoting two feasibility studies of large windfarms. A first module of 1,5 MW was placed into operation at Bisaccia in 1991.

The national wind energy programme in *Japan* is part of the Sunshine Project. A windfarm of approximately 1MW rated power is being constructed in Miyako, Okinawa for completion in 1992. A 500 kW prototype wind turbine is being developed during 1991 -1995. These projects are implemented by NEDO. The programme also includes wind observation and resource assessment by NEDO, and basic research at the Mechanical Engineering Laboratory, Tsuruba.

In the *Netherlands*, around 80 MW of wind turbine capacity was installed by the end of the year and 10 MW were under construction. The national goal aims at 1000 MW installed by the year 2000 and 2000 MW by 2010. The electricity distribution companies plan to have 250 MW erected by 1995. The total wind power capacity by 1995 is estimated at 400 MW. The national wind energy programme, known as TWIN, for 1991-1995 includes subsidies for wind turbine investments and support of industrial development and technological research. The total costs are estimated at 42 MNLG, excluding subsidies. Over 80 % of the presently installed capacity consists of windfarms of 1 MW or more. A 750 kW prototype unit (Windmaster) was put into operation during the year at Halsteren. A 1 MW Nedwind 50 prototype is being designed for installation in 1993.

Norway has excellent wind conditions in coastal areas. The current wind energy programme aims at having 4 MW of wind power installed by 1992. The first windfarm of three 400 kW units was inaugurated in October at Vikna, north of Trondheim. In addition, two 400 kW turbines were installed during the year in the Vesterålen islands north and west of Narvik. At the present time, however, new hydro power stations generate electricity at about half the cost of wind power, on the average.

The current national renewable energy plan in *Spain* foresees about 100 MW of wind power installed by 1995. During 1991, the construction of three large windfarms was initiated: a 3 MW plant at Cabo Villano and the 20 MW PESUR and 10 MW E.E.E. windfarms in the Tarifa area near the Straits of Gibraltar. Another two windfarms are in the planning stage. At the 1,2 MW AWEC-60 wind turbine at Cabo Villano, a crack in the main spar of a blade was detected in May 1991. After repair the machine was back in operation in October.

Sweden has two large-scale wind turbines in operation, the 3 MW machine at Maglarp and a 750 kW unit at Risholmen. The Maglarp turbine, installed 1982, holds the world's record for energy production from a single unit: 27 740 MWh during 21 538 h on line (by November 1991). The 2 MW Näsudden wind turbine was dismantled during 1990 -

1991 to prepare for the installation of the Näsudden II machinery on top of the existing tower. A government-sponsored market stimulation programme through investment subsidy was introduced during the year. The largest installation so far is a windfarm of seven 225 kW units near Varberg on the Swedish west coast.

In the *United Kingdom,* modifications have been carried out on the 60 m, 3 MW wind turbine on Burgar Hill, Orkney. Total running time to end May when the machine was shut down was 3511 h with a cumulative output of 4336 MWh. The 750 kW turbine on Susetter Hill, Shetland has returned to service after repeated shutdowns for modification and repair. The 1 MW machine at Richborough, Kent is performing well. The 500 kW vertical-axis VAWT-850 at Carmarthen Bay, South Wales suffered a blade failure in February. Blade redesign is being undertaken. Prospects of commercial windfarm installation have been stimulated during the year by the government's commitment to the Non-Fossil Fuel Obligation. The proposed windfarms have met with delays due to difficulties in obtaining planning consent.

The world's largest horizontal-axis wind turbine in operation is the 98 m, 3,2 MW Mod 5B at Kahuku Point, Hawaii, *United States*. As of the end of September, the turbine had logged 19 253 operating hours and generated 25 344 MWh. During the spring the machine attained a one month capacity factor of 53 %. Fourteen of the 600 kW Westinghouse machines at Kahuku Point are back in operation following repair and modification.

Since 1981 approximately 1600 MW of windfarm capacity has been installed in California, totalling more than 15 000 units. The energy costs are now nearly one third those of ten years ago. There are promising signs for windfarm installation also in areas outside of California.

The U.S. federal wind technology program is increasing its emphasis on working closely with utilities and industry to apply new technology and to develop new markets. Three contracts to study advanced wind turbine conceptual design have been awarded. High potential components and subsystems will be developed and field tested. Applied research and testing is continuing at the National Renewable Energy Laboratory and the Sandia National Laboratories. The wind technology budget for fiscal year 1992 is 21,2 MUSD, increased from 11,1 MUSD the previous year.

The IEA R&D Wind Programme

1.1 The Implementing Agreement

Two IEA Agreements in wind energy were made in 1977:

- A Programme of Research and Development on Wind Energy Conversion Systems (the "R&D Agreement")
- Co-operation in the Development of Large-Scale Wind Energy Conversion Systems (the "LS Agreement")

Effective 1 January 1991, the two Agreements were merged. The title of the R&D Agreement was amended to read "Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems", or IEA R&D Wind for short. The text of the Agreement was amended to include the activities of the former LS Agreement.

At present, there are 16 Contracting Parties from 13 countries:

Austria	The Republic of Austria;
Canada	The Department of Energy, Mines and Resources;
Germany	Forschungszentrum Jülich GmbH;
Italy	Ente per le Nuove Tecnolgie, l'Energia e l'Ambiente (ENEA); Ente Nazionale per l'Energia Elettrica (ENEL);
Japan	The Government of Japan;
Netherlands	Stichting Energieonderzoek Nederland (ECN);
New Zealand	The Government of New Zealand;
Norway	The Directorate of Energy of the Norwegian Water Resources and Energy Administration;
Spain	Instituto de Energias Renovables (IER) of the Centro de Investigacion Energetica Medioambiental y Tecnologica (CIEMAT);

Sweden	The National Board for Industrial and Technical Development (NUTEK);
United Kingdom	UK Atomic Energy Authority; National Power plc; Scottish Hydro-Electric plc;
United States	The Department of Energy.

The general objectives of IEA R&D Wind are to undertake collaborative R&D projects, called Tasks, and to exchange information on the planning and execution of national large-scale wind systems.

The Tasks are defined in Annexes to the Implementing Agreement. To-date twelve Tasks have been initiated, as shown below. Seven Tasks have been successfully completed. Two Tasks (VIII and IX) are technically completed but the final report is pending.

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 Wind 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 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 Central Electricity Generating Board 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 X	Systems Interaction Never entered into force
Task XI	Base Technology Information Exchange Operating Agent: Department of Fluid Mechanics, Technical University of Denmark To be completed in 1993
Task XII	Universal Wind Turbine for Experiments (UNIWEX) Operating Agent: Institute for Computer Applications, University of Stuttgart, Germany To be completed in 1992
Task XIII	Co-operation in the Development of Large Wind Turbine Systems Operating Agent: National Renewable Energy Laboratory (USA) To be completed in 1993

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 ten manyears per Task. Tasks XII and XIII are mixed cost- and task-shared. the participation in current Tasks is shown in Table 1.1.

Table 1.1 Participation per country in current Tasks. OA indicates Operating Agent

Country	Task VIII	IX	XI	XII	XIII
Canada	x		x		x
Denmark	x	x	OA		x
Germany			x	OA	x
Italy	x		x		x
Netherlands	x	x	x	x	x
New Zealand	x				
Norway	x		x		x
Spain	x	x	x		x
Sweden	x	x	x	x	x
United Kingdom	OA	OA	x		x
United States	x	x	x		OA

1.2 Task VIII Decentralised applications for wind energy

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

- Define cost effective models and techniques suitable for obtaining wind and load data necessary for planning and specifying decentralised wind energy conversion installations;
- Apply and further develop models suitable for analysing the performance of wind-diesel systems.

Nine technical meetings were held during 1985 - 1989, involving about thirty 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 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 revised draft manuscript of the final report, called the *Wind-Diesel Guide Book,* was distributed to the Executive Committee members and Task participants in September 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. Wind-diesel options and their applicability
2. Matching the wind-diesel system to the community
3. Assessing the wind resource
4. Designing a system
5. Wind-diesel case studies
6. Modelling techniques
7. Installation and setting up wind-diesel systems
8. Assessing the economics

The Executive Committee has agreed to have the book published on the open market. A contract has been negotiated with Cambridge University Press, who intend to publish the book and distribute it on the open market.

The Executive Committee decided at its fall meeting to set up a Joint Action on Wind-Diesel Systems in Annex XI (see section 3.3) for continued communication among Task participants .

Participating organisations

Canada	Department of Energy, Mines and Resources
	Atmospheric Environment Service
Denmark	Risø National Laboratory
Netherlands	ECN Research Centre
New Zealand	NZ Meteorological Service
Norway	Norwegian Electric Power Research Institute
Spain	Instituto de Energias Renovables
Sweden	State Power Board
	Chalmers University of Technology
Switzerland	Federal Office of Energy
	Oekozentrum Langenbruck
	Alpha Real AG
United Kingdom	Rutherford Appleton Laboratory
	National Engineering Laboratory
United States	Department of Energy
	Solar Energy Research Institute
	University of Massachussetts
	Atlantic Orient Corporation

Operating Agent

United Kingdom National Engineering Laboratory

1.3 Task IX Intensified study of wind turbine wake effects

This Task was set up in 1985 as a flow-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 UK Central Electricity Generating Board, later National Power plc. The overall objective has been to improve the knowledge of aerodynamic interaction between wind turbines operating in a windfarm.

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, when data were exchanged and models compared. The experimental data and theoretical techniques were brought together in a benchmark exercise based around Näsudden (Sweden) for the evaluation of single wakes and Tændpipe (Denmark) for the evaluation of windfarm models.

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

To cope with the wide divesity of array configurations, the study has seen the development of more reliable wake models and the acquisition of a considerable quantity of experimental and analytical data. The principal conclusions are:

- Site- and machine-specific factorshave a very strong influence on array behaviour.
- Array energy losses are real and significant at spacings below 7 diameters, but less than predicted by earlier wind tunnel tests.
- Turbulence is enhanced in arrays, again less than earlier model studies indicated, but sufficient to cause measurable increases in fatigue damage rates.

It is recommended that further work be considered in the following areas:

- Defining initial conditions for wake models
- 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 large body of data which is building up from existing windfarms and the theoretical models now in existence would form a firm base upon which to build studies in these areas.

A proposal for extended wake effect studies has been submitted to the Executive Committe by one of the UK Contracting Parties. A draft Annex, entitled "Performance of Arrays Wind Turbines", focusing on operational data from full-scaled installations, has been prepared and is being considered for approval.

Participating organisations

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

Operating Agent

UK Central Electricity Generating Board, later National Power plc

1.4 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

As part of subtask B, Topical Experts Meetings are arranged as agreed by the participants, acting in the Executive Committee.

At its fall meeting, the Executive Committe decided to extend the duration of the Task by two years until 31 December 1993. An updated workplan was adopted.

Recommended practices for wind turbine testing and evaluation

The aim of this subtask is to propose recommendations for wind turbine testing to address the development of internationally agreed test procedures. So far, recommendations have been published in eight areas, see Table 1.3.1. The documents are available from selected representatives in the participating countries.

A Standing Committee (SC) is established to review the needs for revising existing recommendations or for preparing new recommendations. The SC takes the necessary steps for establishing ad hoc expert groups, as decided by the Executive Committee, for preparing proposals for revised or new recommendations.

At the suggestion of the SC, the Executive Committee agreed at its fall meeting to have revised editions prepared of Vol 2 Costing of Wind Turbine Systems, Vol 4 Acoustics, and Vol 8 Glossary of Terms. An expert group will be convened to evaluate anemometry issues in power performance testing (power curve).

Table 13.1 Documents in the series of Recommended Practices for Wind Turbine Testing and Evaluation

Vol	Title	1st Ed	2nd Ed	3rd Ed
1	Power Performance Testing	1982	1990	
2	Estimation of Cost of Energy from Wind Energy Conversion Systems	1983	In prep	
3	Fatigue Characteristics	1984	1989	
4	Acoustics. Measurement of Noise Emission from Wind Turbines	1984	1988	In prep
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 prep	

Joint actions

Joint Actions are set up by the Executive Committee in a specific research area of current interest, where a periodic exchange of information is deemed necessary. The Joint Actions take the form of workshops or symposia. Participation is by invitation from the national members of the Executive Committee. So far, four Joint Actions have been initiated:

- Aerodynamics of Wind Turbines
- Fatigue of Wind Turbine Blades
- Offshore Wind Systems
- Wind-Diesel Systems

In the Joint Action on Aerodynamics, the 5th Symposium was held on 3-4 December at the University of Stuttgart, Germany. Proceedings of the 4th Symposium, held in November 1990 at the ENEA Casaccia Centre, Rome, Italy, were published during the report period.

In the Joint Action on Fatigue, a workshop was held on 22-23 April at Risø, Denmark. As a specific result, a proposal for normalization of fatigue data for composites was prepared.

The 3rd workshop in the Joint Action on Offshore WECS took place 23-24 September in Copenhagen, Denmark, including a visit to the Vindeby offshore windfarm.

A Joint Action on Wind-Diesel Systems was established at the fall meeting of the Executive Committee. This Action will enable continued communication among the participants of the concluded Annex VIII.

Topical expert meetings

In the framework of this Annex XI, topical expert meetings are arranged once or twice a year, as decided by the Executive Committee. Attendance is by invitation through the national EC member, and the number of participants is limited to a few per country. Proceedings are published by the German Contracting Party, the KFA Jülich.

The 20th Topical Expert Meeting took place on 7-8 March at FFA, Stockholm, Sweden on Electrical Systems for Wind Turbines with Constant or Variable Speed. The 21st meeting was held on 7-8 October at Chalmers University of Technology, Gothenburg, Sweden on Wind Characteristics of Relevance for Wind Turbine Design. A complete list of the meetings held so far is shown in Table 1.3.2.

Participating organisations

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

Operating agent

Department of Fluid Mechanics of the Technical University of Denmark

Table 1.3.2 IEA Wind Energy Expert Meetings

No	Title	Date	Venue
1	Seminar on Structural Dynamics	12 Oct 78	Munich, Germany
2	Control of LS WECS and Adaptation 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, 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	8-19 Nov 81	Copenhagen
8	Safety Assurance and Quality Control of LS WECS during Assembly, Erection and Acceptance Testing	26-27 May 82	Stockholm
9	Structural Design Criteria for LS WECS	7-8 Mar 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
13	Economic Aspects of Wind Turbines	30-31 May 85	Petten, 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
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, USA
18	Noise Generating Mechanisms for Wind Turbines	27-28 Nov 89	Petten, Netherlands
19	Wind Turbine Control Systems - Strategy and Problems	3-4 May 1990	London, England
20	Wind Characteristics of Relevance for Wind Turbine Design	7-8 Mar 1991	Stockholm, Sweden
21	Electrical Systems for Wind Turbines with Constant or Variable Speed	7-8 Oct 1991	Gothenburg,Sweden

1.4 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 Figure 1.5.1. 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.

Seven organisations from three countries are participating:

Germany	Forschungszentrum Jülich GmbH (KFA); Institute for Computer Applications (ICA), University of Stuttgart;
Netherlands	Netherlands Energy Research Foundation (ECN); Delft University of Technologie (DUT); Stork Product Engineering (SPE);
Sweden	NUTEK (NE); Aeronautical Research Institute of Sweden (FFA)

Operating Agent: Institute for Computer Applications (ICA), University of Stuttgart

Participants met on the following occasions during the year:

- Four technical meetings (25 March, 16-17 July, 14 June on the testfield;14 June at Maastricht, the Netherlands)
- Two measurement campaigns (16-17 July, 13-15 on the testfield)
- 28th IEA R&D Wind Executive Committee meeting (21 October at Lyngby, Denmark)
- EWEC '91 (14-18 October in Amsterdam, the Netherlands)

Main Technical Activities

At ICA, Germany

A Experiments

- Investigation of different rotor types (compare Figure 1.5.2).

  Up to 65 channels were monitored with sampling rates up to 200 Hz. The following hub concepts were operated for a variety of control strategies within a wide range of values for parameters like wind speed, rpm, power output (c_p-values):

  - Rigid hub (different coning angles, rotor tilt, tower tilt)
  - Teetering hub (different teeter springs)
  - Individually flapping blades (different flap springs)
  - Individually lead-lagging blades
  - Combination of flap and lead-lag
  - Teetering hub with flap-pitch coupling
  - Individual flapping with flap-pitch coupling

- Recording of load spectra

  The blade flap bending moments are correlated with different coning, rotor and tower tilt angles for rigid, teetering and flapping hub configurations.

- Operation in upwind configuration has been started

- Different methods for evaluating short-time measurements for the set-up of c_p-lambda diagrams were investigated

- Runs with different generator behaviour ("generator stiffness")

- Runs with constant rpm by pitch control

  Several controllers were simulated via Direct Digital Control. For the promising ones, data were registered and are being evaluated.

- Runs with constant rpm or constant torque by generator control

- Runs with operation at optimum tip speed ratio (torque ~ rpm^2)

  Many measurements were carried out within the possible wind and rpm range (3,5 to 8,0 m/s; 30 to 80 rpm).

- Runs with active and passive yawing

  Active yawing was used to measure reactions under different yaw angles (- 60 to + 60 degrees). For passive yawing, yaw excursions could be observed and monitored for different hub configurations.

- Runs with power control by active yawing

  Power versus stationary yaw angle was measured for the rigid hub configuration in the range of - 60 to + 60 degrees. The reactions of the rigid and teetering hub configurations for several constant yaw rates were monitored and recorded.

- Investigations of some aerodynamic effects (runs with stall control)

B Verification of Numerical Simulation Codes

- Identification and adaptation of the model

  The whole model was re-idealised, taking into account hardware changes and correcting inaccuracies in the old model.

- Further extension of post-processing and evaluation software

- Simulation and comparison with experiments

  Simulations with the program ARLIS (Aeroelastic analysis of Rotating LInear Systems) were performed for one rigid, two teetering and one flapping hub concept, with realistic stiffness and damping parameters and in an rpm and wind speed range also covered by experiments. Numerical and experimental results have been compared, showing tolerable discrepancies (compare Figure 1.5.3)

- Simulation and evaluation

  Part of the "critical" hub configurations and rpm regions was already simulated.

At ECN, the Netherlands

The Dutch participation in the UNIWEX programme considers the following tasks:

1) Experimental study of system dynamic behaviour for different rotor and drive train concepts

2) Validation of computer programs used for the design of wind turbines or components

3) Design of controllers and experimental validation of their behaviour.

A number of experiments have been requested to be used for the different tasks, the major part of which has been executed and is being analysed.

Particularly for 1) and 2), measurements were made with a teetering hub and with individually free flapping blades under stall conditions, up to almost standstill, to explore the stability limits of teetering and flapping motion. Also, measurements with lead-lag flexibility were performed This type of measurements is not available in the literature.

With regard to 2), the effect of reduced aerodynamic damping on flap loads is measured and will be compared with calculational results. Information on wake-induced inflow dynamics will be obtained from executed measurements with pitching transients. Finally, yaw dynamics and power control can be studied from a number of measurements with yaw misalignment, and active yawing with different yawing speeds. Most measurements were done both with constant rpm control and with constant torque control, so that the important question of speed control benefits can also be studied.

As regards 3), an "experimental model" of the UNIWEX (in the form of transfer functions) was estimated from special measurements with random excitation signals on the pitch setting or torque control throttle valve. Based on this, some aspects of the DUWECS response programs were validated and a number of pitch controllers was designed and experimentally evaluated. Some of this work was reported in [8] and [12].

In conclusion it can be stated that the UNIWEX is presently delivering experimental results of high interest, the analysis of which will take the Dutch participants well into 1992.

At FFA, Sweden

The modified UNIWEX turbine was modelled and simulations were made with the aeroelastic program GAROS. Evaluation and comparison with ARLIS results are underway.

Publications in 1991

1 K A Braun, M Müller, H Snel, M Söderberg; *Status Report on UNIWEX*, presented at the 27th IEA R&D Wind EC Meeting, Trondheim, Norway , 16 April 1991

2 B Dressler; *Einfluss verschiedener Abwindmodelle auf die Ergebnisse der aeroelastischen Untersuchung einer Windturbine mit horizontaler Axis*, Studienarbeit, Universität Stuttgart, 1991

3 M Drescher; *Aeroelastische Analyse einer Einblatt-Windturbine und Vergleich mit entsprechenden Zwei- und Dreiblatt-Anlagen*, Diplomarbeit, Universität Stuttgart, 1991

4 H P Klatt; *Installation, Erweiterung und Austesten des Programmsystems ATACYT zur Schalen-Balken Konversion*, Studienarbeit, Universität Stuttgart, 1991

5 H P Klatt; *Computerunterstützte Auslegung der Struktur eines Windturbinen-Rotorblattes*, Diplomarbeit, Universität Stuttgart, 1991

6 H Arnold, H Schwartz; *Beschreibung der Programme zur Auswertung und Darstellung der Messdaten im Projekt UNIWEX*, Interner Bericht, Universität Stuttgart, 1991

7 K A Braun, A Finkel; *Compilation of Data for the the UNIWEX Wind Turbine*, Stuttgart, July 1991

8 H Arnold, G van Baars, P M M Bongers, M Müller, H Schwartz; *Experiments and Validation of Dynamic Models Linked with UNIWEX - First Results*, EWEC '91, Amsterdam, the Netherlands, 14-18 October 1991

9 K A Braun, A Finkel, A Hopf, M Söderberg; *Two Computer Codes for Aeroelastic Analysis of HAWT's, Comparison with Experiments*, EWEC '91, Amsterdam, the Netherlands, 14-18 October 1991

10 H Arnold, K A Braun, A Finkel, A Hopf, M Müller, H Schwartz; *Status Report on UNIWEX*, presented at 28th IEA R&D Wind EC Meeting, Lyngby, Denmark, 21 October 1991

11 J Argyris, K A Braun, A Hopf; *Dynamische Analyse der Rotorgondel der UNIWEX-Versuchswindturbine mit Hilfe der Methode der finiten Elemente (ASKA)*, ICA-Bericht Nr 31, Universität Stuttgart, 1991

12 G van Baars; *Experimental Validation of the UNIWEX Wind Turbine*, Delft University of Technology, 1991

Figure 1.5.1 The Universal Test Wind Turbine UNIWEX at the Ulrich Hütter Wind Test Field near Schnittlingen, Germany

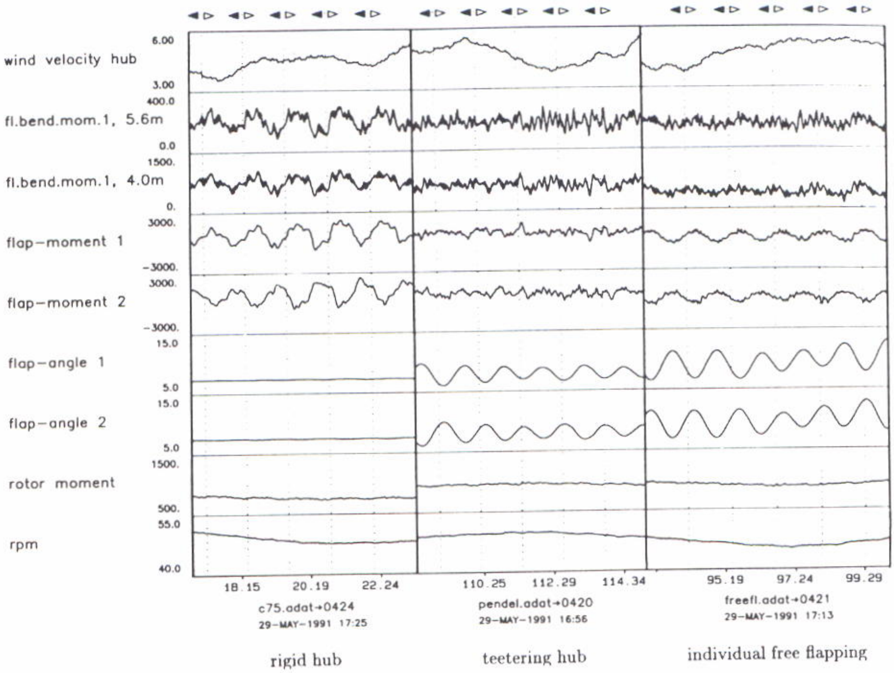

Figure 1.5.2 Simulation of hub concepts

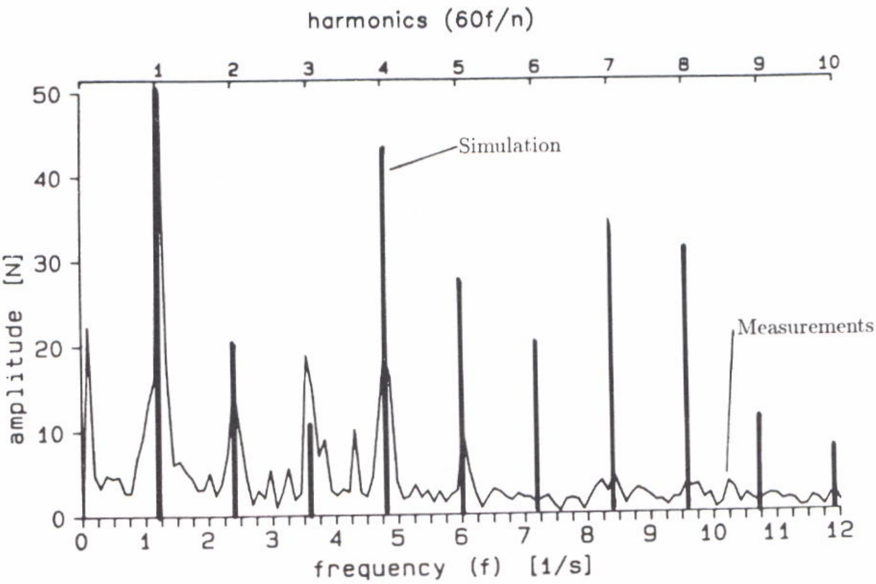

Figure 1.5.3 Comparison of simulation results with measurements. FFT of the flap bending moment at $r = 5{,}6$ m, rigid hub ($\Omega = 7{,}4$ rad)

1.6 Task XIII Cooperation in the development of large-scale wind systems

The Annex governing this Task was formed following the merger of the two IEA wind energy agreements: IEA R&D WECS and IEA LS WECS. The calendar year 1991 is the first of the designated three year duration of the Annex.

The function of the Task is to provide a basis for the free exchange of information on planning and execution of national programmes for large wind turbine systems. For the purpose of this Task, a Large Wind Turbine System (LWTS) is either a single wind machine of approximately one megawatt rating or a group of machines which act together to supply at least one megawatt.

The workplan prepared by the Operating Agent was circulated to the participants prior to the IEA R&D Wind Executive Committee meeting in Trondheim, Norway. It was reviewed and approved by the EC following some minor changes.

In order to expedite the flow of information to and from the Annex, the Annex member from each participating country designates one or more persons known as Contact Persons (CP). These persons are usually closely associated with an electric utility or some aspect of wind energy in their respective countries. Contact Persons in consultation with their Annex XIII Member contribute LWTS information and accident/incident reports as appropriate to the Operating Agent. In exchange they receive the Annex compiled information.

To facilitate the implementation of the Task, an information system will be established and maintained. It will contain specification of all large prototype and many commercial wind machines. The system will receive, circulate to participants, and archive accident/incident reports. Also to be archived and reported by the Operating Agent are total national installed wind power capacity, annual national wind energy generated, and national government plans in support of LWTS. The material which has been submitted so far is being entered into the information system.

A graphical representation of the function of the Operating Agent, as it is presently understood, is shown in Figure 1.6.1.

On 23 and 24 September 1991, a workshop for Annex members and their designated contact persons was held near Tehachapi, California. Contact persons or Annex members or both were present from Canada, Denmark, Italy, the Netherlands, Norway, Sweden, United Kingdom and United States.

At the meeting it was agreed that the Operating Agent should simplify some of the categories of the LWTS data that will be archived, and should further refine the definitions of some technical terms and the duties of some of the participants. These changes are to be circulated before the next EC meeting.

The workshop was held in conjunction with a meeting of the U.S. Utility Wind Interest Group (UWIG). The UWIG was formed by the U.S. DOE and the Electric Power Research Institute (EPRI) for the purpose of furthering the development and integration of wind energy by electric utilities. It is a group made of representatives from twelve U.S. electric utilities which either are now using wind generated energy, or are actively exploring the possibilities for wind. Also included are representatives from EPRI and DOE and their consultants.

