IEA Wind Energy
Annual Report 1992

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Cover picture:
Gamma 60 at Alta Nurra, Sardinia, Italy (1,5 MW rated power)
Näsudden II in Gotland, Sweden (3MW)
Aeolus II at Jade Windpark, Wilhelmshaven, Germany (3MW)
All of them installed in 1992.

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Foreword

This is the fifteenth Annual Report of the IEA collaboration in wind energy, reviewing the activities during 1992. It is also the second report under the amended R&D Implementing Agreement 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), R de Bruijne (the Netherlands), T Kajishima (Japan), P Nielsen (Denmark), D I Page (UK), E Sesto (Italy), E Solberg (Norway) and R Windheim (Germany).

Edinburgh and Nyköping in January 1993

W G Stevenson
Chairman of the
Executive Committee

B Pershagen
Secretary of the
Executive Committee

Contents

Executive Summary

The report reviews the progress during 1992 in the Agreement for Co-operation in the Research and Development of Wind Turbine Systems (IEA R&D Wind), set up in 1977 under the auspices of the International Energy Agency (IEA).

The purpose of IEA R&D Wind is to carry out cooperative research, development and demonstration projects in wind energy. Since 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 systems having a rated power of approximately 1 MW or more.

IEA R&D Wind has 16 signatories from 13 countries: Austria, Canada, Denmark, Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, the United Kingdom and the United States. During 1992, the Technical Research Centre of Finland was invited to join the Agreement. The Contracting Party from New Zealand gave preliminary notice of withdrawal.

Wind energy continues to stand out as one of the most promising renewable energy sources for the near term. Small and medium-sized wind turbines are commercially available in unit sizes up to 500 kW rated power. Present installations are either single units or arrays of units, known as wind farms. Most of the plants are owned by private investors or cooperatives, but utilities are taking an increasing interest in the deployment of large wind systems.

By the end of the year about 22 000 wind turbines were installed in the member countries, representing a capacity of around 2450 MW. The installed wind power increases about 10 % per year at the present. Most of the capacity, about 1600 MW, is found in California, USA. Megawatt-sized wind farms are in operation or under construction also in Canada, Denmark, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden and the United Kingdom. During the year about 40 MW were installed in Germany and Spain, and about 30 MW in the United Kingdom.

There are several wind turbine manufacturers on the market. One of the manufacturers recently delivered its 4000th unit for a total of over 500 MW rated power. The average unit size in today's wind farms is about 110 kW while that of new wind farms is increasing and in 1992 was about 200 kW. Units of 500 kW rated power are now put on the market, and the leading manufacturers are developing megawatt-sized machines.

The national wind energy R, D & D programmes are set to continue. They are to a large extent directed to the development and demonstration of large-scale wind turbines. Operating experience from prototype machines and results of technology research are used in the design of advanced systems in the lead countries. During the year, second generation large-scale prototypes were placed into operation in Germany and Sweden. The first megawatt-sized wind turbine in Italy was connected to the grid in June.

Despite technological advances and a vast resource, wind energy still faces barriers to widespread use, such as lack of competitivity as a result of dropping oil prices, and planning difficulties due to environmental concerns. In most countries, therefore, government-sponsored market incentive programmes are in effect to facilitate the introduction of wind power. The subsidies take the form of investment support, generation credits or tax reliefs. The Commission of European Communities also contributes to the funding of wind system projects.

Although the environment in which the IEA Agreement in wind energy was set up has changed considerably, there is still great interest for collaborative technology research and information exchange. Joint collection and evaluation of operating experience from large wind turbine systems, and the production of recommended practices for wind turbine testing are examples of activities, initiated under the Agreement, for which there is a continuing need.

Nine cooperative research Tasks have been successfully completed since the start of the programme. The total level of effort is typically about ten manyears per Task over a period of three years. The projects are either cost-shared and carried out in a lead country, or task-shared, when the participants contribute in-kind, usually in their home organisations, to a joint programme coordinated by an Operating Agent.

Two Tasks were completed during the report period: Task IX Wake Effect Studies and Task VIII Wind-Diesel Systems. The final report of Task VIII is being printed in the form of a book to be published on the open market in early 1993 . The current Tasks include:

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

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

Task XIII Cooperation in the Development of Large Wind Turbine Systems
Operating Agent: National renewable Energy Laboratory, USA

Task XI has participants from nine countries. Main activities include the preparation of documents in the series of Recommended Practices for Wind Turbine Testing and Evaluation, the undertaking of Joint Actions in specific research areas where a periodic exchange of information is considered necessary, and the organisation of Topical Expert Meetings. So far, eleven documents in eight areas of Recommended Practices have been published, four Joint Actions have been initiated, and 23 Topical Expert Meetings have been held.

Task XII has seven participants from three countries. The final report is now in preparation for this project which has comprised experimental studies of wind turbine aerodynamics, operational behaviour, load spectra and control strategies, and the validation of computer codes for wind turbine design. Use has been made of the UNIWEX experimental wind turbine at the Ulrich Hütter wind test site near Schnittlingen, Germany.

The objective of *Task XIII* is to further the development of large wind turbine systems by means of cooperative action and exchange of information on the planning and execution of national R,D&D programmes. Input to a computerized information system is provided by a network of contact persons in ten countries. During 1992, consensus was reached on the form and content of the material to be collected and disseminated. The information includes national wind energy installation and generation summaries, design and operational data on prototype wind turbines, summary data on wind farms, and government funding levels.

Much of the information exchange takes place at Executive Committee meetings twice a year when the activities in the participating countries are reviewed with emphasis on large-scale systems. The highlights of the national R,D&D programmes and the progress of the cooperative Tasks are summarized in the Wind Energy Newsletter, the second issue of which was published during the year. The current status of wind energy activities in the member countries is described in some detail in the main report and briefly summarized below.

In *Canada* four wind farms with a total installed capacity of 20 MW are being set up in the province of Alberta. The 4 MW prototype machine EOLE has been in operation since March 1988 at a maximum output of 2,4 MW for structural reasons and has generated more than 11 000 MWh of energy in nearly 17 000 hours of generating time. With an availability of about 94 % it has shown the feasibility of large scale highly reliable vertical-axis wind turbine technology.

As of 1 October 1992, the total capacity of grid-connected wind turbines in *Denmark* was 437 MW in 3347 units. The annual generation during 1991 corresponded to 2,3 % of the Danish electricity consumption. The first 100 MW utility programme is now fully implemented and another 100 MW programme will follow. Some delays have been experienced due to planning difficulties. Denmark has nine large-scale wind turbines in operation, all of the three-bladed horizontal-axis type with rated capacity from 630 kW (Nibe) to 2 MW (Tjæreborg). The Elkraft utility and three of the manufacturing companies are developing advanced concepts for around 1 MW rated capacity.

The total installed wind power in *Germany* is 142 MW in 964 units (October 1992), including 98 MW (609 turbines) within the government-sponsored "250 MW Wind" programme. Most of the turbines are located in the North Sea coastal states. The average unit power has increased from below 140 kW in 1989 to about 200 kW today. Advanced wind turbines in the range from 300 to 1000 kW are being developed by German manufacturers, and a 500 kW unit was reently put on the market. Six large-scale prototype machines are in operation, including three 640 kW single-bladed units (Monopteros 50), two 1,2 MW three-bladed units (WKA 60) and one 2 MW two-bladed unit (Aeolus II), which was placed into operation during the year.

The current national energy plan in *Italy* sets a target of 300 MW of wind power by the year 2000. The ENEL utility and the ENEA research agency are cooperating with industry in setting up Italy's first wind power stations. Five different medium-sized wind turbines, three of them Italian-built, are being tested at ENEL's Alta Nurra site in Sardinia. Civil engineering work has started for a new test site in the Apennines. An 11 MW wind farm is to be constructed in Sardinia, and another two or three 10 MW plants will be set up in Central-Southern Italy. The two major Italian wind turbine manufacturers are continuing the development of medium- and large-scale machines, and are also undertaking their own wind farm projects. The 1,5 MW Gamma 60 prototype started installation in April 1992 at Alta Nurra and was connected to the grid in June.

The national wind energy programme in *Japan* is part of the Sunshine Project, directed by AIST, MITI. An experimental wind farm of about 1 MW rated power is under construction on Miyako Island, Okinawa. The conceptual design of a 500 KW prototype has been completed and detailed design is underway. The machine will be manufactured during 1993-1994 by Mitsubishi Heavy Industries Ltd. The Japanese program also includes observation and numerical prediction of wind characteristics, and basic technology research. The first large-scale utility wind farm (5 x 275 kW) was set up in 1991 at Cape Tappi, Honshu. Another utility wind farm (1,1 MW) is under construction at Tomari, Hokkaido.

The national target in the *Netherlands* is for 1000 MW of wind power by the turn of the century. The installed capacity is presently about 100 MW, over 80 % of which in wind farms of 1 MW or more. The electricity companies have announced plans for installing 250 MW by 1995, which should bring the total capacity to 400 MW by then. Subsidies of the order of NLG 40 million per year are available. However, delays have occurred due to planning difficulties and the current best estimate is 200 MW by 1995. A new cooperative organisation has been set up between the utilities to deal with site exploitation.

Norway has excellent wind conditions in coastal areas. The electricity system is dominated by hydro power, currently with a certain amount of surplus power available at a low price. This means that wind energy has to find particular niches in the supply system to be used with profitability, at least in the near term. The research programme has mainly been directed to the study of wind-diesel autonomous systems. A second generation control system is being developed for the experimental plant on the island of Frøya. The demonstration programme aims at having 4 MW of wind power installed by 1993. At present ten wind turbines for 2,9 MW are connected to the grid. The 1,2 MW wind farm at Vikna will be enlarged with two 500 kW units next year.

The target of 100 MW wind power by 1995 in the current national renewable energy plan in *Spain* should be more than realized. During 1992 nearly 40 MW was installed in 233 wind turbines, bringing the total capacity close to 50 MW. The largest concentration of wind turbines in Europe is found in the Tarifa area near the Straits of Gibraltar with 33 MW installed in 272 units, which will produce about 100 000 MWh per year. Three large wind farms, two in the Canary Islands and one in Cataluña, are in the planning stage and are expected to start operation in 1993-94. The three main domestic manufacturers delivered about 300 units, rated at 100 to 180 kW, during the period August 1991 - August 1992. New prototypes rated at 200 and 300 kW are being tested, and a 500 kW model is being developed.

Sweden has two large-scale prototypes in operation, the 3 MW Maglarp machine, installed in 1982, and the 3 MW Näsudden II, completed in 1992 on top of the existing tower of Näsudden I. Maglarp has generated 33 125 MWh during 25 657 hours on line (November 1992), which is world leading for a single wind turbine. An advanced wind turbine, NWP 400, partly based on Maglarp experience and rated at 400 kW, was erected in August near Lysekil on the Swedish west coast, and is operated in parallel to a standard 450 kW machine at the same site. A government-sponsored programme for market stimulation by investment subsidy has been in effect since mid-1991. By September 1992, the total installed capacity was 16 MW in 89 units, excluding the large prototypes.

In the *United Kingdom,* two orders have been issued under the Non Fossil Fuel Obligation, set up in 1990. The first order included 28,4 MW and the second order (November 1991) 192 MW of rated wind power capacity. By the end of 1992 all orders of the first tranche and nearly half of the second tranche had obtained planning consent to the effect that about 33 MW (101 turbines) were installed and 66 MW (221 turbines) were under construction. Of the four large-scale demonstration wind turbines in the UK, the 3 MW WEG LS-1 machine on Orkney started a twelve month monitoring period in February. Since commissioning, the total running time has been 6348 hours and energy production 8441 MWh. The 1 MW machine at Richborough and the 750 kW machine on Shetland were out of service until end-October and mid-November, respectively, due to modification and repair.

In the *United States,* new legislation, enacted in October 1992, provides wind energy generation incentives, access to transmission lines, and other programs helpful to wind energy. The DOE wind energy program is expanding, and the funding amounts to USD 24,0 million for fiscal year 1993. The program includes collaborative ventures with industry to develop advanced wind turbines and to help utilities to integrate wind systems in their normal operations. A National Wind Technology Test Center at Rocky Flats, Colorado, will provide a complete research and development center.

As a consequence of the phasing out of the standard power purchase contracts in effect in California since the early 1980's, and the retirements of outdated wind turbines, the net increase of wind capacity was less than 10 MW during the year. The total installations remain approximately the same, 1600 MW. In October, Hawaiian Electric Industries announced the decision to shut down its wind farm at Kahuku Point, Oahu, consisting of fourteen Westinghouse wind turbines rated at 600 kW each, and the 3,2 MW Mod-5B wind turbine. Operation of the Mod-5B is continuing until a disposition decision is taken. As of the end of September the machine had run a total of 20 561 hours and generated 26 776 MWh.

The IEA R&D Wind Programme

1.1 The Implementing Agreement

The IEA co-operation in wind energy started in 1977. Presently 16 parties, designated by the governments of 13 countries are participating. The co-operation is governed by "The Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems", or IEA R&D Wind for short. The Contracting Parties are:

Austria	The Republic of Austria;
Canada	The Department of Energy, Mines and Resources;
Germany	Forschungszentrum Jülich GmbH;
Italy	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA); ENEL, Società per azione;
Japan	The Government of Japan;
Netherlands	The Netherlands Agency for Energy and the Environment (NOVEM);
New Zealand	New Zealand Meteorological Service;
Norway	The Directorate of Energy of the Norwegian Water Resources and Energy Administration;
Spain	Instituto de Energias Renovables (IER) of the Centro de Investigación 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 objective of IEA R&D Wind is to undertake collaborative R&D projects, called Tasks, and to exchange information on the planning and execution of national large-scale wind systems. Each Task is managed by an Operating Agent, usually one of the Contracting Parties. Overall control of the programme is vested in the Executive Committee, where each Contracting Party is represented.

The Tasks are defined in Annexes to the Implementing Agreement. To-date twelve Tasks have been initiated, as shown below. Eight Tasks have been successfully completed. Two Tasks are technically completed but the final reports are 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 National Engineering Laboratory Technically completed in 1989. Final report pending.
Task IX	Intensified Study of Wind Turbine Wake Effects Operating Agent: UK National Power plc Completed in 1992
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 Tecnically completed in 1992. Final report pending.
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 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	Task XI	Task XII	Task XIII
Canada	x	x		x
Denmark	x	OA		x
Germany		x	OA	x
Italy	x	x		x
Japan				x
Netherlands	x	x	x	x
New Zealand	x			
Norway	x	x		x
Spain	x	x		x
Sweden	x	x	x	x
United Kingdom	OA	x		x
United States	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 *Wind-Diesel Systems*, 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 will publish the book and distribute it on the open market. The manuscript was delivered to the printers during 1992, and the book is expected to be published in early 1993.

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 final report was issued in August 1992. 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 diversity 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 factors have 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.

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.

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 1.4.1. The documents are available from the Operating Agent and selected representatives in the participating countries.

A Standing Committee (SC) is reviewing the needs for revising existing recommendations or for preparing new recommendations. The SC takes the necessary steps for setting up ad hoc expert groups, as decided by the Executive Committee, for preparing proposals for revised or new recommendations. The SC met twice during the report period.

Work on revised editions of Vol 2 Costing of Wind Turbine Systems, Vol 4 Acoustics, and Vol 8 Glossary of Terms made substantial progress during the year.

An expert group has been convened to evaluate anemometry issues in power performance testing (power curve). This work may lead to a new document in the series of Recommended Practices.

Table 1.4.1 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 have taken 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 6th Symposium was held on 30 November - 1 December at ECN, the Netherlands. Proceedings of the 5th Symposium, held in December 1991 at the University of Stuttgart, Germany, were published during the report period.

In the Joint Action on Fatigue, a workshop was held on 15-16 October at the National Renewable Energy Laboratory, Colorado, USA. This meeting also served as a Topical Expert Meeting, see below.

No meetings in the Joint Actions on Offshore Installations and Wind-Diesel Systems took place during the report period.

Topical expert meetings

In the framework of the Annex, 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 22nd Topical Expert Meeting took place on 16-17 June at DEWI, Wilhelmshaven, Germany on the Effects of Environment on Wind Turbine Safety and Performance. The 23rd meeting was held on 15-16 October at NREL, Colorado, USA, on Fatigue of Wind Turbines, Full-Scale Blade Testing and Non-Destructive Testing Methods. 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 1.4.2 IEA Wind Energy Expert Meetings

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
22	Effects of Environment on Wind Turbine Safety and Performance	16-17 June 1992	Wilhelmshaven, Germany
23	Fatigue of Wind Turbines, Full-Scale Blade Testing and Non-Destructive Testing	15-16 Oct 1992	Golden, Colorado USA

1.5 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. 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.

Representatives of the participants met on the following occasions:

- A technical meeting , 30 October, TU Delft
- A measurement campaign, 8-10 July on the testfield
- Two EC meetings (28-29 April, Kaiser-Wilhelm-Koog, Germany and 29-30 October, Alghero, Italy)
- DEWEK 92, on 28-29 October, Wilhelmshaven, Germany
- Wind Energy R&D Contractors Meeting, CDC DG XII JOULE Programme, 3-5 June, Alghero, Italy.

The main technical activities are listed below.

At ICA/University of Stuttgart, Germany

Experiments

During the whole year 1992 a lot of measurements were made with the UNIWEX turbine. A part of them were measurement campaigns for the Dutch participants for further verification of their simulation software.

The majority of the measurements considered the reaction of the turbine,

a) for the rigid hub configuration over the variation of typical parameters, such as rotor-tower distance, rotor tilt angle, coning angle under yawed conditions, constant versus variable rpm, yawed operation for pitch, stall, upwind and downwind operation;
b) for different hub concepts for pitch and stall control both for yawed and non-yawed conditions.

Since the results are given in [19], only a few representative ones are shown here:

- Distance rotor plane - tower
  By simultaneously changing the tower and nacelle tilt angle, the mean distance between the rotor plane and tower was varied, keeping the rotor axis horizontal. No remarkable influence on the flap-wise bending moments could be observed.
- Rotor tilt
  For a downwind configuration with lambda ≈ 10, tilt angles of -7, 0, +7, and +15 degrees were investigated. With increasing angle the amplitudes of the flap bending moment increase, whereas the mean values decrease.
- Coning angle under yaw conditions
  For the downwind configuration with lambda ≈ 9 and two different coning angles (0^o, 7^o) the flap bending moments were evaluated for relative wind directions of $-35^o/0^o/+35^o$.
- Constant versus variable rpm (lambda = constant)
  For downwind operation with lambda ≈ 10 and zero coning, the flap bending moments were monitored at different wind velocities, for both constant and variable rpm (see Figures 1 and 2). As could be expected, the mean values and amplitudes are proportional to v^2_w in the constant lambda case. For constant rpm the difference between the bending moments for different wind speeds is smaller.
- Downwind/upwind, stalled/unstalled, yawed/unyawed
  The turbine was operated for yawing angles of $-40^o/0^o/+40^o$ in upwind and downwind configuration at lambda ≈ 4. The pitch angle was held constant at two different settings, which delivered approximately the same power. This means that for the smaller setting, the turbine operated unstalled and for the higher pitch setting stalled. The results are shown in Figure 3.

- Icing of rotor blades under stalled conditions
  With incoming fog at low ambient temperatures the leading edges of the blades accumulated ice and at ≈ 40 % chord length and an ice-trace of ≈ 3 mm thickness reaching from the blade section with maximum thickness to the tip could be observed. The rotor torque was reduced a factor of two.
- Some aerodynamic effects
  Hysteresis effects were detected for stalled operation and are documented in [12]. Non-stationary effects in the axial downwind flow were provoked by pitch variations and monitored.
- Teetering hub, yawed
  In Figure 4 the reduction in the flap bending moment for a teetering hub compared to a rigid hub operated under 30° yaw is demonstrated.
- Free flapping blades
  If the flapping motions of the blades are strongly damped, the flap angles are slowly reacting on slow wind speed transients, whereas the load amplitudes over one revolution are acting on the structure, see Figure 5. For weak damping, flap amplitudes are higher, the loads consequently lower, as long as the bumps are not hit, see Figure 6.

For most of the measurements Rainflow and Markov evaluations were performed.

Numerical simulation

The re-idealisation of the blade [16], the nacelle [2] and the total turbine [3] based on geometric, static and dynamic measurements, is now documented. The deviations in the first 10 blade eigenfrequencies between the numerical model and the measurements could be reduced to less than 3 %. The old model had deviations of ≈ 10 % in the flap modes and ≈ 20 % in the lead-lag modes. The nacelle had to be remodelled due to significant hardware changes. The lowest eigenfrequency was therefore lowered to 4,53 Hz from 5,67 Hz for the old OPTIWA nacelle. The total turbine, braked and in its rigid hub configuration, was re-idealised using all updates. A vibration test was simulated, see Figure 7; the results are given in Table 1 together with those from the corresponding measurements.

Based upon the re-idealised components, simulation of the aeroelastic behaviour of different configurations of the UNIWEX wind turbine was performed by means of the ARLIS code and laid down in [14] and [18].

The investigations were conducted for the rigid, teetering and the individually flapping hub concepts (7° coning). Selected measurements for each of the hub concepts were simulated both for (almost) steady state cases and gusts. Correspondence was quite good and seems to be sufficient for qualification of the code. With this in mind, simulations covering the whole operational rpm-range of the UNIWEX turbine ($3 < \Omega < 8$ rad/s) were conducted for the three hub concepts mentioned before. Only a few highlights of the results can be given here.

- Flap displacements over Ω
  In Figure 8 amplitudes and mean values of the flap-wise blade tip displacements are given versus Ω (rpm). An operation with lambda = 8 was simulated, which means that $v_W \sim \Omega$. It can be seen from Figure 8 that the mean values for rigid and teetering hub are almost the same, whereas for the amplitudes teetering and flapping hub behave in the same way.
- Flap displacements over one revolution
  Whereas the rigid hub exhibits only small elastic blade tip excursions (see Figure 9), the two other hub concepts show (apart from their mean values) a very similar behaviour. This is due to the fact that, as a result of their design philosophy, they react in a similar way to unsymmetric rotor loads.
- Flap-wise bending moments
  Figure 10 shows the moments at radial position r = 1 m. For the flapping blades, the bending moment is close to zero, as it should be. The teetering hub reacts with teeter excursions on asymmetric rotor loads (wind shear, tower wake) and therefore has considerably smaller amplitudes than the rigid hub. The two answers on the tower wake can be seen at $t/T \approx 25$ % and 75 %, whereas the rigid hub exhibits only one large answer.

Documentation

In 1992 much of the work performed in the course of the project has been documented. On the simulation side, reports on the blade [16], the nacelle [2], the total plant [3], the aeroelastic simulation [14,15,18], the code [11,21] have been prepared. Outside the project, an application [22] and a parameter study in the context with ARLIS [17] were documented.

On the experimental side the calibration methods [4,5], the evaluation software [6], measurements and their evaluation [8] were documented. Specific topics were the determination of data needed for the numerical models [10], the blade loads with the parametric coning, tower and rotor tilt [7], the power coefficients under yawed configurations [9] and aerodynamic effects [12].

The final report is nearing completion and will be published in 1993.

At ECN, DUT and SPE, the Netherlands

The Dutch participation in the UNIWEX progamme 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.

In order to facilitate the analysis of the different campaigns, the 290 experimental runs at present available to the Dutch participants have been organized in a database structure. For each data channel, the mean value, the standard deviation and the range of measured quantity are recorded in the database, together with the global operation conditions (hub type, control type, average tip speed ratio, etc). A number of analyses are being performed on the basis of these data, such as the relation between input and loads, depending on flapping stiffness and tip speed ratio.

With the help of the database, the user can select campaigns of specific interest for further analysis. For example, a number of runs is being used for validation of the load prediction computer programs used by the Dutch participants. Specific topics of interest are teeter stability limits and soft blades in flap or in plane direction. So far it has been possible due to unknown damping applied during the measurements to maintain operation.

Finally a number of pitch controllers for constant speed operation were designed by the Delft University of Technology on the basis of a derived "experimental" model, exising of transfer functions obtained from specially designed measurements. A number of controllers were successfully applied to the UNIWEX.

The total work done by the Dutch participants to this Annex will be reported in the beginning of 1993.

Conclusions and outlook

Both the testbed UNIWEX and the simulation software developed for aeroelasticity have proven their usefulness. This software was successfully applied to seven different commercial wind turbines, demonstrating the technology transfer to industry already achieved. The UNIWEX turbine became integrated in several new research projects of the Commision of European Communities (Dynamic Inflow; Aero-

Acoustics), thus justifying the intellectual and material investments of the last years.

For the future, it would be highly desirable to implement recent developments into the numerical code (aerodynamics; parallel computing). The turbine could and should be used for further in-depth experimental investigations.

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3 J Argyris, K A Braun, A Hopf; Dynamische Analyse der UNIWEX-Versuchswindturbine mit Hilfe der Methode det finiten Elemente (ASKA), ICA-Bericht Nr 33, Universität Stuttgart, 1992

4 H Arnold, H Schwartz; Kalibrierungen an der UNIWEX-Windturbine, ICA-Bericht Nr 37, Universität Stuttgart, 1992

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14 A Finkel; Simulation of the aeroelastic behaviour of different configurations of the UNIWEX wind turbine - identification, simulation, evaluation, ICA-Report No 40, Universität Stuttgart, 1992

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16 H P Blatt; Computerunterstützte Auslegung der Struktur eines Windturbinen-Rotorblattes, Diplomarbeit, Universität Stuttgart, 1992

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18 J Argyris, K A Braun, A Finkel; Aeroelastische Simulation der UNIWEX Windturbine, Deutsche Windenergie-Konferenz 1992, Wilhelmshaven, 28-29 Oktober 1992, Proceedings

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20 K A Braun; Jahresbericht 1992 über die Aktivitäten der Universität Stuttgart auf dem Ulrich Hütter Testfeld der Neckarwerke Esslingen, Oktober 1992

21 J Argyris, K A Braun, A Finkel; Simulation of the aeroelastic behaviour of innovative wind turbines, Presentation in front of the OECD-group of experts on economic implications of information technologies, Stuttgart, October 1992

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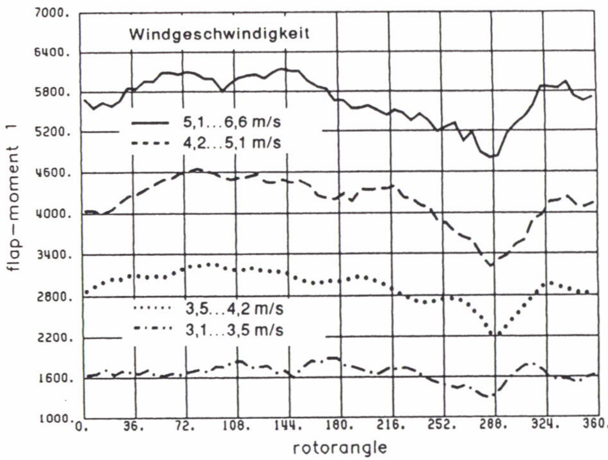


Fig. 1: Flap moments for $\lambda = const$, coning 0°

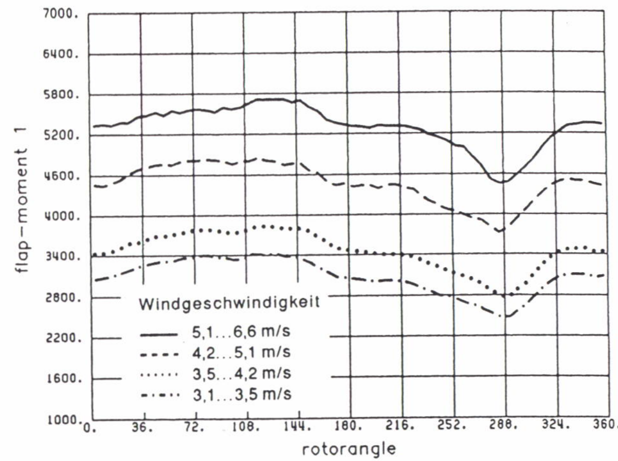


Fig. 2: Flap moments for const. rpm, coning 0°

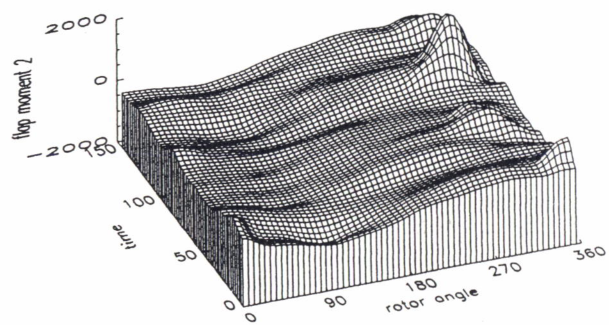


Fig. 5: Free flap, strong damping

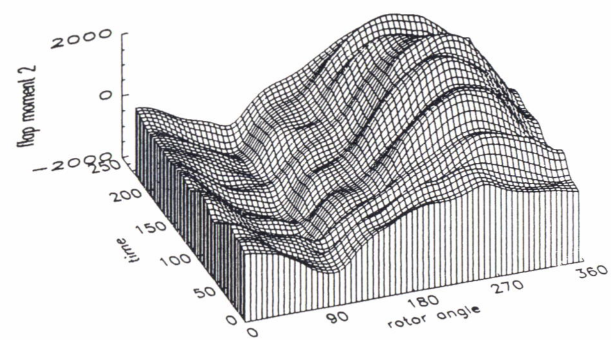
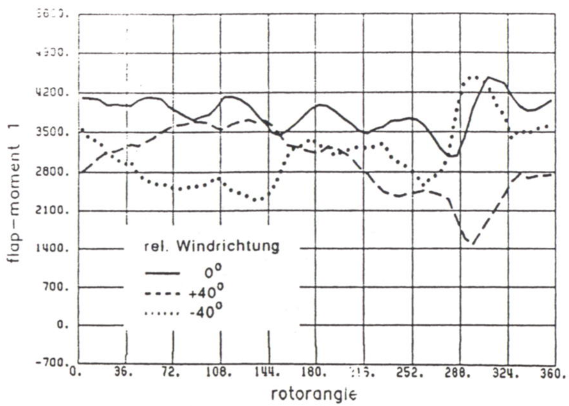
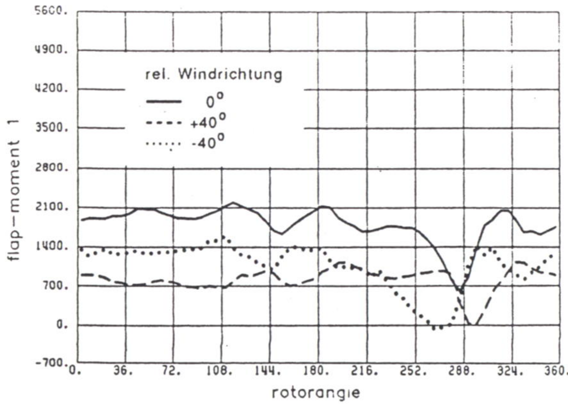


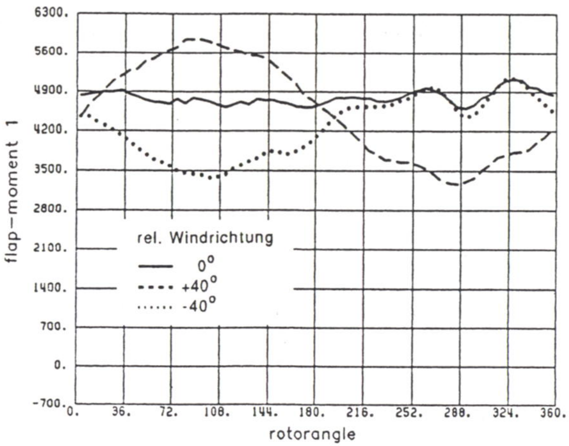
Fig. 6: Free flap, weak damping



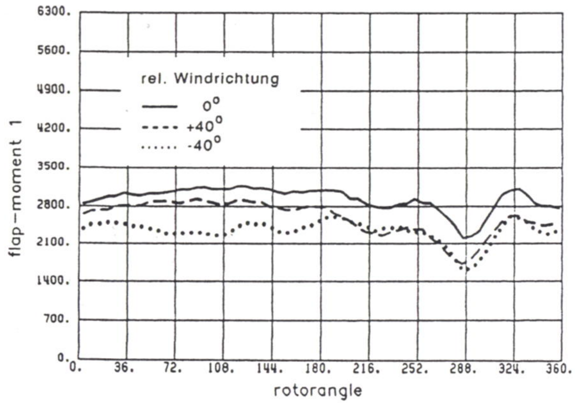
down-wind, stalled



down-wind, unstalled (reduced α)



upwind, stalled



upwind, unstalled (reduced α)

Fig. 3: Flap-wise bending moments for different modes of operation (coning 0°)

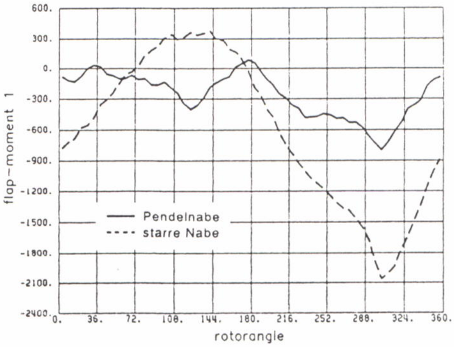


Fig. 4: Flap moments for rigid and teetering hub, stalled, 30° yaw

i	Eigenfrequenzen	
	FE-Rechnung	Messung
1	2.51 Hz	2.5 Hz (2.5 Hz ... 2.6 Hz)
2	2.90 Hz	2.9 Hz (2.8 Hz ... 3.0 Hz)
3	3.03 Hz	3.0 Hz (2.91 Hz ... 3.07 Hz)
4	4.24 Hz	4.3 Hz (4.2 Hz ... 4.35 Hz)
5	4.55 Hz	4.6 Hz (4.4 Hz ... 4.8 Hz)
6	6.02 Hz	6.0 Hz (5.9 Hz ... 6.2 Hz)
7	6.04 Hz	6.4 Hz (6.35 Hz ... 6.6 Hz)
8	9.29 Hz	9.3 Hz (9.3 Hz ... 9.8 Hz)
9	9.93 Hz	10.0 Hz (9.9 Hz ... 10.3 Hz)
10	9.96 Hz	10.0 Hz (9.9 Hz ... 10.3 Hz)

Tab. 1: Calculated and measured eigenfrequencies for the UNIWEX turbine (braked, rigid)

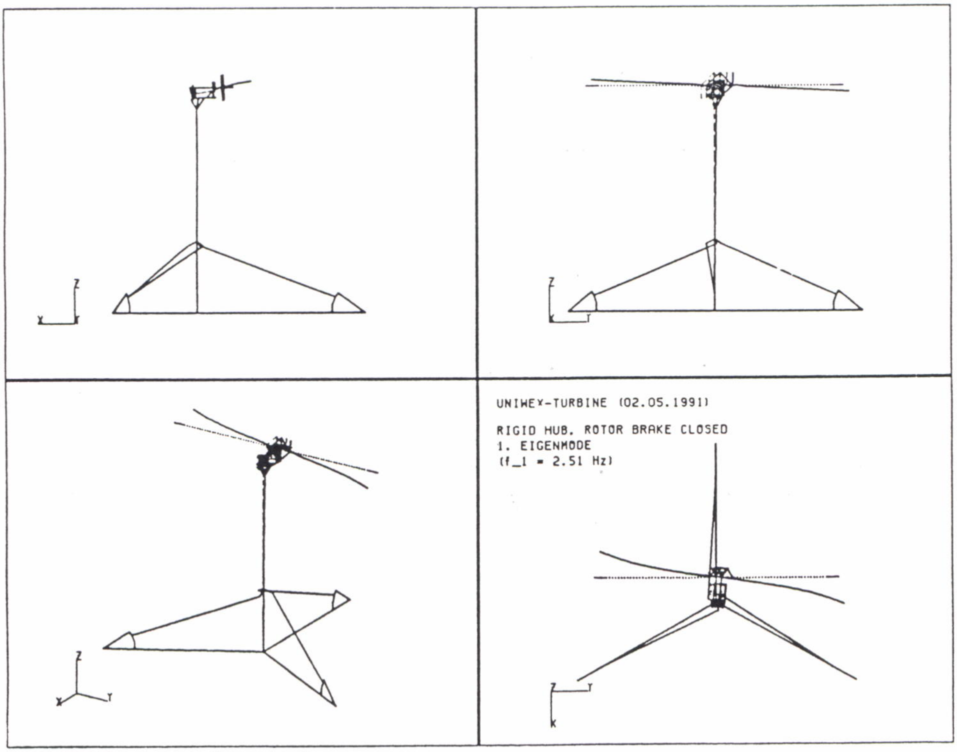


Fig. 7: First eigenmode of the UNIWEX turbine

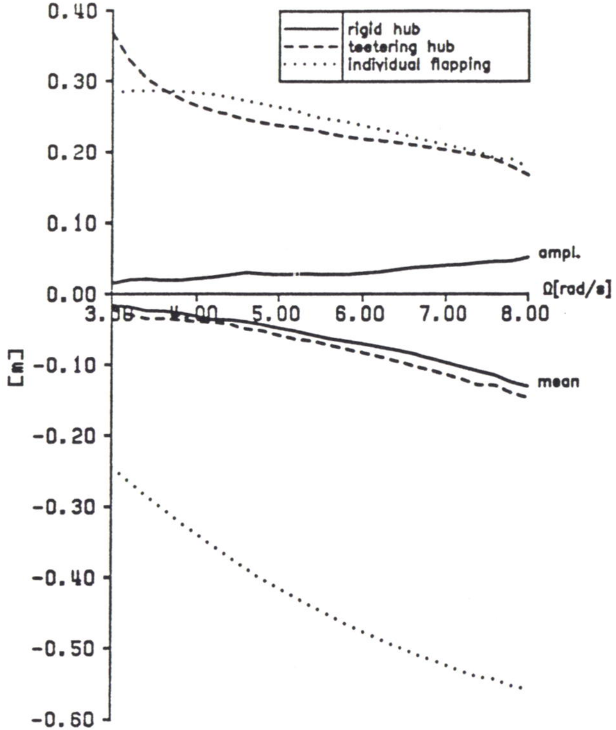


Fig. 8: Flap-wise displacements of the blade tip versus Ω

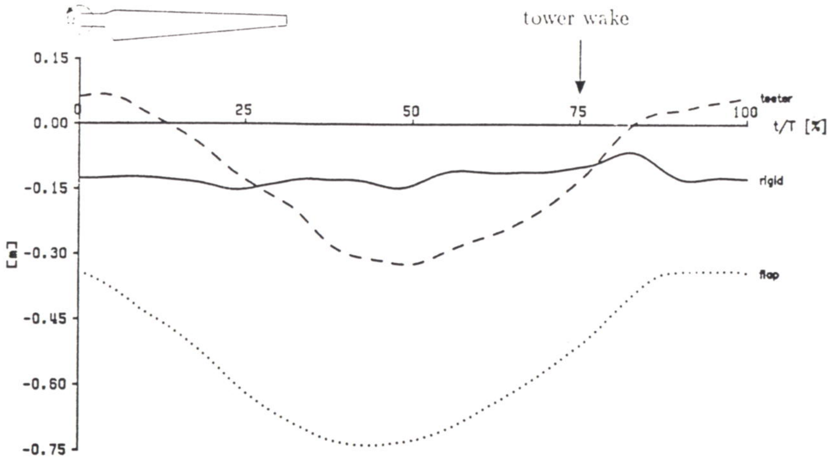


Fig. 9: Flap-wise displacements of the blade tip versus time

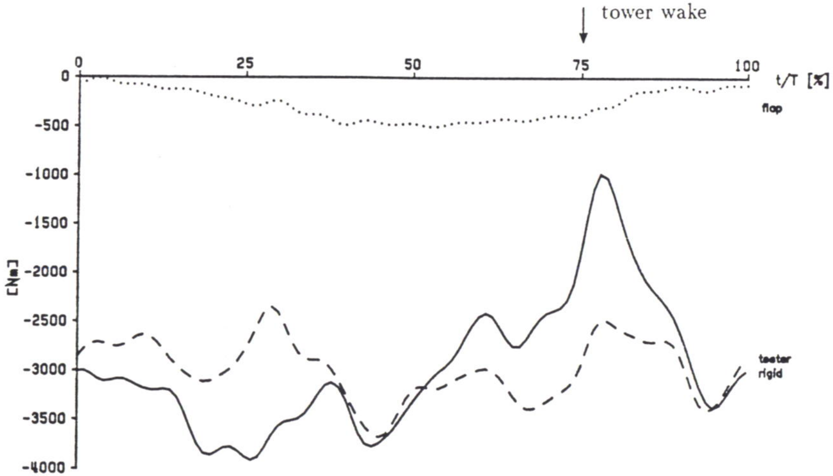


Fig. 10: Flap-wise bending moments

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

Introduction

The purpose of this Task is to further the development of large-scale wind turbine systems (LWTS) by means of co-operative action and exchange of information on the planning and execution of national LWTS research, development and demonstration programmes. For the purpose of this Task, a LWTS is defined as either a single large turbine or a group of smaller turbines with a combined power of approximately 1 MW or more. In order to participate in the Task, it is necessary that a country engage in national projects on the development, construction and operation of at least one LWTS.