By holding these meetings at the same location, the informal exchange of information and views by the members of both groups was facilitated.

The region adjacent to Tehachapi is the site of one of the three major windfarm districts in California. One of the local windfarm developers, the Zond Corporation, hosted both the IEA and the UWIG groups on a tour of the new "Wind River" extension of their facility. This installation includes 340 turbines for a total power of 77 MW.

An abbreviated summary of design and performance data for wind turbines larger than 500 kW as of October 1991 is shown in Figure 1.6.2.

Participating organisations

Canada	Department of Energy, Mines and Resources
Denmark	Ministry of Energy
Germany	Forschungszentrum Jülich GmbH
Italy	Ente Nazionale per l'Energia Elettrica (ENEL)
Netherlands	Stichting Energieonderzoek Nederland (ENC)
Norway	Directorate of Energy
Spain	Instituto de Energias Renovables
Sweden	National Board for Industrial and Technical Development (NUTEK)
United Kingdom	Scottish Hydro-Electric plc
United States	Department of Energy

Operating agent

The United States National Renewable Energy Laboratories (NREL) in Golden, Colorado.

IEA Large Scale Wind Systems Annex XIII

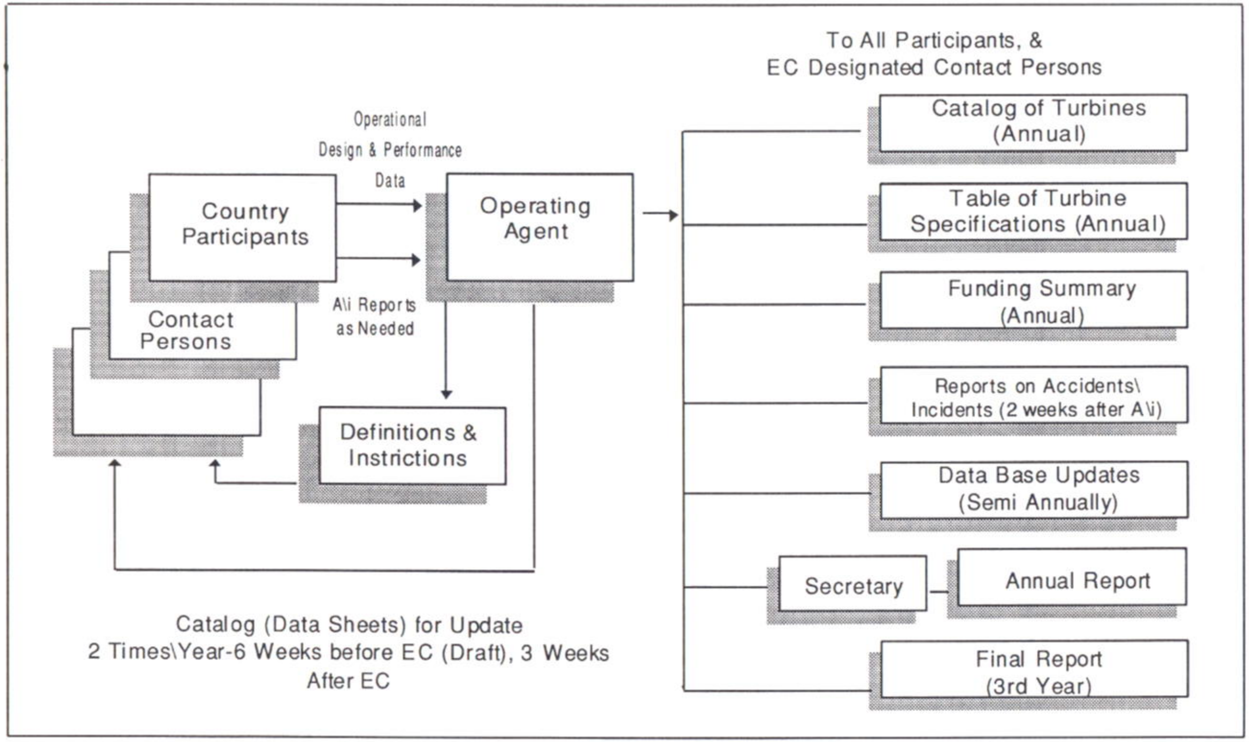

Figure 1.6.1 IEA R&D Wind Annex XIII logistics

WIND ENERGY CONVERSION SYSTEMS LARGER THAN 500kW

COUNTRY	MACHINE		SPECIFICATIONS												
MEMBERS	MANUFACTURER	MODEL	AXIS (HOR. OR VERT)	# OF BLADES	UP OR DOWN WIND	ROTOR MATER-IAL	ROTOR DIA. (m)	HUB HT. (m)	SWEPT AREA (m2)	RATED WIND SPEED (m/s)	RATED POWER (kW)	GEN TYPE	WEIGHT TOP OF TOWER (thousands of kg)	TOWER (thousands of kg)
BELGIUM	WINDMASTER-VUB		H	2	U	GRP	46.0	63.0	1662	16.0	1000	I		
CANADA	SHAWINGAN	EOLE	V	2		S	64.0	56.0	4000	23.0	4000	A	344.0	(Rotor)
CANADA	INDAL TECHNOL	6400	V	2		A	24.4	21.3	595	18.2	522	I	20.2	(Rotor)
DENMARK	SEVERAL	NIBE-A	H	3	U	WOOD	40.0	45.0	1256	13.0	630	I	80.0	47.0
DENMARK	SEVERAL	NIBE-B	H	3	U	WOOD	40.0	45.0	1256	13.0	630	I	80.0	47.0
DENMARK	DWT	WINDANE 40	H	3	U	GRP/W	40.0	45.0	1257	15.0	750	I	60.5	47.0
DENMARK	DWT (BLADES)	2MW	H	3	U	GRP	60.0	60.0	2827	15.0	2000	I	156.0	500.0
W. GERMANY	M.A.N.	WKA 60	H	3	U	GRP	60.0	50.0	2827	12.2	1200	S		470.0
W. GERMANY	MBB	MONOPT. 50	H	1	U	CRP	50.0	60.0	1963	11.0	640	S		
W. GERMANY	MBB	MONOPT. 50	H	1	U	CRP	50.0	60.0	1963	11.0	640	S		
W. GERMANY	M.A.N.	WKA 60 LAND	H	3	U	GRP	60.0	60.0	2827	17.2	1400	S		
W. GERMANY	MBB	AEOLUS II	H	2	U	CRP	80.0	77.0	5027		3000			
W. GERMANY	DORNIER/LAV.	EOLE-D	V	2			64.0	56.0	4000	23.0	2000			
W. GERMANY		HSW 750	H	3	U	GRP/W	40.0	45.0	1257	14.0	750	A	20.0	47.0
ITALY	AERITALIA	GAMMA 60	H	2	U	GRP	66.0	60.0	2827	13.5	1500	A	95.0	145.0
NETHERLANDS	STORK-FDO	NEWECS-45	H	2	U	GRP	45.0	60.0	1590	13.9	1000	A	31.7	59.0
NETHERLANDS	WINDMASTER NL	500	H	2	U	GRP	33.0		856		500	I		
NETHERLANDS	NEWINCO	NEWINCO 500	H	2	U	S	34.0		908		500	I		
SPAIN	ASINEL, M.A.N.	AWEC 60	H	3	U	GRP	60.0	46.0	2827	12.2	1200	I	186.0	92.0
SWEDEN	KMW AB	WTS-75	H	2	U	S/GRP	75.0	77.0	4418	12.5	2000	I	205.0	1500.0
SWEDEN	KKRV	WTS-3	H	2	D	GRP	78.0	80.0	4778	14.0	3000	S	191.0	281.0
SWEDEN	HOWDEN	750 kW	H	3	U	WE	45.0	35.0	1590		750	S		
SWEDEN	KVAERNER-MBB	NASUDDEN II	H	2	U	CRP	80.0	77.0	5027		3000	S		1500.0
U.K.	WEG	LS-1	H	2	U	S/GRP	60.0	45.0	2827	17.0	3000	S	197.0	654.0
U.K.	WEG	LS-2	H	2										
U.K.	HOWDEN	750 kW	H	3	U	WE	45.0	35.0	1590		750	S		
U.K.	HOWDEN	1MW	H	3	U	WE	55.0	45.0	2376		1000			
U.K.	VAWT LTD	500kW	V	2		GRP					500	I		
USA	BOEING	MOD-5B	H	2	U	S	99.0	61.0	7698	20.5	3200	C	265.3	160.5
USA	HAM. STANDARD	WTS-4	H	2	D	GRP	78.0	80.4	4778	15.0	4000	S	198.2	192.8
USA	WESTINGHOUSE	WWG 0600	H	2	U	WE	43.0	31.0	1452	13.0	600	S	36.2	34.8

Key:

Development Stage	Rotor Material		Generator Type
P/# = Prototype/number of machines	S = Steel	GRP = Glass Fiber Reinforced Plastic	S = Synchronous
C/# = Commercial/number of machines	A = Aluminum	CRP = Carbon Fiber Reinforced Plastic	I = Induction
Source	WE = Wood Epoxy		A = AC/DC/AC
MFG = Manufacturer			C = Cycloconverter

Figure 1.6.2 Design and performance data for wind turbines larger than 500 kW

WIND ENERGY CONVERSION SYSTEMS LARGER THAN 500kW

EST. ANNUAL ENERGY PRODUCTION					PERFORMANCE				
100% Availability, No Losses Average Wind Speeds Measured at 10m									
5.0 m/s	6.5m/s	8.0 m/s	DATE OF INITIAL OPERAT.	DEVEL-OPMENT STAGE	TOTAL RUN HOURS	TOTAL ENERGY PRODUCED (MWh)	COMMENTS	INFO UPDATE	INFO SOURCE
				P/					
3990	7105	9230	7/87	P/1	10395	6730	Automatic Var. Speed Mode	11/90	EMR
297	602	1064	5/87	C/2	5873	557	Testing New Rotor & Ctrls.	7/90	EMR
			9/79	P/1	6146	1313	Refurbishment & New Blades	9/90	DEFU
	1300	14597	8/80	P/1	23178	6384		9/89	DEFU
947	1861	2693	11/86	C/5	13194	Avg. 3485	1 Unit Damaged by Fire	9/90	DEFU
	4500		12/87	P/1	1880	1180	Unattended Operation	12/90	DEFU
		2400	Fall '89	C/1	1800	950		10/90	IEA
		2000	Fall '89	C/3				10/89	IEA
			'92/'93	C/1				1/89	MFG.
			Spring '91	C/1				1/89	MFG.
			Fall '91	C/1				1/89	MFG.
			'92	C/1				1/89	MFG.
			'91					10/89	IEA
	4300		7/92	P/3			First of 3 Units	9/91	IEA
		2300	6/86	P/1			3/87 – 8/88 Out of Op.(Blade)	10/89	IEA
			5/89	C/1				10/89	IEA
			11/89	C/1				10/89	IEA
			11/89	P/1	745	487		4/91	IEA
4082	6989	8821	2/83	P/1	11350	12600		10/89	IEA
4883	8703	11158	7/82	P/1	19435	25216		10/89	IEA
				C/1	500			10/89	IEA
			11/91					10/89	IEA
1695	4319	7371	10/87	P/1	3012	3800		4/91	NSHEB
				P/			Detailed Design Stage	10/87	IEA
			6/88	P/1	1609	766		4/91	NSHEB
			2/90	P/	2150	798		4/91	
				P/					
6112	10623	14128	7/87	P/1	18228	24040		7/91	HERS
4954	9949	14221	1/82	P/1	4100	8000		8/87	MFG.
935	1766	2447	12/85	C/15	13980	Avg. 3237	Blade mode complete 7/91	2/91	HERS

Source: International Energy Agency
Wind Energy R&D Agreement
Large Scale Wind Systems, Annex XIII
October, 1991

National activities

2.1 Canada

Introduction

The annual wind energy R&D budget is around CAD 700 000. The effective budget is increased with co-funding from the recipient or other institutions. A few basic research projects are fully funded.

The study "Canadian Wind Energy Technical and Market Potential" sponsored by the Department of Energy, Mines and Resources (EMR) is nearing completion.

EMR continues to support two test facilities, the Alberta Renewable Energy Test Site (ARETS) in Alberta and the Atlantic Wind Test Site (AWTS) in Prince Edward Island. These facilities are also co-funded by their respective provincial governments. The ARETS, which tests wind and photovoltaics water pumping systems, is in the process of being moved fom Lethbridge to Pincher Creek. The AWTS concentrates on testing mainly electricity generating wind turbines, wind/diesel test bed and resource assessment of two sites to find a suitable windfarm site.

Adecon Energy Systems are testing SL-38, a 150 kW VAWT, near Toronto and are also assembling a 300 kW VAWT. Adecon is going to install ten of the SL-38 machines in their Pincher Creek, Alberta, windfarm (see below).

Lavalin Inc has completed the design of a 250 - 300 kW VAWT. The manufacture of this design is uncertain due to the reorganisation of Lavalin.

Next year IREQ, Hydro Quebec, is planning to set up a high-penetration wind/diesel demonstration at AWTS. The system would consist of four wind turbines (30 to 80 kW range) and two 50 kW diesel generators with appropriate dump loads.

Five machines that will make the first phase of the two Alberta windfarms (9 and 1,2 MW) are being installed.

The utility of the province of Saskatchewan has invited proposals for a 10 MW windfarm.

Project AQUILO

The 500 kW VAWT, manufactured by Indal Technologies Inc of Mississauga, Ontario, is continuing its testing at AWTS after repairing the bottom bearing, which took a few months.

Project EOLE

The 4 MW VAWT, called EOLE, was installed at Cap Chat, Quebec, in January 1987. The machine has been running in automatic mode since its commissioning in March 1988. Currently the machine is being operated up to a maximum of 13,5 rpm and a cut-out wind speed of 17 m/s. The corresponding maximum output is about 2,4 MW.

The rotor was inspected during August 1990. The most critical joints, the blade/strut joints, were inspected for cracks and tightness of bolts. No cracks were detected and all the bolts were found to be properly torqued.

However, a crack in rotor blade was discovered on 1 May 1991. In the days preceding the discovery, an unfamiliar noise warned the operator until the crack became visible.

The crack occurred on the second blade section below the lower strut, a location which was not expected to be too highly stressed. A local defect could be the source of the crack. The crack was cleaned up to stop the propagation, and double steel plates (16 mm thick, 440 mm wide) were bolted around the cracked blade section, on the inner and outer surfaces and the leading and trailing edge webs. The turbine was back in operation on 21 June. So far the repair seems to be working.

The performance summary for EOLE up to 10 September is as follows:

		31 March 1991	10 Sept 1991
Total electricity generated	kWh	8 029 707	8 582 707
Generating hours	h	12 087	13 027
No. of starts/stops		4399	4737
Availablity	%	96,28	93,73

The monthly energy production is given in table 2.1.1

Table 2.1.1 EOLE Net Energy Production (kWh)

Month	1988-89	1989-90	1990-91	1991-92
July	71 540	80 000	172 500	155 400
August	100 520	122 230	2 300[1)]	211 714
September	247 520	193 200	174 200	
October	161 560	276 500	157 700	
November	361 130	225 540	220 100	
December	334 670	422 660	326 100	
January	266 280	245 000	326 100	
February	282 660	278 300	302 300	
March	264 390	312 700	175 400	
April	152 180	197 000	154 400	
May	85 330	153 300	5 400[2)]	
June	56 770	120 900	38 800[2)]	

Total net production: 8 071 774 kWh [3)]

1) inspection of turbine
2) blade crack repair
3) including 618 380 kWh from 11 September 1987 to July 1988

Windfarms

30-Turbine windfarm in Alberta

On 1 February 1991, the Alberta Office of Renewable Energy Technology announced the project of a 30-turbine windfarm to be located at Cowley Ridge, southwest Alberta. The windfarm will consist of ten U.S. Windpower turbines of 100 kW, 16 m rotor diameter, variable pitch, downwind, and twenty of 400 kW, 33 m diameter, variable speed/pitch, upwind. It will be capable of generating 9 MW of electricity, which will be sold to TransAlta Utilities Corporation at about 5 cents/kWh.

The wind farm is expected to cost 11,4 MCAD over three years and will be financed entirely by U.S. Windpower. Construction, operation and maintenance of the windfarm will be performed by Wind Power Inc, an Alberta company.

The siting has been approved and construction began in October. Nine 100 kW turbines will be installed before the end of the year.

10-Turbine Windfarm in Alberta

On 31 March 1991, the energy minister of Alberta announced another windfarm project, a 10-turbine windfarm to be built near Pincher Creek in southwest Alberta. The windfarm will be capable of generating 1,5 MW of electricity, which will be sold to TransAlta utilities at about 5 cents/kWh. The 150 kW vertical-axis turbines will be supplied by Adecon Energy Systems, which will establish a subsidiary in Alberta to construct, service, and operate the windfarm.

The project cost is estimated at 2 MCAD of which up to 600 000 CAD will be provided by Southwest Alberta Renewable Energy Initiative. The siting has been approved and construction has started. Two turbines will be erected before the end of the year and the others will be installed next spring.

10 MW Windfarm in Saskatchewan

SaskPower, the utility of the province of Saskatchewan, has initiated proposals for a 10 MW windfarm.

20 m laminated wooden blades. Since then, the machine has operated satisfactorily.

It is intended to prolong the the lifetime of both turbines by 7 to 10 years in order to test their operation with the wood technology. The average wind speed at the site is 7,1 m/s at hub height (45 m). Assuming 100 % availability, the annual energy production will be about 1300 MWh per turbine.

The Masnedø windfarm

ELKRAFT Power Co Ltd, the regional utility of Zealand, operates a windfarm comprising five units of WINDANE 40, manufactured by Danish Wind Technology Ltd. The site is on Masnedø, a small island close to the southern coast of Zealand. The main specifications for these machines are similar to those for Nibe B.

As of 31 December 1991, the operating statistics were as follows:

Turbine:	MAV 81	MAV 83	MAV 84	MAV 85
Running time, hrs	16 677	17 160	18 037	17 968
Energy output, MWh	4316	3682	4762	5436
Average power, kW	259	215	264	303

The five turbines were installed in late 1986. Commissioning progressed well until October 1987 when a fire completely destroyed one of the turbines (MAV 82). It has now been rebuilt and placed back into operation. The design of the new wind turbine is in many ways an improvement over the previous one. This means among other things that the machine is more cost effective.

Most of the turbines have had gearbox failures. As a result they have all been modified. As a safety precaution, the maximum power output of all turbines is temporarily limited to 450 kW, until the power control system is able to prevent excessive power peaks caused by wind gusts.

Surface cracks have been observed in a number of turbine blades. Until recently, provisional repairs were made, either at the site or in the workshop. Two turbines are now equipped with new wooden blades, and the remaining three turbines are provided with new fibreglass blades.

The Tjæreborg wind turbine

In 1988, ELSAM, the regional utility of Jutland and Funen, commissioned a 2 MW wind turbine at Tjæreborg south of Esbjerg on the west coast of Jutland. This machine has a 60 m upwind rotor with three pitch-controlled cantilevered fibreglass blades and a 1: 68 epicyclic gearbox. The generator is of the induction type. The 60 m tower is made of concrete.

As of 31 December 1991, the machine had operated for 6779 hours and produced 4444 MWh of electricity.

In August 1989, one year after the turbine was commissioned, its gearbox failed by fracture of the main gear wheel. The damaged parts were quickly replaced by the manufacturer, but then high temperature was found at the two bearings of the output shaft. This has further reduced the number of operational hours, but the installation of an improved bearing with better lubrication and cooling has now solved the problem. Recently, a 1P sound from the first main bearing was observed. This is caused by friction between the bearing and the main shaft, but until further notice, the machine will run in normal unattended operation.

The Avedøre wind turbine

ELKRAFT is designing a 50 m/1 MW wind turbine with blades that can be used in both pitch and stall control. The machine is scheduled to be installed in March 1993 at the Avedøre power station 10 km south of Copenhagen.

Small-scale wind turbines

Data accumulated over the past five years for both private and utility-owned turbines are shown in Figure 2.2.1.

By the end of 1990, the total number of grid-connected small-scale wind machines was 2881 units. The total electric capacity was 343 MW and the annual power production was 604 GWh, which corresponds to 2 % of the Danish electricity consumption. The corresponding numbers at 1 October 1991 are: 3113 units, 385 MW and 520 GWh (nine months period).

The latest development trend shows that the traditional Danish design concept is unchanged. Stall regulation is still the most common means of power limitation, although pitch control is gaining ground.

Generally, two types of towers are used: steel lattice towers or tubular towers; in both cases they are 30 to 35 m high.

The power range is rapidly expanding. In 1991, machines with ratings of 400 to 450 kW have been sold by the manufacturers. This will soon also apply to 500 kW machines, for which prototype testing is underway.

Utility windfarms

In 1985, an agreement was reached between the Danish government and the utilities, committing them to install 100 MW in windfarms over the next five years. There has been a delay, however, caused by difficulties in getting planning permissions. At mid-91, a total of about 85 MW had been installed, and the agreement will be fully implemented by the end of 1992.

Table 2.2.1 shows the experience and economy of Danish utility windfarms, illustrated by data from the first eight windfarms in the ELSAM area on Jutland covering the period 1988-1990. The reported O&M costs are based on experience.

The average cost of energy for these windfarms is 0,0563 ECU per kWh assuming 20 years lifetime and a real interest rate of 5 %. With an interest rate of 7 %, the average cost of energy would be 0,0648 ECU/kWh. Detailed studies show that from 1987 to 1990, the cost of wind-generated energy decreased by about 25 %.

Table 2.2.2 shows a cost break-down for the above-mentioned eight ELSAM windfarms. Data from windfarms and clusters of wind turbines in the ELKRAFT area would show a similar result.

Offshore windfarm

The first Danish offshore windfarm was commissioned in mid-1991. The site is in the ELKRAFT area at Vindeby, northwest of Lolland in the Baltic sea. The windfarm consists of 11 wind turbines in two rows. The water depth varies between 2 and 6 m. The distance from the shoreline ranges from 1200 to 2400 m, and the distance between the turbines is approximately 300 m. Each turbine is rated at 450 kW, and the hub height and rotor diameter are 37,5 and 35 m. Figure 2.2.2 shows the transportation of the concrete foundations to the site at sea, and Figure 2.2.3 shows the completed windfarm.

Vindeby is a pilot project motivated by the increasing difficulty of getting acceptance of onshore windfarm siting. Although the specific energy output is expected to be about 60 % higher than for average onshore sites, or about 1130 compared to 700 kWh per m^2 of swept rotor area, the cost of energy produced by this windfarm (0,08 ECU/kWh) is estimated to be 50 % higher than for average inland sites. It is anticipated, however, that this figure would be lowered by using larger turbines on the same foundations, as the design criterion for these has been ice load. The total costs of the project, including a two-year measurement programme, were 10,5 MECU.

Table 2.2.1 ELSAM-Area: Experience and Economy for Eight Windfarms

Total installed capacity	MW	42,7
Number of units		240
Swept area per kW	m^2	2,5
Average unit size	kW	178
Total investment per kW	ECU	1028
Total investment per m^2	ECU	410
Annual output per kW	kWh	2005
Capacity factor	%	22,8
O&M costs per kWh	ECU	0.0085
Depreciation period	years	20
Capital costs per kWh, 5 % per year	ECU	0,0478
Capital costs per kWh, 7 % per year	ECU	0,0562
Cost of energy, incl O&M, at 5 %/yr	ECU/kWh	0,0563
Cost of energy, incl O%M, at 7 %/yr	ECU/kWh	0,0648

Table 2.2.2 ELSAM Area: Cost Break-Down for Eight Windfarms

(Costs in thousands)	kECU	%
Project management	1783	4,1
Wind turbines	29757	67,8
Foundations	3763	8,6
Local el. installations	3451	7,9
Grid connection	2386	5,4
Control centres	337	0,8
Roads	922	2,1
Land costs	1198	2,7
Miscellaneous	289	0,6
Total costs, incl site costs	43886	100,0

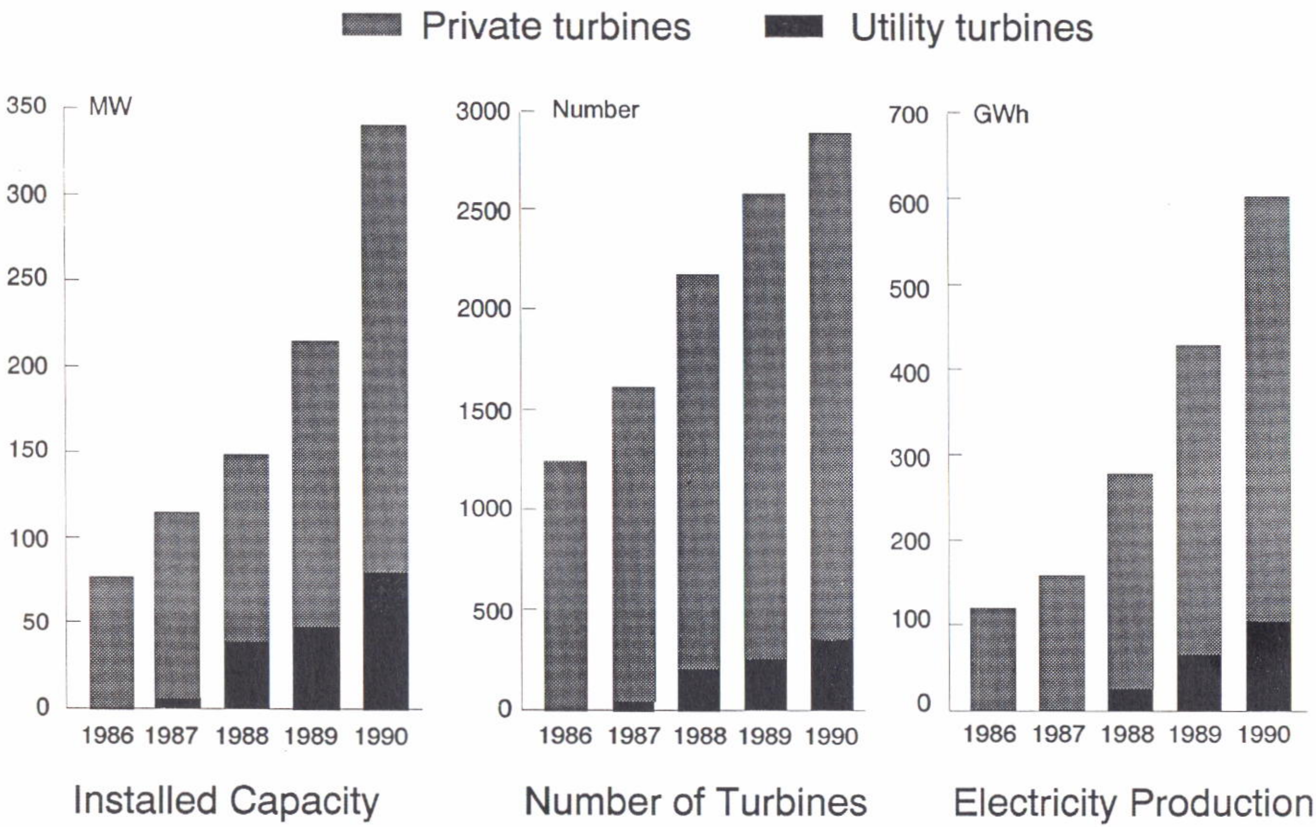

Figure 2.2.1 Accumulated data for wind turbines in Denmark

Figure 2.2.2 Concrete foundation for an offshore windfarm

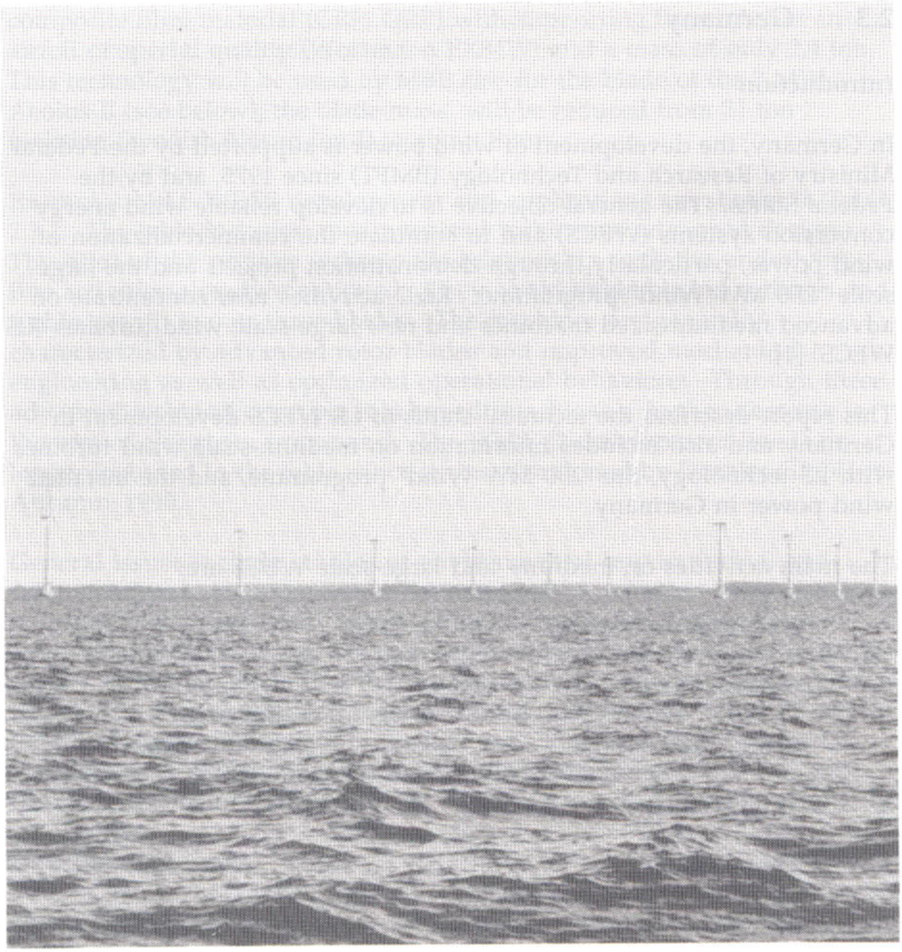

Figure 2.2.3 Offshore windfarm at Vindeby

2.3 Germany

Introduction

In Germany, the development of wind power is supported by the Federal Ministry of Research and Technology (BMFT) since 1975, and by the Federal States. The general objective is to develop reliable wind energy conversion systems (WECS) and to stimulate the commercialization of wind power, particularly through demonstration projects and the large scale "250 MW Wind" programme. R&D activities now concentrate on advanced medium-sized machines and new large-scale wind turbines (LS WECS) [1].