An important component of the organization for this Task is the network of wind specialists called Contact Persons. The Implementing Agreement specifies that each Participant should designate one or more Contact Persons for his country who have familiarity with some aspect of wind energy. These persons will be in a position to help in collecting and reporting the data needed by the Task. A list of currently designated participants and Contact Persons is attached as Table 1.6.1.

The special Annex XIII workshop

The most important activity this year was the workshop for Contact Persons and Participants which was hosted at the offices of the Research Association of Danish utilities (DEFU) in Lyngby, Denmark on 11 September 1992. Fifteen persons were present at the workshop with representation from eight of the ten Annex member countries.

The broad purpose of the workshop was to form a consensus among the participating countries on the form and content of the material which each country agrees to supply to the Task. This work entailed detailed examination of technical definitions, consideration of ease of collection, and discussion of problems of sensitivity and proprietary data.

At the end of its meeting the workshop had approved a set of forms and procedures for data collection, decided on a plan for the organization and use of Contact Persons, and agreed on definitions of the material being collected.

Data forms

The workshop attendees agreed on the format of a set of data sheets for each of the five areas of interest for Task XIII. They are:

1 National energy summary form
2 Regional energy summary form (optional)
3 Wind farm data forms
4 Prototype wind turbine forms
5 Commercial wind turbine forms

The data collection procedure instituted by the workshop is as follows: Blank forms are distributed directly to each Contact Person in each country. This person will fill in the required information in his area of expertise and forward these forms to the Annex Participant for his country. When that Participant has received all of these completed forms, he will judge whether the complete set represents the appropriate balance of information for his country. After the editing and supplementation that he deems necessary, this Participant will present the packet to the Operating Agent or his representative at the next regular Executive Committee meeting.

Other workshop results

Numerous other matters to ensure uniformity were handled during the workshop. A few typical examples follow:

One of the definitions examined was wind machine *availability*. During a given period, the fraction of that period during which the machine is in routine operation, or could be in routine operation if there were wind, is its availability. This definition is independent of whether wind is present or not.

Another agreement was that *energy output* or *power level* is the energy output or power level measured at the point of delivery to the grid or external interface, and not the total energy output or power level produced by the wind farm or machine.

Incidents or accidents involving LWTS will also be reported on a voluntary basis under Annex XIII. The accident/inicident report form allows Annex members to report unusual events involving their wind turbines in a confidential and timely manner to the other members. In view of the potentially sensitive nature of this type of report, it was decided to let each member or contact person choose the method of reporting, namely, either as a formal A/I report or an oral report to the EC.

During the workshop it was suggested to add a third category to the A/I classification, namely that of "break down". This milder category would encourage the exchange of technical data of possible use to fellow Annex members. Accident/incident reporting would still be available and would prove to be valuable in preventing repeat problems.

Other information

In accordance with the agreement at the Annex workshop, packets of input forms were distributed to the Contact Persons and Participants prior to the Autumn Executive Committee meeting. Information from the Participants is now being processed and merged in preparation to dissemination back to the Annex Participants early in the new year.

The updated Summary Table for Large Wind Systems is shown in the attached table (p 42). This material is an abridgement of the material on the completed forms which were just received and which is now being merged into the Annex data base.

Wind Energy Research, Development and Demonstration Government Funding has been compiled for all the countries who are participating in the R&D Wind Agreement, and is shown in Figure 1.6.3. Note that total funding for member countries for 1992 has increased 12 percent over the previous year. Government funding is now approaching the equivalent of USD 185 million annually for R,D&D. This includes market development incentives in several countries.

Table 1.6.1 Names and affiliation of Annex XIII Participants and Contact Persons. Listed by country.

Chairman	W G Stevenson Scottish Hydro-Electric plc	
Operating Agent	P W Cariin U.S. National Renewable Energy Laboratory	
Consultant	B Rasmussen Wind Energy Consultant, Denmark	
COUNTRY	ANNEX PARTICIPANT	CONTACT PERSON
Canada	R S Rangi Energy, Mines and Resouces	Ms M Jones Renewable Energy Info Center
		A Watts Energie Eolienne, Institute de recherche d'Hydro-Quebec
Denmark	B Maribo Pedersen Technical University of Denmark	K S Hansen Dept of Fluid Mechanics
Germany	R Windheim Forschungszentrum Jülich GmbH	J P Molly DEWI
		G Dantz Überlandwerk Nord-Hannover
		Mr Nimz Windenergiepark Westküste
		Mr Hoppe-Kilpper Institute fur solare Energie-versorgung
		Mr Postmeyer Husumer Schiffswerft
		Dr Boullion PreussenElektra Windkraft AG
		G Huss M.A.N. Technologie AG
		Mr Benndorf PreussenElektra Hauptverwaltung
		G I Grom Jade Windenergie GmbH
		Dr Brauer Messerschmidt-Bölkow-Blohm Energie- und Prozesstechnik

Italy	E Sesto ENEL CREL	G Botta ENEL CREL
Netherlands	H G Douma NOVEM	J H B Benner Communicatie En Adviesbureau
Norway	E Solberg Norwegian Water Resources and Energy Administration	J Hernes Nord-Trøndelag Elektrisitetsverk
		S Kotheim Sør-Trøndelag Kraftselskap
		T A Nygaard Institutt for Energiteknikk
Spain	E Soria Instituto de Energias Renovables	F Avia Instituto de Energias Renovables
Sweden	O Sandberg NUTEK	K Averstad Vattenfall AB
United Kingdom	W G Stevenson Scottish Hydro-Electric plc	J Rea Power Technology Center
		M B Anderson Renewable Energy Systems
United States	D F Ancona U.S.Dept of Energy	M Haller SeaWest Energy Group Ltd
		W Steely Pacific Gas & Electric Co
		M W Miller HERS Wind Farm
		A Mikhail Zond Systems Inc

WIND ENERGY CONVERSION SYSTEMS LARGER THAN 500kW

COUNTRY: MEMBERS	MACHINE: MANUFACTURER	MACHINE: MODEL	SPECIFICATIONS: AXIS HOR. OR VERT.	#OF BLDS	UP OR DWN WIND	ROTOR MATER-IAL	ROTR DIA. (m)	HUB HT. (m)	SWEPT AREA (m2)	RATED WIND SPD (m/s)	RATED PWR (kW)	GEN TYPE	WEIGHT TOP OF TOWER (thousands of kg)	WEIGHT OF TOWER (thousands of kg)	EST. ANNUAL ENERGY PRODUCTION (MWh) 100% Avail, No Losses Wind Speeds at 10m: 5.0 m/s	6.5m/s	8.0 m/s	DATE OF INITIAL OPERAT.	DEVEL-OPMENT STAGE	PERFORMANCE: TOTAL RUN HOURS	TOTAL ENERGY PROD. (MWh)	COMMENTS	INFO DATE	INFO SOU-RCE
BELGIUM	WINDMASTER-VUB		H	2	U	GRP	46.0	63.0	1662	16.0	1000	I							P					
CANADA	SHAWINGAN	EOLE	V	2		S	64.0	56.0	4000	23.0	4000	A	344.0 (Rotor)		3990	7105	9230	7/87	P/1	10395	6730	Automatic Var. Speed Mode	11/90	EMR
CANADA	INDAL TECHNOL	6400	V	2		A	24.4	21.3	595	18.2	522	I	20.2 (Rotor)		297	602	1064	5/87	C/2	5873	557	Testing New Rotor & Ctrls.	7/90	EMR
DENMARK	SEVERAL	NIBE-A	H	3	U	WOOD	40.0	45.0	1256	13.0	630	I	80.0	47.0				9/79	P/1	6146	1313	Refurbishment & New Blades	4/92	DEFU
DENMARK	SEVERAL	NIBE-B	H	3	U	WOOD	40.0	45.0	1256	13.0	630	I	80.0	47.0		1300	14597	8/80	P/1	25699			12/91	DEFU
DENMARK	SEVERAL	TVIND	H	3	D	GRP	54.0	53.0	2290		2000	S							P/1					
DENMARK	DWT	WINDANE 40	H	3	U	GRP/W	40.0	45.0	1257	15.0	750	I	60.5	47.0	947	1861	2693	11/86	C/5	17500 Avg.		Operational	12/91	DEFU
DENMARK		TJAEREB2MW	H	3	U	GRP	60.0	60.0	2827	15.0	2000	I	156.0	500.0		4500		12/87	P/1	6779		Unattended Operation	12/91	DEFU
GERMANY	M.A.N.	WKA 60	H	3	U	GRP	60.0	50.0	2827	12.2	1200	S		470.0			2400	Fall '89	C/1	1800	950		11/92	IEA
GERMANY	MBB	MONOPT. 50	H	1	U	CRP	50.0	60.0	1963	11.0	640	S					2000	Fall '89	C/3				11/92	IEA
GERMANY	M.A.N.	WKA 60 LAND	H	3	U	GRP	60.0	60.0	2827	17.2	1400	S						Spring	C/1				11/92	IEA
GERMANY	MBB	AEOLUS II	H	2	U	CRP	80.0	77.0	5027		3000							Fall '92	C/1				11/92	IEA
GERMANY	HUSUMER SCH.	HSW 750	H	3	U	GRP/W	40.0	45.0	1257	14.0	750	A	20.0	47.0				'93					11/92	IEA
GERMANY	TACKE	TW 500	H	3	U	GRP	36.0	35.0	1018	14.5	500	A	25.1	35.0	543	1043	1521	'93					11/92	IEA
ITALY	AERITALIA	GAMMA 60	H	2	U	GRP	66.0	60.0	2827	13.5	1500	A	95.0	145.0		4300		9/91	P/3			First of 3 Units	8/91	IEA
NETHERLANDS	HOLEC	HOLEC500	H	3	U		35.0		962		500								P			Full Span Pitch		
NETHERLANDS	STORK-FDO	NEWECS-45	H	2	U	GRP	45.0	60.0	1590	13.9	1000	A	31.7	59.0			2300	6/86	P/1			3/87 – 8/88 Out of Op.(Blade)	10/89	IEA
NETHERLANDS	WINDMASTER NL	500	H	2	U	GRP	33.0		855		500	I						5/89	C/1				10/89	IEA
NETHERLANDS	WINDMASTER	WINDMAST750	H	2	U	WE	40.0	50.0	1257	14.0	750	I	41.0						C			Full Span Pitch		MFG.
NETHERLANDS	NEWINCO	NEWINCO 500	H	2	U	S	34.0		908		500	I						11/89	C/1				10/89	IEA
SPAIN	ASINEL, M.A.N.	AWEC 60	H	3	U	GRP	60.0	46.0	2827	12.2	1200	I	186.0	92.0				11/89	P/1	2400	559		2/92	IEA
SPAIN	MADE										500								P					
SWEDEN	KMW AB	WTS-75	H	2	U	S/GRP	75.0	77.0	4418	12.5	2000	I	205.0	1500.0	4082	6989	8821	2/83	P/1	11350	12600		10/89	IEA
SWEDEN	KKRV	WTS-3	H	2	D	GRP	78.0	80.0	4778	14.0	3000	S	191.0	281.0	4883	8703	11158	7/82	P/1	23079	29847	Maglarp	2/92	NUTEK
SWEDEN	HOWDEN	750 kW	H	3	U	WE	45.0	35.0	1590		750	S							C/1	500			10/89	IEA
SWEDEN	KVAERNER-MBB	NASUDDEN I	H	2	U	S	75.0		4418		2000								P	11400	13000		1988	IEA
SWEDEN	KVAERNER-MBB	NASUDDEN II	H	2	U	CRP	80.0	77.0	5027		3000	S		1500.0				11/91					10/89	IEA
U.K.	WEG	LS-1	H	2	U	S/GRP	60.0	45.0	2827	17.0	3000	S	197.0	654.0	1695	4319	7371	10/87	P/1	4758	6375		3/92	NSHEB
U.K.	WEG	LS-2	H	2															P/			Detailed Design Stage	10/87	IEA
U.K.	HOWDEN	750 kW	H	3	U	WE	45.0	35.0	1590		750	S						6/88	P/1	2480	1206		11/91	NSHEB
U.K.	HOWDEN	1MW	H	3	U	WE	55.0	45.0	2376		1000							2/90	P/	2150	798		4/91	
U.K.		HSW750	H	3	U	GRP/W	40.0	45.0	1257	14.0	750	A	20.0	47.0					C			Pitched Tip		
U.K.	VAWT LTD	500kW	V	2		GRP					500	I							P/					
USA	BOEING	MOD-5B	H	2	U	S	99.0	61.0	7698	20.5	3200	C	265.3	160.5	6112	10623	14128	7/87	P/1	20561	26776	Operational	9/92	HERS
USA	HAM. STANDARD	WTS-4	H	2	D	GRP	78.0	80.4	4778	15.0	4000	S	198.2	192.8	4954	9949	14221	1/82	P/1	4100	8000		8/87	MFG.
USA	WESTINGHOUSE	WWG 0600	H	2	U	WE	43.0	31.0	1452	13.0	600	S	36.2	34.8	935	1766	2447	12/85	C/14		36384		9/92	HERS

Key:

Development Stage
P/# = Prototype/# of machines
C/# = Commercial/# of mach.

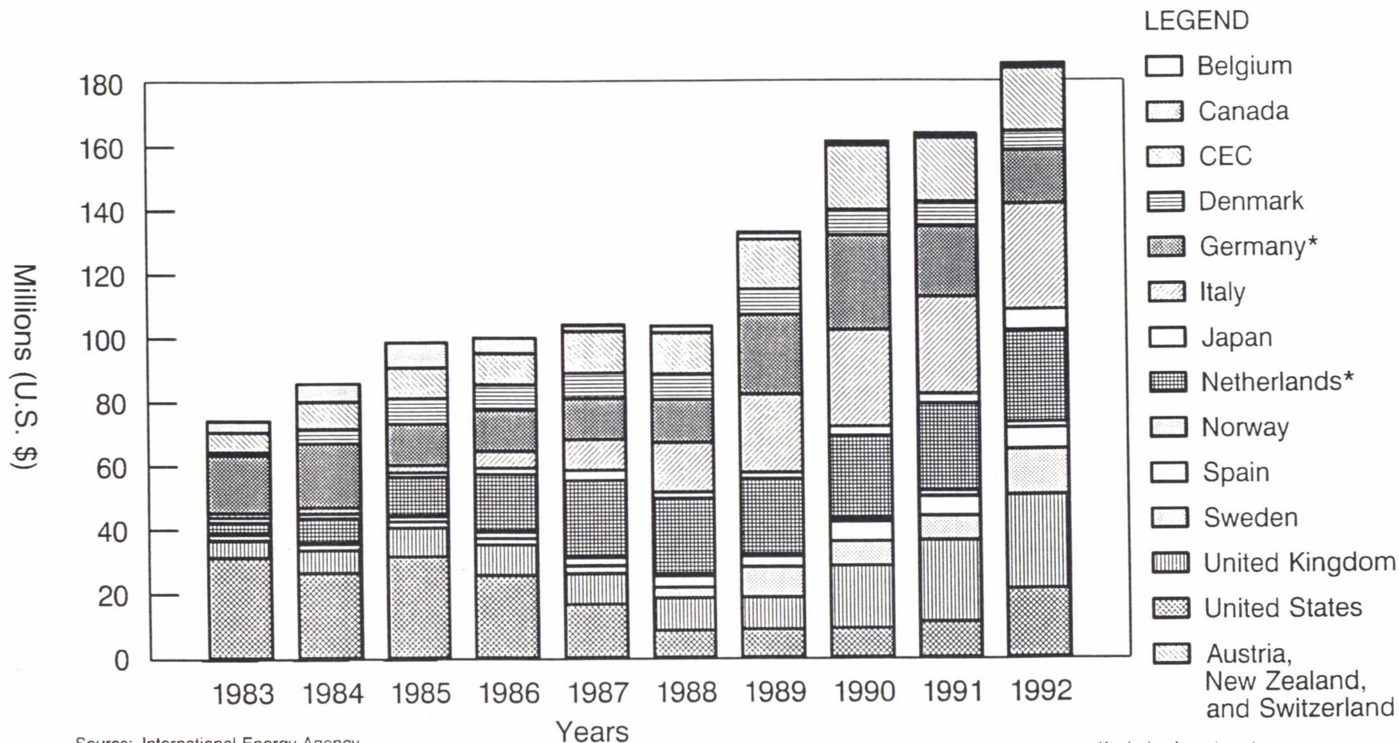
Source
MFG = Manufacturer

Rotor Material
S = Steel
A = Aluminum
WE = Wood Epoxy
GRP = Glass Fiber Reinforced Plastic
CRP = Carbon Fiber Reinforced Plastic

Generator Type
S = Synchronous
I = Induction
A = AC/DC/AC
C = Cycloconverter

Source: International Energy Agency
Wind Energy R&D Agreement
Large Scale Wind Systems, Annex XIII
December, 1992

WIND ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION GOVERNMENT FUNDING



Source: International Energy Agency
Wind Energy Conversion Systems Agreement
Executive Committee 10/92

*Includes Investment or Operating Subsidies

CE10164.02

Figure1.6.3 Government funding of wind energy research, development and demonstration

National activities

This chapter overviews the wind energy R&D programmes and the status and prospects of wind energy utilization in the member countries with emphasis on large-scale applications. The text is based on contributions by members of the Executive Committee as listed in the Foreword.

2.1 Canada

In Canada, wind enery R&D began about 15 years ago. A considerable amount of technology base exists and technology development is continuing.

A number of Canadian designs of wind turbines have been successfully field tested. For example, a 50 kW vertical axis wind turbine designed by Indal Technologies of Mississauga has been in operation at Christopher Point on Vancouver Island since 1981. It has generated 470 000 kWh in 27 848 hours of generating time. It has displaced about 250 to 450 tonnes of CO_2, which would have been produced if the same amount of energy had been generated by fossil-fuelled plants.

The 4 MW prototype machine EOLE at Cap Chat, Quebec, has been in operation since March 1988. It has generated 11 056 MWh of energy in 16 851 generating hours. With an availability of about 94 % it has shown the feasibility of large-scale highly reliable VAWT technology. The lack of commercialization of this and other designs in Canada is due to the poor domestic market resulting from the drop in oil prices.

Owing to environmental concerns in the western countries, the activity in wind energy is now on the increase again. In Canada, a number of utilities are responding to public pressure and have started to accept electricity generated by independent producers.

The cost of producing wind energy has been dropping steadily. Currently in Canada at a good wind site the average cost is about 0,07 CAD/kWh. The best current utility buy-back rate is about 0,052 CAD/kWh. The buy-back rates are likely to increase with increasing cost of conventional sources of energy.

Even with current buy-back rates, four wind farms with a total installed capacity of 20 MW are to be installed in Alberta under the South West Alberta Renewable Energy Initiative (SWAERI), an agency set up by the provincial government of Alberta.

Wind technology is already economical in some remote Canadian communities. The current technology is being developed/modified to take advantage of this niche market.

Outlined below are the goal and the main elements of the strategy for the Canadian wind energy R&D program, along with a discussion of the future plans for various elements of this program.

Goal

The goal of the Canadian wind energy R&D program is to establish a technology base in Canada (i. e. analytical tools and manufacturing facilities) and to make wind energy a safe, reliable and cost effective source of energy supply for the domestic and export market.

Funding

The total federal funding for wind energy R&D for the year 1992/93 is about CAD 750 000.

Elements of the program

The main elements and the current activities of the Canadian wind energy program are:

- Resource assessment
- Technology development
- Wind turbine testing facilities
- Technology transfer

The program is administered by the Department of Energy, Mines and Resources (EMR).

Resource assessment

EMR is co-funding wind resource surveys in Alberta (with SWAERI and TransAlta Utilities), in Prince Edward Island (with Atlantic Wind Test Site) and is planning a similar assessment in Saskatchewan. A private company, Canadian Agra, is currently carrying out a resource assessment on their lands on the east shore of Lake Huron. The project is co-funded equally by Canadian Agra, EMR and Ontario Hydro.

Technology development

The major component of the wind energy program since its inception has been the development of Canadian-based technology. In the past, three companies were involved in the design and manufacture of wind turbines: Indal Technologies, Adecon Energy Systems and LavalinTech. Benvest Capital, the new owners of LavalinTech, have withdrawn their involvement in wind energy as they do not have the necessary expertise. Even though Indal had very successful designs, it withdrew a few years ago due to lack of market. Adecon is still in the field, and is assembling a 300 kW VAWT near Toronto.

Dutch Industries (DI) of Regina, Saskatchewan, has been building a Canadian-designed water-pumping turbine and expects exports of about CAD 500 000 this year. The company has obtained rights to manufacture the 80 kW Lagerwey turbine designed in the Netherlands. DI has also signed a contract to manufacture 44 towers for the Chinook project, one of the 10 MW wind farms in Southern Alberta.

A private company (Lam, Bérubé and Co.) have taken over the operation of Project EOLE and have expressed interest in designing and manufacturing wind turbines.

Wind/diesel development

Hydro-Québec has begun a three-year, 1,67 MCAD project to demonstrate a community scale high-penetration wind/diesel system at the Atlantic Wind Test Site (AWTS). EMR and Hydro-Québec are contributing about 0,5 and 1 MCAD respectively, with AWTS contributing the balance (in labour etc.)

Wind turbine testing facilities

Current activities at AWTS include the validation of several simulation models for wind/diesel hybrid systems, testing and evaluating an 80 kW Lagerwey wind turbine for manufacture under licence in Canada, and testing and evaluation of new prototypes.

The Alberta Renewable Energy Test Site (ARETS) tests wind-water and photovoltaic-water pumping systems for agricutural applications. About 8 to 10 systems are tested annually.

Technology transfer

EMR co-sponsors annual workshops in topics such as wind/diesel technology and industry updates. An international wind/diesel workshop was held in June 1992 in Prince Edward Island. The department also supports the annual general meeting of the Canadian Wind Energy Association (CanWEA).

2.2 Denmark

Introduction

The Danish programme for the development of large-scale wind turbines is sponsored jointly by the national government, the Commission of the European Communities and the Danish electric utilities.

Refurbishment of the 630 kW Nibe A wind turbine with a new 40 m stall-controlled rotor is completed, and the machine is now in test operation. The wind farm at Masnedø, south of Zealand, consisting of five 750 kW machines and operated by ELKRAFT, is in normal operation. In Jutland, ELSAM is proceeding with the test operation of the 2 MW Tjæreborg wind turbine south of Esbjerg. A 1 MW prototype machine for Avedøre near Copenhagen is in the manufacturing stage and is expected to be ready for commissioning by the end of 1993.

As of 1 October 1992, the total number of grid-connected small-scale wind turbines in Denmark, privately or utility owned, was 3347 and the total installed capacity was 437 MW. The energy generation during the first nine months of 1992 was about 590 GWh, corresponding to 2,5 % of the Danish electricity consumption.

The first 100 MW utility programme will be fully implemented by the end of 1992. It was expected that a new 100 MW programme would be completed by the end of 1993. This programme is, however, delayed due to planning difficulties.

The development of private, small-scale wind turbines is no longer promoted by investment subsidies. Reasonable pay-back rates and exemption from electricity taxation are now the main economic incentives.

The Nibe wind turbines

The two 630 kW wind turbines at Nibe in northwest Jutland, Nibe A and B, were commissioned in 1979/80. Both turbines have three-bladed 40m upwind rotors with active yawing. The A machine is stall-controlled and the B machine has full-span pitch-control.

As of 1 December 1992, the operating stastistics for the two Nibe turbines were as follows:

Nibe A:	Running time	7447 hours
	Energy output	1613 MWh
Nibe B	Running time:	28 342 hours
	Energy output	7706 MWh

Due to blade malfunctions, Nibe A has been operating only a few hours since 1983. The first blades were made of a combined iron/fibreglass construction supported by nine bracing rods, These blades were rather soon damaged by metal fatigue. Now the A machine has been provided with cantilevered, laminated wooden blades. Power limitation is achieved by stall control. The design work was funded by the Danish government and the refurbishment by the ELSAM utility.

Originally, the blades of the B machine were fabricated with an outer section made of fibreglass and an inner section of fibreglass shells attached to a tapered steel spar. In February 1984 the blades were replaced by three new 20 m laminated wooden blades. Since then this machine has operated satisfactorily.

It is intended to prolong the lifetime of both turbines by 7-10 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 per turbine will be about 1300 MWh.

The Masnedø wind farm

ELKRAFT, the regional power company of Zealand, operates a wind farm comprising five units of WINDANE 40, manufactured by "Danish Wind Technology Ltd". The site is 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 1 December 1992, the operating statistics were as follows:

Turbine:	MAV 81	MAV 83	MAV 84	MAV 85
Running time, hrs	18 656	21 454	22 696	22 912
Energy output, MWh	4926	4792	5989	6707
Availability, %	38	89	94	91

The availability is average for 1992.

The five Masnedø turbines were installed late in 1986, and 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. The same turbine experienced in Spring 1992 an overspeed accident (three times normal rpm) but no serious damage has been observed.

Most of the turbines have had gearbox failures. As a result of this, they have all been modified. As a safety precaution, the maximum power output of all turbines was for a certain period limited to 450 KW, until the power control system was able to prevent excessive power peaks caused by wind gusts. The pitch control system now seems to operate well.

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. Now two of the turbines are 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 power company 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 30 m fibreglass blades and a 1: 68 epicyclic gearbox. The 2 mW generator is of the induction type. The 60 m tower is made of concrete.

As of 1 October 1992, the machine had operated for 11 234 hours and generated 7708 MWh of electricity. The cumulative time of availability was 16 353 hours. Operation and availablity over the last five years is illustrated in Figure 2.2.1. In August 1989, one year after commissioning, 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 operating hours, but the installation of an improved bearing with better lubrication and cooling has now solved the problem. Later, a 1P sound from the first main bearing was observed. This is caused by friction between the bearing and the main shaft, but only for a short time after a start from cold condition.

During 1992 outage time has mainly been caused by planned maintenance work.

The Avedøre wind turbine

ELKRAFT has designed a 50 m/1 MW wind turbine with blades that can be used in both pitch and stall control. The site is the Avedøre power station 10 km south of Copenhagen.

The machine is now in the manufacturing phase, and commissioning is scheduled for October 1993. The turbine will first, for a period of about one year, be operated in the stall mode. Then some minor mechanical modifications will be made in order to change the operational mode to pitch control. A measurement system will collect all relevant data during both periods.

Small-scale wind turbines

Data accumulated over the past six years for both private and utility-owned turbines are presented in Figure 2.2.2.

By the end of 1991, the total number of grid-connected small-scale machines was 3230, the total electrical capacity was 410 MW, and the annual energy production was 730 GWh. This corresponds to 2,3 % of the Danish electricity production. The corresponding numbers for 1 October 1992 are: 3347 units, 437 MW and 590 MWh (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 - 35 m high.

The power range is rapidly increasing. In 1992, machines with ratings of 400 - 450 kW have been commercially available, and this will also soon apply to 500 kW machines, for which prototype testing is in progress. The utilities have asked for tenders of 1 MW machines, so this machine size is expected to be included in the range of commercially available machines rather soon.

By 1 November 1992, new accounting rules for wind-generated electricity came into force. From that date the electric utilities pay private wind turbine owners DKK 0,65 (0,082 ECU) per kWh delivered to the grid. There are no longer any installation subsidies.

Utility wind farms

In 1985, an agreement was reached between the Danish government and the electric utilities, committing them to install 100 MW in wind farms over the next five years. There has been a delay caused by difficulties encountered in getting planning permissions. The agreement will, however, be fully implemented by the end of 1992.

The 1985 agreement will be followed by another 100 MW agreement (1990 agreement) to be implemented before the end of 1993. As a first step, a joint government/utility committee in cooperation with local authorities has recommended a number of suitable sites. Despite this, the implementation of the 1990 agreement is at least one year delayed due to local opposition to wind turbines.

The experience and economy for Danish wind farms was outlined in the Annual Report 1991. More recent data are not available.

Offshore wind farm

The first Danish offshore wind farm was commissioned in mid 1991. The site is in the ELKRAFT area at Vindeby, northwest of Lolland in the Baltic Sea. The wind farm 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 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 respectively.

Although the specific energy output is expected to be about 60 % higher than for average onshore sites, or about 1130 versus 700 kWh per m^2 swept rotor area, the cost of energy produced by this wind farm is estimated to be 50 % higher than for average inland sites. The total costs of the project, including a two year measuring programme, were 10,5 MECU. The reported availability is higher than 96 %.

New approval and certification system

In May 1991, a new approval and certification system for Danish wind turbines was introduced as a result of two years of preparation by the Danish Energy Agency, the Test Station for Wind Turbines at Risø, the Danish manufacturers, the Danish Wind Power Association and various insurance and certification companies. The previous system of type approvals consisted mainly of a general design review and a review of the load and strength calculations. The general purpose of the new approval and certification system is to improve the quality level of Danish wind turbines.

The new system specifies requirements for documentation of all design criteria, such as load cases and loads, fatigue evaluation, safety levels, power curves, noise emission, quality procedure for manufacturing, transporting, installing, and subsequent servicing of the wind turbines. The manufacturers must also have a fully implemented and certified quality assurance system according to ISO 9002.

All wind turbines to be installed in Denmark after 1 July 1992 must be approved and certified according to the new system. Furthermore, it is a condition for obtaining export guarantees from the Danish Wind Turbine Guarantee A/S that wind turbines must be approved and certified according to the new system.

The new approval and certification system is managed by the Danish Energy Agency, assisted by the certification secretariat at Risø.

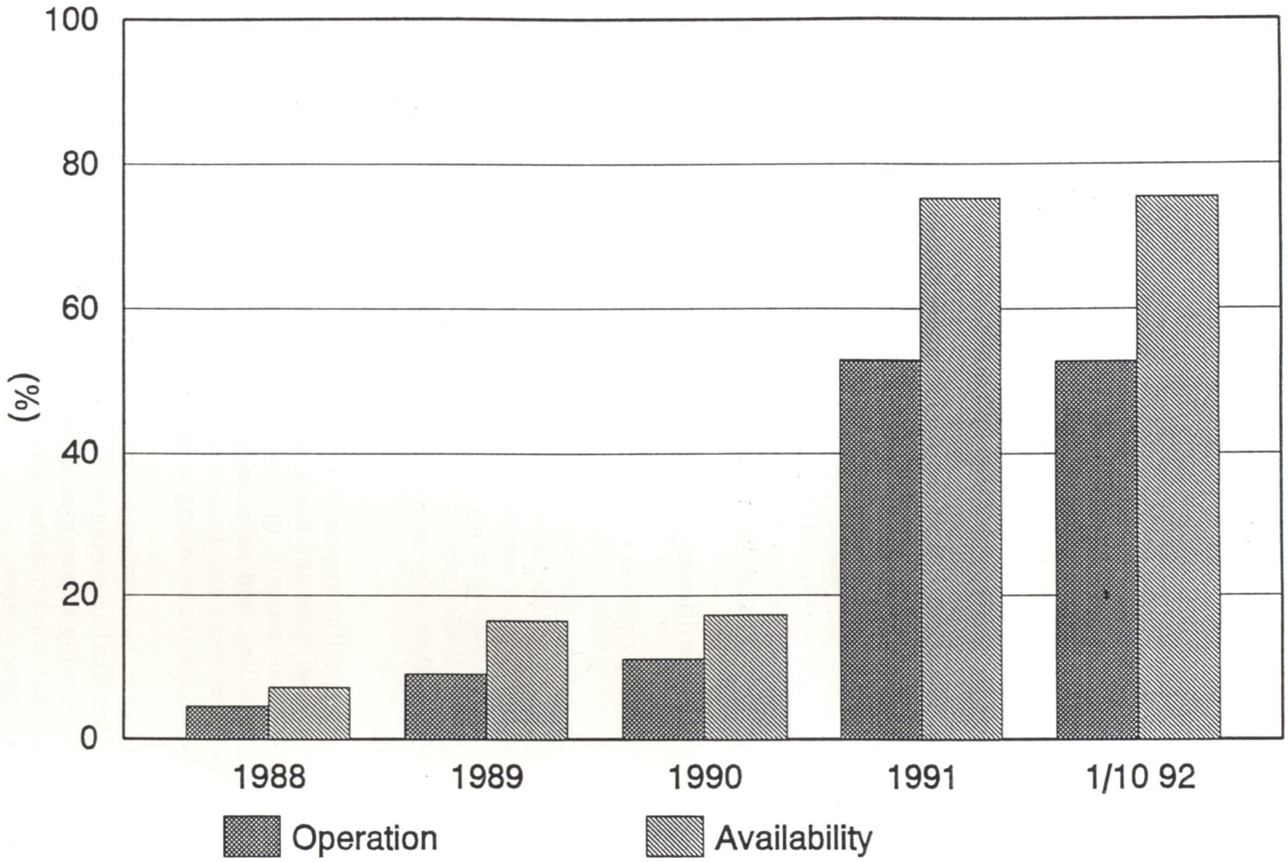


Figure 2.2.1 The Tjæreborg wind turbine: operation and availability

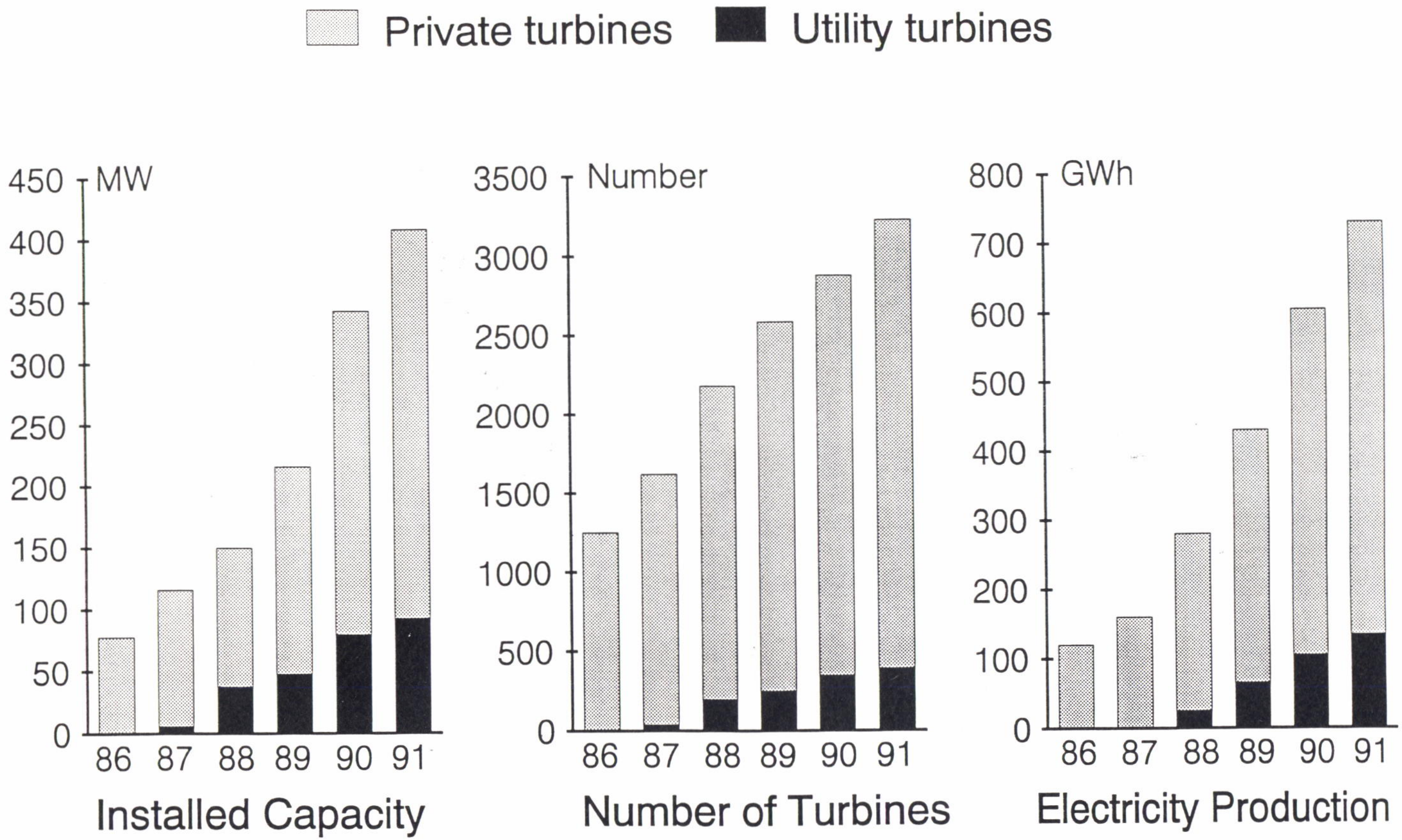


Figure 2.2.2 Accumulated data for wind turbines in Denmark

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. In addition, non-utility electricity producers receive 90 % of the utilities' selling price of electricity according to a new law. The general objective of these supports is to develop reliable wind energy conversion systems (WECS) and to stimulate the commercialization of wind power through demonstration projects and the large scale "250 MW Wind" programme. R&D activities now concentrate on advanced medium-sized machines and on new large-scale wind turbines (LS WECS) [1].