This report describes the technical status of LS WECS development in Germany and also includes information on medium-scale wind turbines with LS technology, the "250 MW Wind" programme, and the installed wind power in Germany.

The main activities on medium- and large-scale WECS are:

- Wind measurements
- Technical R&D
- Turbine development
- Applications
- General issues

As turbulence and other variations in the wind inflow are the principal source of fatigue loads and resulting stresses for a wind turbine of any size, detailed knowledge of the wind as the source of energy is necessary. Wind measurements with meteorological towers corresponding to the height of the top of the rotating blade (130 m for AEOLUS II, see below) and numerical modelling have been carried out and are continuing.

Technical R&D covers the aerodynamics of the rotor blades, structural dynamics, advanced components, and optimized systems. For example, the UNIWEX project at the University of Stuttgart aims at investigating improved design strategies in order to reduce investments and improve technical reliability. The decisive parameters such as rotor stressing, smoothness of operation, and aeroelastic stability are being investigated both experimentally and numerically. This project is a cooperative task in the IEA R&D Wind progamme (see section 3.5). The results of this kind of research influence turbine development. For example, the 28 m blade for the 640 kW Monopteros 50 wind turbine by MBB is made of composite fibre material (CRP, GRP) with supporting foam. It has an airfoil of special quality (Wortmann FX84W) and a mass of only 2,4 ton. This technology will be used by MBB also for the blade of the 3 MW Aeolus II (see below); the blade mass will be reduced from 21 ton (existing Swedish Näsudden I) to about 8 ton.

Examples of LS WECS development and applications are shown in Table 2.3.1. The table includes medium-sized turbines of advanced design. The titles of the projects indicate the relationship with the underlying five activities already mentioned. They cover single-bladed turbines and turbines with two or three blades. The machines are generally characterized by advanced rotor blades and improved mechanical engineering as well as optimized operational behaviour. Through these advanced technical concepts it is hoped to achieve a further decrease in the cost of electricity from wind. The EOLE-D development line is no longer included in the table, since it was abandoned by Dornier GmbH in Autumn 1990.

General issues include studies of environmental impact (noise) and safety, and technical support for the approval of turbines. They also cover investigations of the wind energy potential in the FRG, recently re-considered with respect to the new Federal States in Eastern Germany [2]. A new wind map, including Eastern Germany, is shown in Figure 2.3.1. Also worth mentioning is the project "Study of Offshore Wind Energy in the European Community", funded by the CEC, the BMFT and the UK Department of Energy and carried out by Germanischer Lloyd AG and Garrad Hassan and Partners Ltd.

Development lines

Monopteros

As shown in Table 2.3.1, this development line started already in the late seventies. The aim was an advanced concept of a single-bladed wind turbine with a counterbalance as proposed by F X Wortmann. A development up to 1 MW turbine size was only being pursued in Germany. A successful experimental unit, Monopteros 400 near Bremerhaven, see Table 2.3.2, with a rated power of 400 kW, formed the basis of the projects "Adaptation of the Development of Monopteros 50" and for the "Jade Windpark: 3 Monopteros 50". The new 640 kW Monopteros 50 has a soft tower and a generator system with a speed range. A steel shell tower with no guys allows a wide operational flap angle from minus nine to plus twenty degrees for the downwind rotor. The three Monopteros 50 were completed in 1989, see Figure 2.3.2. First operational results have been published [3].

Wind measurements at the Jade Windpark with a 130 m mast shall support the measuring programmes for the Monopteros turbines and the Aeolus II, see also No 3 in Table 2.3.2.

WKA 60

The WKA 60 is a typical representative of the European one-megawatt class of three-bladed wind turbines, which includes similar turbines in Denmark, Great Britain, the Netherlands and Spain. The first machine, with a rated power of 1,2 MW, was installed on the 2 km^2 island of Heligoland, located 65 km NW of Cuxhaven in the Heligoland Bight, see Table 2.3.2.

The turbine is erected in the harbour near the mole. The concrete foundations are about 10 m offshore in approximately 5 m deep water. Even if this machine is of "conventional" design, it still takes into account the special conditions of the island regarding meteorology and the energy system available. Special wind conditions, caused by the island's steep sandstone rock, influence the load assumptions for the rotor (height of rock: 50 to 60 m, distance from turbine: 900 m in a direction of 300 to 350 degrees). Results from a special wind measurement programme with an 80 m lattice tower will supplement existing wind data. The annual output is estimated at 5,1 GWh (90 % availability, 7,8 m/s annual mean wind speed at 10 m).

The island's main energy supply system consists of diesel units (2 x 1,7 MW for electricity) with waste heat utilization including a heat pump and a desalination plant. The minimum demand for electric power is about 1 MW and the maximum 2,5 MW. The wind turbine operates parallel to the diesel units and is equipped with a special "shaft-driven" generator system of a type which is often used on ships. Since the shaft speed can vary within wide limits, a frequency converter system is needed to provide constant supply frequency. The electrical system thus consists of a synchronous generator, a static inverter and a rotating phase shifter.

WKA 60 was completed in Autumn 1989. The turbine is in normal operation since April/May 1990. From March 1990 to September 1991 it generated 1900 MWh during 4050 hours connected to the island's grid. Examples from a detailed measurement programme are shown in Figure 2.3.3.

The new energy supply system including WKA 60 was realized in the framework of the "Demonstration Programme for Wind Energy" of the CEC. The CEC also supported the Spanish-German machine AWEC-60 (cf section 2.8). This is also a 1,2 MW three-bladed machine, which is based, in principle, on WKA 60 but includes some important innovations in the framework of Spanish-German cooperation. The project aims at developing, manufacturing and testing the turbine. Contrary to the demonstration project WKA 60, the AWEC-60 project has an R&D character. This is evident particularly in the subsystems, such as the electrical system, the design of the glassfibre reinforced blades and the control strategy. Table 2.3.3 shows a comparison of the WKA 60 and AWEC-60 turbines, including the new WKA 60 II turbine, see below.

The main aim of this advanced development is a further cost reduction for the generated electricity. Cooperation with the German partner consisted on the one hand of the adaptation of the WKA 60 concept to the Spanish turbine, and on the other hand of R&D work for the innovative subsystems mentioned. In addition, the German manufacurer, M.A.N. - Nürnberg delivered the drive train. AWEC-60 was completed in Autumn 1989.

Wind energy programme PreussenElektra

Since the beginning of 1987, the utility PreussenElektra AG has been engaged in a wind energy programme for electricity production by the operation of advanced LS WECS. Further knowledge of the long-term behaviour of the turbines and of the expected decrease in wind electricity costs will also be obtained. The programme is part of recent activities by several German utilities to investigate renewable energy sources in an advanced approach. In particular, these activities cover photovoltaics (300 kW up to 1 MW in a later phase, Rheinisch-Westfälische Electricitätswerke AG), solar energy in combination with hydrogen technology (several 100 kW plant with 350 kW photovoltaics, Solar-Wasserstoff Bayern GmbH), and wind/solar-energy supported pumped storage plant (640 kW Monopteros, Hamburger Electricitätswerke AG, see below).

In particular, PreussenElektra AG proposed to erect and operate two LS WECS at two different German coastal sites, The PreussenElektra AG, the BMFT, the coastal states Lower Saxony and Schleswig-Holstein agreed to share the installation costs in the ratio PreussenElektra/BMFT/coastal state = 50/25/25. In the meantime, PreussenElektra AG has shifted its wind energy activities to two new companies, the PreussenElektra Windkraft Niedersachsen GmbH and the PreussenElektra Windkraft Schleswig-Holstein GmbH.

Projects in connection with the wind energy programme are listed under heading 3 in Table 2.3.1. A planning phase for the following LS WECS demonstration projects has been running since May 1987 and was completed in December 1989. Two special LS wind turbines will be operated:

- An advanced Aeolus II, based on the Swedish 2 MW Näsudden machine on the island of Gotland in the Baltic, and developed in Swedish/German cooperation. Site: Jade Windpark near Wilhelmshaven in Lower Saxony.
- An advanced WKA 60 II, based on WKA 60/AWEC-60 technology. Site: Kaiser-Wilhelm-Koog in Schleswig-Holstein on the foundation of Growian.

The sites of the two turbines are marked on the map in Table 2.3.2. The tower of Aeolus II is alredy erected, see Figure 2.3.2. Other components are being manufactured, see Figure 2.3.4. Aeolus II will be installed in Spring 1992. Main data, status 10/91, are shown in Figure 2.3.5. WKA 60 II was erected at Kaiser-Wilhelm-Koog in late Summer 1991, see Figure 2.3.6.

Other wind energy projects in the PreussenElektra programme include wind measurements at the Jade Windpark, and financial support for parallel engineering projects at MBB and M.A.N., the manufacturers of Aeolus II and WKA 60 II.

Wind/solar-energy supported pumped-storage plant

In this case, the already existing pumped-storage plant Geesthacht, about 20 km east of Hamburg, will be used, see map in Table 2.3.2. This is a 2,8 million m^3 basin on a ridge 85 m above the river Elbe. The power of the plant is 120 MW, and the capacity 600 MWh. The owner is Hamburger Electricitätswerke AG (HEW). HEW plans to support the filling of the basin with a pump driven by electricity from the wind. The wind power will be delivered by a 640 kW Monopteros from MBB. Photovoltaic power of 60 kW (AEG) will supply the control system. The aim of the project is to demonstrate the combination of different subsystems. At the same time this extended plant will be used as a reference with considerable potential for further applications around the world. The BMFT and the Federal State of Schleswig-Holstein support the project financially. The project is delayed due to difficulties in getting the building licence. First rotation of the wind turbine is expected in late 1992.

HSW 750

This is the largest wind turbine to be built by Husumer Schiffswerft. It will be installed in 1992, see map in Table 2.3.2. HSW 750 is a three-bladed upwind machine with a rotor diameter of 40 m and a rated rotor speed of 39 rpm. The hub is fixed, and the rotor tips are pitch-controlled. The rated power is 750 kW at 14 m/s wind velocity. The project is jointly funded by the CEC (28,3 %) and the BMFT (20,7 % = 1,5 MDEM)

New medium-sized wind turbines

E-36 is a new development of the manufacturer Enercon. E-36 is a 400 kW wind turbine with a direct-driven generator without gearbox. The three-blade rotor has a diameter of 36 m, and the hub height is approximately 40 m. The variable speed of the rotor ranges from 15 to 37 rpm. The turbine will be installed in Spring 1992 and operated by the Energieversorgung Weser-Ems AG (EWE). The turbine will be integrated in the 3,3 MW Windpark Hamswehrum NW of Emden at the mouth of the river Ems. Enercon plans to enlarge the concept up to 1 MW.

The HM-Rotor-300 is a vertical-axis wind turbine, manufactured by Heidelberg Motor and erected at the Kaiser-Wilhelm-Koog Wind Test Site. Like the E-36, this turbine has no gearbox and a directly driven generator. The low rotor speed also helps to reduce noise. The development and installation of this turbine is funded at 50 % by the BMFT. More HM Rotor 300's are planned for installation at sites near the North Sea coast from 1992. The manufacturer believes that the design can be economically scaled-up to 1 MW.

TW 500 is a stall-controlled 500 kW wind turbine, manufactured by Tacke Windtechnik. The three-bladed rotor has a diameter of 36 m. The airfoil of the GRP blades is the NACA 63-200 series. The steel tower carries the nacelle at a hub height of 35 m. The annual energy production at the site (Borkum Island, North sea) is estimated at 1 GWh. The machine will be operated by Windkraft Nordseeheilbad Borkum GmbH. The final construction permit is not yet obtained since many areas of the island are protected as nature reserves and since the island is located in the national park "Niedersächsisches Wattenmeer". So far, the manufacturer has no plans to scale-up the wind turbine size.

Funding

For details of funding, budget and policies reference is made to the governmental annual report [1]. Many details of selected LS WECS projects may be obtained from Table 2.3.1. For 1991, the funding of wind energy R&D projects, including demonstration but excluding the 250 MW Wind programme, was about 10,5 MDEM. For 1992, 9.2 MDEM are already tied up in ongoing projects. BMFT support is about 50 % of the total costs. Additional funding may be provided by the Federal States, some examples may be seen in Table 2.3.1. Further support is obtainable from CEC programmes.

The support for the 250 MW Wind programme can be roughly estimated since it depends on wind turbine technology, availability and particularly on the site. As the "250 MW" refer to a wind speed of 10 m/s, this corresponds to a rated power of about 375 MW (factor of 1,5). If the annual operational time (equivalent hours at rated power) is taken as between 1300 h (inland) and 2600 h (coastal area) and the support is 0,06 DEM/kWh (see below), the required funding is 30 to 60 MDEM per year. For each project, the duration of the support is limited to 10 years. These numbers are no allocations, see ref [1], but they demonstrate the magnitude of this large-scale experiment.

Highlights 1991 and future activities

The total wind power capacity is growing rapidly especially because of the 250 MW programme. Since the beginning in Summer 1989, nearly 50 MW has been installed by the turn of the year. Further research for the utilization of wind energy is nevertheless considered necessary. New materials will help to improve not only the costs but also the lifetime of wind power plants. For outputs of 400 kW and more, development work is needed to obtain more reliable data on the technological as well as the economic side. This aim is supported by wind turbine demonstration programmes and, in principle, by the 250 MW programme.

Research and development could be continued for LS WECS, stimulated by the increased interest shown by the utilities. Three LS WECS of more than 1 MW rated power will produce data on availability, dynamic stresses in correlation with gusts, and grid interconnection issues. Current investigations confirm earlier studies that a considerable contribution in the 1 % range to the country's electricity production could be obtained preferably with LS WECS. First recommendations, taking into account the characteristics of the grid and the limited number of sites in a densely populated country, are to concentrate the wind turbines in certain areas.

In other fields, particularly those involving smaller plants, R&D work is expected to be brought to an end. Information important to the utility industry, such as reliability, maintenance, lifetime, annual electricity production and installation costs, have moved into the foreground of interest. The following points are characteristic of the present situation:

- LS WECS projects are being realized more and more within the framework of international cooperation to combine different technical approaches in the partner countries. This is also stimulated by CEC programmes (WEGA).

- The increasing positive attitude towards renewable energy sources in Germany is revealed by the recent foundation of new research institutes in several federal states. A German Wind Energy Research Institute has been initiated in Wilhelmshaven, initiated by the federal state of Lower Saxony. In June 1989, Schleswig-Holstein announced a permanent test station, which uses the infrastructure of the site of the concluded 3 MW Growian experiment.

- The German parliament has passed a bill for new electricity prices for renewable energy fed into the grid. Payment for produced wind electricity to private wind turbine operators by utilities increased from max 0,092 DEM to 0,166 DEM (in general 90 % of the utilities' selling price to the end consumer) as of 1 January 1991.

- Interest in participating in the 250 MW programme was permanently high in 1991. By the end of 1991, 2888 applications for 686 MW_{10} (measured at 10 m/s wind speed) had been submitted, counted from the beginning of the programme in 1989. Although applications for around 180 MW_{10} have been withdrawn meanwhile for various reasons, the remaining applications give the BMFT enough flexibility for its selection process. By the end of 1991, applications for 79 MW_{10} had been approved. From these 79 MW around 34 MW are in operation (334 turbines, 245 approved applications). Next year a further 50 MW_{10} are expected to be approved. So far no LS WECS participate in the 250 MW programme, but the average turbine size - presently about 200 kW - is growing as well as applications for windfarms.

  The 250 MW programme foresees two types of grants. In the normal case, the operator receives a grant in proportion to the generated electricity. If it is used by himself he receives 0,08 DEM for each generated kWh, and if he feeds it into the grid he gets 0,06 DEM. In the latter case he receives an additional compensation fee of 0,166 DEM/kWh paid by the utility. As an exception and as an alternative to the normal case, private applicants and farmers can choose an investment grant for one wind turbine, which depends on the geometric dimensions of the turbine and which is now limited to 90 000 DEM.

  In any case, the 250 MW programme involves a compulsory 10-year scientific measuring and evaluation programme WMEP to obtain long-term experience of wind turbine operation. Each wind turbine, for which grants have been accorded by the BMFT, is connected to a central processing unit collecting relevant data for further evaluation. This long-distance measuring network will be the largest of its kind in Germany. In addition, the operators have to report any anomalities during the 10-year observation period. BMFT's contractor for WMEP is ISET in Kassel, who will publish all relevant data [4]. These publications should contribute to the further optimization of wind systems.

- Planning and construction permits by local authorities are an increasing problem. Especially at the North Sea coastal line, the authorities are increasingly confronted with both the interests of renewable energy users and those who are defending the existing landscape or are outright opposed to wind turbines. Therefore, some communities have started to designate special sites for possible wind systems in their community plans, preferably for windfarms. This procedure, however, will take some time and thus leads to delays in the realization of planned wind turbines. Advanced planning guidelines are already developed by three ministries of the federal state of Schleswig-Holstein [5]. Generally, good wind turbine sites are limited. Therefore, LS WECS may be a possibility for using the best places in an effective way.

- As already mentioned, all analysis shows a tendency towards larger wind turbines. An ad hoc committee on large wind installations has been set up in May 1991 who will submit their final report in early 1992.

- The number of operating wind turbines is rapidly increasing. According to Windkraft-Journal 3/91, 605 wind turbines with a rated power of 80,8 MW were noted. Together with a further completion of the 250 MW programme since Summer 1991 of about 15 MW, corresponding to about 120 turbines, the total installed wind power in Germany may reach 96 MW by the end of 1991.

  Due to the 250 MW programme and the investment programmes of the different state governments, wind power is growing rapidly, particularly in Schleswig-Holstein. Here, wind power now supplies about 1 % of the electricity consumption with abuot 300 turbines and about 60 MW installed capacity. In Autumn 1991, the utility Schleswig-Holstein AG counted 513 further applications for grid connection of single turbines with a total rated power of about 130 MW and 167 applications for windfarms with a total rated power of about 150 MW.

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[3] H Stemme, S Mickeler, A Preiss; *Entwicklung von Einblattrotor-Windenergiekonvertern: vom Prototyp M400 zur Vorserie (MON 50),* Available by MBB-Energie- und Industrietechnik, P.Box 1828, D-2870 Delmenhorst, Telefax 494 2218 5618

[4] ISET, WMEP, Königstor 57-61, D-3500 Kassel, Telefax 561 7294 100

[5] Amtsblatt für Schleswig-Holstein 1991, S. 560 ff, Sept 23, 1991; Grundsätze zur Planung von Windenergieanlagen, Available through Federal Government Schleswig-Holstein, D-2300 Kiel, Telefax 431 596 4401

[6] In case a report will be published, the German EC Member will be able to distribute a limited number

Table 2.3.1 LS WECS (rated power > 400 kW) Projects in the Federal Republic of Germany

1 MONOPTEROS DEVELOPMENT LINE

- Single-blade LS WECS MONOPTEROS: manufacturing documentation for the 5 MW prototype and construction of an experimental unit plant
  MONOPTEROS 400 (MBB, Munich); 01.07.78–31.12.82; DM 28.5 million (BMFT: 100%)
- Measuring programme MONOPTEROS 400 (MBB, Munich); 01.07.82–30.06.85; DM 10.0 million (BMFT: 100%)
- Long-term test of MONOPTEROS 400 (MBB, Munich); 01.07.85–30.09.87; DM 0.176 million (BMFT: 100%)
- Adaptation development for MONOPTEROS 50 (MBB, Munich); 01.08.85–31.07.88; DM 8.70 million (BMFT: 50%)
- JADE Windpark: 3 MONOPTEROS 50 (JWE, Wilhelmshaven); since May 85; DM 24.6 million (C.E.C. DM 2.3 million; Federal State of Lower Saxony DM 14.8 million)
- Wind measurements Wilhelmshaven (University of Hanover, Hanover); 01.04.87–30.04.92; DM 1.67 million (BMFT: 100%)

2 WKA 60/AWEC 60

- Development of a medium-sized wind turbine around 1 MW (M.A.N. Technologie GmbH, Munich); 01.08.84–30.06.89; DM 9.8 million (BMFT: 65%)
- Energy System Heligoland (Gemeinde Helgoland, Heligoland); 01.08.84–31.12.89; DM31.4 million; (BMFT: 2.48 million DM for DM 11.54 million wind turbine)
- AWEC 60 Spanish/German Cooperation (M.A.N. Technologie GmbH/ASINEL); 01.03.87–31.12.89; DM 3.3 million (BMFT: 50%)
- Wind measurements Heligoland (German Weather Service, Seewetteramt Hamburg); 01.08.87–31.12.1992; DM 1.8 million (BMFT: 100%)
- WKA 60 measurement programme (M.A.N. Technologie GmbH, Munich); 01.11.88–31.12.92; DM 3.7 million (BMFT: 50%)

3 WIND PROGRAMME PREUSSENELEKTRA
WINDKRAFT NIEDERSACHSEN/SCHLESWIG HOLSTEIN GMBH

- Utilization of wind energy by LS WECS (planning phase) (PreussenElektra AG); 01.05.87-31.12.88; DM 0.7 million (BMFT: 50%)
- Development of the AEOLUS II rotor blade (MBB, Munich); 01.08.87-30.09.91; DM 5.9 million (BMFT: 50%)
- Engineering for the adaptation of a WKA 60 type turbine – WKA 60 II (M.A.N. Technologie GmbH, Munich); 01.05.88–31.03.91; DM 1.6 million (BMFT: 50%)
- AEOLUS II
  (PreussenElektra Windkraft Niedersachsen GmbH, Hanover); 01.09.88–31.03.92; DM 21.4 million (BMFT: 20.5%, Land Niedersachsen: 20.5%); in addition DM 4.15 million to manfacturer MBB from C.E.C.
- WKA 60 II
  (PreussenElektra Windkraft Schleswig-Holstein GmbH, Hanover); 01.02.89–30.06.92; DM 14.3 million (BMFT: 25%, Land Schleswig-Holstein 25%)
- Measuring programme AEOLUS II (PreussenElektra Windkraft Niedersachsen GmbH, Hanover); 01.10.91–31.05.95; DM 0,6 million (BMFT: 50%)
- Measuring programme WKA 60 II (PreussenElektra Windkraft Schleswig-Holstein GmbH, Hanover); 01.10.91–31.05.95; DM 0,6 million (BMFT: 50%)

4 WIND/SOLAR SUPPORTED PUMP STORAGE PLANT

Wind (MON 50) Solar (60 kW) supported pump storage plant Geesthacht (Hamburger Electricitätswerke AG, Hamburg); 20.02.89 – 31.05.1993; DM 11,8 million (BMFT: 40%, Land Schleswig-Holstein: 10%)

5 HSW 750

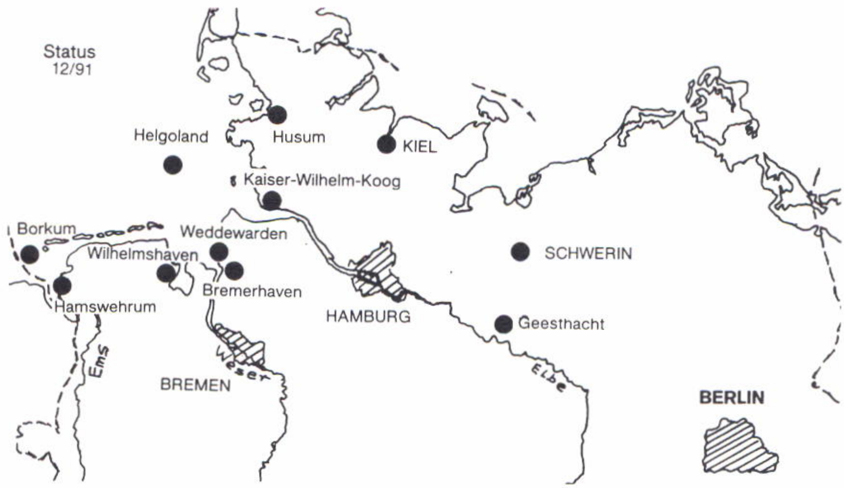
Development and test of a 3-bladed 750 kW windturbine (Husumer Schiffswert, Husum); 01.04.89 – 31.12.1992; DM 7,1 million (BMFT: 20%, CEC: 29%)

6 E – 36

Erection of an advanced 400 kW turbine with a directly driven generator without gear box (Energieversorgung Weser-Ems AG, Oldenburg) 01.09.91 – 28.02.1992; DM 1,24 million (BMFT: 50%)

7 T W 500

Erection of a stall-controlled 500 kW turbine on the island Borkum (Windkraft Nordseeheilbad Borkum GmbH, Borkum); 01.12.90 – 30.06.1992; DM 1,17 million (BMFT: 25%, Lower Saxony: 25%)



	Typ	Location ●	Power	Realization
1.	MON 400 MON 50	Weddewarden Wilhelmshaven	400 kW 3 à 640 kW	82 – 90 Summer 89
2.	WKA 60 AWEC 60	Helgoland Cabo Villano (Spain)	1.2 MW 1.2 MW	Antumn 89 Summer 89
3.	AEOLUS II WKA 60 II	Wilhelmshaven Kaiser Wilhelm-Koog	3 MW 1.2 MW	91/92 Autumn 91
4.	MON 50	Geesthacht	640 kW	92/93
5.	HSW 750	Husum	750 kW	91/92
6.	E-36	Hamswehrum	400 kW	Spring 92
7.	TW 500	Borkum	500 kW	Spring 92

Table 2.3.2 Prototype LS WECS, rated power > 400 kW, in Northern Germany. Numbers 1...7 refer to Table 2.3.1.