The main activities on medium- and large-scale WECS are: wind measurements, wind technology R&D, turbine development, applications, and general issues.

Detailed knowledge of the wind as the source of energy is necessary since turbulence and other variations of the wind are the principal causes of fatigue loads and and resulting stresses for a wind turbine of any size. Wind measurements using meteorological masts, 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.

Wind technology 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. Rotor stressing, smoothness of operation and aeroelastic behaviour are being studied both experimentally and numerically. This project is a cooperative task in the IEA R&D Wind Agreement, see section 1.5.

The results of this kind of research influence turbine design. For example, the 28 m blade for the 640 kW Monopteros 50 wind turbine, developed by MBB, is made of composite fibre material (CFRP and GFRP) with supporting foam. It has an airfoil of special quality (Wortmann FX84W) and a mass of only 2,4 ton. The same technology is used for the blade of Aeolus II (see below); the blade weight is reduced from 21 ton for the Swedish Näsudden I to about 9,6 ton.

Examples of LS WECS developments and applications are shown in Table 2.3.1. The table includes medium-sized turbines of advanced design. The project titles indicate the relation to the underlying activities already mentioned. They cover single-, two- and three-bladed turbines. The machines are generally characterized by advanced rotor blades and improved mechanical design as well as optimized operational behaviour. The advanced technical concepts will hopefully lead to a further decrease of the generating costs.

General R&D issues include studies of environmental impact (noise) and safety, and technical support for the certification of wind turbines. They also cover assessments of the wind energy potential in the FRG, recently considered with respect to the new Federal States in Eastern Germany [2]. A new wind map including Eastern Germany, has been published by the German Weather Service. In addition, regional wind resource planning is continuing, especially in the German coastal states. Also worth mentioning is the "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 and Garrad Hassan and Partners Ltd.

The 250 MW Wind Programme is accompanied by a ten-year scientific measuring and evaluation programme, called WMEP, for the installed turbines. Detailed evaluation of projects from WMEP should contribute to the above mentioned main activities aiming at further development of wind technology. The status of the 250 MW programme is described below.

Monopteros

This line of development started already in the seventies. The aim was an advanced concept of a single-bladed wind turbine with a counterbalance, as proposed by F X Wortmann. A successful experimental unit, Monopteros 400, near Bremerhaven with a rated power of 400 kW, formed the basis for the the projects "Adaptation development for Monopteros 50" and "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 - 9 to + 20 degrees for the downwind rotor. The three Monopteros 50 were completed in 1989, see Tables 2.3.1 and 2.3.2. Further development is uncertain, as the manufacturer MBB has stopped wind energy activities.

Wind measurements at the Jade Windpark with a 130 m mast is supporting the measuring programmes for the Monopteros turbines and the Aeolus II, se Table 2.3.1.

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, the Netherlands, Spain and the United Kingdom. The first machine, having 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 the 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 the 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 electric power demand is about 1 MW and the maximum 2,5 MW. The wind turbine operates in parallel to the diesel units and is equipped with a special "shaft-driven" generator system of a type often used on ships. Since the shaft speed can vary between wide limits, a frequency converter system is needed to supply constant frequency. The electric 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 service since April/May 1990. At the end of 1991, a blade was partly damaged by a lightning stroke. The GRFP blade was not protected against lightning and the nearby 80 m lattice tower was not affected by the stroke. The turbine was out of operation until May 1992 for repair of the blade. Total energy produced to 17 September 1992 is 3,33 GWh. From 1 June 1992 to 17 September 1992 the energy production was 720 000 kWh.

The new energy supply system 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. This is also a 1,2 MW three-bladed machine, based in principle on WKA 60 but including some important innovations in the framework of Spanish-German cooperation. 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 the advanced development for AWEC-60 is a further reduction of the generating costs. Cooperation with the German partner consisted of adaptation of the WKA 60 concept to Spanish conditions and of R&D work for the innovative subsystems mentioned. In addition, the German manufacturer, M.A.N. - Nürnberg, delivered the drive train. AWEC-60 was completed in Autumn 1989.

In the meantime, the developer of the WKA 60, now M.A.N. Dezentrale Energiesysteme GnbH, has abandoned further wind energy activities.

Wind energy programme PreussenElektra

Since the beginning of 1987, the utility PreussenElektra 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 the expected decrease in generating 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, the activities cover photovoltaics (300 kW up to 1 MW in a later phase, Rheinisch-Westfählische Electricitätswerke AG), solar energy in combination with hydrogen technology (several 100 kW plant with 350 kW photovoltaics, Solar-Wasserstoff Bayern GmbH), and wind/solar supported pumped storage plant (Hamburger Electricitätswerke AG, see below).

In particular, PreussenElektra AG proposed to install and operate two LS WECS at two different German coastal sites. PreussenElektra, the BMFT, the coastal states of 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 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 turbines are now erected:

- An advanced Aeolus II, based on the Swedish 2 MW Näsudden I machine on the island of Gotland in the Baltic, and developed in Swedish/German cooperation. Site: Jade Windpark near Wilhelmshaven in Lower Saxony, see Figure 2.3.1;

- An advanced WKA 60 II, based on WKA 60/AWEC-60 technology. Site: Kaiser-Wilhelm-Koog in Schleswig Holstein on the foundation of Growian, see Figure 2.3.2.

The site of the two turbines are marked on the map in Table 2.3.2. Aeolus II was installed in August 1992. The main design data are shown in Table 2.3.5. WKA II was erected in late Summer 1991. Due to the high penetration of wind power at this particular site, a special filter for higher electricity harmonics was developed and installed in WKA II to guarantee a good power quality. Operation of the turbine started in September 1992.

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. The utility plans to support the filling of the basin with a pump, driven by electricity from wind. The wind power will be delivered by a turbine of about 500 kW rated power. A 60 kW photovoltaic unit will supply power for the control system. The aim of the project is to demonstrate the combined operation of different subsystems. At the same time the plant will serve as a reference with a considerable potential for application around the world. The BMFT and the state of Schleswig-Holstein support the project financially. The project is delayed and first rotation of the wind turbine is expected in late 1993.

HSW

This is the largest wind turbine to be built by Husumer Schiffswerft. It will be installed in January 1993 at the test site in Kaiser-Wilhelm-Koog, see Table 2.3.2. HSW 750 is a three-bladed upwind machine with a rotor diameter of 40 m and a rated rotational 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 speed. 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 by the manufacturer Enercon. It is a 400 kW wind turbine with a direct-driven generator without gearbox. The three-bladed 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 was installed in Spring 1992 and is operated by the Energieversorgung Weser-Ems AG (EWE). The turbine is integrated in the 3,3 MW Windpark Hamswehrum, northwest of Emden at the mouth of the river Ems, see Figure 2.3.3. Enercon plans to enlarge the concept up to 1 MW, see No. 8 in Table 2.3.1.

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 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 with support from the CEC. The manufacturer believes that the design can be economically scaled-up to 1 MW, and realisation is planned is planned with CEC support, see No. 9 in Table 2.3.1.

TW500 is a stall-controlled 500 kW wind turbine, manufactured by Tacke Windtechnik AG. 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 the 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 was difficult to obtain since many areas of the island are protected as nature reserves and since the island is located in the national park "Niedersächsisches Wattenmeer". The operation of the turbine, now erected near the island's harbour, started in September 1992, see Figure 2.3.5.

Funding

For details of funding, budget and policies reference is made to the government annual report [1]. Data on selected LS WECS projects may be obtained from Table 2.3.1. For 1992, the funding of wind energy R&D projects, including demonstration but excluding the 250 MW Wind programme, is about 12 MDEM, see [3]. BMFT support is about 50 % of the total cost. Additional funding may be provided by the Federal States, some examples can be seen in Table 2.3.1. Support is obtainable from the CEC.

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. 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 (0,036 USD/kWh), the required annual funding is 20 - 40 MDEM for the total installation of 250 MW rated power. For each project the duration of the support is limited to 10 years. These numbers are no allocations but they demonstrate the magnitude of this large-scale experiment. Ref [3] shows the following funding of the programme: 1989: 0,2 MDEM, 1990: 3,8 MDEM, 1991: 7,8 MDEM, 1992: 13,5 MDEM. These numbers reflect the rapid build-up phase of the programme.

In addition, the government-sponsored activities include the promotion of field tests of wind turbines and hybrid systems, like wind-diesel systems, under various climatic conditions, e g in overseas countries. From ref [3] the wind part is estimated to reach 4 - 5 MDEM 1992. This will increase as a new programme, called "Eldorado-Programme Wind", was established in 1991.

Promoting wind power in Germany

The total wind power capacity is growing rapidly especially as a result of the 250 MW Wind programme. Since the beginning in Summer 1989, nearly 100 MW have been installed in this programme, see Figure 2.3.6. The totally installed wind power in Germany is 142 MW in 964 turbines.

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 principally the 250 MW Wind programme.

Research and development could be continued for LS WECS, stimulated by the increased interest 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 [2].

In other fields, particularly involving smaller plants, funding of R&D work is no longer considered necessary. Information of importance to the utility industry, such as reliability, maintenance, lifetime, annual production, and installation costs, have moved into the foreground of interest.

The following points are characteristic of the present situation:

- LS WECS prototypes 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 the CEC programmes (WEGA).

- An Ad Hoc Committee on LS WECS under the auspices of the BMFT discussed strategies for the utilization of wind energy by large-scale machines. The committe was composed of 17 experts from the German wind industry, utilities and research institutes, and experts from neighbouring countries and the CEC. The mandate included the following points: Status of wind energy utilization, potential and environmental effects of LS WECS, development of LS WECS, and technical and economic aspects.

The final report of the committee concluded that the existing potential could be advantageously used by LS WECS. The environmental effects were considered favourable, including the reduction of CO_2 emissions. Technology and generating costs should be developed to a more acceptable level. The report recommended the support of manufacture and test of wind turbines with a rotor diameter > 45 m by several manufacturers, and of the operation of about 10 machines per type. In addition, the funding of a research programme, tuned to the needs of the manufacturers, should reduce the risk of the manufacturers and improve the knowledge for optimizing LS WECS.

- The increasing positive attitude towards new energy sources in Germany is emphasized by the recent establishment of new research institutes in several federal states. A German Wind Energy Research Institute (DEWI) has been set up in Wilhelmshaven by the state of Lower Saxony. DEWI arranged a national wind energy conference in Autumn 1992 with more than 200 participants. In June 1989, Schleswig-Holstein announced a permanent test station, which uses the infrastructure of the Growian site. Besides other turbines, the HM-Rotor 300 of Heidelberg Motor is being tested,and from January 1993 the HSW 750 as well.

- An important milestone for promoting wind energy in Germany was reached when a new law was passed in 1991, committing the utilities to pay about 0,16 DEM/kWh (0,10 USD/kWh) to other producers of electricity from wind. This corresponds in general to about 90 % of the utilities' selling price to the end consumer.

- The present situation is considered to be a direct result of wind energy R&D and promotion programmes by the Federal Ministry for Research and Technology (BMFT). In 1986, two demonstration programmes were initiated for wind turbines in the range of 80 to 800 kW. These were followed in 1989 by the "100 MW Wind" programme aimed at the deployment and market introduction of small and medium-scale WECS up to an installed capacity of 100 MW, including a ten-year test, measurement and evaluation programme.

Early in 1991, the 100 MW Wind programme was extended to become the "250 MW Wind" programme. As a result of the German unification, 50 MW is reserved for applicants and sites in the new German states. The programme is being implemented by BMFT in cooperation with the Project Management Biology, Energy, Ecology (BEO) and the Federal States concerned.

Under the "250 MW Wind" programme investors will receive an additional 0,06 DEM/kWh from BMFT for every kWh produced, which means that financial support depends on the amount of electricity fed into the grid. It is believed that this incentive will motivate owners and operators to carefully maintain their wind power facilities to achieve highest possible output.

As the technical development of small and medium-sized wind turbines is still progressing rapidly, and since a goal of particularly high priority is the promotion of a large variety of systems, the 250 MW will be installed over a period of about five years until 1996. Currently proposals for about 50 MW per year are being accepted. Thus it will be possible to include new systems and technologies in the future. Additional criteria which will decide whether a proposal can be accpted or not are (1) the need for demonstration of a particular type of turbine; (2) the need for demonstrating the quality of a particular site; and (3) a certain balance among investors and producers of wind turbines.

The 250 MW programme is accompanied by a compulsory scientific measurement 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. The long-distance measuring network will be the largest of its kind in Germany. In addition, the operators have to report any anomalities during the ten-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.

To date, the number of proposed installations is greater than 6000 with a rated power of more than 1000 MW. This means that less than 25 % of the proposals can be accepted. Figures 2.3.6 - 2.3.8 from WMEP show the actual status. Sites are largely distributed among the Federal States in Northern Germany, such as Schleswig-Holstein, Niedersachsen and Mecklenburg-Vorpommern. Proposals reflect the great variety of more than 40 different turbines and more than 20 different European manufacturers. The analysis demonstrates a trend to increase the power of individual units from an average of below 140 kW in 1989 to about 200 kW today. Proposers are frequently private persons and farmers (65 %), and 30 % are small companies. Utilities only account for less than 1 %. Many facilities are single wind turbines. Thus the largest wind park in Germany at present, rated 12,5 MW and comprising 50 turbines, in North Friesland in the state of Schleswig-Holstein, is being supported by the programme.

• The environmental and aesthetic issues arising from the extensive deployment of wind turbines will be more apparent as the general public become fully aware of the situation and will no doubt stimulate the discussion on the benefits and disadvantages of wind power technology. It is hoped that the "250 MW Wind" programme will contribute towards the reconciliation of the different positions and interests and provide facts and data required to ensure the viability and general acceptance of wind power.

References

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2 W Maier; *Nutzung der Windenergie in Deutschland*, Resch Verlag, D-8032 Gräfeling; ISBN 3-87806-136-6

3 ISET, WMEP, Königstor 57-61, D-3500 Kassel, fax 561 7294 100

4 BMFT-Referat, Öffentlichkeitsarbeit: *Erneubare Energiequellen*, Bonn, Juli 1992, ISBN 3-88-135-244-9

5 Lyn Harrison; *Windpower Monthly* , October 1992, p 25ff

Fig. 2.3.1: AEOLUS II near Wilhelmshaven, 3 MW

Fig. 2.3.2: WKA 60 II, Kaiser Wilhelm-Koog, 1.2 MW

Fig. 2.3.3: E – 36 near Hamswehrum, 400 kW

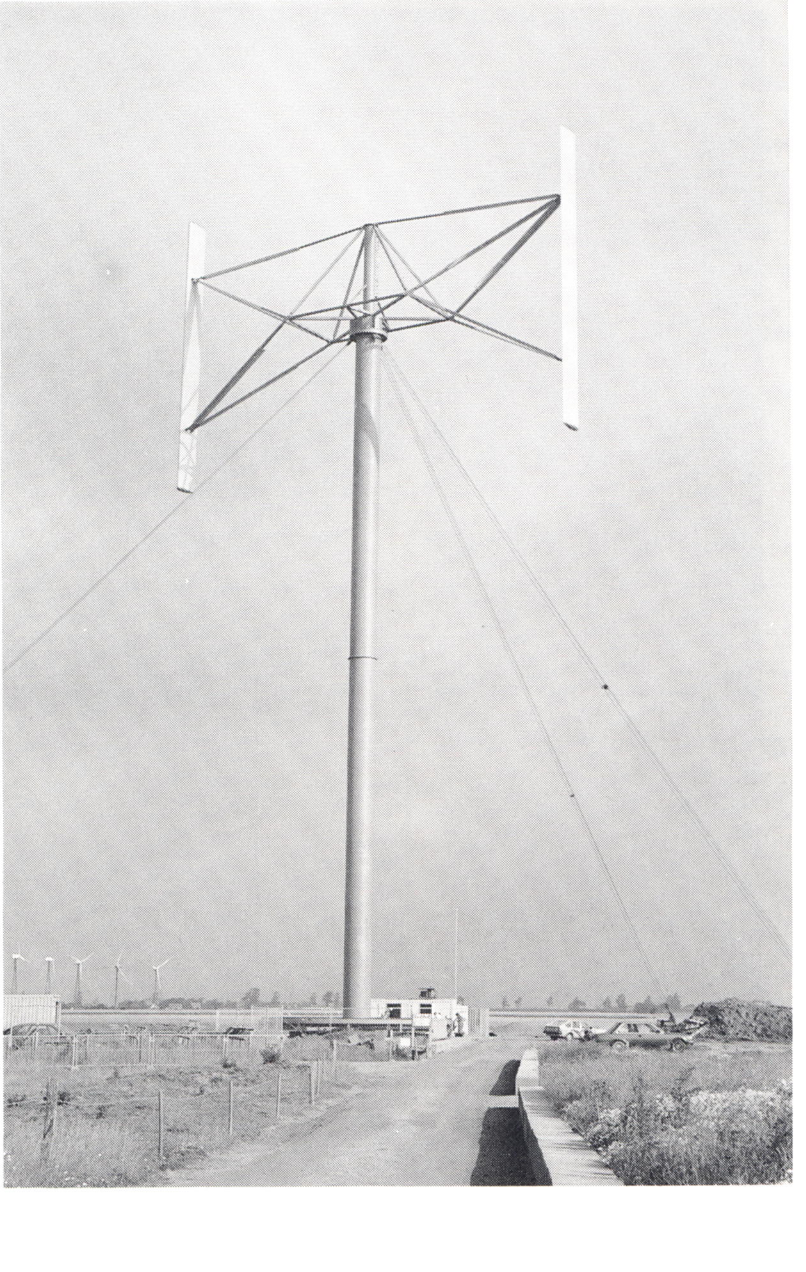
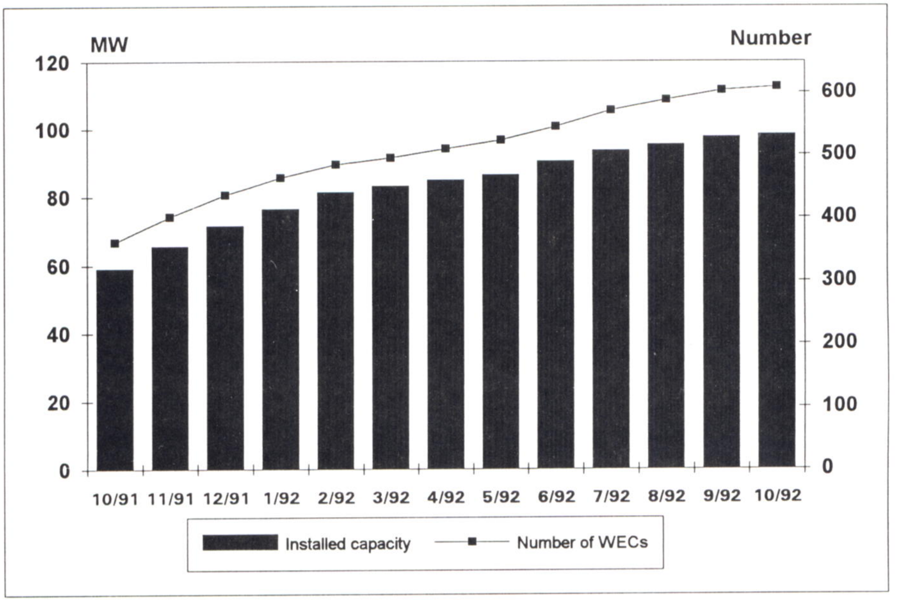


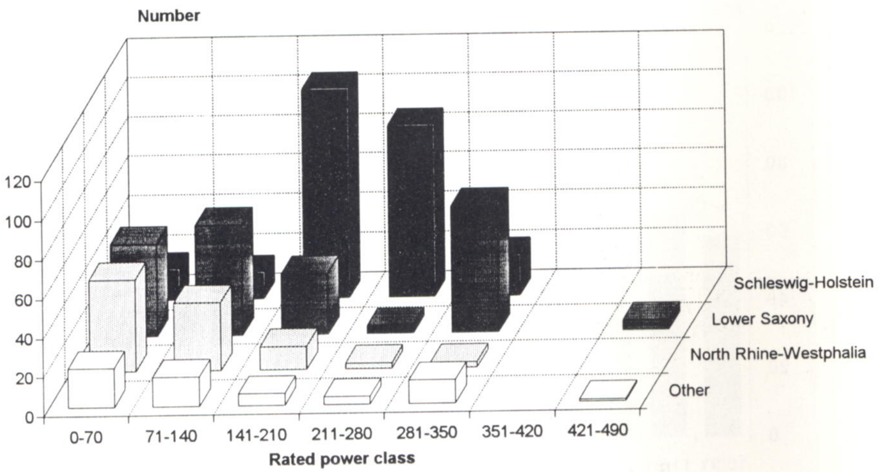
Fig. 2.3.4: HM-Rotor-300, Kaiser Wilhelm-Koog, 300 kW

Fig. 2.3.5: TW 500, Borkum, 500 kW



WECs in WMEP (October 31,1992)		
Month of admission	**Number**	**Installed rated capacity [MW]** (acc. to manufacturers ratings)
10/91	362	59,084
11/91	402	65,534
12/91	437	71,594
1/92	464	76,484
2/92	485	81,414
3/92	495	83,094
4/92	510	84,894
5/92	523	86,379
6/92	545	90,454
7/92	571	93,561
8/92	588	95,371
9/92	603	97,576
10/92	**609**	**98,273**

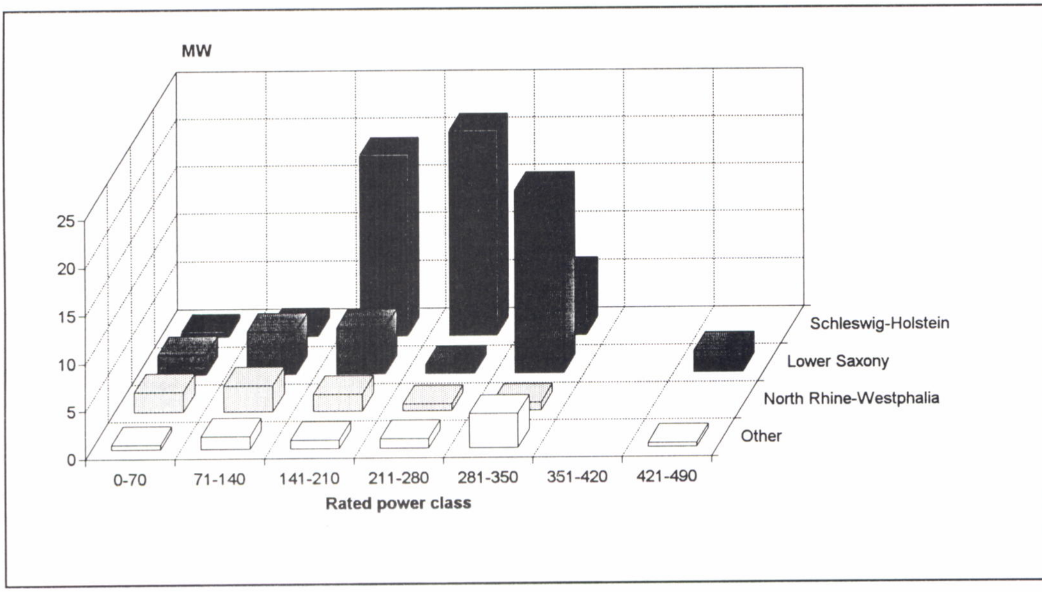
Fig. 2.3.6: WMEP: Installed rated power/number of turbines. Period: 1 year



Number of WECs by Germanstate / Rated power class (October 31,1992)

Germanstate	Rated power class							
	0-70 kW	71-140 kW	141-210 kW	211-280 kW	281-350 kW	351-420 kW	421-490 kW	Total
Baden-Wuerttemberg		1			1			2
Bavaria	6							6
Brandenburg					1			1
Bremen			2				1	3
Hamburg	2		1					3
Hesse	3	2	1	3				9
Mecklenburg-Vorpommern	3	7	1	1	7			19
Lower Saxony	47	56	31	4	64		5	207
North Rhine-Westphalia	47	35	12	3	3			100
Rhineland-Palatinate	6	2	1		3			12
Saxony		3						3
Schleswig-Holstein	16	14	106	87	21			244
Total	**130**	**120**	**155**	**98**	**100**		**6**	**609**

Fig. 2.3.7: WMEP: Number of turbines as function of power class and Federal States

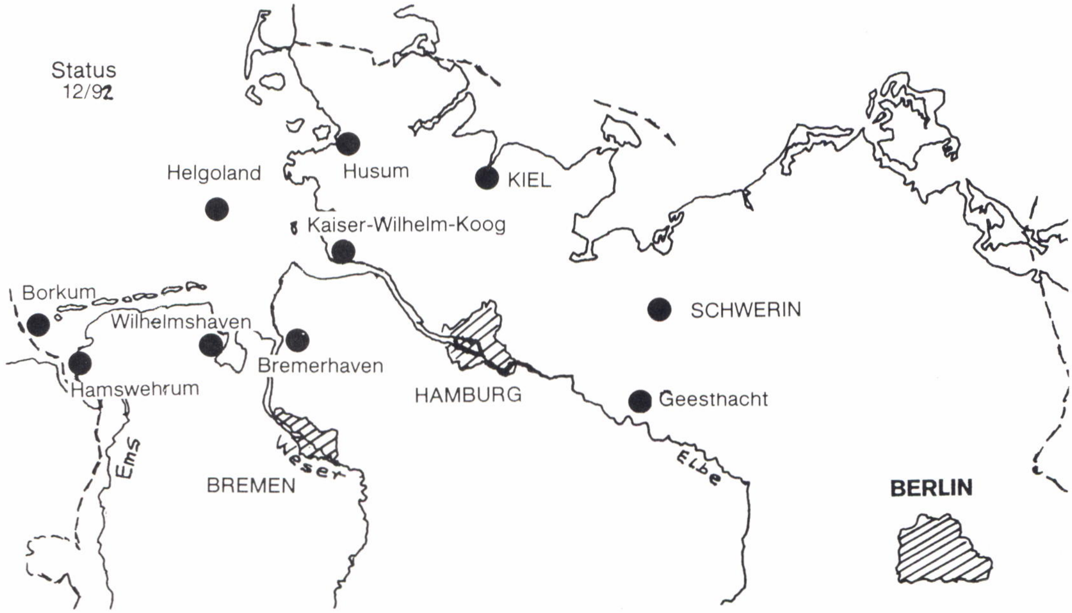


Installed rated capacity by Germanstate / Rated power class (October 31,1992)								
Germanstate	**Rated power class**							
	0-70 kW	**71-140 kW**	**141-210 kW**	**211-280 kW**	**281-350 kW**	**351-420 kW**	**421-490 kW**	**Total [MW]**
Baden-Wuerttemberg		0,095			0,3			0,395
Bavaria	0,161							0,161
Brandenburg					0,3			0,3
Bremen			0,3				0,45	0,75
Hamburg	0,06		0,15					0,21
Hesse	0,11	0,18	0,15	0,75				1,19
Mecklenburg-Vorpommern	0,112	0,63	0,15	0,25	2,1			3,242
Lower Saxony	2,067	4,485	4,825	0,975	19,1		2,25	33,702
North Rhine-Westphalia	2,135	2,77	1,825	0,75	0,86			8,34
Rhineland-Palatinate	0,06	0,16	0,15		0,9			1,27
Saxony		0,255						0,255
Schleswig-Holstein	0,563	1,14	18,98	21,495	6,28			48,458
Total [MW]	**5,268**	**9,715**	**26,53**	**24,22**	**29,84**		**2,7**	**98,273**

Fig. 2.3.8: WMEP: Installed rated power as function of power class and Federal States

Table 2.3.1: **WECS Projects in Germany, rated power ≧ 400 kW**

1 MONOPTEROS 50 – 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); 01.09.88–31.12.92; 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); 01.02.89–31.12.92; 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 (≈500 kW) 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 – 30.06.1994; 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 – 30.06.1992; 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 – 31.12.1992; DM 1,17 million (BMFT: 25%, Lower Saxony: 25%)
8 E – 55 1 MW 3 bladed turbine, no gear box, new generator type (Enercon), to be contraced end 92 with DG X II, EC; grant: 1400 k ECU. See ref. [5]
[9] 1.2 MW H-Rotor Development, manufacturing and testing of a vertical-axis wind turbine H-Rotor with 1.2 MW (Union Fenosa SA, Heidelberg Motor GmbH, WIP, RWE) to be contraced with DG X II, EC; grant: 1600 k ECU. See ref. [5]



	Typ	Location •	Power	Realization
1.	MON 50	Wilhelmshaven	3 à 640 kW	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	92 Autumn 91
4.	?	Geesthacht	≈ 500 kW	93
5.	HSW 750	Kaiser Wilhelm-Koog	750 kW	93
6.	E-36	Hamswehrum	400 kW	Spring 92
7.	TW 500	Borkum	500 kW	92

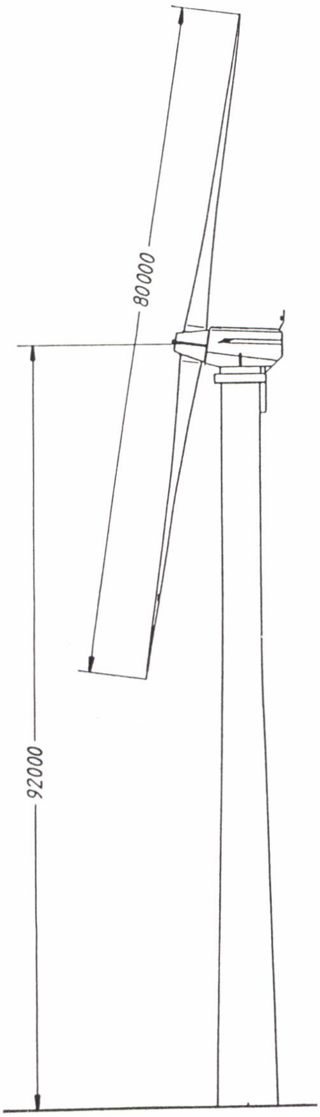
Table 2.3.2: Protypes, rated power ≧ 400 kW, in Northern Germany. The number 1...7 refers to the Table 2.3.1

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

Table 2.3.4: SYSTEM DATA: HSW 750, TW 500, E – 36

	HSW 750	TW 500	E – 36
Rotor			
Number of blades	3	3	3
Diameter m	40	36	36
Hub	Fixed	Fixed	Fixed
Hub heigt m	45	35	40
Rated speed rpm	39	31	15 – 37
Orientation	upwind	upwind	upwind
Rotor blades			
Material	GFRP	GFRP	GFRP/Epoxy
Airfoil	NACA	NACA 63 – 200	FX 84
Control	Tip	Tip; stall	Full span blade pitch
Max. power coeffizient	0.415	0.449	
Gearbox			
Type	2 planetary	spur gear box	no gear box
Ratio	1 : 38	1 : 49	
Yaw drive System			
Type	electromechanical	electromechanical	electromechanical
Tower			
Type	conical/5 parts	conical	cylindrical/2 parts
Material	steel	steel	prestressed concrete
Generator			
Type	Asynchronous	Asynchronous	directly driven generator
Rated power kW	750	500	400
Operation			
Cut-in m/s	4	4	3,5
Rated m/s	14	14,5	12,0
Cut-out m/s	24	25	25



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	9.6 t each
Hub	19.0 t
Nacelle complete	120 t
Tower	1410 t

Table 2.3.5: AEOLUS II. Main design data

2.4 Italy

Introduction

As already described in previous reports, the wind energy sector in Italy involves four organisations:

- ENEA (the Italian Energy, New Technologies, and Environment Agency) which is a state-owned organisation, playing, among other things, the role of industrial promoter in the aforementioned fields.

- ENEL, which is Italy's main utility company. Formerly known as the National Electricity Board, in August 1992 ENEL was set up as a joint-stock company in view of being privatized. This process is currently under way and is expected to be completed in the course of 1993.

- The Alenia group, resulting from the merger of the Aeritalia and Selenia companies at the beginning of 1991. Alenia entrusted the manufacture of medium and large wind turbines to the WEST company, which had been set up for this purpose by Alenia itself, Ansaldo and Belleli.

- The Riva Calzoni company, which has been a well-known manufacturer of mechanical and hydraulic equipment for over a century. Some years ago, Riva Calzoni entered the field of wind turbine manufacturing within a framework of a cooperation agreement with the German MBB group.

Research, design and testing work is aimed, on the one hand, at assessing Italy's usable wind potential, and, on the other hand, at developing a few Italian wind turbine models, such as the medium-sized machines Medit by Alenia/WEST and M30 by Riva Calzoni, and the large (1500 kW) GAMMA 60 machine made by Alenia/WEST.

The sector of turbine development has since the beginning seen a close cooperation between manufacturers, ENEA (providing technical and financial support) and ENEL (mainly cooperating in the testing of prototypes). Partial financial support has also been granted by DG XVII of the Commission of European Communities.

More recently, the four organisations mentioned above have been collaborating also in the sector of wind plant siting after a joint "Siting Commission" was set up in 1990 with the aim of putting together all data acquired up to that time, so as to get to the point of drawing up a comprehensive map of sites actually suitable for wind farm installation.

The scope of wind energy activities was also enlarged in late 1988 as a consequence of the new National Energy Plan (PEN), which set a target of 300 MW of wind generating capacity to be installed with medium-sized machines by the year 2000.

To comply with PEN, both the ENEL company and ENEA have since the end of 1988 undertaken a few projects aimed at setting up Italy's first wind power plants (wind farms), both for demonstration purposes and for promoting the wind energy industry in meeting internal demand. On the other hand, wind turbine manufacturers, i. e. the Alenia/WEST and Riva Calzoni companies, have also embarked on their own installation of a few small plants.

Generally speaking, it can be stated that a cumulated wind capacity of about 11 MW has been installed in Italy so far, including experimental units. A more careful survey of the plants that are actually in operation at the present is now being made by ENEA. As a rough estimate, currently operating wind capacity may be put at about 6 - 7 MW.

Installed capacity is likely to grow to a more significant figure in the next years as a consequence of both existing projects (see the following sections) and possible commitments of private investors encouraged by the legislative measures that were already described in the 1991 report. These measures provide for incentives to wind energy investors through subsidization of plant design and construction costs (Laws no. 9 and 10 passed in January 1991), as well as by means of premium payments for wind-generated electricity sold to ENEL.

As for premium payments, it should be recalled that the latest directive issued by CIP, the Interministerial Committee on Prices, (Directive No. 6 of 29 April 1992) has, among other things, allowed a price of 150 - 166 ITL/kWh (0,10 - 0,12 USD/kWh) for those plants that have come on line after 30 January 1991 and make available their full capacity or a fixed share of it. This price will be allowed over the first eight years of plant operation, then it will drop to 72 ITL/kWh. In case the investor also benefits from grants under the above-mentioned Law No. 10, the energy price is reduced to 120 - 136 ITL/kWh.

More detailed information of the various spheres of activity mentioned in the foregoing is given in the following sections with reference to each of the organisations involved.

ENEA

The general strategy underlying ENEA's wind energy programme is to contribute to the market penetration of wind energy in Italy in accordance with PEN, on the one hand by supporting Italian manufacturers in their development of technically and financially competitive wind turbines, and, on the other hand, by identifying suitable sites for wind power plants.

ENEA's programme features the following areas of activity:

- The pinpointing of sites and development of siting methodologies.
- Development of planning methods and wind turbine technology
- Development of machines
- Development of wind turbine plants.

The main objective of pinpointing sites is to produce, within the framework of the aforementioned Siting Commission, set up in cooperation with ENEL and the manufacturers, a national wind map containing information relating to areas suitable for power plants. Wind, meteorological, land, and legislative data banks are being set up.

As regards the development of planning methods and wind turbine technology, ENEA's staff are engaged in research in cooperation with universities and research organisations, as well as, of course, with manufacturers.

With regard to the development of machines, the main areas of activity involve the design of wind turbine prototypes, such work being confined to the more innovative, more highly "transferable" aspects; wind turbine instrumentation and field tests; and the development of innovative subsystems.

In the short term, attention is being focused on the final phase of testing of the medium-sized wind turbines Medit and M30, in order to meet the immediate requirement: that of being in a position to test substantial clusters of these machines at power plants of significant size (5 - 10 MW). In addition, ENEA plans, together with WEST, to develop a more advanced, second generation Medit wind turbine (the variable speed Medit Mk 3). The medium-term commitment is that of developing the large GAMMA 60 wind turbine (by WEST), and the medium-large M55 wind turbine (by Riva Calzoni).

With regard to the development of combined wind-diesel generator systems, ENEA is taking part in a research project within the framework of the European Community's JOULE programme, the aim of which is to set up a computer code for the optimisation of system components.

Lastly, as regards the development of power plants, the medium-term aim is to study the feasibility and general design of two 10 MW wind power plants to be built in the regions of Campania and Emilia-Romagna, respectively. The task of conducting these studies has been entrusted to Alenia/WEST for the former plant and to Riva Calzoni for the latter.

ENEL

Introduction

The ENEL company, in its utility role, has a keen interest in pointing out possible wind farm sites and ascertaining the performance of available medium-sized and large wind turbines. To this end, ENEL has been conducting wind surveys (over 90 measuring stations installed so far) in several parts of Italy, and micrositing studies at some selected sites.

Technology assessment has been in progress at the Alta Nurra test site in Sardinia on five medium-sized units. At the same site, the 1500 kW GAMMA 60 prototype has also been under test since mid-1992.

In addition to technology assessment under seaboard climatic conditions (already under way at Alta Nurra), the first phase of ENEL's wind farm programme also provides for the testing of medium-sized machines at a mountain site with harsh environmental conditions, in order to check the feasibility of installing possible wind farms on the ridge of the Apennines. High-altutude experiments have required the construction of a new test site at Acqua Spruzza near Frosolone in the Molise region (see below).

Within the second phase of ENEL's programme, a wind farm with up to 40 units for an overall capacity of about 11 MW is going to be set up at Monte Arci in Sardinia. Information on this project is also given below. The setting up, in Central-Southern Italy, of a further 2-3 plants totalling another 10 MW as a whole, is also provided for in the programme, but the relevant sites have not yet been chosen by ENEL.

In addition, it should be recalled that, by terms of an agreement with the Italian Government, ENEL is also considering the possibility to set up a further 40 MW of wind capacity within the next five years, so as to reach a total capacity of 60 MW.

Lastly, ENEL has also been drawing up specifications for the manufacture of stand-slone wind generating plants that the company would use in some areas such as Calabria to supply remote dwellings. On-the-spot checks of the performance of prototypes produced by manufacturers in accordance with these specifications will subsequently be performed by ENEL before purchasing the systems.