Table 2.3.3 System Data WKA 60/WKA 60 II/AWEC-60

		WKA 60	WKA 60 II	AWEC 60
Rotor				
Number of blades		3	3	3
Diameter	m	60	60	60
Hub		Fixed	Fixed	Fixed
Hub heigt	m	60	60	46
Rated speed	rpm	23	23	23,3
Speed range	rpm	18 – 25,3	16 – 25,3	20,7 – 25,6
Tilt angle	degree	4	4	4
Orientation		upwind	upwind	upwind
Rotor blades				
Material		GFRP	GFRP	GFRP
Airfoil		NACA 44 ... series	NACA 44 ... series	NACA 44 ... series
Max. power coeffizient		0.465	0.465	0.465
Gearbox				
Type		2 planetary, 1 spur	2 planetary, 1 spur	2 planetary, 1 spur
Ratio		57,7	57,7	47,8
Control				
Blade		Full span blade pitch control (hydraulic actuator)	Full span blade pitch control (hydraulic actuator)	Full span blade pitch control (hydraulic actuator)
Power		Generator torque control	Generator torque control	Generator torque control
Yaw drive System				
Type		hydraulical	hydraulical	hydraulical
Yaw rate	°/s	0,3	0,3	0,8
Tower				
Type		cylindrical/conical base	cylindrical	cylindrical/conical base
Material		steel concrete	prestressed concrete, prefabricated	steel
1. Bending Mode	Hz	0,75 – 0,78	0,64 – 0,65	0,7
Generator				
Type		Synchronous with Ac/static frequency converter	Synchronous with Ac/static frequency converter	Asynchronous with oversynchronous cascade
Rated power	kW	1200	1200	1200
Operation				
Cut-in	m/s	5	4,8	5,2
Rated	m/s	12	12	12,1
Cut-out	m/s	24	24	24,0
Max design	m/s	65	64	65

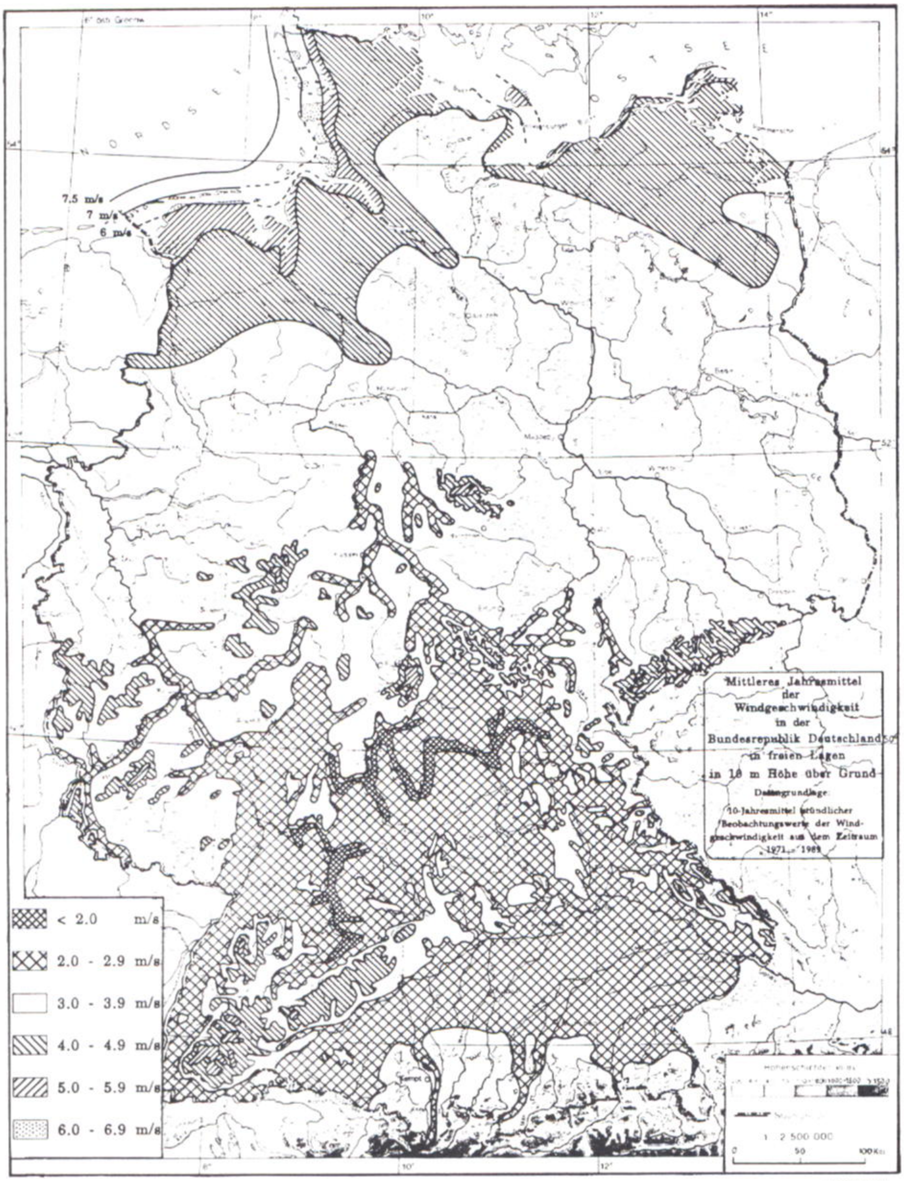
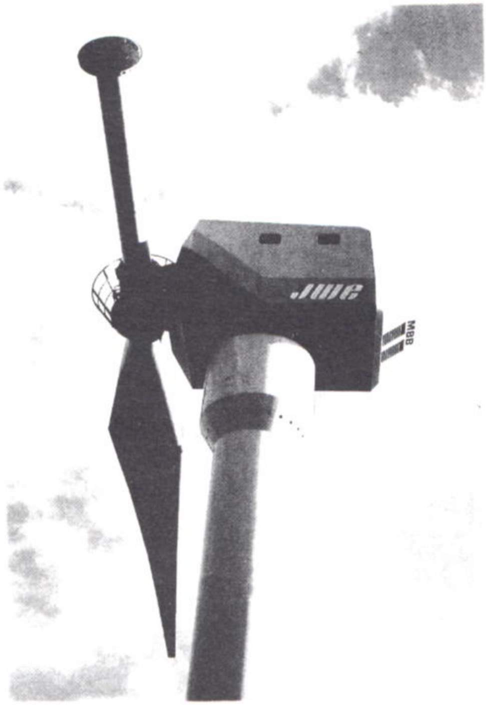


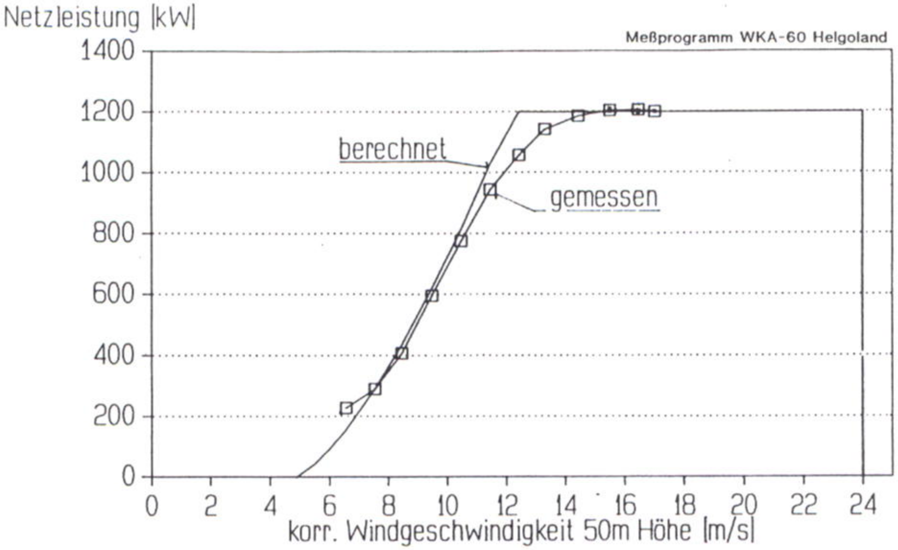
Fig. 2.3.1: Wind Map Germany. Mean Annual Wind Speed 10 m above ground level. German Weather Service.

Figure 2.3.1 Wind Map of Germany. Mean Annual Wind Speed 10 m Above Ground. Prepared by the German Weather Service



single-bladed MONOPTEROS 50

Figure 2.3.2 Jade Windpark with the three single-bladed Monopteros 50 and the tower for the 3 MW Aeolus II. Summer 1991



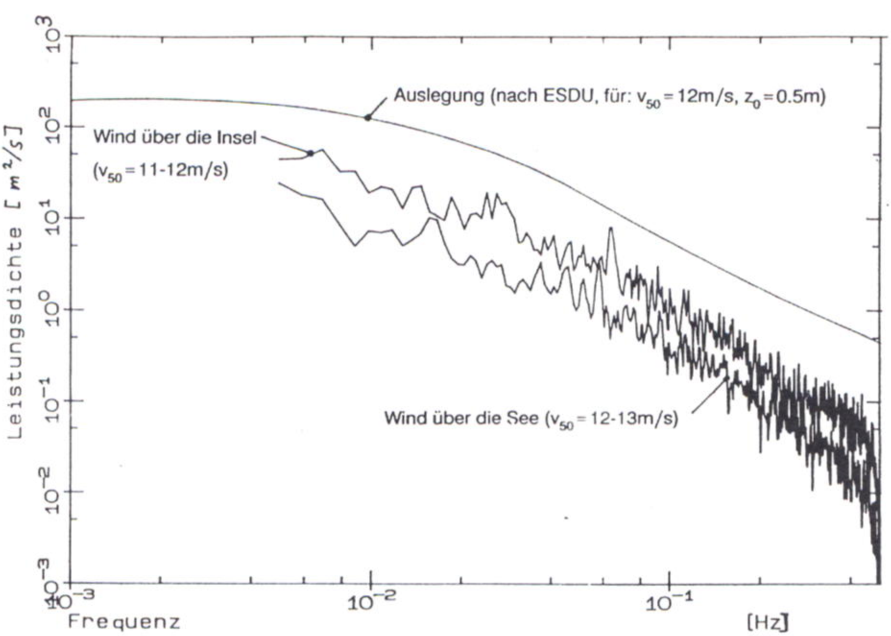


Figure 2.3.3 Examples from the Measuring Programme WKA 60. Above: Power curve, measured and calculated Below: Comparison of gust spectra, measured and designed; Power density versus frequency; wind velocity at hub height 50 m

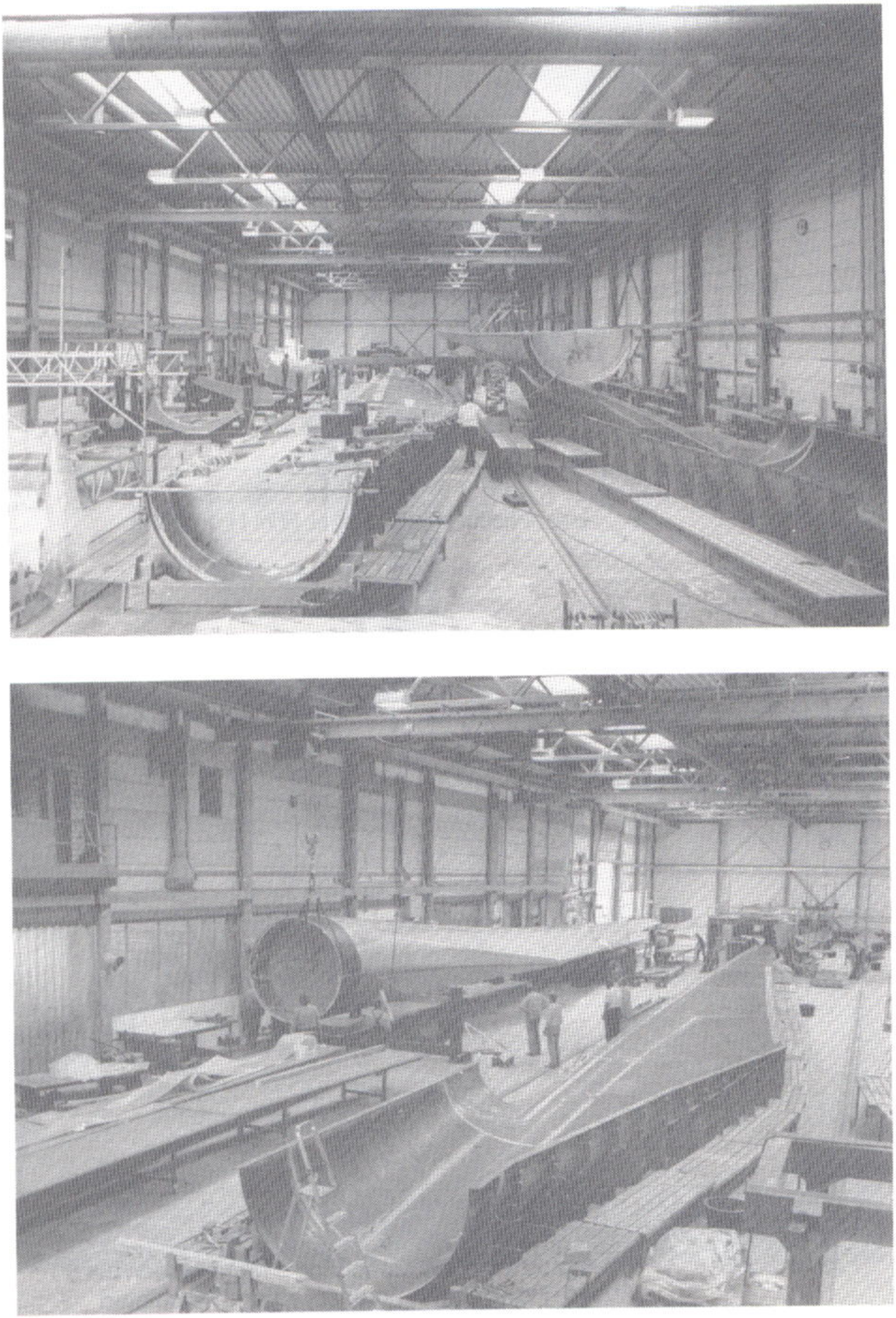
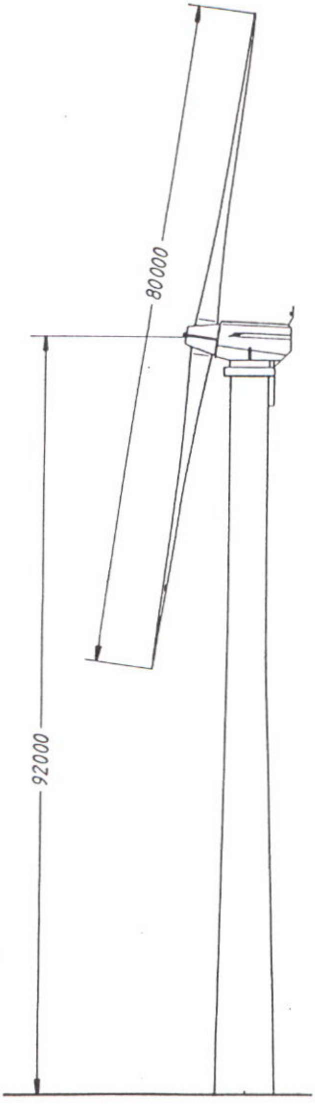


Figure 2.3.4 Aeolus II. Manufacturing of the CRP/GRP rotor blades



Tower	
Material	reinforced concrete
Height	88 m
Diameter	6.20 – 4.5 m
Rotor	
Hub height	92 m
Number of blades	2
Diameter	80 m
Speed	16 – 21 RPM
Rotor position	upwind
Control	Pitch
Tilt angle	8°
Gear type	Epicyclic/Bevel
Rotor Blades	
Length	38.8 m
Material	CRP/GRP reinforced deposits
Airfoil	FX84-W-series
Chord length	4.4 m max.
Electrical system	
Generator system	Synchron, converter
Variable speed	1140 – 1500 RPM
Rated power	3,0 MW
Voltage	ca. 1000 V
Design Data (at hub height)	
Windspeed cut in	6 m/s
rated	14.15 m/s
cut out	25 m/s
survival	75 m/s
Life time	25 years
Energy output (90 % availability)	7.3 GWh/a at 8.6 m/s
Weights	
Blades	8.0 t each
Hub	19.0 t
Nacelle complete	95.0 t
Tower	1410 t

Figure 2.3.5 Aeolus II. Main design data, status 10/91

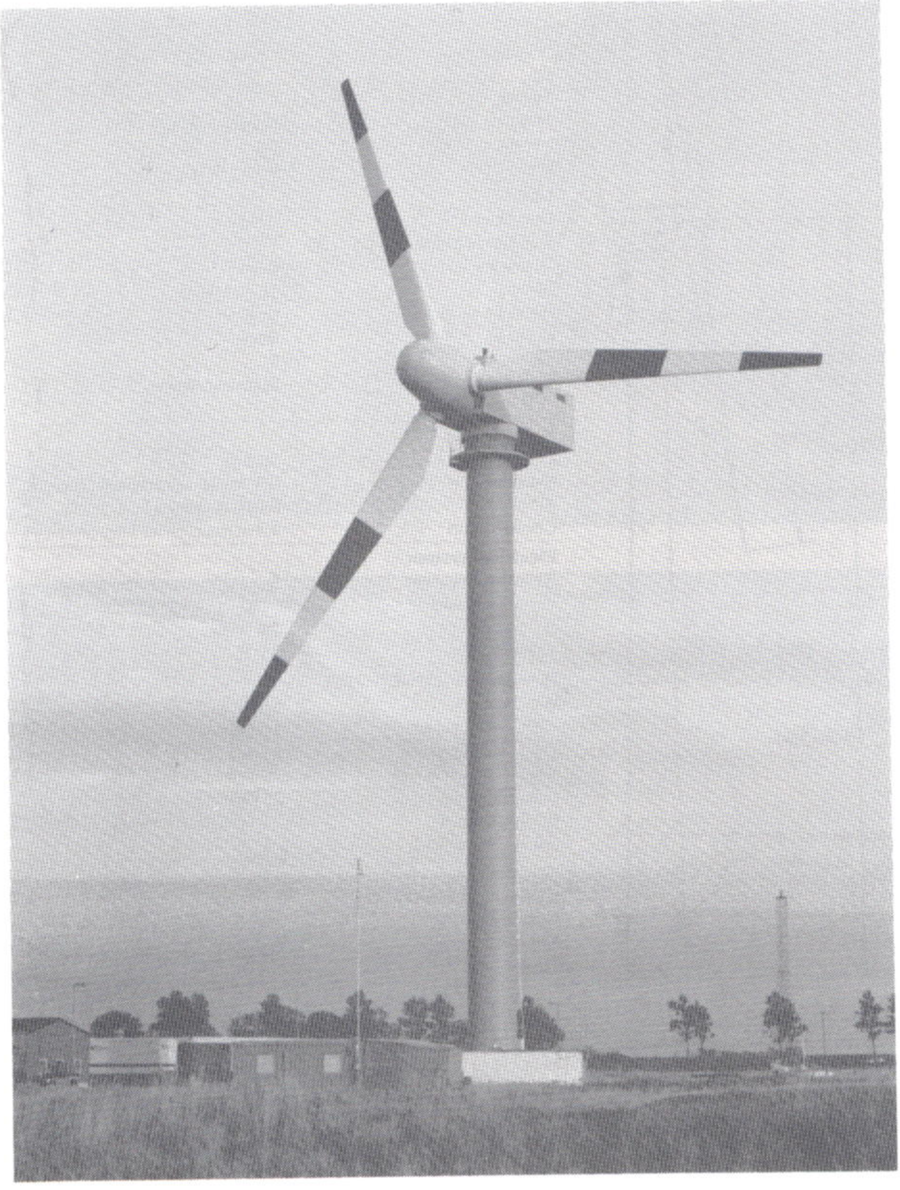


Figure 2.3.6 WKA 60 II, Kaiser-Wilhelm-Koog. Rated power 1,2 MW

2.4 Italy

General

For some years the main wind energy activities have been carried out within the framework of a national programme providing for cooperation between two state-owned organisations, ENEA and ENEL, and the Italian wind turbine manufacturers.

Specifically, ENEA (the Italian Board for New Technologies, Energy and the Environment) has been supporting a number of wind energy projects both financially and technically, while ENEL (the National Electricity Board, i e the main electricity utility of Italy) has been engaged in both wind turbine testing and the siting and planning of wind power plants, to comply with the lines laid down in the Government's National Energy Plan, which sets a target of 300 to 600 MW of wind generating capacity to be installed by the year 2000.

Italy's major wind turbine manufacturers are WEST and Riva Calzoni. Up to now, these manufacturers have developed three machine prototypes, on which detailed information was given in previous reports, with support from ENEA, ENEL, and DG XVII of the Commission of European Communities:

- MEDIT (33 m, 225 kW) by WEST
- M30 (33 m, 200 kW) by Riva Calzoni
- GAMMA 60 (60 m, 1500 kW) by WEST.

The MEDIT and M30 prototypes have been operating continously at ENEL's Alta Nurra site in Sardinia, while industrialized versions of both machines have been, or are in the process of being, developed. Riva Calzoni has also been engaged in the design of a 55m, 800 kW machine, the M55, based on the M30 concept.

The nacelle of the GAMMA 60 prototype has been undergoing long-term tests at the WEST workshop, in view of the erection of the unit at Alta Nurra.

As for programmes relating to wind power plants for production purposes, ENEL has been working on a project, launched in 1989 and aimed at installing two 10 MW windfarms. In addition, in October 1991 ENEL's Board of Directors decided to plan for a further number of wind power plants for an overall capacity of 40 MW, so as to achieve the goal of 60 MW wind generating capacity within the next five years.

ENEA, on its part, is promoting two feasibility studies, each regarding the setting up of a windfarm of about 10 MW capacity.

It is also worth recalling that important legislative measures have recently been taken in Italy to encourage private investors in the renewable energy field.

On 14 November 1990, the Italian Government fixed at 170 ITL/kWh, for a period of five years, the price ENEL has to pay to private producers or municipal utilities who sell the energy produced by their own grid-connected wind power plants.

Additional incentives have then been provided by law No. 10 of 9 January 1991. According to this law, the use of renewable energies is to be considered in the public interest, and the various regions of Italy are expected to choose the most suitable areas to be devoted to renewable energy installations. Law No.10 also provides for grants for those who carry out feasibility studies on, or set up generating plants from, renewable energy sources. With regard to wind power it may be pointed out that, among other things, plants over 3000 KW in capacity are entitled to a grant of up to 30 % of the investment cost (50 % for demonstration plants).

Wind turbine development

This section provides information on the progress of the more significant activities of Italian manufacturers to develop competitive medium-sized wind turbines for the present market, as well as advanced large-sized machines

The WEST company

WEST (Wind Energy Systems Taranto) is an Alenia (IRI Finmeccanica Group) company for the development and manufacture of wind energy systems within the Alenia Commercial Systems sector. WEST is the industrial exploitation of the experience and technology which have become available within Alenia (formerly Aeritalia) over many years of advanced projects.

a) MEDIT 320

The series fabrication of the MEDIT 320 wind turbine of 320 kW rated power has already started at the WEST production facilities to cover various orders, including one from ENEL for 38 units for the first 10 MW windfarms in Sardinia and in the Apennines (see below). MEDIT 320 is the industrial model derived from the 225 kW prototype, installed at Alta Nurra and extensively tested to identify performance and design margins as well as possible design improvements of both cost and performance. The main features of MEDIT 320 are shown in Table 2.4.1

Table 2.4.1 Main data for MEDIT 320

Number of blades		2
Rotor diameter	m	33
Rotor position		upwind
Hub height	m	26
Hub		rigid
Gearbox		oscillating
Power regulation		pitch control
Yaw control		active
Rated power	kW	320
Wind speed @ 10 m:		
cut in	m/s	3,2
rated	m/s	11,5
cut out	m/s	17,5
survival	m/s	50

b) Campania Wind Power Plant Module

A first windfarm module of 1,5 MW, which includes four MEDIT 320 and three small wind generators of the AIT 03 type (30 kW) has been put into operation at Bisaccia in the Campania region (southern Italy), see Figure 2.4.1. Its annual energy production is estimated at about 3000 MWh. The module represents the initial phase of a large windfarm with the possibility of having more than 12 MW of installed capacity.

c) GAMMA 60

GAMMA 60 is a large-sized wind turbine with innovative features to make a cost-effective machine. The main features (teetered hub, fixed pitch, broad range variable speed, yaw control), already described in previous Annual Reports, have been designed in order to increase the annual energy yield, on the one hand, and to eliminate all control components from the rotating parts, on the other, thus allowing for a simpler machine with lower manufacturing and maintenance costs.

All the GAMMA subsystems were completed by the end of June 1990, and, after successful workshop tests, assembly of the nacelle and erection of the tower were performed, in the WEST workshop and at the Alta Nurra site in Sardinia, respectively.

After completion of the assembly in 1991, an extended series of tests has been conducted, first on the hydraulic and mechanical systems, and then, after installation of the control and data acquisition system, on the overall system, without blades, see Figure 2.4.2.

The final tests, which were completed in 1991, were carried out by means of a special feedback simulator, controlled by a VAX computer. The purpose of these tests was to simulate the operation of the machine in every conceivable operating mode in order to check:

- the adequacy of the interface of the control and data acquisition system with sensors and actuators;
- the correct operation of the data acquisition;
- the correct implementation of the regulation algorithms;
- the correct behaviour of the electric and hydraulic actuation devices;
- the stability of the behaviour during long runs (endurance tests);
- the validity of the machine modeling (identification tests).

The installation of the machine at the site will occur during the first months of 1992.

The Riva Calzoni Company

Since the beginning of 1991, Riva Calzoni activities have been re-organised. The wind energy department is now part of the new division DEA (Divisione Energia e Ambiente), which concentrates Rive Calzoni's activities in the energy field.

In this frame the industrial production of the M30, the single-bladed machine developed in cooperation with MBB from Germany with partial support from ENEA and CEC, was started.

Besides the M30, Riva Calzoni is going to develop a much larger single-bladed wind turbine, the M55, a MW size unit. This will represent the most cost-effective single-bladed machine obtainable with the present Riva Calzoni industrial technology.

a) M30

Up to 1991, about 20 units have been manufactured, see Figure 2.4.3, according to a programme, meant to satisfy the order of ENEL for 38 M30 to be installed in the first two Italian windfarms (see below). In the meantime many efforts were made to optimize the design of the prototype, presently operating in Sardinia. Further improvements have been defined and will be implemented on a new version of M30 during the next year. The main improvements are as follows:

- increase of the rated power from 200 to 250 kW;

- completely new concept for the hub design;

- new blade, specially designed for the highest energy efficiency with the lowest noise.

Several experimental activities on the prototype in Sardinia are also in progress. Among these activities an R&D project is in progress with the cooperation of Garrad & Hassan within the CEC JOULE programme.

b) M55

The design phase for the M55 development started in 1990. The M55 design, see Table 2.4.2 and Figure 2.4.4, originated from the positive experience with M30. M55 represents the maximum size version achievable by a single-bladed unit with a typical medium size technology. However, many features are absolutely innovative, folllowing from Riva Calzoni's experience on single-bladed units. They are meant to exploit the advantages deriving from the single-bladed concept:

- possible adoption of two different generating systems:
  . low range variable speed - two generators;
  . broad range variable speed - one generator;

- rotor design according to a completely new concept;

- further conceptual improvements (with respect to the M30) in the flap, pitch and yaw systems;

- new computer control system to allow the highest level of adaptation to the site conditions;

- steel or concrete tower will be available depending on the specific requirements.

In spite of the unit being particularly suited for low wind areas, the single blade concept allows a safe installation even in sites where wind characteristics (turbulence, survival wind speed etc) are the worst.

Table 2.4.2 Main data for M55

Rotor		
Type of wind turbine		horizontal-axis
Orientation		downwind
Diameter	m	55
Number of blades		1
Blade material		fibre
composite		
Power regulation		aerodynamic
Pitch control system		full span
Rated tip speed ratio		7,4
Optimal tip speed ratio		11
Gearbox		
Type		parallel axis
Number of stages		2
Ratio		1:49,2
Generator		
Type		induction
Rated power	kW	800/160
Number of poles		4/6
Yaw system		active
Tower		
Type		cantilever
Material		steel
Height	m	58
Performance		
Wind speeds (at hub height)		
cut-in	m/s	3,5
rated	m/s	13
cut-out	m/s	25

Progress of current windfarm projects

As already mentioned, ENEL and ENEA have embarked on a number of projects aimed at installing Italy's first large wind power plants for demonstration purposes as well as to promote a volume of demand, sufficient to justify the manufacture of wind turbines in Italy on an industrial scale and in line with prices on the world market.

ENEL's activities

In early 1989, ENEL launched a programme aimed at constructing two demonstration windfarms. Each plant should have an installed capacity around 10 MW, and should be made of medium-sized machines. Before starting construction of these plants, the programme provides for a preliminary phase of technology comparison, in which the state of the art of Italian medium-sized wind turbines should be checked by running Italian units side by side with similar foreign-made machines. This comparison is to be performed at two typical environmental situations, representing almost all the prospective sites so far pointed out by wind energy surveys in Italy:

- a site with seaboard climatic conditions;

- a mountain site in the Apennines.

a) Preliminary machine testing

As for the seaboard site, comparative tests started in April 1991 at the Alta Nurra facility in Sardinia, Figure 2.4.5. Since then, a 300 kW MS-3 machine , made by the Wind Energy Group from the United Kingdom, and a Windane 34 machine by Vestas-DWT from Denmark, have been operating together with the MEDIT and M30 prototypes already mentioned. At the end of the year, a 320 kW MEDIT unit has also been installed to have a wider experience of the behaviour of this machine. Even though preliminary conclusions on the machines' performance are at present being drawn, an overall testing period of two years is considered necessary for the complete assessment of all technology aspects.

As for the mountaineous environment, a new test site will be constructed in the Apennines in Central Italy. The area chosen is located at Acqua Spruzza, in the commune of Frosolone, at an altitude of 1360 m a s l. Eight machines, namely two units of each of the Italian and foreign models under test at Alta Nurra, will be installed. This will make it possible to assess their performance in a harsh environment with heavy snowfalls, ice accretion, and high turbulence. ENEL has also received financial support from DG XVII of the CEC for construction of this facility.

At present the executive plans of the test site have been completed, the eight machines delivered, and the construction contracts assigned. All building permits required have also been obtained from local authorities, although with considerable delay due to unexpectedly complex and lengthy procedures. For this reason the construction phase will not be allowed to start until the spring of 1992, no civil engineering work is possible at the site during the winter months. Completion of the plant is expected during the first half of 1993.

b) Windfarm construction

The first 10 MW windfarm will be located in Sardinia, in a seaboard climate, and will consist of 40 units of the MEDIT and M30 models. The site will be an area on Monte Arci, a mountain ridge near the coast at about 750 m a s l. The preliminary design of the plant has been completed and the procedures for permits from planning authorities are now in progress. Construction should start in the second half of 1992.

The second windfarm should be set up in the Apennines. This will involve 32 machines of the MEDIT and M30 models to be installed at Acqua Spruzza, thus enlarging the test area, or at another site in the Apennines. Construction of this plant will start after the viability of wind energy plant in a harsh mountain environment has been shown by tests in the Acqua Spruzza test field.

For two years now, ENEL has been engaged in micrositing studies all over the area of Monte Arci and Acqua Spruzza, involving both on-site surveys by 15 m and 40 m measuring masts, and the use of mathematical models, to define the optimal layout of machines.

In this connection it might be recalled that micrositing activities have also been undertaken by ENEL at Celle San Vito, in the Puglia region, to define the possible site where a plant with the first two 1,5 MW GAMMA 60 units could be set up after successful testing of the GAMMA 60 prototype.

ENEA's activities

ENEA is promoting two feasibility studies of windfarms in the Emilia-Romagna and Campania regions. If constructed, these plants would be financed by their respective regional authorities, which would be the owners, and would feed the power produced into the local ENEL grid.

The study of a possible 10 MW plant in Emilia-Romagna (northern Italy) has been entrusted to Riva Calzoni. The search has lead to the pinpointing of ten possible sites, where wind measurements are now being performed in cooperation with ENEL to select the optimal site.

The second study, relating to the Campania region in southern Italy, has been committed to Alenia/WEST and is also underway. As already mentioned, a small grid-connected cluster of four 320 kW MEDIT and three 30 kW AIT-03 units has been installed near Bisaccia in 1991. In principle, it could be the starting point of a capacity up to 12 MW.

Figure 2.4.1 The four MEDIT units of the Wind Power Plant Module at Bisaccia (Campania)

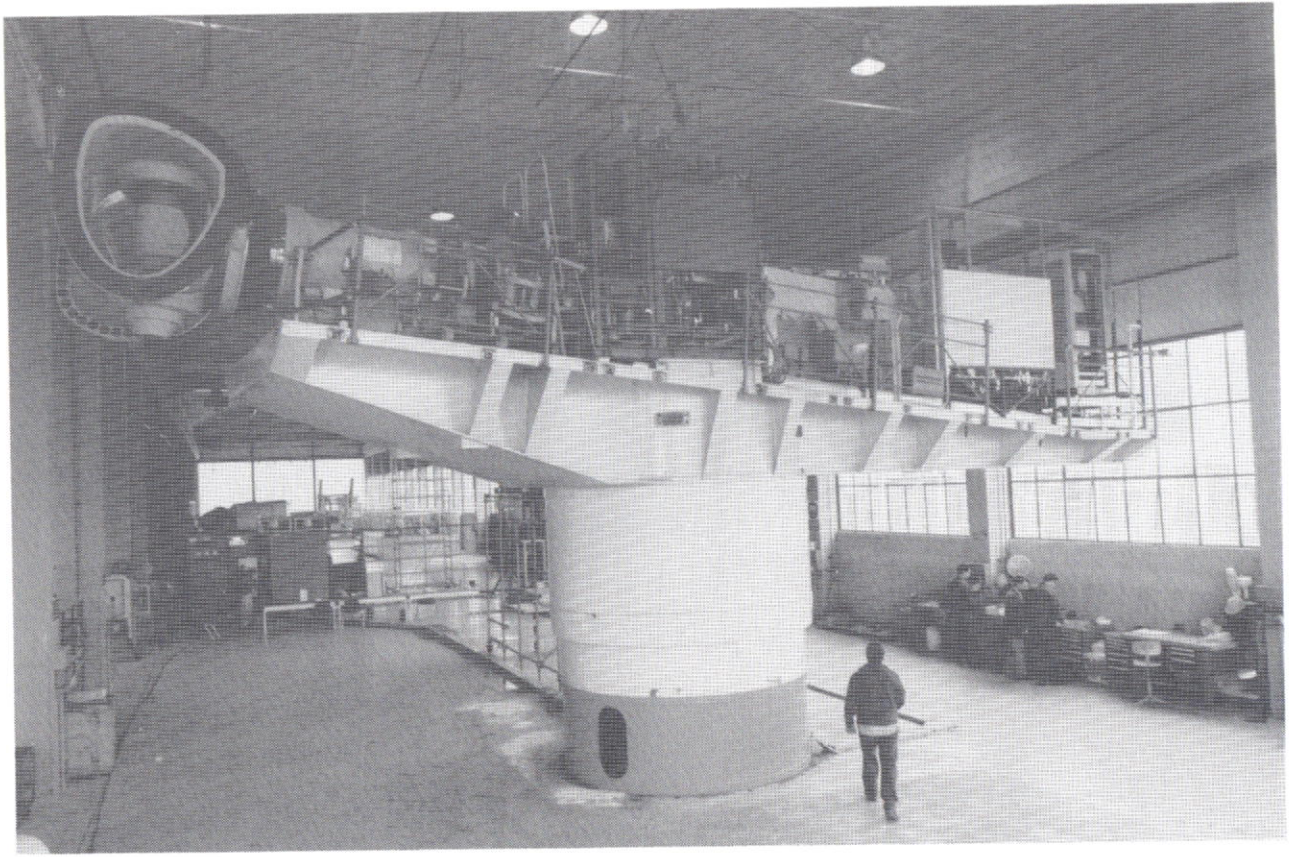


Figure 2.4.2 The GAMMA 60 nacelle under test at the WEST workshop

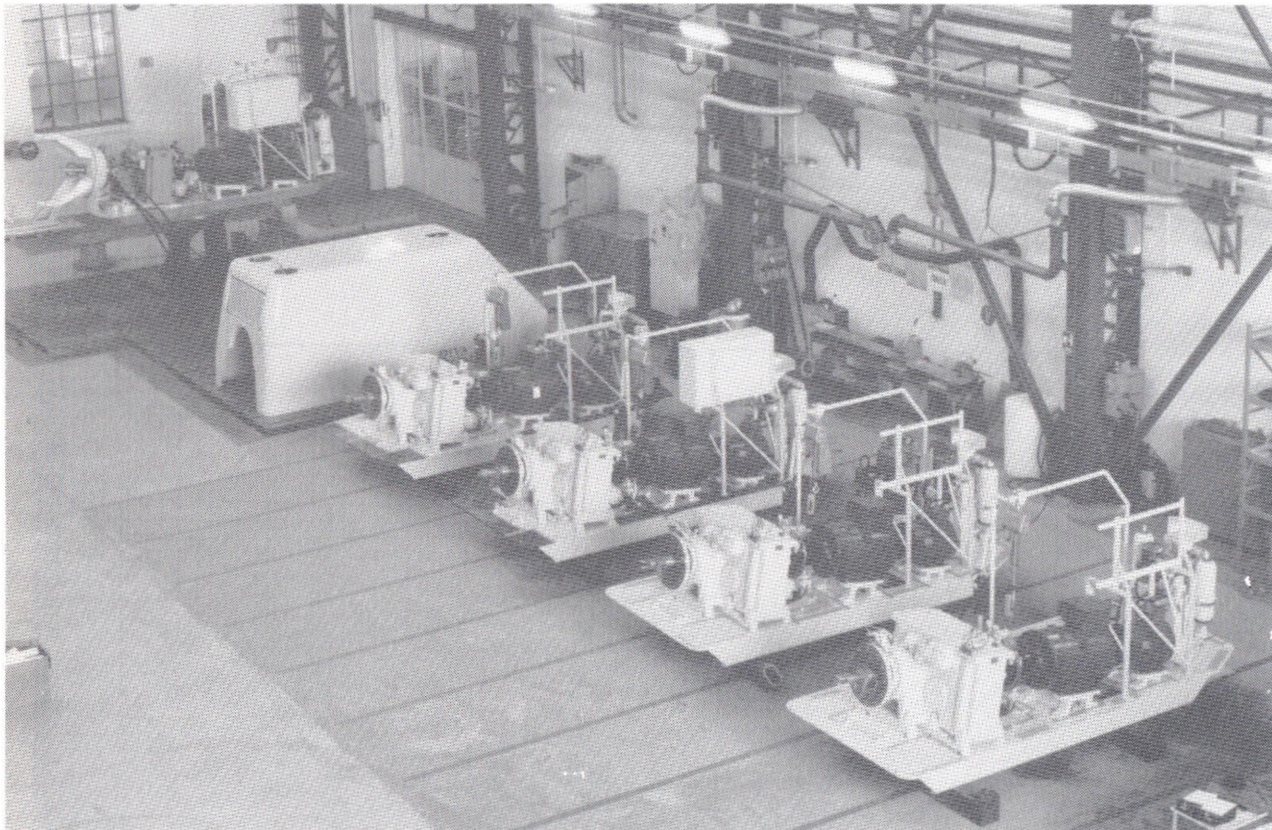


Figure 2.4.3 M30 units under fabrication at the Riva Calzoni workshop

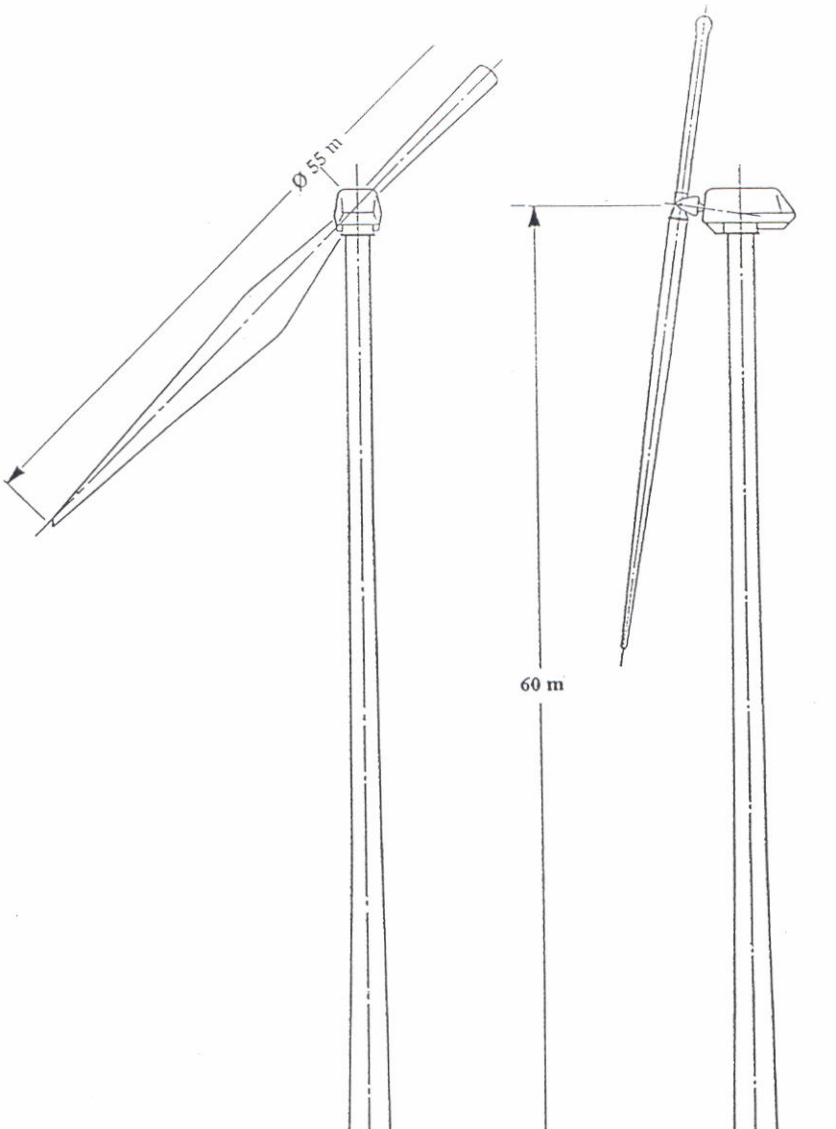


Figure 2.4.4 Main features of the 800 kW M55 machine

Figure 2.4.5 Partial view of ENEL's Alta Nurra site

2.5 Japan

Wind energy programme

The Japanese wind energy programme is part of the Sunshine Project, under the Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI). The use of wind energy is also supported by the Agency for National Resources and Energy (ANRE) of MITI and by other governmental agencies. In addition to these national programmes there are several wind energy projects in the private sector.

The Sunshine Project restructured its wind energy R&D programme during 1990 - 1991. Four subprogrammes are in progress:

- Wind observation and resource assessment
- Development of utilization technology for WECS
- Development of 500 kW class WECS
- Basic wind energy research

The first three subprogrammes are implemented by the New Energy and Industrial Technology Development Organisation (NEDO), established in 1980. NEDO's total budget was equivalent to 745 MUSD for fiscal year 1990. In the wind energy field, NEDO has completed projects such as the development of a "100 kW class pilot plant" and "Basic technology for MW class WECS". NEDO's budget for wind energy is equivalent to 3,1 MUSD for FY 1991 and 6,5 MUSD for FY 1992.

Wind observation and resource assessment

Japan has strong winds in the northern parts and on southern islands such as Okinawa. To complement the existing network of ordinary meteorological observations, NEDO has been measuring wind characteristics in high masts (40 - 140 m) at selected sites since 1983. In 1990 the number of observation sites was increased by 13 and in 1991 another 10 sites were put into operation. The measurements will be used to obtain a firm estimate of the country's wind energy potential and to seek suitable areas for wind turbine siting.

Development of utilization technology for WECS

The objective of this project, which started in 1990, is to develop control technology and obtain operational data for windfarms. An experimental windfarm of approximately 1 MW rated power will be constructed at

Nishi-hennazaki on the island of Miyako, Okinawa. Two 250 kW wind turbines and six smaller units will be installed during 1991 - 1992. Operational tests and integration studies into a small-scale grid are scheduled to start in 1992.

Development of 500 kW class WECS

The objective of this project, which started in 1991, is to develop a cost-effective 500 kW wind turbine. As an initial step a full-scale prototype will be designed and constructed during 1991 to 1995. Further development of a demonstration plant will also be carried out. Testing and operation of the prototype will be performed in the subsequent two years. In 1996, the test results will be assessed and the schedule for developing the demonstration plant reviewed.

The prototype will be a three-bladed upwind pitch-controlled machine with a rigid hub. The specifications are shown in Table 2.5.1.

Table 2.5.1 Specifications of 500 kW Class WECS

Wind Turbine		
Rated output	kW	500
Rotor diameter	m	38
Rotor speed	rpm	32
Number of blades		3 (GFRB material)
Rated wind speed	m/s	13
Cut-in wind speed	m/s	6
Cut-out wind speed	m/s	24
Generator		
Type		Induction
Rated output	kW	500
Voltage, phase, pole	V	6000, 3-phase, 4-poles
Frequency	Hz	50
Tower		
Type		Monopole
Hub height	m	38
Control system		
Power regulation		Pitch-control
Yaw orientation		Yaw-control

Basic research

Basic studies are carried out since 1978 at the Mechanical Engineering Laboratory (MEL), Tsuruba, on rotor aerodynamics, control systems, noise and vibration, and airfoil sections. Operational tests are performed on a small experimental wind turbine.

2.6 The Netherlands

Introduction

In the last few years, two government-sponsored programmes in particular have been essential to wind energy developments in the Netherlands. The 1986-1990 Integral Wind Energy Programme (IPW) was intended to initiate the large-scale application of wind energy in the Netherlands and to provide an incentive for the further development of cost-effective wind turbines. The 1986-1990 National Wind Energy Research Programme (NOW) was intended to back this endeavour with technological, economical and environmental research, and as such became the follow-up of the the first two NOW phases, which formed the basis of wind energy research in the period 1976-1985.

These programmes have facilitated the development of wind energy as a realistic energy option for the coming decades. An example of this development is evident in the energy distribution companies' plans to invest in the erection of enough wind turbines to generate 250 MW in the next few years. The implementation of the IPW has contributed to the maturing of the industry involved in wind energy, the presence on the market of reasonably reliable wind turbines, and to the creation of a useful impression of their siting possibilities. Furthermore, the NOW has contributed to the accumulation of wind technology know-how in the Netherlands.

Meanwhile, the interest in energy conservation and sustainable sources of energy has increased significantly, partly due to a concern for the environment. At the same time, energy prices have risen less than predicted, and the technology required for cheap and reliable wind turbines has proved more problematic than expected. As a result of these developments, the promoting role played by the government will, for the time being, remain necessary for further application of wind energy. The Ministries of Economic Affairs and of Housing, Regional Development and the Environment have therefore requested Novem to develop a new programme for the support of this application. This National Support Programme for the Application of Wind Energy in the Netherlands (TWIN) integrates implementation support, industrial product development and support research into one programme. This integration was considered useful as the market parties involved, the operators and manufacturers, are currently in a position which allows them to play a more guiding role in relation to these activities.

The introduction and application of wind energy in the Netherlands

In 1976, the wind turbine made a comeback on the energy supply scene. After a hesitant start, more and more parties became interested. A number of manufacturers in the Netherlands pioneered the development and production of wind turbines, and the first turbines were erected, partly due to WIR (former Dutch legislation for encouraging industrial investment) and non-profit subsidies.

This development threatened to cease in around 1986. The wind turbine technology proved more problematic than initially expected and the costs fell reluctantly, due to the lack of demand. Consequently, prospective investors adopted a reserved attitude towards wind energy. Sales stagnated, making it impossible for manufacturers to invest adequate funds in the further development of reliable and cost-effective wind turbines. The vicious circle had closed, only to be broken again in 1986 with the Integral Wind Energy Programme (IPW 1986-1990), which was commissioned by the Ministry of Economic Affairs and carried out by Novem.

In the IPW, the government expressed its opinion on the desirable extent of wind energy application in the Netherlands. The basic aim of government policy on this issue since 1986 has been the installation of enough wind turbines to produce 1000 MW by the year 2000. The publication of the Energy Conservation Paper by the Ministry of Economic Affairs in mid-1990 added an energy conservation target of 33 PJ per year by 2010, which corresponds to an installed capacity of about 2000 MW.

In the last few years these goals have started to reach fruition under the IPW. The installed capacity prior to 1986 amounted to over 16 MW. The IPW target - the development of a wind energy capacity of 100 to 150 MW - will be realized. The growth is expected to continue. The energy distribution companies have announced plans to invest in a wind energy capacity of 250 MW until the year 1995. Private investors are also expected to remain active. The government has announced a new system of subsidies to bolster these activities.

In the light of the above, the installed wind energy capacity is likely to increase to around 400 MW in 1995.

The results of the IPW and NOW programmes

The year 1986 saw the launch of the 1986-1990 Integral Wind Energy Programme (IPW) and a new phase of the National Wind Energy Programme (NOW 1986-1990).The objectives of the IPW focussed on achieving the following by 1991:

- an installed wind turbine capacity of 100 to 150 MW;
- the availability of reliable and cost-effective wind turbines.

The purpose of the NOW 1986-1990 was: "to conduct general support research to render a contribution to the government policy targets regarding the introduction of wind energy in the Netherlands, namely the development 150 MW of wind power by 1991 and 1000 MW by the year 2000."

The situation at the start of the programme was that a number of parties were prepared to invest in wind energy, provided that cheaper and more reliable wind turbines would be available. A large number of manufacturers were prepared to answer these requirements, provided that a sufficient number of orders were placed. The primary aim of IPW was to break this deadlock. It proved successful.

The current situation is that subsidies have been granted for the development of a total wind power capacity of 128 MW; the price/performance ratio of wind turbines has improved by approximately 40 % and the Dutch wind turbine industry has continuity prospects. The current price/performance ratio amounts to an average kWh rate, calculated on the basis of all wind turbines, of about 0,30 NLG; the average kWh rate of the latest turbines placed at the proper locations amounts to approximately 0,20 NLG.

The target regarding the cost price of wind energy has not yet been reached, however. This is due in particular to the fall in energy prices after 1985. Consequently, government support for further application of wind energy will remain necessary for the time being. In addition, the IPW has shown that the siting of wind turbines frequently encounters obstacles. Noise pollution, harm to birds or landscape disfigurement and the resulting administrative problems necessitate a follow-up of the guidance activities in the IPW.

In the period 1986-1990, the NOW offered a framework for support research. This comprised technological research, aimed at the development and improvement of wind turbines, and research into landscape, integration and other aspects. As regards technological research, the NOW contributed to the accumulation of a solid basis of know-how in the field of materials and fatigue properties, load effects, possibilities for the reduction of noise emission, and flexible components for advanced turbines (tip adjustment, blade attachement and the like). Furthermore, international developments were monitored in a number of fields, including that of stall control. The know-how developed in the NOW in the fields of noise emission reduction, material expertise and fatigue properties has led to concrete improvements of existing turbines. In other fields, the results have assumed rather a "proof of concept" form. They have been tested in theory and (laboratory) practice but still require further development for concrete application.

With regard to environmental and other aspects, the NOW produced an effective insight into the energy output of wind turbines, the danger to birds and the possibilities of generating electricity offshore. With the pilot wind power plant in Sexbierum, the Netherlands has a unique opportunity to study the effects of windfarms. Table 2.6.1 summarizes the achievements of the NOW 1986-1990.

Continuation of the support research activities is crucial to the further development of wind energy applications. However the place and position of those activities will have to be adjusted. The initiative of the public utility companies and the concentration of the wind turbine manufacturers allows and necessitates further exploration of the market. In addition to consolidating the knowledge base, technological developments in the coming years will have to concentrate particularly on the concrete application of know-how by the various market parties. Research into environmental and other aspects will have to focus on supporting wind energy projects to be carried out in the coming years.

Present state of affairs

In late 1991, the installed wind turbine capacity in the Netherlands amounted to approximately 80 MW, with another 10 MW under construction. The system of investment subsidies run by the Ministry of Economic Affairs and the wind energy plan adopted by the energy distribution companies are particularly important to the further expansion of this capacity in the coming years. They contribute to continuity on the market, enabling manufacturers to concentrate on improving their products, enabling them to benefit from the effects of large-scale production. The power companies' plan to erect 250 MW of wind power in the coming years is of crucial importance, offering the suppliers a clear perspective of continuity.

The last few years have seen a distinct concentration on the supply side. Newinco and Bouma have merged into Nedwind under the Hollandia Kloos' flag, while Holec and Windmaster Nederland have also been combined to one concern (Begemann). In addition to these two Dutch turbine manufacturers, with their capacity for 250 kW or larger units, two other manufacturers are active in the production of smaller turbines.

Table 2.6.1 Main results of the NOW programme

Scope of the NOW	Main results 1986-1990
Load and fatigue research	• draft guidelines for basic material • application of the WISPER load spectrum • model for wake effects in windfarms
NEWECS 45	• turbine evaluation
Wind turbine adjustment	• theoretical model
Siting research	• 1000 MW feasibility study
Bird research	• inventory of nuisance to birds, e.g. at the Urk windfarm
Energy output	• energy output calculation manual • methodology for charting wind supply
Draft data	• manual of draft wind data I, II and III
Noise	• RHOAK calculation model • improvement of Holec turbine
Certification	• NEN 6096/2 guideline • national consensus
Offshore	• preliminary research
Flexhat	• definition of safety strategy of conversion and control system • design and testing of passive tip adjustement • design of flexible hub and rotor with tip control

Large-scale systems

IPW installed and under construction	90 MW
Planned IPW capacity	35 MW
IPW result	125 MW
(IPW goal: 100-150 MW)	

Windfarms

Over 80 % of the installed capacity consists of 20 windfarms of 1 MW or more. The largest windfarms are:

Urk (+ extension)	HMZ 300	15 MW
Lelystad (+ extension)	HMZ 300	10,5 MW
Maasvlakte	Newinco 500	8 MW

Wind turbines > 500 kW:

Newecs 45	1000 kW	Medemblik	routine operation
Newinco (Nedwind)	500 kW		series
Windmaster	500 kW	Halsteren	six units
Holec	550 kW	Urk	prototype
Windmaster	750 kW	Halsteren	prototype

The 1 MW Nedwind 50 prototype under design will be installed in 1993.

Government policy on the application of wind energy

The government's current concern for the development of sustainable energy sources, including wind energy, originated in the seventies. The club of Rome and two oil (price) crises made the western world aware of an imminent shortage of fossil fuels and the risks of dependence on oil imports. In response, the Dutch government and the other OECD countries formulated a new energy policy. The core of this new policy amounted to the diversification of energy sources and the increased efficiency of energy consumption (conservation).

The policy has contributed to a reduction, though not elimination, of the dependence on mineral oil. The recent history of the Gulf once more demonstrated the vulnerability of the oil supply. In addition, another important development has become apparent in the last few years. It is becoming increasingly clear that the current volume of fossil fuels being consumed has unacceptable consequences for the global climate. Acidification and the greenhouse effect are major issues. In the National Environmental Policy Plan (NMP and NMP-plus), the government has expressed its ambition to cope with these problems. This has significantly increased the importance of economizing on the issue of fossil fuels.

The Energy Conservation Paper (Policy Plan concerning Energy Conservation and Recurring Energy Sources, June 1990), published in concurrence with the National Environmental Policy Plan Plus, sets ambitious goals with respect to energy conservation and diversification. As regards wind energy, the goals envisage a realization of wind power amounting to 1000 MW by the year 2000, which would save 17 PJ of primary fuel per year, and to an expansion of that power to 2000 MW in 2010. This is intended to realize a saving of approximately 33 PJ of primary energy per year. To implement these objectives, the Energy Conservation document provides for the following activities:

- The government will continue to support investments in wind turbines for the generation of electricity.

- With respect to the siting problems, the Ministries for Housing, Regional Development and the Environment and of Economic Affairs have taken initiative of promoting consultations with the provinces and municipalities. Realization of the objectives will require considerable administrative endeavours at local, regional and national levels.