Alta Nurra Test Site

At the Alta Nurra site in Sardinia, four medium-sized wind turbines (the 225 kW Medit prototype by Alenia/WEST, the 200 kW M30 prototype by Riva Calzoni, a 300 kW MS-3 unit by WEG from the United Kingdom, and a 400 kW Windane 34 unit by Vestas-DWT from Denmark), featuring different characteristics, have been tested together since April 1991.

A Medit 320 (or Medit I) wind turbine has also been under test at Alta Nurra since the spring of 1992. The Medit 320 is the 320 kW rated, industrialized version of the Medit prototype. The overall energy produced by these machines has, by the end of 1992, reached nearly 1,5 million kWh (annual wind speed at the site is 5 m/s).

In addition to data recording of energy production, reliability and availability of all machines, and experimental determination of the relevant power curves, specific measurements have also been made in respect of noise and electromagnetic interference.

Installation of the 1500 kW GAMMA 60 prototype started at Alta Nurra in early April 1992. After thorough functional checks, the machine was connected to the grid for the first time in June. Further information on GAMMA 60 will be given in the Alenia /WEST section (see below).

Acqua Spruzza Test Site

The Acqua Spruzza site is located in the Apennines at an average altitude of 1360 m a.s.l. and has been chosen for its very good wind resources (annual average wind speed 7 m/s at 15 m above ground) and its climatic conditions (heavy snowfalls, icing, high wind turbulence), which make it suitable for its specific purposes.

The site will host eight wind turbines, specifically two Medit 320 units, manufactured by WEST (Italy), two M30 units by Riva Calzoni (Italy), two MS-3 units by WEG (United Kingdom), and two Windane 34 units by Vestas-DWT (Denmark). Total installed capacity will therefore be 2440 kW, and total energy yield may be estimated at about 6000 MWh per year.

The test site is financed entirely by ENEL, which has been granted partial support by DG XVII of the Commission of European Communities.

A preliminary plan of the test site was prepared in late 1989 and then delivered to the municipality of Frosolone in February 1990 together with an application for a building permit. The whole procedure including permitting by regional authorities took an unexpectedly long period of 28 months and caused considerable delay in respect of the work time schedule.

In the executive design phase, special attention was devoted to harmonizing the plant with the landscape in compliance with specific requests from local authorities.

Civil engineering work started at the Acqua Spruzza site in July 1992. The plant is now expected to be completed by the autumn of 1993.

Monte Arci wind farm project

ENEL's first large wind plant will be built in Sardinia, in the province of Oristano. The land involved is a part of the large Monte Arci plateau, at an average altitude of about 750 m a.s.l., 8 km from the sea (Gulf of Oristano.

The plant will be equipped with up to 40 Italian-made wind turbines, specifically: 320 kW Medit 320 and 250 kW M30-A units. Total capacity will be around 11 MW. The annual energy output may be estimated at between 15 and 20 GWh (an annual wind speed of 5,7 m/s at 15 m above ground has been measured).

DG XVII of the Commission of the European Communities has granted the project its partial funding within the framework of the THEMIE programme.

In September 1991 the preliminary design of the wind farm was submitted to the concerned authorities for the building permit after ample information on the project had been provided to the municipalities and people involved. A definitive response is expected to be given shortly.

In drawing up the plant design, special attention was devoted to the need to minimize the impact on the local environment, bearing in mind that forestation activities are in progress in some parts of the plateau, and that local authorities intend to enhance the role of this area as a tourist resort. The total area over which machines would be spread has, therefore, turned out to be considerably larger than usual in wind farms. With reference to the Monte Arci site, ENEL has also embarked on studies aimed at assessing the interaction between the wind power plant and the environment during both construction and operation.

6

Alenia/WEST

The WEST Company

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

Medium size machines

The basic commercial product of WEST is Medit 320, in series production since 1991 in WEST production facilities. Medit 320 is the industrial model derived from the 225 kW prototype installed in Sardinia. As of the end of 1992, 48 units have already been manufactured (28 in 1992), improvements being introduced as a consequence of the results of operation of the machines already installed. Production plans for the forthcoming years are based upon an annual production rate of up to 100 wind turbines, and an existing backlog of about 15 MW. The main features of Medit 320 are shown in Table A.

Table A Main data for Medit 320

Number of blades	2
Rotor diameter	33 m
Rotor position	upwind
Hub height	26 m
Hub	rigid
Gearbox	teetered
Power regulation	pitch control
Yaw control	active
Rated power	320 kW
Wind speed @ 10 m	
cut-in	4,2 m/s
rated	11,5 m/s
cut-out	17,5 m/s
survival	50 m/s

WEST is also working on the development of a new model, Medit Mk 3, whose general background philosophy comes from the experience in the development of the prototype Gamma 60 and in the industrial production of Medit 320.

In fact, Medit Mk 3 will essentially be a turbine embodying the Gamma concepts with improvements and simplification that are expected to allow minimum series production costs, maximum energy capture and adequate availability.

The prototype is foreseen to be installed in 1993 and field tested in 1994.

Large size machines

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 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.

A description of the activities performed in the last phases of the programme is reported in the following.

After completion of the assembly in 1991, a series of in-depth operating tests were carried out on the integrated system in the WEST workshop.

The basic requirement of these tests was to have the machine operating in real time, in all possible operating conditions, in order to test the overall system, with special attention to hydraulics, the drive train and the supervisory and control hardware and software.

The tests performed with this system have assured the proper behaviour of the actuation devices (hydraulic and electrical) and sensors, the stability of this behaviour for extended operation, the validity of the modeling of the wind turbine, the proper implementation of the regulating algorithms and supervision strategies.

After completion of all the above steps, the nacelle was made ready for shipment to the site in the first months of 1992.

In the meantime the various site activities had been completed at the Alta Nurra site:

> Foundations for the WTG tower and for two 100 m high wind measuring towers. The foundations of the tower, due to the nature of the ground at Alta Nurra, consist of a reinforced concrete plinth, set on 25 vertical piles of the same material.
>
> Power station building, located near the base of the WTG tower, housing, among other things, the AC/DC/AC converter.

Construction of the cable conduits, smoothing out of the ground, building of access roads.

All civil works were completed within the spring of 1990.

The tower was transported to the site in eight separate sections; the first section was embedded in the reinforced concrete foundations, while the others were welded to each other on the ground in three separate pieces with lengths 16, 16 and 24 m respectively. Each piece was then hoisted and welded to the piece below it.

Assembly of the WTG tower was completed in Summer 1990.

Nacelle erection, by means of two 450 ton cranes, took place on 9 April 1992; all other installation activities were completed by the end of the same month, see Figure 2.4.1.

Thanks to the fine tuning of the system in shop, for which a relatively long period of time was spent, the site activities were very rapidly completed, so that the first rotation of the machine occurred on 3 June, one month after completion of site installation.

Static and rotation tests on the machine were performed under controlled conditions (i.e. below the proper supply limit) in order to check the overall operation of the equipment and of electric, mechanical and control components, and to ensure that the operating parameters recorded were in line with the targets laid down during the design stage.

Tests in various operative conditions have then been performed in order to confirm that the equipment performs according to plan.

Wind farm developments

Among WEST's major programmes in the field of wind farm development is the Campania wind farm, the first Italian wind farm made up of medium-sized machines, see Figure 2.4.2.

The first module, consisting of four Medit 320 and three AIT 03 (30 kW of rated power), was connected to the grid in the beginning of 1992. After some setup activities on the control and actuation systems, it came to full operation in the spring. A second module with two Medit 320 and 13 AIT 03 was installed and connected in the second half of the year.

Other installations have been made in Sardinia (Villagrande, two Medit, Oristano, one Medit and Alta Nurra, one Medit), in Molise (Sannio. one Medit) and in Abruzzo (Sangro, three Medit). Other installations are under way.

Riva Calzoni

Introduction

Since the beginning of this year, Riva Calzoni activities in the wind energy field have been concentrated on M30 activities. The industrial production of the 250 kW M30-A (see Figure 2.4.3) has reached a commercial level with some units already installed. Wind farm planning is going well with many sites being evaluated through wind monitoring.

The development of the M30 series is going on with the completion of the M30-S1 prototype, an improved version of the 250 kW M30-A with a new rotor, hub and blade. This rotor will prelude to the M30-S2 (Figures 2.4.4 and 2.4.5), an upgraded generator version of 350 kW rated power, which should be ready for the end of 1993.

M30

A lot of activities are going on to promote wind farm development in Italy. Wind monitoring activities have been enlarged from two monitoring sites in 1991 to more than 19 sites in 1992. Almost half of these sites have good prospects for small M30 realizations. Up to 35 units of the M30 series have been produced for different customers.

Within the framework of these activities, the first wind farm ever built by an Italian municipality was set up in the commune of Tocco de Casauria in the Abruzzo region in Central Italy and started operation in July 1992. The plant (see Fig 2.4.6) includes two 200 kW M30 wind turbines. An average wind speed of about 6 m/s has been measured at the site during these two years. The predicted energy yield is about 1500 MWh/year.

The municipality was granted the major funding share within the FESR-VALOREN European Community programme. The remaining part of the plant cost was financed by the municipality itself, by the Abruzzo region and by ENEA.

Several experimental activities on the 200 kW prototype in Sardinia are also in progress. Among these activities, an R&D programme was completed within the CEC JOULE programme. According to this experiment, further improvements will be implemented on the MS30-S1 and MS30-S2, which will be realized during next year.

The main improvements are the following:

- Increase of the rated power from 250 to 350 kW;
- Completely new concept for the hub design and assembly;
- New blade, especially designed for the highest energy efficiency with the lowest noise;
- New electric generation system with semi-variable speed for load reduction.

M55

Research activities on the M55 (see 1991 report) have been kept on a lower priority in 1992 to concentrate the resources on the new M30-S1 and S2, which will be a main key to develop the M55. Activities on the M55 will be emphasized more in next years when the M30-S2 will be a very competitive wind turbine.

Future perspectives

At the end of next year the M30-S2 production will start, including new design improvements in order to get a more reliable and simple wind turbine, always on the basis of operating experience of the first commercial installation.

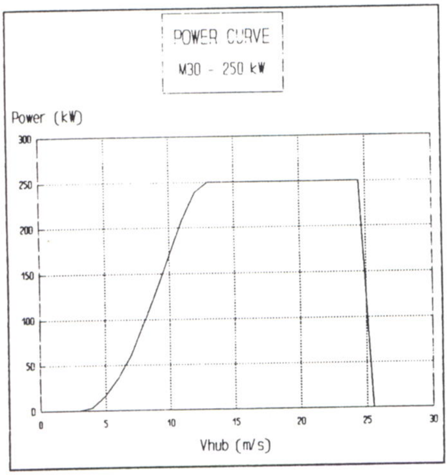
The machine cost will be very low and interesting on the market, showing the good perspectives of the single-blade technology reaching its commercial phase.

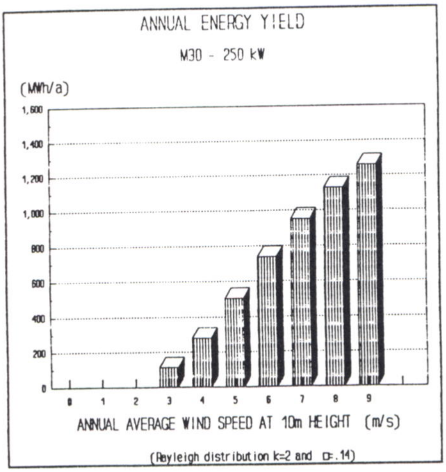
Figure 2.4.1 The 1,5 MW GAMMA 60 at Alta Nurra

Figure 2.4.2 Partial view of the wind farm set up by WEST near Bisaccia in the Campania region

M30 A - 250 kW WIND GENERATOR

ENERGY PRODUCTION





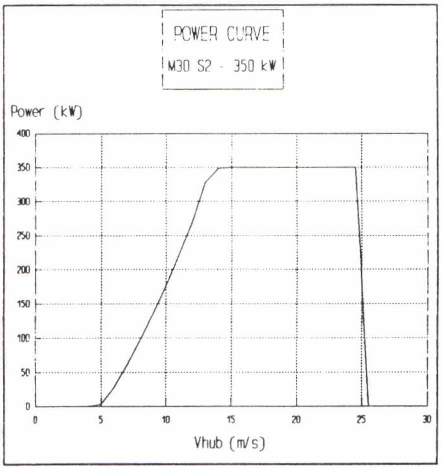
TECNICAL CHARACTERISTICS

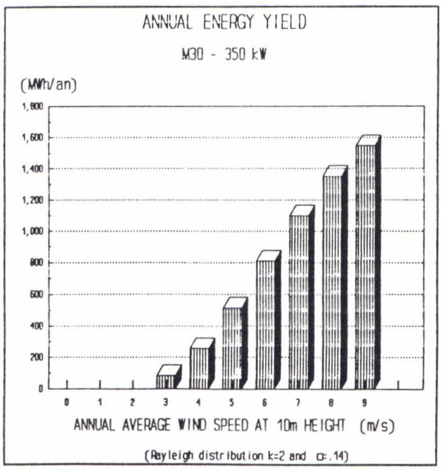
ROTOR	
Blade Number	1
Diameter	33 m
Speed	39.9 / 60.3 RPM
Rotor position	downwind
Hub type	teetering hub
Pitch angle range	0° and 90°
ROTOR BLADE	
Blade + counter weight arm lenght	22 m (one part)
Chord length	0.26 - 1.77 m
Material type	CRP/GRP (Epoxy)
Profile type	FX84-W series
TOWER	
To Hub Height	33 m
Shape	polygonal conical
Diameter	1.6 - 1.1 m
Material	painted galvanized steel
ELECTRICAL SYSTEM	
Generator type	asynchronous (induction)
Generator number	2 (low+ high wind speed)
Generator power	250 kW / 55 kW
CONTROL	
Type	Computer + electro-mechanical logic
Pitching System	hydraulic actuators
Yawing System	active
Parking	feathered blade, flap locked
DRIVE TRAIN	
Gear	2 stage / parallel shaft
Gear ratio	1 : 25.6
Manual brake	disc (maintenance)
PERFORMANCE	
Rated power	250 kW
Windspeed at rated power	12 m/s
Operating range	3.5-25 m/s
Starting windspeed	4 m/s
Survival windspeed	55 m/s (at hub height)
Lifetime	30 years

Figure 2.4.3 Characteristics of the M30-A wind turbine

M30 S2 - 350 kW WIND GENERATOR

ENERGY PRODUCTION





TECNICAL CHARACTERISTICS

ROTOR	
Blade Number	1
Diameter	33 m
Speed	53 / 55.6 RPM
Rotor position	downwind
Hub type	teetering hub
Pitch angle range	0° and 90°
ROTOR BLADE	
Blade length	16 m
Counter weight arm	5.5 m (separate section)
Chord length	0.6 - 2.06 m
Material type	CRP/GRP (Epoxy)
Profile type	FX84-W series
TOWER	
To Hub height	33 m
Shape	polygonal conical
Diameter	1.6 - 1.1 m
Material	painted galvanized steel
ELECTRICAL SYSTEM	
Generator type	asynchronous (induction)
Generator slip	5°
Generator power	350 kW
CONTROL	
Type	Computer + electro-mechanical logic
Pitching System	hydraulic actuators
Yawing System	active
Parking	feathered blade, flap locked
DRIVE TRAIN	
Gear	2 stage / parallel shaft
Gear ratio	1 : 28.3
Manual brake	disc (maintenance)
PERFORMANCE	
Rated power	350 kW
Windspeed at rated power	13 m/s
Operating range	3.8-25 m/s
Starting windspeed	4.3 m/s
Survival windspeed	55 m/s (at hub height)
Lifetime	30 years

Figure 2.4.4 Characteristics of the M30-S2 wind turbine

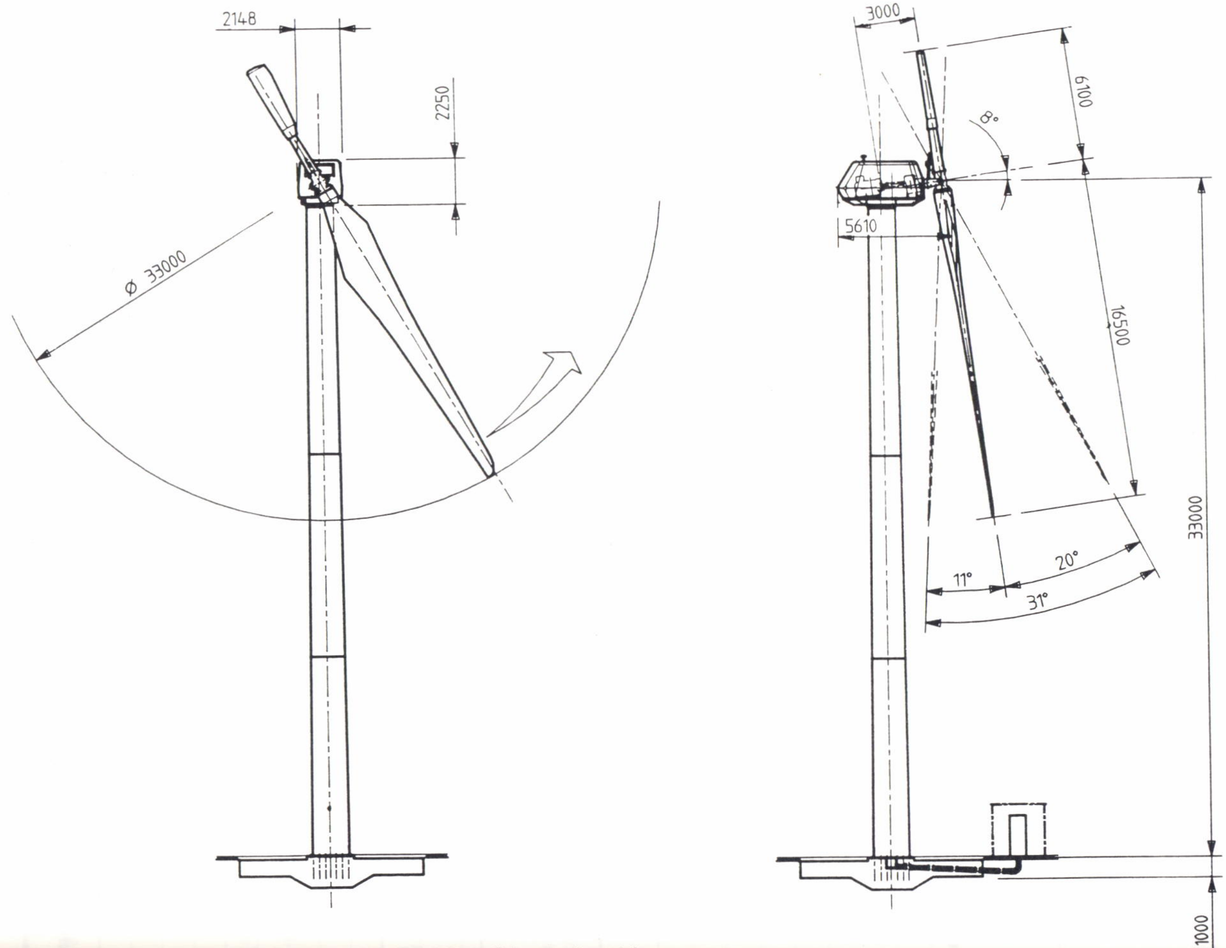


Figure 2.4.5 Overall drawing of the M30-S2 wind turbine

Figure 2.4.6 M30 units installed at Tocco de Casauria (Abruzzo region)

2.5 Japan

Introduction

Since 1978, the Japanese wind energy R&D programme has been directed by the Sunshine Project Promotion Headquarters (S/S H.Q.) in the Agency of Industrial Science and Technology (AIST) of the Ministry of Trade and Industry (MITI). The New Energy and Industrial Technology Development Organization (NEDO) plays the main role in the construction and operation of the large scale test plants in the project. The Mechanical Engineering Laboratory (MEL) and the National Institute for Resources and Environment (NIRE) are carrying out basic research in wind energy and are supporting the Sunshine Project by evaluating the activities of NEDO.