- Legislation and agreements are to be established on payments to private operators for electricity returned to the grid, certification of wind turbines and adjustment of siting policy.

- General information will be distributed to operators, local government and the general public, and technical information will be provided to designers, assembly companies and local government.

- Technological development and innovation in the production of wind turbines will continue to receive support.

In addition, great importance will be attached to the energy distribution companies' initiative to install 250 MW of wind power in the period to 1995.

The long-range TWIN programme 1991-1995 expands on government policy plans in this field. This policy provides more than ever before for an integral approach to the development of wind energy applications in the Netherlands. It devotes attention to providing support in the operation, stimulating development of wind turbines which perform better and are more cost-effective. This integration is made possible, partly due to the IPW, by the development of a solid market demand for large numbers of wind turbines, while the industry is capable of incorporating the results into their products in cooperation with the scientific community.

Besides the integration of market and technological developments, the TWIN programme also breaks with the earlier trend, which can be characterized with the term "technological push". The development of a mature industry and an ambitious market demand allows and necessitates extension of the role to be played by the market in the further development of the wind energy option. Accordingly, TWIN explicitely provides for the market parties involved to play a guiding role.

Developments of research in the Netherlands

In the last few years, Dutch research efforts in the field of wind energy have to a considerable extent been directed and financed by means of various national research programmes in this field. In addition, other activities in the Netherlands are important: research and development shaped by the industry, wind energy research conducted by the ECN (Netherlands Energy Research Centre) and the TNO (Dutch Organization for Applied Scientific Research) within both institutes' basic and target subsidy programmes, university research activities financed by the Ministry of Education and Science, research carried out by the electricity industry (distribution firms, KEMA [Dutch quality-control institute for electrical materials and appliances], SEP [Cooperative electricity production companies]), and research within the scope of international development. The TWIN programme reacts to this with a view to efficient use of public funds.

In the ECN's "own" programme, in which approximately 2 MNLG is spent each year on wind energy, attention is focussed on aerodynamics, durability and fatigue, electric conversion and regulation, criteria for certification and standards, and offshore applications. The character of this ECN target subsidy programme differs from that of the TWIN. The latter concentrates on the stimulation of research activities, which are deemed necessary for the relization of conrete policy objectives. The primary purpose of the ECN target subsidy programme is the improvement of the institute's research potential, in order to be able to react adequately to possible assignments from third parties. In other words, for the ECN, the target subsidy programmes are the preparatory stage for potential Novem assignments or contract research for third parties. The programme, therefore, is specifically oriented towards the development of measuring methods, simulation models, test procedures and the like.

As for university activities, the Institute for Wind Energy at the Technical University of Delft plays an important role, both in research and in researcher training. The research focusses predominantly on fundamental aspects, such as aerodynamics and loads.

The research conducted by KEMA, which was commissioned by various distribution companies, includes subjects like certification, windfarm outputs and windfarm regulation.

Novem intends to pay particular attention to the interplay between the various research programmes. Possible forms of cooperation will be stimulated. The section of the TWIN programme concerning the transfer of know-how will endeavour to process the results of national and international research conducted by institutes other than Novem.

Wind energy subsidies

Two types of subsidy are available: an investment subsidy, provided by the Ministry of Economic Affairs, and an incentive for the application of wind turbines with low noise emission levels, provided by the Ministry of Housing, Physical Planning and the Environment. The expression to calculate the amount of subsidy is:

$S_1 = k_1 * (1{,}5*A + P)$ NLG, where

k_1 = a constant which depends on the size of the machine or the legal status of the (future) owner, see Table 2.6.2

A = the swept rotor area (m^2)

P = the rated power (kW).

The maximum value of S_1 is $S_1 = k_2*A$. For the value of k_2, see Table 2.6.2.

Table 2.6.2 Subsidy constants for wind energy projects

1991	Utilities	Non-utilities	
		$A < 400\ m^2$	$A > 400\ m^2$
k_1	185	240	300
k_2 max	350	480	600

1992	Utilities	Non-utilities	
		single	windfarms
k_1	175	175	240
Max 1)	35 %	35 %	40 %

1) percentage of project costs

There are two conditions which have to be fulfilled in order to receive subsidies:

1) the wind turbine types to be applied have to meet the requirements, formulated in the draft standard on the safety of wind turbines NEN 6096/2; version 1.0, November 26, 1990.

2) The wind turbine has to be certified by ECN before April 1, 1991, provided that the certification contract was signed before December 1, 1990.

the subsidy S_2 for "silent" wind turbines is

$$S_2 = 25 * A \text{ NLG in 1991, and}$$
$$S_2 = 50 * A \text{ NLG in 1992}$$

The condition which has to be fulfilled in order to receive this subsidy is that the immission relevant acoustic source power level L_{wr}(dB(A)) should meet the following conditions:

$$L_{wr} < 22\log D + 65 \text{ dB(A) in 1991}$$
$$L_{wr} < 22\log D + 64 \text{ dB(A) in 1992}$$

The main components of the TWIN programme

Component I: Implementation

a) Aim

To implement wind energy in the Netherlands at an average rate of 60 MW per year, thereby realizing a wind power capacity in 1995 of 400 MW that will save 7 PJ of primary energy per year.

b) Realization

The wind turbines will be commissioned by the distribution companies and private operators. Financial support for investments and feasibility studies is provided for in a special subsidy regulation. This regulation was gazetted on 28 December 1990. The amount of subsidy available will be published annually. Novem is responsible for this regulation.

In addition to implementation of this subsidy regulation, the programme provides for the possibility of contributing to the funding of specific studies and research projects which provide support in the siting of wind turbines.

c) Activities

- Implementation of the subsidy regulation.
  The installed wind power capacity should expand to 400 MW by 1995. A subsidy regulation has been announced in view of the cost price of wind turbines and the expected cost price development. This includes not only investment subsidies, but also subsidies for low-noise turbines (see previous section). The main characteristics is that the amount of the investment subsidy depends on both the rotor diameter and the generator capacity. In addition, a distinction has been made between investment subsidies for private operators and distribution companies.

- Support for project realization and information
  The realization of wind energy projects entails a variety of problems. If the intended rate of implementation is to be achieved, a number of problems regarding project realization will have to be clearly recognized and resolved. For this reason, operators will be offered support in the development of locations, by providing them with know-how, having project-oriented research conducted, or mediating in conflicts, for example. Information on the relevant results will be provided to interested operators, licensors, participants and other parties involved.

- Spatial integration and information
  An administrative agreement has been concluded between the national government and seven provinces regarding the development of over 1000 MW of wind turbine capacity. Municipalities will receive support in the concrete execution of this administrative agreement by providing support to a number of sample projects. Those interested will be informed of the results of these projects.

- Reporting the effects of birds
  In accordance with the proposal made by the Coordination Committee on Nuisance to Birds, the desirability of research into the effects on birds will be examined per wind energy project.

- Monitoring
  A variety of data (costs, output, malfunctions/availability, noise) on wind turbines located in the Netherlands will be collected and analysed. The results will be used for purposes including the evaluation of the TWIN programme objectives and for directing the research within components II and III of this programme.

Component II: Industrial development

a) Aim

Improvement of the price/performance ratio by about 30 % and improvement of the placement capacity of wind turbines. Reduction of the cost price and increase in the quality, lifetime and reliability of wind turbines should help to realize an average cost price of wind energy, generated at the proper locations of 0,14 NLG/kWh (the current state of technology yields a cost price of 0,20 NLG/kWh).

The improvement of safety, noise reduction and the increased size of available turbines will contribute to optimal utilization of the siting potential in the Netherlands. Concrete milestones in this respect are the reduction of the average noise production of the present turbines by 6 dB(A) and the expansion of the available capacity range with a turbine having a rotor diameter of 40-55 m, at a cost price of generated electricity not exceeding 0,20 NLG/kWh.

b) Realization

Projects within this component must be initiated by the wind turbine manufacturers. This will frequently necessitate the introduction of scientific know-how. The activities related to this component are intended to support industrial research and development.

This programme element implies a change compared to the policy conducted to date. This does not concern generic support, but a specific instrument to improve the quality and price/performance ratio of wind turbines that are selected on the basis of their significance to the further implementation of wind energy.

c) Activities

- Product improvement
  The energy distribution companies are chiefly responsible for the demand of wind turbines, particularly turbines with rotor diameters ranging between 25 and 35 m (250 to 500 kWh). The expectation is that the price/performance ratio and siting capacity of these turbines can still be improved.

  The industry is as yet unable to bear the total development costs involved. Part of these will funded from the TWIN programme, namely the further development and improvement of the existing wind turbine types. Wind turbine manufacturers are particularly eligible as contract parties. The know-how available at research institutes and engineering firms will have to be used to accomplish the necessary improvements as efficiently as possible, including know-how concerning aerodynamics, materials, loads, design tools, components and the like.

In addition to the wind turbine in the Netherlands, there is also a market for special wind turbine types (including very small models) intended for export. This programme component also involves a moderate degree of support for projects concerning the improvement of these special wind turbines.

Turbine development
In view of the necessity of limiting emissions and the expected development of the price/performance ratio of wind turbines, there are prospects for a market after 1995. Due to the limited space available in the Netherlands, it is necessary for wind turbines with a rotor diameter of approximately 40 to 55 m to be available after 1995. Given the time at which these wind turbines will have to be available, the development of wind turbines in this capacity category will have to be based on current technology. This will prevent unnecessary risks posed by the introduction of new technology and is linked to industrial trajectories already underway. In addition, on the basis of current technology, wind turbines in this capacity range are expected to be capable of achieving a price/performance ratio similar to the current wind turbines with a rotor diameter between 25 and 35 m. Conventional concepts are therefore applied in the development of wind turbines with a rotor diameter of between 40 and 55 m. In relation to wind turbine development, again, wind turbine manufacturers are the first eligible contract parties. Also, in order to realize this development, full use will have to be made of the know-how available at the research institutes.

Within this line of research, attention will have to concentrate on the development of wind turbines with a rotor diameter in excess of 35 m, based on tested technology. These turbines are intended for application after 1995 and will have to show better prospects of spatial integration than the current turbines. To achieve this, it will be necessary to introduce know-how in the same disciplines as mentioned in product improvement. The following subjects are also important:

- The possibilities of stall, in possible combination with pitch control;
- Support in the design stage and the creation of an industrial development trajectory;
- Support for the industrial development and testing of wind turbines in this category.

Component III: Technological development

a) Aim

The creation of techno-scientific preconditions for continued industrial product improvement and development, and to complete a practical evaluation of the technological innovations currently under development.

b) Realization

The activities related to this component will be primarily carried out by the scientific institutes and research agencies. Programme direction provided by the industry and operators offers the possibility to coordinate the accumulation of know-how with the practical situation. Market parties will be regularly consulted in regard to the programming , progress and results of these activities. For his purpose, a platform will be set up to advise Novem in broad outlines on the projects to be initiated. An attempt will be made to increase commitment on the part of the industry, in order to guarantee the applicability of the results.

A practical evaluation of the technological innovations that are being developed is also provided for. The technical and economic values of the various innovations will be established on the basis of a modified version of an existing turbine, serving as a representative scale "reference model". This project will be set up in consultation with the industry and research institutes.

c) Activities

- <u>Solving technological problems</u>
  The development of wind turbines requires a solid basis of scientific know-how. This must contribute to solving present and potential future problems in the industrial product development and improvement process. Research in the fields of aerodynamics, fatigue, loads, stall control, components and materials is considered necessary in this regard. This research will focus on the application of the results in the (industrial) design process and in the international development of standards, and will have to lead to the production of usable design tools.

- <u>Evaluation of technological innovations</u>
  The development of wind turbines for the longer term is oriented towards wind turbine types which will exploit the wind energy potential in the Netherlands to the full. This means that the available land surface must be used as efficiently as possible, while meeting the preconditions regarding cost price, noise production, and

integration into the landscape. This requires the availabilty of a differentiated range of wind turbines in various size categories, including large wind turbines. The desired wind turbine cost price reduction, for large turbines in particular, requires the use of simple and relatively light designs. The required technological innovations have already been covered in the NOW. This has led to a number of promising results.

The research concerns load reduction by using flexible components, allowing a lighter design. Wind turbines can be simplified through the use of alternative control systems. In addition to the research on rotor aerodynamics and control, loads and fatigue, relevant materials and components, attention will be devoted, in close consultation with the aforementioned platform, to the following subjects:

- Completion of the current FLEXHAT research;
- Construction of the "reference model" and practical evaluation of the various components and systems. A relevant test criterion is the question of whether these innovations will make the existing turbines cheaper and create opportunities for the development of cost-effective large turbines;
- Definition of an industrial development trajectory for large wind turbines. The industry will have to act as an initiator. An examination will be made as to whether this development can be set up or supported at international level.

Component IV: Offshore

a) Aim

The formulation of a development trajectory for wind turbines at sea. The main activities are to be started after 1993.

b) Realization

Potential institutes/companies that have specific expertise in realizing offshore projects, the wind turbine industry and research institutes will be involved in carrying out these activities.

c) Activities

The Energy Conservation Paper provides for the location of approximately 200 MW at sea. The high infrastructure costs of wind turbines at sea necessitate the development of large wind turbines. In addition, the corrosive climate will entail specific demands, while the requirements regarding safety and noise production could be reconsidered.

The development of wind turbines for use offshore can be applied more effectively once the usability of new technical concepts for turbines with a rotor diameter in excess of 55 m has been examined. For this reason, the specific offshore development activities will be started at the end of this long-range programme (in 1993). The activities of this component mainly concern research into the planning possibilities and the specific technical requirements important to offshore wind turbines. Moreover, a development trajectory for offshore wind energy will be defined, and international developments will be closely followed.

Component V: Transfer of know-how and programme support

a) Aim

Making the available know-how accessible and usable, and carrying out any activities required to test the current programme against market developments.

b) Realization

The exchange of know-how and experience in the field of the development and application of wind energy between the various parties involved is extremely important. The research institutes, engineering agencies, industry, operators and the administrative bodies involved will be closely engaged in the process.

c) Activities

Activities such as organizing workshops, symposia and conferences, publishing brochures, general data collection and the like will receive support within the scope of this component. For this purpose, Novem will formulate a communication strategy dealing with the entire system of know-how utilization: the generation, flow, transformation, consolidation, and utilization of know-how. The strategy, which is still in the development stage, will discuss the role of the parties involved in the network in question and the communication activities to be developed in that context. The development of the communication strategy will also concern the role that information could play, particularly with respect to the spatial integration of wind energy and the reinforcement of the social basis.

In addition to the transfer of know-how, a certain degree of programme support and further development of the programme is also desirable. This will include exploratory studies, inventory of international developments, overview studies and the like. A significant part of the activities will also concern the promotion of international cooperation and the exchange of know-how with foreign countries.

Timetable and financial means

The total costs of the long-range TWIN programme 1991-1995, exclusive of subsidies for investments and feasibility studies, are estimated at more than 42 MNLG.

Component I comprises support for the implementation of wind energy. A budget of 7,5 MNLG is considered necessary for the purpose. Both the Ministry of Economic Affairs and the Ministry of Housing, Regional Development and the Environment will provide a contribution.

Compnent II focusses on the industrial product development and improvement, for which 15 MNLG is considered necessary, allowing for the funds that the industry believes it is capable of allocating for R&D.

Component III comprises technological development. The budget required for this component is estimated at 15 MNLG and will be spent on techno-scientific support of industrial product development, the completion of the "reference model" and the intended practical evaluation. Novem and other institutes will contribute to the research on technological development.

The budget for component IV, offshore, is estimated at 3 MNLG, the emphasis being on post-1993 activities.

Component V comprises activities for the transfer of know-how and programme support, for which 1,8 MNLG is considered necessary.

2.7 Norway

The Norwegian wind energy programme has two main activities:

- Research and development, budget 3,4 MNOK for 1991
- Introduction and demonstration, 1,4 MNOK for 1991

The objectives are to survey the wind energy potential and to assess the utilization of wind energy, to promote Norwegian industry in the field, to support the construction of demonstration plants and to inform potential users of the results.

The Norwegian Water Resources and Energy Administration (NVE) is coordinating the programme, which is carried out with participation of electric utilities, manufacturing industries, and research institutions.

Studies of the integration of wind power into existing grids show that the conditions are favourable in certain coastal areas with high winds. The wind energy potential along the coast has been estimated at about 12 TWh (billion kWh) per annum in the cost range of 0,35 - 0,65 NOK/kWh. The Norwegian hydro power system can integrate a substantial amount of wind power without problem. At the present time, however, new hydro power generates electricity at about half the cost of wind power, on the average.

The target of the current wind power programme is to have around 4 MW of generating capacity installed by 1992. At the end of 1991, about 2,9 MW was installed, yielding about 7 GWh per year. This is a tiny fraction of the total electricity production in Norway, which was about 120 TWh in 1990, supplied entirely by hydro power.

The first windfarm, consisting of three 400 kW units, was inaugurated in early October 1991 at Vikna north of Trondheim. The annual energy output is expected to be 3,2 GWh. The installation cost was 12,9 MNOK, 50 % of which was funded by the government. In addition, two wind turbines, each of 400 kW rated power, were installed during 1991 in the Vesterålen islands, west and north of Narvik.

Wind-diesel autonomous systems have been studied in Norway since 1986. A demonstration plant with a 55 kW wind turbine and a 50 kW diesel engine has been tested against consumer load since June 1989 at Titran on the island of Frøya off the coast of Trondheim. Development of a second generation wind-diesel system started in 1990 at the Electric Power Research Institute, Trondheim, in cooperation with EB energy, a member of the ABB group.

2.8 Spain

Wind energy programme

The year 1991 was a break-through for the utilization of wind energy in the Spanish electricity generating system. During the year, the construction of three large windfarms was initiated:

- The 3 MW windfarm at Cabo Villano in the northwest corner of the Iberian peninsula;

- The 20 MW PESUR and the 10 MW E.E.E. windfarms in the Tarifa area near the Straits of Gibraltar.

Two additional windfarms have been approved and are now in the planning stage:

- The 10 MW Jandia windfarm at Fuerteventura, Canary Islands;

- The 4 MW Tortosa windfarm at the mouth of the river Ebro.

In summary, a total of 33 MW of wind power capacity is under construction and will be operational during 1992. Another 20 MW is in the planning stage.

The third national renewable energy plan, PER-89, for the period 1989 - 1995, foresees about 100 MW of wind power by 1995. The total investments are estimated at 13 600 MESP (≈ 105 MUSD), of which slightly less than half is expected to come from public funds.

Windfarms

Presently, eight windfarms for a total of 5,31 MW rated power are in operation as indicated in Table 2.8.1. The locations are shown in Figure 2.8.2.

Generally, the energy production is low for the windfarms installed during 1988, because of their experimental character. This contrasts with the excellent results obtained at the new windfarms, for example Tarifa, where availability factors of about 95 % and capacity factors of about 36 % are reached.

The three large windfarms now under construction are expected to begin operation next year, see Table 2.8.1. The windfarms of PESUR and E.E.E will, together with Tarifa and Monte Ahumada, provide the largest concentration of wind turbines in Europe with a total of 272 units and a capacity of 33 MW. The annual production is expected to be about 100 000 MWh, equivalent to 175 000 barrels of oil.

The windfarm at Cabo Villano is in an advanced stage of construction with the installation of 20 MADE AE-20 150 kW wind turbines. It is expected that the complete windfarm will be connected to the grid in Spring 1992. Together with the existing AWEC-60 and the two Vestas machines, the total installed power will be 4,5 MW.

It is foreseen that the installation of new wind turbines will continue during the next years. Another four windfarms are now in the planning stage. They are expected to start operation during 1993 and 1994 with a capacity of 20 MW. 15 MW would be installed in the Canary Islands and the rest in the north-east of the Peninsula (Tarragona).

Including isolated installations of private owners, the total installed wind power will be close to the proposed goal of 100 MW in 1995.

The AWEC-60 project

Introduction

The AWEC-60 project (Advanced Wind Energy Converter - 60 m rotor diameter) was conceived in Spring 1985 by a Spanish-German consortium formed by a manufacturing industry (MAN Neue Technologie GmbH), two research organisations (CIEMAT-IER and Asinel) and a utility (Union Fenosa S.A.). The aim was to develop, manufacture, test and operate a large-scale wind turbine of 1,2 MW rated power. The project is supported by DG XII of the CEC, the BMFT (Germany) and Ocide (Spain).

The first rotation of the wind turbine took place in October 1989 and the acceptance tests were completed in March 1990. Since then the wind turbine is in operation under the supervision of Union Fenosa S.A. At the end of May 1991 more than 800 hours connected to the grid were completed and the cumulated energy output was 514 800 kWh.

During a programmed revision of the wind turbine in May 1991, a crack in the main spar of blade number two was detected. The blade was dismounted for repair. It was re-assembled during the first week of October and the machine was put into operation again during the following week . After several hours of operation, the blade was checked and some tests were performed which demonstrated that the repair had been successful.

Monitoring and Evaluation

Monitoring and evaluation of the wind turbine has been performed within the scope of the JOULE programme of the CEC DG XII, the "Follow-up of WEGA Projects". These projects pursue the analysis of the results from measurements on the three wind turbines in the WEGA programme, in such a way that a maximum of information can be obtained in a coordinated action between WEGA projects.

The short-term objectives , i e those to be achieved within the time frame of the project, are:

- To obtain better and unified technical reports from the projects and ensure that the same weight is attached to essential issues in all three projects;

- To create a comprehensive and well documented data base consisting of time series describing the aerodynamics as well as the mechanical behaviour of the turbines.

The long-term objective is that the data base with time series shall be available to researchers in the wind energy and aerodynamics fields and in this way help to introduce wind energy in the European electricity supply system in an economic and safe way.

The project is carried out among the following LWTS owners:

- Vestkraft I/S, operating the Tjæreborg wind turbine in Denmark

- Power Gen Plc, operating the Richborough wind turbine in England

- Union Fenosa S.A. operating the AWEC-60

The reports by the contractors shall be prepared according to common template reports, one for each subject. The following reports are in preparation:

- Measurement System Calibration
- Duty Cycle Measurement System
- Loads During Normal Operation
- Extreme Loads and System Events
- Fatigue Loads Characteristics
- Aerodynamic Behaviour of the Rotor
- Control Quality Analysis
- Power Curve Sensitivity Analysis
- Cost of Operation and Maintenance

Operation and Maintenance Experience

The statistics for the twelve-month period May 1990 through April 1991, including cumulated operating hours and energy output, are shown in Figure 2.8.3. The distribution of manhours for repair and maintenance work during the same period is as follows (see also Figure 2.8.4):

Component	Percent of total manhours
Rotor	7
Pitch mechanism	6
Drive train and gearbox	2
Generator	2
Yaw system	20
Hydraulic unit	2
Control system	7
Auxiliary systems	14
Other maintenance	40

The main work on the rotor system concerned repairing, checking and painting the blades. It was also necessary to make several modifications in the shape of the spinner to prevent inleakage of water into the hub.

The manhours spent on the pitch mechanism reflects the incident which occurred with the sensor of the pitch angle position, and several check-outs in other parts of the blade actuators.

The work on the drive train, generator, hydraulic unit and control system has been for trimming the systems. The main part was carried out before April 1990.

The yaw system has required a large number of hours for repair and maintenance, being one of the most critical parts of the wind turbine.

The auxiliary systems include the cooling system of the generator and nacelle, the tower, the nacelle and the diesel set. The main part of the maintenance took place at an early stage of the project (before April 1990).

Other maintenance includes the remaining parts of the plant, for instance the meteorological mast, the electric grid, the data acquisition system and the control room and shows a continuous increase in the manhours spent. The frequent thunderstorms and gales and the very corrosive environment necessitate a continuous maintenance programme.

Pilot projects and demonstration plants

Wind/diesel plant at Epila (Zaragoza)

The system is based on a 30 kW Ecotecnia 12/30 wind turbine and a 20 kVA diesel generator connected to an isolated grid, supplying power to two centrifugal pumps and an irrigation system, see Figure 2.8.6.

The system has two different operation modes. When the diesel generator is not connected to the grid, the wind turbine works directly on the pumps with a wide frequency variation margin (rotational speed of the wind turbine). When the diesel is connected to the grid, the whole system works with constant frequency and voltage.

After several months of operation, the system configuration appears to be a reliable solution for irrigation applications. The variable frequency driving the pumps demonstrates very good behaviour and absorbs fast wind speed changes.

Wind/diesel system for supplying electricity to a fishermen village at Jandia (Fuerteventura, Canary Islands)

This project, which is supported by the Valorem programme of the CEC, is in the final stages of construction. All civil works have been completed and all subsystems have been procured.

The plant consists of a Vestas 220 kW wind turbine and two diesel systems of 60 kW each, see Figure 2.8.5. It supplies electrical energy for the following services: reverse osmosis seawater desalination, public lighting, domestic uses (lighting, household appliances etc), cold storage room for fish conservation, and sewage water biological treatment.

The plant is scheduled to start operation in Spring 1992.

Industrial activities

The Spanish wind turbine manufacturers have experienced a high activity during 1991 due to the ongoing windfarm installations. During the period August 91 - August 92, the three main manufacturers, Made, Ecotecnia and AWP (Abengoa Wind Power), will deliver around 300 units rated between 100 and 150 kW.

New developments include the Made AE-25 with 25 m rotor diameter rated at 300 kW. The prototype will start operation and testing in February 1992. The Made company is also working on the next development step, a 500 kW unit which is in the stage of preliminary design.

Ecotecnia is working on a modification of the 20/150 model, scaling it up for 24 m rotor diameter and rated at 200 kW. The commercial version will be known as Ecotecnia 24/200. Ecotecnia is also marketing a new stand-alone wind turbine, rated at 40 kW.

The Immetusa company continues to manufacture wind turbine blades, under licence of Stork. From the beginning of its activity, the company has fabricated more than 3000 blades.

R&D activities

The wind energy R&D activities are continuing at public and private institutes, but no new R&D programmes have been launched during 1991. Several university groups (Univ. Politécnica de Las Palmas, Univ. Politécnica de Madrid, Univ. Politécnica de Salamanca) are carrying out studies and R&D projects in different fields, for example assessment of wind characteristics, wind-diesel systems, wake effects, and fatigue characteristics of laminated composites for use in wind turbine blades.

The main centre for R&D projects is the Instituto de Energias Renovables (IER) of CIEMAT. This institute has been working in various fields of wind energy research since 1985. Several projects are in progress, e g:

- The evaluation of AWEC-60 referred to above;

- The JOULE project "Reference Procedure to Establish Fatigue Stresses for Large-Sized Wind Turbines";

- Activities in the field of composite materials and their application to new blade manufacturing processes;

- Operation of the "Fatigue Test Plant for Blades of Small and Medium-Sized Wind Turbines";

- Environmental studies. Due to the fast increase of wind energy utilization in Spain with the installation of more than 300 wind turbines during 1991 and 1992, the Institute has started a number of studies of the environmental aspects of windfarms, for example visual impact, noise effects, impact on animal life, and social influence on neighbouring population.

WINDFARMS IN OPERATION IN SPAIN - UPDATE November 30, 1991

WINDFARM			WINDTURBINES			MACHINES N°	YEAR	ENERGY OUTPUT (MWH)	
NAME	LOCATION	TOTAL POWER (MW)	MANUFACTURER	MODEL	RATED POWER (kW)			1990	ACCUMULATED
GRANADILLA	GRANADILLA TENERIFE (CANARY ISLANDS)	1,38	MADE ECOTECNIA W.E.G. CENEMESA VESTAS ENERCON	AE-20 20/150 25/250 FL-19 V 25 34	150 150 250 300 200 330	1 1 1 1 1 1	1990 1990 1990 1990 1990 1991		1700
LA MUELA	LA MUELA (ZARAGOZA)	0,55	GESA GESA	10/3 AE 15 AE 18	30 75 110	12 1 1	1987 1988 1988	363	1342
ESTACA DE BARES	MAÑON (LA CORUÑA)	0,36	GESA	10/3	30	12	1987	588	1427
ONTALAFIA	ALBACETE	0,30	ECOTECNIA	12/30	30	10	1988	337	1109
TARIFA	TARIFA (CADIZ)	0,45	ECOTECNIA ECOTECNIA	12/30 20/150	30 150	10 1	1988 1989	783 442	2767 1008
MONTE AHUMADA	TARIFA (CADIZ)	1,38	MADE CENEMESA	AE-20 FL-19	150 330	7 1	1989		
CABO CREUS	GERONA	0,59	GESA GESA	AE 15 AE 18	75 110	2 4	1990		
CABO VILLANO	CAMARIÑAS (LA CORUÑA)	0,30	VESTAS VESTAS	V 25 V 20	200 100	1 1	1990	676	1530

WINDFARMS UNDER CONSTRUCTION - UPDATE November 30, 1991

WINDFARM			WINDTURBINES			MACHINES N°	YEAR	ENERGY OUTPUT PREDICTED (MWH/year)
NAME	LOCATION	TOTAL POWER (MW)	MANUFACTURER	MODEL	RATED POWER (kW)			
PESUR	TARIFA (CADIZ)	20	MADE A.W.P.	AE-20 AWP-100	150 100	33 150	1992	68.000
E.E.E.	TARIFA (CADIZ)	10	ECOTECNIA MADE	20/150 AE-20	150 150	50 16	1992	32.000
CABO VILLANO (2nd PHASE)	CAMARIÑAS (LA CORUÑA)	3	MADE	AE-20	150	20	1992	9.000

WINDFARMS AT PLANNING STAGE - UPDATE November 30, 1991

WINDFARM			WINDTURBINES			MACHINES N°	YEAR	ENERGY OUTPUT PREDICTED (MWH/year)
NAME	LOCATION	TOTAL POWER (MW)	MANUFACTURER	MODEL	RATED POWER (kW)			
JANDIA	FUERTEVENTURA (CANARY ISLANDS)	10	ACSA-VESTAS	V 27	220	45	1992	
BAJO EBRO	TORTOSA (TARRAGONA)	4	ECOTECNIA DANWIND	20/150 27/225	150 225	14 8	1993	
LEVANTERA	TARIFA (CADIZ)	0,6	T.B.D.		150	4	1993	

Table 2.8.1 Windfarm Data

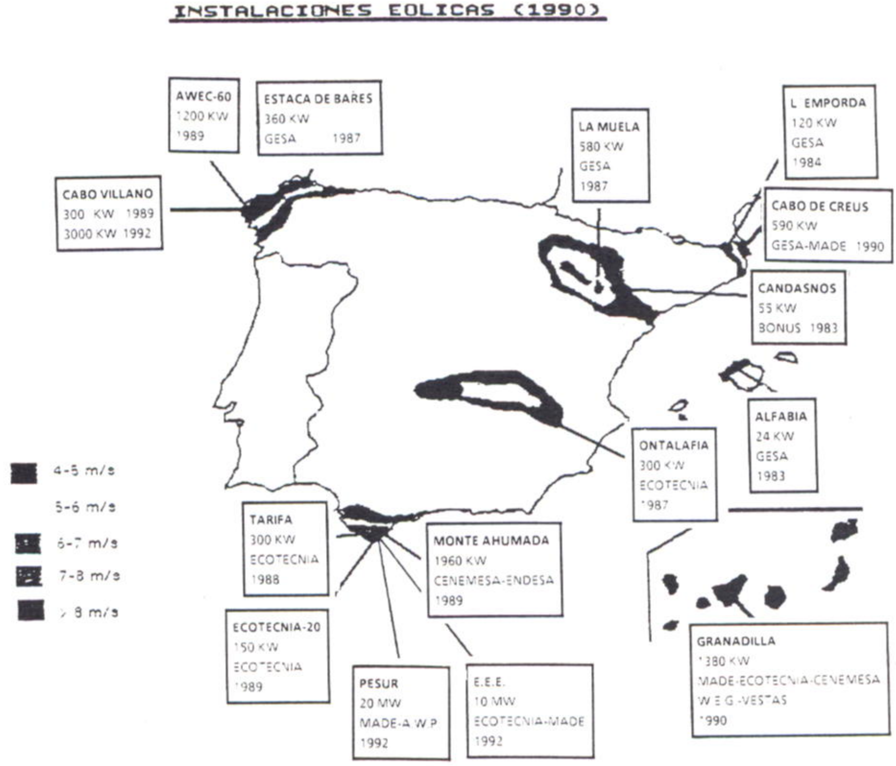


Figure 2.8.2 Location of Windfarms

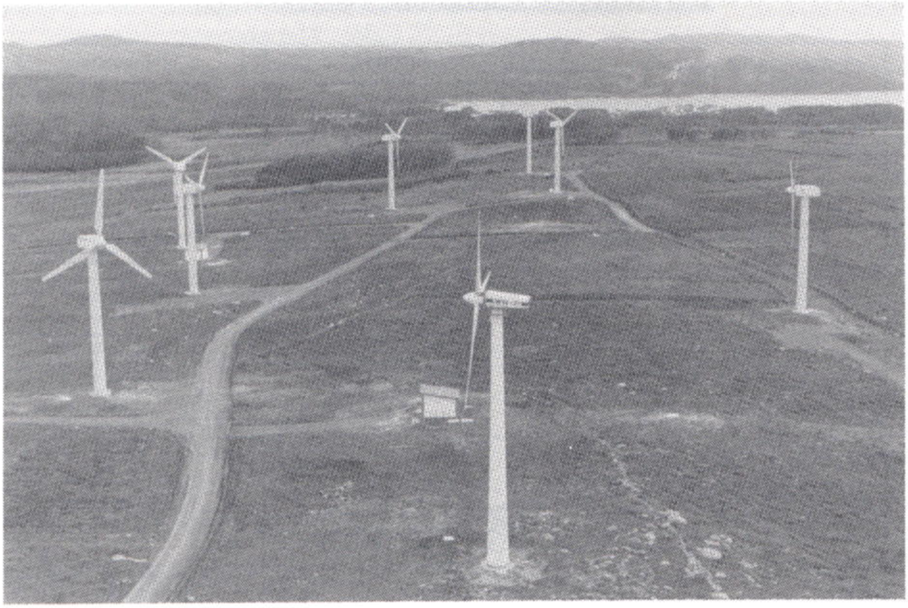
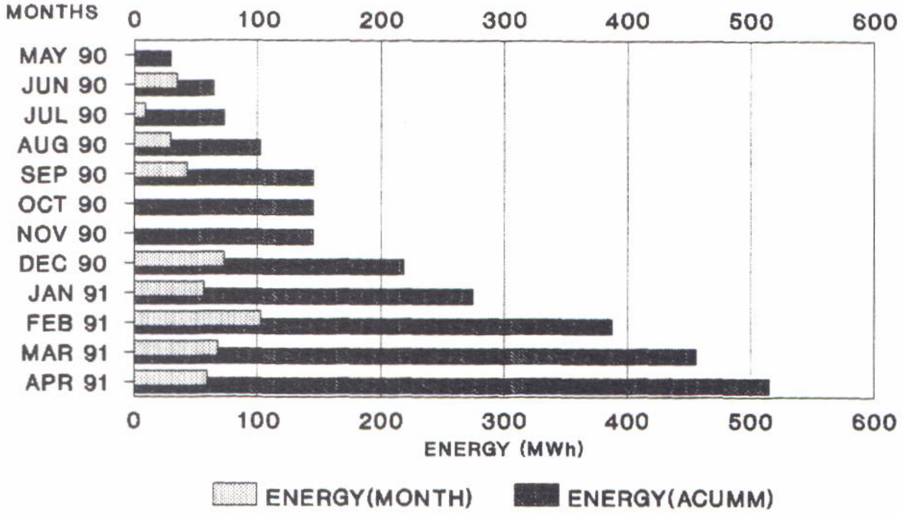


Figure 2.8.3 Windfarm at Cabo Villano

Figure 2.8.4 The Monte Ahumada windfarm at Tarifa

AWEC-60 PROJECT
PERIOD MAY 1990-APRIL 1991



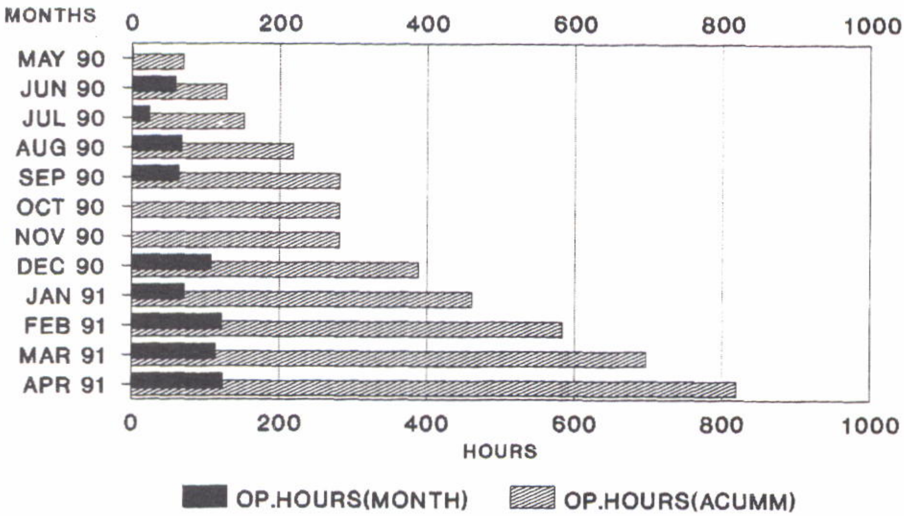
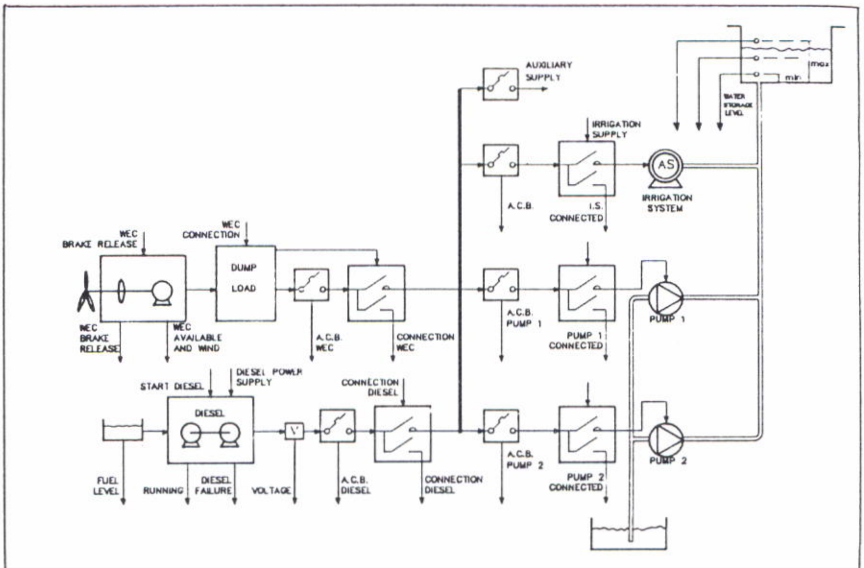
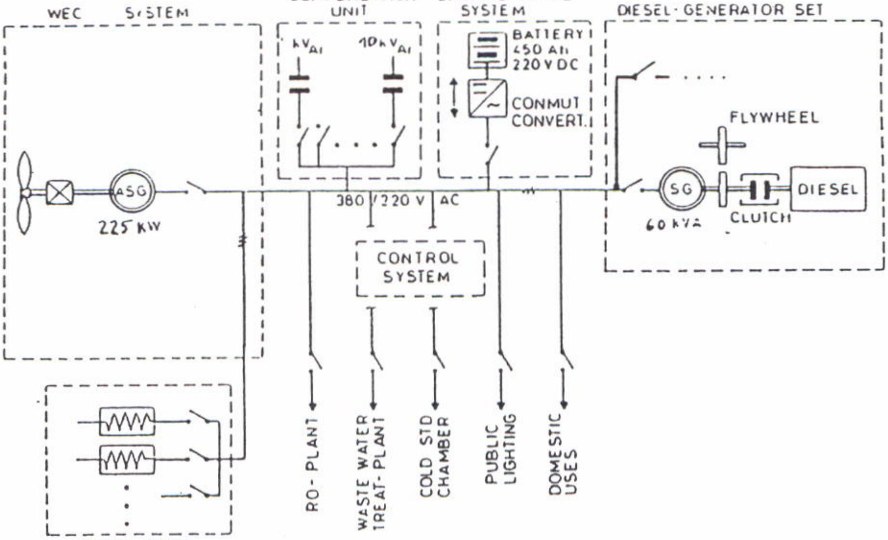


Figure 2.8.5 AWEC-60 Performance Data



System configuration with main control signals.

Wind-Diesel at Epila (Zaragoza)



Wind-Diesel at JANDIA (Fuerteventura)

- SIMPLIFIED UNIFILAR DIAGRAM OF THE WHOLE SYSTEM

Figure 2.8.6 Schemes for Wind-Diesel Plants at Epila (Zaragoza) and Jandia (Fuerteventura)

2.9 SWEDEN

Wind energy programme

The government is sponsoring wind energy in three ways:

- A three-year (1990-1993) research programme with a total budget of 41 MSEK (≈ 7 MUSD);

- Support of development and demonstration projects at maximum 50 % of the cost from the Energy Technology Fund, established in 1988. Increased priority is given to large-scale wind turbines of approximately 1 MW rated power or larger;

- Market stimulation by investment subsidy of wind power plants with minimum 60 kW rated power at 25 % of the cost, effective 1 July 1991.

The programmes are managed by Nutek, a new government agency, formed 1 July 1991 by combining the activities of three former agencies, including the National Energy Administration.

The utilities are increasingly involved in the development and utilization of wind energy. They jointly own the Utilities' Wind Power Company (KVAB) for carrying out studies and projects of common interest, and are sponsoring the demonstration of new energy technologies, including wind systems, through the Swedish Energy Development Corporation (SEU). Vattenfall AB (formerly State Power Board) has a substantial development programme for wind power.

Basic research

The funding of the research programme is rather evenly distributed over the three-year period, which means about 14 MSEK (2,5 MUSD) per year. The work is mainly carried out at universities and national research institutes. The Aeronautical Research Institute (FFA), Stockholm, is performing studies in aerodynamics, structural mechanics, materials, acoustics, control technology, safety and standards. Basic wind research is carried out at the Department of Meteorology, University of Uppsala (MIUU). Electric machinery for wind systems is studied at the Chalmers University of Technology (CTH), Gothenburg, who also operate the Wind Turbine Test Station on the island of Hönö off the west coast of Sweden. The following ongoing research projects may be mentioned:

- Study of low-level jets, i e strong air currents at about 100 m height in coastal regions in spring and early summer (MIUU);

- Wake effect studies at the Alsvik windfarm on the island of Gotland in the Baltic (FFA, MIUU);

- Tests of stall regulation, variable rotor speed and teetering at Hönö (CTH, FFA);

- Study of masking effects of the background on wind turbine noise (FFA);

- Wind tunnel tests of yaw control in cooperation with CARDC, Peoples Republic of China (FFA);

- Development of the rain-flow-count method for wind turbine design (FFA).

Market stimulation

Over a five year period, 250 MSEK (≈ 44 MUSD) are allocated for subsidizing the installation of wind power plants at 25 % of the investment cost. This should correspond to about 100 MW installed capacity by 1996.

By September 1991, the total installed capacity (excluding Maglarp and Näsudden) was about 6 MW. Since the start of the new programme on 1 July 1991, about 4 MW additional capacity had been approved by Nutek in the new programme. The applicants include local utilities, farmers and groups of private people.

The largest installation so far is a windfarm of seven 225 kW wind turbines (Vestas) near Varberg on the Swedish west coast by the local utility, see Figure 2.9.1 The windfarm is expected to generate 3,3 GWh of electricity per year. Another 11 machines are being erected mainly in South Sweden and on the islands of Öland and Gotland in the Baltic.

To qualify for subsidy, the wind turbines must be certified. A certification procedure has been set up. The owners who have received a subsidy are taking part in an evaluation programme of wind turbine performance.

Maglarp

The 78 m, 3 MW Maglarp wind turbine, installed in 1982, resumed operation on 17 March after repair and modification of the gearbox. By 29 November, the machine had generated 27 740 MWh during 21 538 hours on line. The cumulated output is world-leading for a single wind turbine. The Maglarp machine will continue operation by the Sydkraft utility, from 1 January 1992 without government support.

Näsudden

The 75 m, 2 MW Näsudden wind turbine, installed in 1983, was dismantled during 1990/1991 to prepare for the installation of the Näsudden II machinery on top of the existing tower.

Näsudden II/Aeolus II is a joint Swedish/German project for an 80 m/3 MW wind turbine. Näsudden II will be operated by Vattenfall and Aeolus II by PreussenElektra (see section 2.3). Kvaerner Turbin AB, Sweden are supplying the machineries and Messerschmidt-Bölkow-Blohm (MBB), Germany the blades. The cost of the Swedish part of the project is estimated at 100 MSEK (≈ 17 MUSD) and is financed by Vattenfall, SEU and Nutek in the proportion 50/25/25.

The following design advancements from Näsudden I to Näsudden II may be noted:

- The blades have a new design with carbonfibre-glassfibre composite as compared to steel-glassfibre in Näsudden I. The weight of a blade has decreased from 20 to 9 tons in spite of the increased rotor diameter from 75 to 80 m;

- The rated power is increased from 2 to 3 MW;

- The nacelle has a load-carrying beam bed and a light shell in contrast to Näsudden I where the shell was load-carrying. The weight of the nacelle including hub and generator has decreased from 210 to 165 tons;

- The pitch control system has been considerably simplified and all hydraulic equipment has been moved from the hub to the nacelle;

- The rotor speed has been reduced from 25 rpm in Näsudden I to decrease the noise emission. Näsudden II has two fixed rotor speeds, 14 and 21 rpm, whilst Aeolus II uses variable speed between 14 and 21 rpm;

- The hub height of Näsudden I and II is 79 m, Calculations show that a larger hub height would be cost-effective. Aeolus II has 90 m hub height.

- In summary, the energy cost from a Näsudden II - Aeolus II unit is predicted to be roughly half that of Näsudden I, mainly because about 40 % more energy is produced with about 25 % less material in the nacelle.

Delivery of the German machine is due in early 1992 and of the Swedish unit two to three months later. Assembly of Aeolus II is expected during next spring and of Näsudden II during Summer 1992.

The performance of the two units will be compared in a three-year evaluation programme.

A preliminary design study of a third generation 3 MW machine started in late 1991 by Vattenfall together with Kvaerner industries. The aim is to cut the costs by half as compared to those of Näsudden II. If the results are good, a group of five units may be built, possibly at Näsudden.

Risholmen

In 1988, KVAB installed a 750 kW Howden wind turbine on the island of Stora Risholmen in the outer harbour of Gothenburg. After modification of the blade tip actuator system, the machine resumed operation in October 1990. The machine was taken over by the owner in December 1991.

The machine was shut down on 15 September due to oil leakage in the hydraulic system. Inspection of the tip actuator system revealed a crack which required repair. It is expected that the machine will be back in operation in early 1992.

The machine has produced 2368 MWh during 6615 hours on line.

WTS 400

Vattenfall has decided to install two 400 kW wind turbines at Basteviksholmen near Lysekil on the Swedish west coast. One of the turbines will have an advanced design, and the other will be a commercially available machine for reference. The funding model will be the same as for Näsudden II, i e 50 % Vattenfall, and 25 % each by SEU and Nutek.

The design of the advanced machine was completed during the autumn by Nordic Wind Power. The unit was ordered by Vattenfall in December for installation in August 1992. The reference machine, a 450 kW Bonus Mk 2, has been ordered and will be erected in June 1992.

The conceptual design is for a 35 m rotor diameter, stall-controlled, variable speed machine with a teetered hub and possibility of testing yaw control. The main data are shown in Table 2.9.1 and a general view in Figure 2.9.2.

Table 2.9.1 Main data for WTS 40

Rotor diameter	m	35
Hub height	m	40
Rated power	kW	400
Rated wind speed	m/s	13
Rotor speed	rpm	variable
Number of blades		2
Rotor location		upwind
Power control		stall
Generator		asynchronous
Gearbox		planetary
Weight excl foundation	kg	28 000

A design study for a second generation advanced wind turbine in the 500 - 1000 kW rated power range is scheduled to start in mid-1992.

Siting studies

The national wind energy siting study, reported in 1988, proposed sites for an annual electricity production of 3 to 7 TWh (billion kWh) onland and 20 TWh offshore. For comparison, the total Swedish electricity generation in 1990 was 140 TWh.

As a follow-up of the national study, Vattenfall studied the installation of 300 MW of wind power onland in their own distribution area. The study, which was published in September, shows a generation potential of 2,3 TWh/yr for 300 m minimum distance to nearest buildings, and 1,2 TWh/yr for 500 m distance, for sites having wind conditions better than 4,0 MWh/m^2 per year at 100 m height. If wind conditions better than 4,5 MWh/m^2.yr are required, the potential decreases to 1,5 and 0,9 TWh/yr, respectively. Installation of one hundred 3 MW units in the best wind energy areas is estimated to yield 0,7 - 0,8 TWh/yr. Based on Näsudden II technology, the cost of energy is estimated at 0,50 to 0,75 SEK/kWh (0,09 - 0,13 USD/kWh) with 5 % real interest rate and 25 year depreciation period.

Offshore WECS

Sydkraft AB installed in 1990 a 220 kW wind turbine offshore at Nogersund in the province of Blekinge in south Sweden. The turbine is located 250 m from the shoreline at a water depth of 7 m. It is mounted on a steel tripod with concrete legs. During the first year of operation the wind turbine produced about 400 000 kWh which is about 80 % of the estimated production.

The Blekinge project for the study of a 98x3 MW offshore windfarm was completed during the year. The wind turbine design was based on

Näsudden II technology. The work included conceptual design of the electrical and control system and of the support structure, planning of operation and maintenance, study of environmental conditions, and planning for siting approval. The cost of energy was estimated at 0,76 SEK/kWh (≈ 0,13 USD/kWh) with 5 % interest rate and 25 years depreciation time. This is not competitive with presently predicted energy generation costs by other means in Sweden.

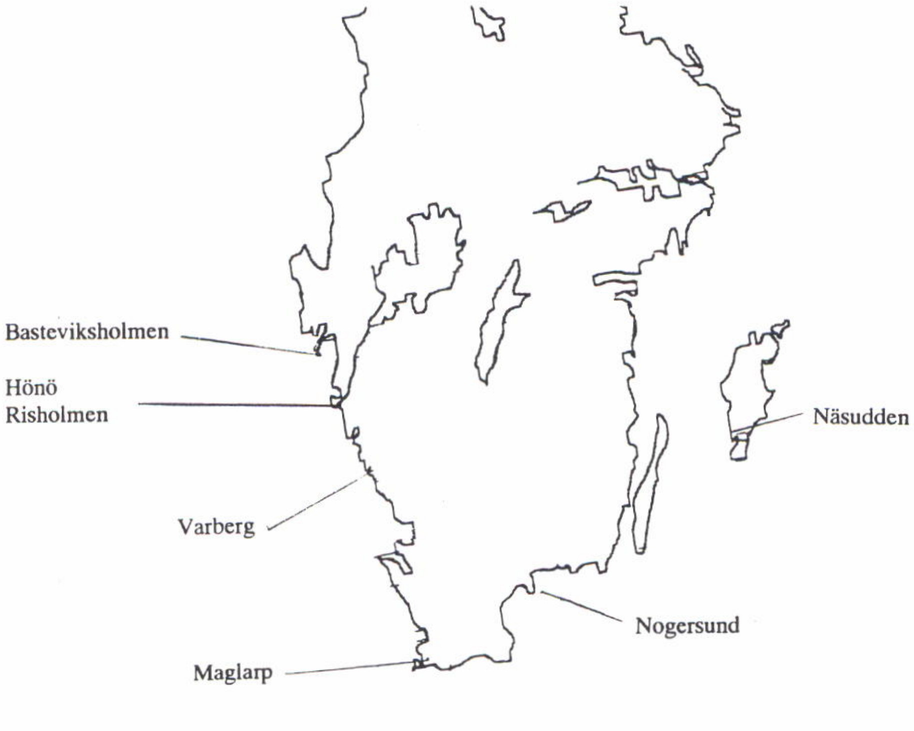


Figure 2.9.1 Location of large wind systems in Sweden.

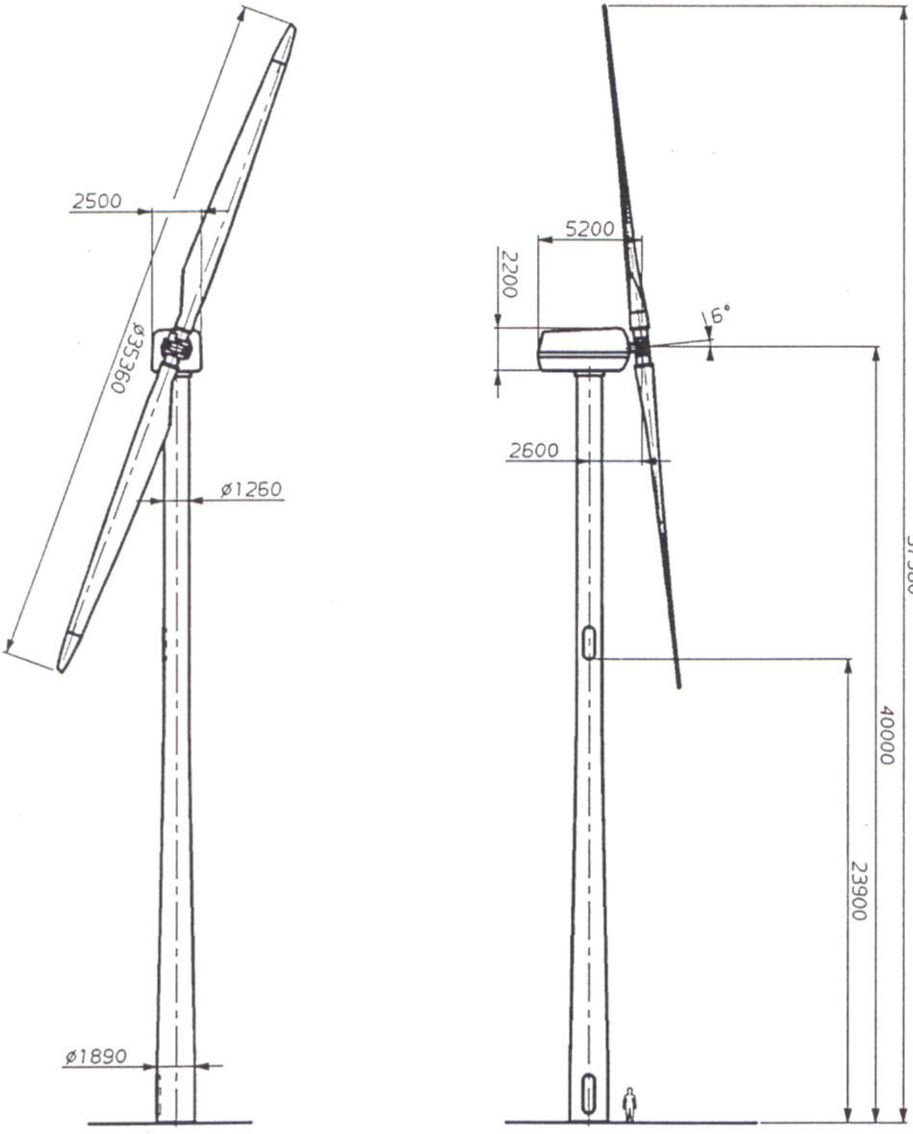


Figure 2.9.2 General view of WTS 400

2.10 United Kingdom

Introduction

As the United Kingdom's wind energy programme moves from the development phase through the technology transfer phase towards commercial exploitation, the most significant stimulus to the uptake of the technology in England and Wales has been the introduction of the Non-Fossil Fuel Obligation (NFFO).

This scheme requires the regional electricity companies to purchase a proportion of non-fossil fuel capacity, and guarantees a premium price (until 1998) for the electricity so produced. It has been announced that 600 MW "declared net capacity" will be reserved for renewable energy plant.

The first tranche of this 600 MW was announced at the end of 1990 and the second tranche was announced in November 1991. These tranches include proposals for both new windfarms and single machines, as well as existing plant.

A new company, known as National Wind Power Plc, was launched during the year, jointly owned by National Power Plc, British Aerospace Plc and Taylor Woodrow Construction Holdings Ltd. The company plans to develop at least 250 MW of wind power by the year 2000.

While clearly it will be the medium scale machines which are closest to being economic within the NFFO time scale, it is encouraging that preliminary studies indicate that the cost of energy from large scale machines may well be comparable, if not lower, as infrastructure and grid connection savings are realised. Studies of the design and economics of large scale machines are therefore set to continue to feature in the UK programme.

Research and development

The wind energy R&D programme of the Department of Energy is in three phases:

- Phase I (mid 70s to mid 80s) in which the programme identified feasible technologies, their costs, their technical potential as contributions to the supply and the possible timescale of that contribution;

- Phase II (mid 80s to early 90s) in which a collaborative cost-shared technology development programme is being conducted to identify the contributions to be expected from those renewable sources which could be economic now or show promise of being so in the future; the phase also includes the technology transfer process necessary for the creation of a successful market;

- Phase III (early 90s to late 90s) in which it is envisaged that the demonstration and technology transfer activities will be completed.

Major activities during 1991 included studies of the wind resource and environmental impact; development, demonstration and monitoring of horizontal- and vertical-axis machines; studies of windfarms, electrical integration and offshore systems; as well as cost modelling and forecasting. R&D studies continued on aerodynamics, structural dynamics, materials, and component development.

The change of emphasis of the R&D programme towards full-scale testing was shown by the commissioning of a 300 kW WEG MS-3 "test bed" machine at the National Engineering Laboratory test site, Myres Hill, Scotland. A second machine will be used for windfarm development.

Large machines

Wind Energy Group's LS-1 at Scottish Hydro-Electric's Demonstration Centre on Orkney

The 60 m diameter 3 MW horizontal-axis wind turbine generator built on Burgar Hill, Orkney by the Wind Energy Group Ltd (WEGL) for the Department of Energy (DEn) and Scottish Hydro-Electric Plc (HE) has completed pre-commissioning tests. Post-synchronisation test programme is complete with the machine having run at its rated output of 3MW and at slightly reduced output in parallel with diesel generation on Orkney when isolated from the mainland grid. Total running time to end February 1990 was 2333 hours with a cumulated output of over 2900 MWh.

Following discovery on 28 February 1990 of the structural failure of a secondary load carrying member in the trailing edge assembly of one blade, the machine was temporarily out of service for repair and reinstatement. Repairs were complete by end July 1990, and a further period of testing was started.

In October a problem was identified in the main brake in that after application it failed to fully release, causing overheating. Remedial action was taken and the machine was back in service by early February 1991.

Normal operation was severely curtailed by precautions taken to avoid further instances of overheating. After discussion with the brake manufacturer it was agreed that the brake should be dismantled and shipped back to works for inspection. This was done in June 1991. In July a review of the reports and discussions produced from the inspection remained inconclusive as to the the basic cause of the brake malfunction.

As a result WEGL proposed dispensing with the main brake in its present form and modifying it to provide a parking brake, comprising a single disc acted upon by two or three callipers, activated by the existing pneumatic system. This proposal was based on the contention that the two independent fail safe pitch control systems serving the blade tips constitute two independent aerodynamic brakes, acting direct on the rotor, which satisfies internationally accepted criteria for safe wind turbine braking systems. The proposal has been accepted and the modifications will be carried out and the machine back on service by the end of the year. There will follow a twelve month monitoring period. Total running time to end May 1991 when the machine was shut down was 3511 hours with a cumulative output of 4336 MWh.

Medium size machines on the same site

The 250 kW 20 m diameter Wind Energy Group MS-1 prototype unit at Burgar Hill, Orkney has continued to operate satisfactorily since the last report with only minor problems. To the end of October the machine had operated for 27 654 hours and generated 2679 MWh.

The Howden HWTL 300 kW HAWTG at Burgar Hill, Orkney was taken out of service in March 1990 due to a fracture in one of the intermediate shafts in the gearbox. The machine had operated for 1071 hours and generated 164 MWh. The gearbox has been repaired and was back in service in the last week of September 1990. To the end of October 1991 the machine had operated for 1457 hours and generated 241 MWh.

Howden HWP-750 at Scottish Hydro-Electric site in Shetland

HE has monitored the wind regime at two sites on Shetland which can accomodate large scale wind turbines. With the benefit of a CEC Demonstration funding, a Howden750 wind turbine generator has been installed on Susetter Hill, Shetland. The machine was operational and producing power to the grid in January 1989.

In February 1989 it was checked after 100 hours of operation. At that time it was observed that severe wear was occurring on the flanks of the gears within the high speed shaft coupling. After 165 hours of operation (April 1989) a failure occurred in a bracket which locates the the blade tip actuator hydraulic cylinder. After investigation it was determined that the failure was due to a design fault. The mounting bracket required to be redesigned. The opportunity was taken to reinspect the high speed shaft coupling. The machine was out of service from June 1989. New mounting brackets and high speed coupling were fitted in November 1989. The machine was returned to service in December 1989. After about 100 hours of operation a further actuator failure occurred. A new hydraulic unit was fitted in June 1990 to balance the tip operation of the three blades.

In addition to the new hydraulic unit for the blade tip actuators it was found that the blade tips would not always align with the main blades when required to do so. This was found to be due to corrosion, caused by ingress of moisture into the body of the actuator, increasing the system friction and preventing full range operation. The actuator bodies were modified by machining to accomodate O-ring seals to prevent moisture penetration and coating all internal cavities with a corrosion preventing grease.

A further sticking blade tip was found to have been caused by a particle of steel having become embedded in the surface of the PTFE/bronze tip thrust washer. A new washer was fitted and subsequent operation has been trouble free.

The above modifications greatly improved the operation of the machine, but after a further period of operation another problem was experienced with the blade tip misalignment. The wind speeds at site are such that the machine frequently operates for prolonged periods with the blade tips in a power limiting position. In this situation even minute leakage in one hydraulic system as compared to the other two causes misalignment of a blade tip, resulting in increased vibration. Correction of the misalignment requires the blade tips to be moved to the full run position, but this cannot always be done while the machine is in a power limiting situation because it would generate excessive power.

Vibration monitoring has been modified to a two stage system. When the first stage is reached the machine is stopped and immediately restarted by remote control from the Lerwick Power Station. This stopping and starting equalises the blade tip settings and the machine then runs normally for a further period before the procedure requires to be repeated.

In December 1990 a crack was observed in the trailing edge of one of the blades, and closer examination revealed a similar, but less severe, crack in one of the other blades. The cracks were in a low stress area of the blade and followed the joint line between the two blade halves. The cause appeared to be lack of penetration by the epoxy resin making the original joint. The cracks were routed out in a V form and filled with thixotropic crack filling resin after it had cured, and the joint was then finished with a glass cloth and epoxy laminate. This repair was carried out at the beginning of February 1991 and has so far proved to be effective.

During the period when the blade repair was being carried out, the blade tip actuator on blade 2 was removed for inspection, as it had been noted that it had not been operating smoothly. The problem was found to be a worn thrust washer, which was replaced before the machine was returned to service.

After a period operation of 774 hours further problems were experienced with blade tip actuators, and all three blade tips have been removed to fit redesigned thrust washers and actuating pinks, rod and bushes.

Problems had been experienced with power control during strong winds, resulting in relatively large variations in power output causing trips on overcurrent. The control programme algorithm has been modified and no further overcurrent rips have occurred.

The failure of a hydraulic union resulted in contamination of the slip rings connecting the rotating transducers to the data logging system. New slip rings have been fitted and all transducers have been re-connected.

The mechanical components of the blade tip control have been further modified. The tip thrust washer has been replaced by a new design of "Ni-Ex" which has its grease pressure maintained by centrifugal force.

The fulcrum pins on the hydraulic actuator ram have been chrome-plated and ground to improve the finish of the bearing surface, and new "Ampep" bushes have been fitted.

The machine has been returned to service and all the data-logging equpiment has been re-commissioned. The total running hours to mid-November 1991 were 2480 and the output totalled 1206 MWh.

The machine will shortly be taken over by HE and the two year monitoring period for performance and structural behaviour will commence.

Howden HWP-100 at PowerGen's Richborough Power Station, Kent

Jointly funded by DEn, CEC, PowerGen and Howden, the HWP-1000, which was formally inaugurated in July 1990, is now the subject of a comprehensive DEn funded monitoring campaign in collaboration with the CEC as an extension of the WEGA project. With Howden's withdrawal from active involvement in wind energy, Renewable Energy Systems Limited have been engaged to undertake the monitoring in collaboration with PowerGen.

Previously reported tip synchronisation problems caused by hydraulic distribution imbalance have now been solved and the machine is performing well.

VAWT-850 at National Wind Power's Demonstration Centre at Carmathen Bay, South Wales

This vertical-axis machine suffered a blade failure in February 1991. It is now known that the blade manufacturer made fundamental design errors with the blade; there was no inherent fault with the machine design. Blade redesign is being undertaken with the intention of reinstating the machine. The whole site has been shut down since the incident but will reopen as soon as National Power have concluded their own enquiry into the overall safety issues. The other machines at the site are Howden 28 m/300 kW, WEG 33 m/300 kW and VAWT 25 m/130 kW.

Windfarms

The proposed windfarms in England and Wales previously reported have made very slow progress. Due to lack of experience of this type of project and the absence of planning guidelines, local planning authorities have been reluctant to determine applications and, even if favourably inclined, some opposition has been encountered by national consultative bodies such as the Countryside Commission. Consequently, of the five windfarm projects accepted into the first tranche of the NFFO, three have been "called in" for a Public Enquiry, and the other two have met with considerable delays, based on visual and noise impact.

WindElectric's windfarm at Delabole, Cornwall

This will be the first UK windfarm, consisting of 10 Windane-34 machines (total installed capacity 4 MW) and is a private commercial venture by WindElectric at Delabole in Cornwall. National Power Plc and South Western Electricity Plc have taken equity in the company. Planning consent was considerably delayed due to possible noise intrusion but construction started in Autumn 1991 and completion is scheduled for January 1992.

National Wind Power's windfarm at Cemmaes, Mid-Wales

This windfarm was the first to be the subject of a Public Enquiry. The Countryside Commission objected to the scheme on the grounds of visual intrusion. The hearing took place in April and a favouable decision was announced in October. Construction is expected to start in later 1991.

National Wind Power's windfarm at Kirby Moor, Cumbria

This windfarm is also the subject of a Public Enquiry. The County Council objected to the scheme on the grounds of visual intrusion. The hearing took place in July but no decision has yet been announced.

Yorkshire Wind Turbines' Ltd windfarm at Ovenden Moor

After prolonged planning negotiations, this windfarm has also been called in for a Public Enquiry. This time the Department of the Environment wished to examine the impact of the project on the environment. The date of the hearing has not yet been fixed.

Yorkshire Water's Plc windfarm at Chelker

This project has now received planning consent and the installation of four 300 kW machines is proceeding.

Proposed National Power, PowerGen, DEn windfarms

The joint DEn/National Power windfarm of 22 x 300 kW machines proposed for Cold Northcott in Cornwall is expected to be the first utility windfarm to obtain planning consent. Contract negotiations for its construction are nearing completion.

The joint DEn/PowerGen windfarm proposed for Capel Cynon has been abandoned.

Offshore demonstration machine

A DEn feasibility study will report early in 1992.

2.11 United States

Industry status

Wind energy has proven to be one of the most cost-competitive new renewable energy technologies for the United States' bulk power market. Wind generating capacity interconnected with utilities in the U.S. at the end of 1991 totaled approximately 1600 MW. This installed capacity was comprised of over 15 000 machines. Figure 2.11.1 shows the growth of the installed capacity base and the annual increase in electricity production despite a slowing of new capacity installations.

Increased windfarm installation and operating experience, coupled with continued research and development efforts, have resulted in a major reduction in energy costs. Today's utility-interconnected machines produce power at costs of 0,07 to 0,10 USD/kWh (at 6 m/s annual wind speed sites as measured at 10 m height) and 0,06 to 0,08 USD/kWh (at 7 m/s sites) rivaling many non-renewable sources. These costs are nearly one-third those of ten years ago. Wind resource is abundant as well, if not always located near load centers. A recent study completed by Pacific Northwest Laboratory found that adequate wind resources for cost-effective energy production are found in almost all regions of the United States, althuogh the Midwest, West, Northwest, and Northeast tend to have the best winds.

Despite technological advances and a vast resource, however, wind energy still faces widespread barriers to utility interconnection. These take the form of transmission issues, intermittency, and utility reluctance to adopt new technologies. These barriers, coupled with wind energy costs that in most situations are not yet competitive with conventional base load sources of energy, have led to a shortage of profitable utility contracts, the ultimate market driver. Although near-term markets are scarce, there are promising signs for the mid-term in areas outside of California. A joint venture was recently announced to develop a 250 MW wind plant in the mid-west, with an option for an additional 250 MW after five years. Plans for a 10 MW windfarm in the state of Minnesota were announced and several small installations are being planned in the Eastern U.S. as well. It is becoming more the norm for wind energy to be seriously considered in generation expansion plans.

Program goal and objectives

The U.S. Federal wind technology program has set its goal "to assist utilities and industry in developing new markets and applications for wind systems and to develop advanced wind turbine technology to be economically competitive as an energy source in the mid-term marketplace". Support for utility and industry program activities now occupies an important place in the program mission in addition to the continuing efforts to advance technology through R&D.

To achieve the program goal, two specific objectives have been identified for the five year program:

- Increase performance 50 %, lower first costs 10 - 15 %, increase availability to > 95 %, lower O&M to around 0,01 USD/kWh, and double machine lifetime. This translates to a goal of 0,04 USD/kWh at 5,8 m/s sites.

- Expand the domestic market to regions beyond California, with a target of having utility-interconnected windfarms in the Great Plains and the Northeast by the end of the decade.

Providing results from the program to the industry and utilities is a key element. One activity already underway to implement this strategy is the Utility Wind Interest Group, being sponsored by the Electric Power Research Institute and the National Renewable Energy Laboratory (NREL), formerly the Solar Research Institute. The goal of this organization is to support the integration of wind technology into electric utility generating and transmission systems. Its focus is on disseminating up-to-date, accurate information about wind power to utilities, via brochures, workshops and regional meetings.

In addition, certain technology support program activities will work to expand markets for small-scale, on- and off-grid systems and for wind/hybrid systems and to develop expected opportunities for international joint ventures and marketing.

Program structure

The wind technology program is structured in two main elements, Utility and Industry Programs and Applied Research Programs. Elements of these programs are described below:

A Utility and Industry Programs

One key area of emphasis in the program is working with the industry and utilities in the application of wind technology. A range of projects is being used to explore near-term markets, develop and apply new technology to existing problems, and to encourage new applications for wind power plants.

Advanced Turbine Program

The goal of the Advanced Wind Turbine (AWT) Program is to support industry's efforts to incorporate advanced technology into today's turbines for the marketplace in the near-term (1993-1994), and to provide the next generation of innovative wind turbines for the mid-term (late 1990s).

The AWT Program is comprised of three components. The first phase began in 1990 with the award of three contracts to study advanced wind turbine conceptual designs, see Figure 2.11.2. The second phase, the AWT Near Term Product Development Program, will allow high potential component and subsystem concepts from the first phase design studies, or independently conceived, to be developed and field tested in 1993/1994. These concepst may include advanced blades, hubs, aerodynamic and adaptive controls, power electronics, and support structures.

The third component of the AWT Program is the AWT Next Generatiopn Technology Project. Scheduled to begin in 1992, this effort will lay the foundation for the next generation of utility-class advanced wind turbines. Innovative designs, either independently conceived or derived from earlier AWT Program efforts, will be completed in 1994-1995. The highest potential designs will be fabricated and field tested in an effort that will continue through 1997.

Cooperative Programs With Industry

The goal of several recently initiated programs is to work with industry to solve near-term problems in windfarms and to stimulate new markets. These are cost-shared efforts aimed at maximizing the participants' return on their R&D investment. 2,5 MUSD has been allotted to provide matching funding for eight companies participating in cost-shared R&D efforts. The work to be undertaken will address a variety of concerns and will include such projects as the development of new turbine blades, the solving of daily windfarm operational problems, development of improved wind/diesel hybrid systems, and research into reduced efficiency caused by the accumulation of insects on turbine blades.

B Applied Research Program

Applied research is necessary to ensure that fundamental design tools will be available for performing detailed designs of future advanced wind turbines. For example, the program has developed new computer models for aerodynamic performance, structural dynamics, and yaw dynamics that run on personal computers. These codes are being used by many wind turbine companies and university research programs. However. enhancements to the models are required to predict the behaviour of advanced rotor configurations that will result from advanced coceptual design studies.

Aerodynamic research currently underway involves exploring the characteristics of the wind at actual wind turbine sites (atmospheric fluid dynamics) and investigates the aerodynamic phenomena experienced and created by wind turbines during operation. One of the efforts has been the analysis of Combined Experiment pressure measurements to determine the effects of delayed stall on wind turbine steady and dynamic loads. Testing is done on the heavily instrumented research turbine operated by NREL at their test facility at Rocky Flats, Colorado, see Figure 2.11.3. Aerodynamic investigations on vertical-axis turbines are being undertaken at Sandia National Laboratories (SNL). Much of SNL's efforts, in support of all areas of applied research, have been conducted on the 500 kW, 34 m vertical-axis wind turbine test bed located in Bushland, Texas.

A new Structural Test Facility, located at NREL, has been developed to perform static and dynamic tests of wind turbine components, such as blades. Static tests will determine ultimate strength limits and weak points in the component design for later detailed investigation. Dynamic tests using hydraulic actuators will submit components to cyclical fatigue loads similar to those experienced during actual operation.

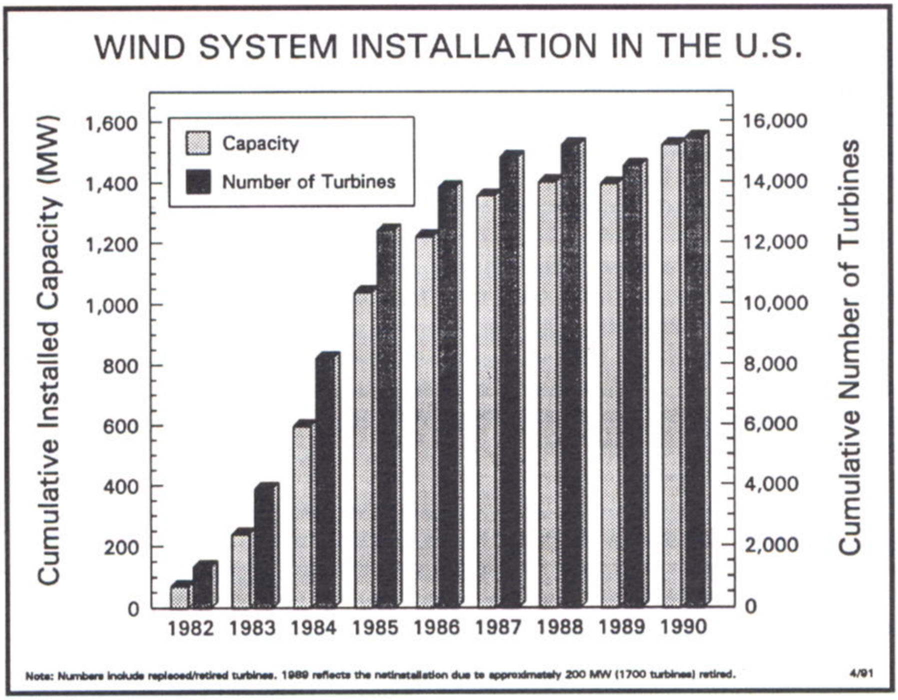
Research is continuing into the effect of wind turbines on operational control and power quality in utility grids, electrical utility interconnection, and wind/hybrid systems. Because wind turbines usually operate in clusters, research on controls and adaptive controls will take a systems approach to all operational control issues. The goal of activities in this area is to define electrical characteristics and controls that will minimize undesirable power fluctuations and maximize the energy contribution that wind turbines can make to a utility grid.

Work is continuing on development of advancd airfoils and blade designs, variable speed generator and advance drive train research, advanced tower concept development, and evaluation of aerodynamic rotor brakes.

Operational testing is continuing on the 98 m diameter, 3,2 MW Mod-5B turbine, located on Oahu in the Hawaiian Islands and operated by Hawaiian Electric Renewable Systems. As of the end of September 1991, the turbine had logged 19 253 operating hours and generated 25 344 MWh. During the spring of this year, the Mod-5 attained a one month capacity factor of 53 %.

Program funding levels

The budget for the Fiscal Year 1992 is 21,2 MUSD, increased from 11.1 and 8,7 MUSD in the two previous fiscal years. The additional funding will continue the first phase of the advanced wind turbine project and also begin a program with industry for the development of near-term applications.



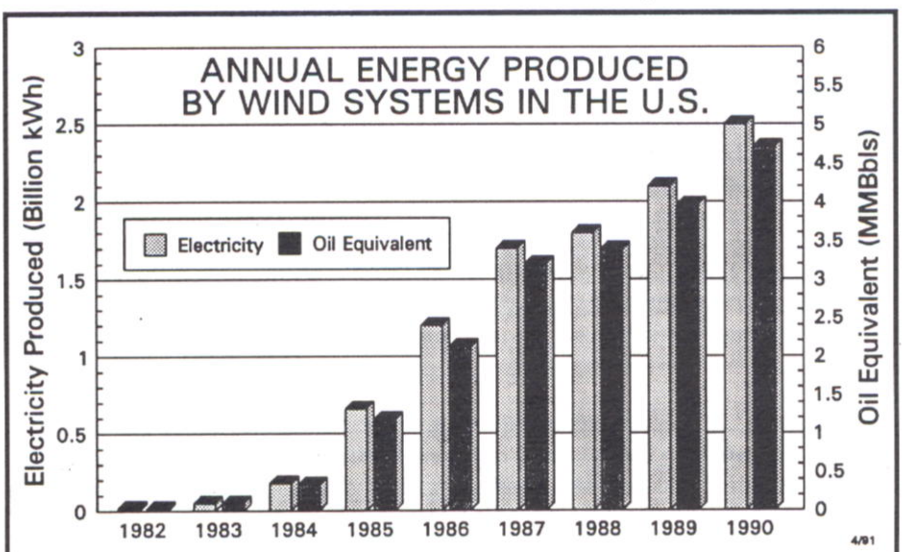
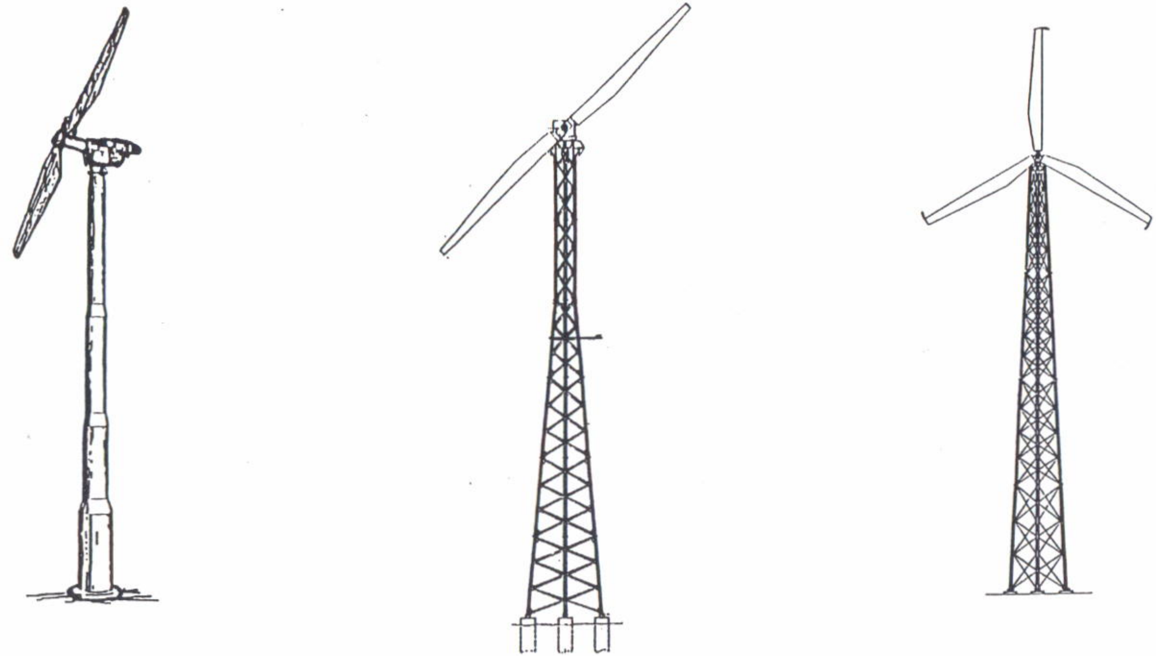


Figure 2.11.1 U.S. Installed Wind Turbine Capacity and Annual Energy Production



150 kW
150 ft tower height
70 ft rotor diameter

275 kW
80 or 120 ft tower height
86 ft rotor diameter

50 kW
80 ft tower height
50 ft rotor diameter

Figure 2.11 2 Advanced Wind Turbine Conceptual Designs

Figure 2.11.3 Combined Experiment facilities at the National Renewable Energy Laboratory

Executive Committee activities

The 27th meeting of the Executive Committee (EC) was held on 16 and 17 April 1991 at the Norwegian Electric Power Research Institute (EFI), Trondheim, Norway. The attendance was 21 persons, including representatives from 11 member countries, Operating Agents and observers, see Figure 3.1. On 18 April a visit was made to the wind-diesel plant on the island of Frøia off the coast of Trondheim.

The 28th meeting took place on 21 and 22 October at the Research Association of the Danish Electric Utilities (DEFU), Lyngby, Denmark. 23 persons attended. A visit to the offshore windfarm near Vindeby off the northwest coast of Lolland was made on 23 October.

Mr H J M Beurskens (the Netherlands) and Dr P L Surman (UK) served as Chairman and Vice Chairman during the year. At the fall meeting, Mr W G Stevenson (UK) and Dr E Sesto (Italy) were elected Chairman and Vice Chairman for 1992.

Some changes in membership were announced during the year. The updated list of EC Members and Alternate Members is attached (see Appendix).

At the EC meetings, the progress of the ongoing Tasks was reviewed and proposals for new cooperation were discussed. The necessary administrative decisions were taken. Information was exchanged on the national wind energy R&D programmes and large-scale wind systems in the member countries.

At the spring meeting, the EC adopted the draft workplan for the new Task XIII Large Wind Turbine Systems, which incorporates and strenghtens certain activities in the completed IEA LS WECS Agreement.

At the fall meeting, a conformed copy of the Implementing Agreement was adopted, including the full text of the current Annexes. The new Implementing Agreement supersedes the previous R&D and LS Agreements.

The first issue of Wind Energy Newsletter appeared in August 1991 and was well received by the wind energy community. The EC acts as an editorial board for the Newsletter, which is technically edited by R J Templin (Canada) and produced by Novem, the Netherlands. The Newsletter, which reviews the progress of the IEA R&D Wind Tasks and the national wind energy activities, will be issued twice a year from 1992.

Figure 3.1 The 27th IEA R&D Wind Executive Committe Meeting at EFI, Trondheim, Norway, 16 -17 April 1991

Appendix

IEA R&D Wind Executive Committee

(M = Member, A = Alternate Member)

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IEA Wind Energy
Annual Report 1991

Wind energy stands out as one of the most promising renewable energy sources in the near term. The exploitation of wind energy is promoted by national programmes for advanced technology research and market stimulation in many countries.

Thirteen countries collaborate since 1977 in wind energy research and development under the auspices of the International Energy Agency. The programme includes joint research projects and information exchange on large wind systems.

The report reviews the progress of the joint projects during 1991 and highlights the national wind energy activities in the member countries.

By the end of the report period more than 20 000 grid-connected wind turbines were in operation in the member countries, representing an installed power of around 2200 MW. The performance of wind turbines continues to improve as the technology matures.

The average unit rated power was 180 kW in new plants and is increasing. Commercial machines in the 400 - 450 kW range were delivered during the year. Prototype megawatt-sized wind turbines are in operation or under construction in the lead countries.

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