The budget for wind energy in the Sunshine Project increased from JPY 370 million in fiscal year 1990 to 549 MJPY in FY 1991 and 981 MJPY for FY 1992 (corresponding to 7,7 MUSD).

A number of suitable sites for wind turbines have been identified in Japan, but they are located in complex terrain. This fact has bearing on the R&D for reliable and economical wind energy technology.

After completion of the 100 kW Pilot Plant in 1986 and further research for a large-scale wind turbine, a new R&D programme was initiated in 1990. As a result, the basic design of a 500 kW class wind turbine and the construction of a 1 MW experimental wind farm started in FY 1991.

During FY 1992 NEDO is engaged in three main activities: development of the 500 kW wind turbine prototype, construction of the 1 MW experimental wind farm, and wind observation and resource assessment.

The 500 kW wind turbine prototype

The conceptual design of the 500 kW prototype has been completed. As already described in the Annual Report 1991, it is a three-bladed upwind machine with a rigid hub, 38 m rotor diameter and GFRP blades. The trial manufacture of blades and the detailed design of the turbine are under way. The turbine will be manufactured by Mitsubishi Heavy Industries Ltd.

Utilization technology

An experimental wind farm of approximately 1MW rated power is under construction on Miyako Island, Okinawa. A 250 kW wind turbine was installed in FY 1991 and another will be erected in FY 1992. Based on the performance of the first two machines, the method of operation and position of additional units will be investigated in FY 1993. The wind conditions are worse than expected and the operation was affected by some typhoons this year.

Wind observation

As a complement to the nation-wide network for local meteorological observations, NEDO has been measuring wind characteristics at selected sites since 1983. The number of sites in each period is: 13 in FY 1990, 10 in FY 1991, and 15 in FY 1992. The Japanese Wind Map will be updated in FY 1992. In addition, NEDO is acquiring fine-mesh data in the Rumoi area, Hokkaido, in order to study the validity of numerical simulation over complex terrain.

Basic research

MEL has been investigating basic aspects of rotor aerodynamics, structural mechanics, vibration, aeodynamic noise etc. since FY 1978. MEL is operating a two-bladed variable speed 15 kW experimental wind turbine generator system, called WINDMEL, with a teetered rotor, a soft tower and variable pitch/free yaw control systems.

NIRE is developing methods for numerical prediction of wind characteristics in some typical topographies.

Industrial activities

The first wind farm of more than 1 MW in Japan was built by Tohoku Electric Power Co. in 1991 at Cape Tappi on the northern coast of Honshu facing the Streets of Tsugaru. It has five 275 kW three-bladed pitch-controlled units with 28 m rotor diameter. In the period from April to September 1992, the energy production was 865 MWh with an availability factor of 96 %. The wind conditions are getting better in the last half of FY 1992 than the 6,1 m/s average at 30 m height during the above-mentioned period.

Major electric power companies have their own wind energy projects aiming at a total installed power of 3700 MW by 1995. Hokkaido Electric Power Co. has started the construction of a 1,1 MW wind farm at Tomari, which is expected to be completed in 1993.

2.6 The Netherlands

Introduction

In the late eighties the number of wind turbines in the Netherland started to increase rapidly. In the period 1987 - 1992 the installed capacity increased from 30 to 110 MW. At the end of 1992 another 100 MW was under construction or in preparation, see Figure 2.6.1.

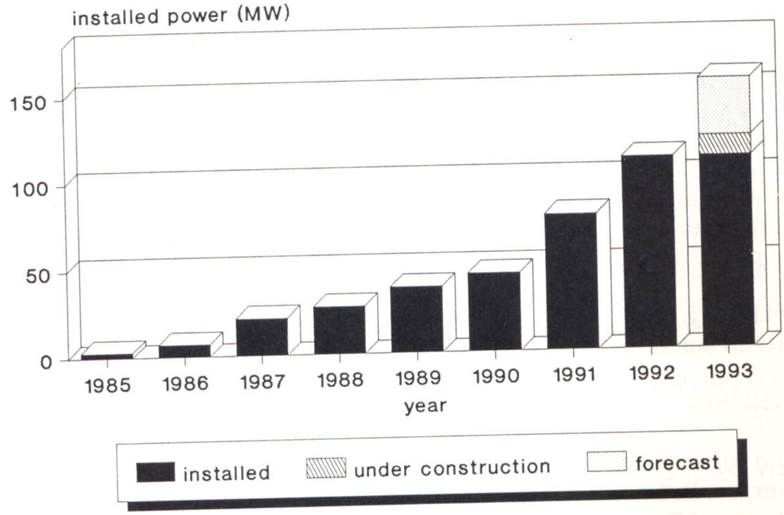


Figure 2.6.1 Wind energy in the Netherlands

In the Policy Plan concerning Energy Conservation and Renewables of the Ministry of Economic Affairs (June 1990), the government sets ambitious goals with respect to energy conservation and the use of renewable energy sources. With regard to wind energy these goals encompass the installation of wind power amounting to 1000 MW by the year 2000, which would save approximately 17 PJ of primary fuel per year, and further growth of the installed wind power to 2000 MW in 2010, 200 MW of which should be installed offshore. In comparison, the total primary annual energy consumption in the Netherlands is about 2700 PJ.

TWIN programme

In order to realize the government's ambitious objectives, a national programme is in place to stimulate the use of wind energy. This National Support Programme for the Application of Wind Energy in the Netherlands 1990 -1995 (TWIN) concentrates on removing financial and planning obstacles which inhibit the use of wind energy and on contributing to the development and improvement of wind turbines in the Netherlands. TWIN is managed by the Netherlands Agency for Energy and the Environment (NOVEM).

The general objective has been translated into a number of operational objectives of TWIN. These objectives, which are to be met by 1995, are formulated below.

Implementation

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

This programme component allows investment grants up to 35 % of the total project cost for wind energy installations. All preparation aspects, such as physical planning and obtaining building permits, are included in the project.

Industrial development

The aim is to improve the cost/performance ratio by approximately 30 %.

As of 1995, reduction of the turbine cost and turbine lifetime will have to result in an average wind energy cost, generated at proper locations, of 0,14 NLG/kWh (0,07 USD/kWh), compared to the 1990 state of technology where the average cost level is 0,20 NLG/kWh.

The improvement of safety, noise reduction and the increased size of available turbines will contribute to the efficient use of the existing wind turbine sites in the country. Concrete targets in these respects are the reduction of the average source noise emission level by 6 dB(A) and the extension of turbine size range up to rotor diameters of 40 - 55 m.

Technological development

The aim is to provide the technical conditions for a continued industrial product improvement and development of present generation wind turbines.

In consultation with the market parties involved, the wind turbine expertise will be used to provide solutions for current and anticipated problems in industrial product improvement and development.

One of the essential technology development activities is the so-called FLEXHAT project. The aim of this project, which is co-financed by the Commission of the European Communities, is to develop and test components for application to medium and large size machines. The developed components have the potential of reducing the investment cost by 30 % compared to present technologies. Integral tests have been carried out, using the 25 m HAT facility at Petten, to demonstrate the proper functioning of the components developed and to provide the industry with sufficient design data.

The aims are pursued by means of the following methods:

- Simplification of auxilliary systems and reduction of the number of components by the application of passive elements.
- Damped transmission of loads exerted by the wind and induced by the grid through the application of flexible sub-structures.

The innovative components are:

- Blade tip controls, passively activated by centrifugal and aerodynamic forces.
- Elastomeric teetering hub. A layout will be evaluated which is simplified compared to the elastomeric bearings applied in the Mod-2 (USA) and Maglarp (Sweden).
- Flexbeam for reduction of dynamic loads in the blade root sections.
- Control strategies implementing load characteristics which enable the functioning of the passive tip controls in the prescribed way.

After mounting the blades, the final experimental part of the FLEXHAT project started, see Figure 2.6.6.

The diameter of the rotor is 22 m. The electrical conversion system consists of a d.c. generator feeding a twelve pulses electronic power converter. It is controlled in such a way that the power is kept constant at a preset rated power level, while allowing wide range of variable rotational speeds.

At a rotational speed of 6 rad/s the tips start to pitch. As the wind speed increases, the rotational speed and the pitch angle vary accordingly. In this way the power is kept constant above the rated wind speed.

The rotor testing programme is essentially concluded by the end of 1992. The main results are as follows.

Reduction of blade loads according to design has been met. In fact, the dynamic 1P loads at the blade root were reduced by a factor of three relative to the stiff rotor with passive pitch control, and by a factor of two relative to the stiff rotor operating at constant rotor speed in stall condition. The reduction of the loads was achieved at accompanying 1P teeter amplitudes, appreciably (2x) smaller than expected, so that further design optimization can result in even smaller blade loads.

Stable operation was not always observed during the first part of the test. In fact, a severe but still limited instability occurred during start and (emergency) stop at higher wind speeds (> 15 m/s). Moreover, an intermittent instability occurred during normal operation. At these instabilities an interacting second flap-first torsion mode of the blades was measured.

Suppression of these instabilities was achieved successfully by installing a damper between the tip and the fixed inner blade part. At this modification of the rotor, also the connection rods between the tip and the inner blade was replaced in order to increase the torsional stiffness. In the second part of the test after the modifications, no instabilities were observed during start, stop and operation at high wind speed.

In the FLEXHAT safety concept, the rotor speed is protected against overspeed by the two independent passive pitch systems. Yawing out of the wind in combination with a small brake is envisaged as the auxilliary system for bringing the rotor to standstill. It has been shown during the test that the additional blade root bending loads, while yawing, are only of minor importance. The feasibility of yawing as an auxilliary safety system for a teetered rotor has been established herewith.

Offshore development

This programme component concentrates on formulating a development scenario for wind turbines at sea. The main activities are to be started after 1993.

Dissemination of knowhow and programme support

The aim is to make the available knowhow accessible and usable for the industry and operator/owner of the wind turbines, to promote international cooperation and to keep track of developments abroad.

Funding

The estimated funding for the TWIN programme is shown in Table 2.6.2

Table 2.6.2 Estimated funding for TWIN. Amounts in million NLG.

Component	1991	1992	1993	1994	1995	Total
Investment grants	40	42	*	*	*	*
Implementation support	1,5	1,5	1.5	1,5	1,5	7,5
Industrial development	4,0	3,5	3,5	2,5	1,5	15,0
Technological development	3,0	3,5	3,5	2,8	2,2	15,0
Offshore	0,1	0,2	0,2	1,0	1,5	3,0
Dissemination of knowhow	0,4	0,4	0,4	0,3	0,3	1,8
Total (excl. investment grants)	9,0	9,1	9,1	8,1	7,0	42,3

* The amount of subsidy available is published by the government annually.

ECN programme

In addition to TWIN there are other important wind energy R&D programmes in the Netherlands, conducted by ECN (Netherlands Energy Research Foundation), Delft Technical University, TNO (Dutch Organisation for Applied Research), KEMA (Dutch institute for quality control of electrical materials and appliances), and by the industry itself.

ECNs wind energy programme, which is financed directly by the Ministry of Economic Affairs, had a budget of 3 MNLG in 1992. Important elements of this programme are:

- The construction of a 23 m diameter rotor equipped with pressure holes at three radial positions to measure the pressure distribution during operation. This facility will be used for research on dynamic stall and dynamic inflow phenomena (draft Annex XIV, see section 3).
- Research in fatigue properties and evaluation methods for large blades. The determination of so-called stress reserve factors gives vital information to further optimizing the use of blade materials.
- The development of variable speed electrical conversion with appropriate control systems.
- Computational programs (wind field description, aerodynamic and structural dynamic response programs, lifetime and stress calculations). A series of programs forming an integrated package has been completed by means of a description of the models manual and verification procedure.

Main results and future activities

Implementation

Investment subsidies have been available since 1986. The projects for which subsidy has been allocated represent a total power of more than 200 MW, of which 50 % is already realized and operational. The remaining 100 MW are planned to be erected in 1993 - 1994. In 1993, an increase of the installed capacity to approximately 150 MW is foreseen.

Most of the subsidized wind turbines are installed by utilities, as shown in Figure 2.6.3. The ten largest wind farms are listed in Table 2.6.4.

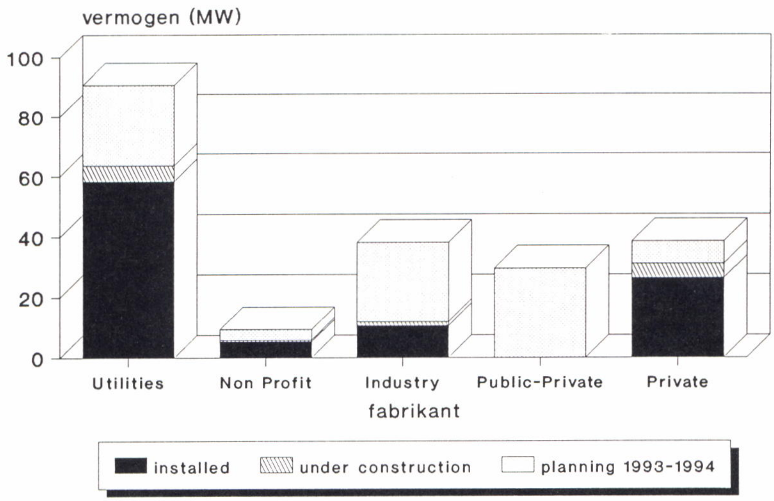


Figure 2.6.3 Market share per investor for approved projects 1986 - 1992

Table 2.6.4 The ten largest wind farms

Name	Location	Manufacturer	Diam. m	Number	Inst. power MW
IJseelmij	Nordoostpolder	Windmaster	25	50	15,0
Lelystad	Lelystad	Windmaster	25	35	10,5
EGD	Uithuizermeedum	Micon	26	40	10,0
GEB Rotterdam	Maasvlakte I	Nedwind	35	13	6,5
SEP Proefwind centrale	Oosterbierum	Holec	30	18	5,4
GEB Rotterdam	Maasvlakte II	Nedwind	35	10	5,0
GEB Rotterdam	Hartelkanaal	Nedwind	35	10	5,0
PEN Ulketocht	Wieringermeer	Nedwind	35	10	5,0
PNEM Volkerak	Volkeraksluis	Nedwind	35	10	5,0
Windpark Nederland	Roggeplaat	Enercon	33	12	4,1

In 1992 the construction of a 3 MW demonstration project on the island of Curaçao, the Netherlands Antilles, was started. This project is co-financed by TWIN, the CEC Thermie programme, and the Curaçao Kodela utility. Twelve Nedwind turbines will produce 2 % of the island's electricity demand by the end of 1993. Special attention is given to the high local wind speeds and corrosion protection in the aggresive, salty climate.

Industrial development

The industry is working on further improvement of their wind turbines, which has resulted in a general decrease of the cost/performance ratio by more than 10 %.

Nedwind's 35 m/500 kW is now used in many wind farms. This type will be scaled-up to 40 m rotor diameter. The erection of a 50 m/1 MW prototype is foreseen for 1993.

The results from Windmaster Nederland's first 40 m/750 kW wind turbine at Halsteren look promising.

During the year Lagerwey installed more than fifty 18 m/80 kW and is developing a 250 kW prototype.

The market share per manufacturer is shown in Figure 2.6.5

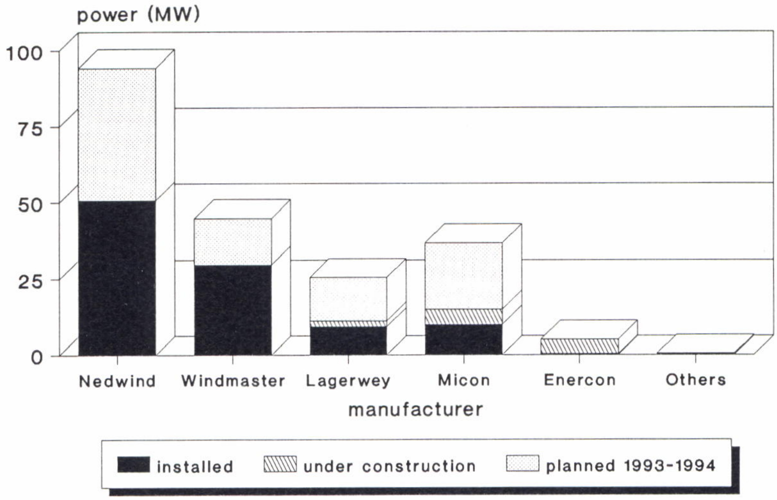


Figure 2.6.5 Market share per manufacturer for projects approved 1986 - 1992

Technical development

Involvement of the industry in the technical development is crucial. In 1991 an industrial platform was formed with representatives from leading industries. The platform advises NOVEM on the planning, progress and results of R&D projects.

In 1992, studies were completed on:

- design guidelines for stall regulated wind turbines;
- a literature survey of new airofoil families;
- validation of a computer code for the prediction of aerodynamic noise emission from wind turbines;
- methodology and case study for probabilistic safety analysis;
- safety factors of gearboxes;
- analyses of effects of measures for the reduction of mechanical noise emission.

In 1993, studies will be carried out on:

- validation of 3D-effects in stall;
- comparison of national standards with regard to IEC and CEC development of standards;
- long and short term research on aerodynamic noise emission;

- verification of computer codes for a 1 MW stall-regulated wind turbine through extensive measurements on a ptototype;
- effects of production tolerances on blade performance;
- fatigue properties of glass-fibre reinforced polyester;
- dynamic inflow;
- stochastic wind field simulation and generators.

Increasing commitment of the industry through financial participation in R&D projects will be pursued in order to guarantee the applicability of the results.

In 1992 an evaluation of the FLEXHAT programme was started, which will be completed in 1993. The further progress of the programme will depend on the results of the evaluation.

Offshore

Preliminary activities in order to get a view of the possibilities to use offshore wind farms has been started. These activities will be continued in a wider set of activities, leading to a view on the long term market development.

Figure 2.6.6 The FLEXHAT rotor mounted on the 25 m experimental wind turbine of ECN, Petten. The test concept is designed and engineered by Stork Product Engineering in cooperation with ECN. The test programme will be concluded in the first half of 1993. (Photo: Jos Beurskens).

2.7 Norway

Wind energy programme

The Norwegian wind energy programme is supported by the Ministry of Petroleum and Energy and is managed by the Norwegian Water Resources and Energy Administration (NVE). The general objective of the programme is to create a basis for the utilization of wind energy where it may be profitable, and to stimulate industrial activities in the wind energy field.

The programme has two areas of activity:

- Research and development, budget 3,6 MNOK for 1992
- Introduction and demonstration, 8,5 MNOK for 1992

The programme is implemented with the participation of utility companies, manufacturing industries, and research institutions.

Research and development

Wind-diesel autonomous systems have been studied since 1986. A demonstration plant with a 55 kW wind turbine and a 50 kW diesel engine was completed in 1989 and has been tested against consumer load on the island of Frøia off the coast of Trondheim. A second generation wind-diesel control system will be developed and installed at Frøia. the development work is being undertaken in cooperation between the Norwegian Electric Power Research Institute (EFI) and ABB Energy as the industrial partner.

In the second generation wind-diesel control system a self-commutated converter will be used instead of the line-commutated converter used in the present control system. The new system will be used for converting existing diesel power plants to wind-diesel operation. The clutch used between the generator and the diesel in the first system will be dispensed with in the second system. A programme for testing the new control system will follow after installation of the system.

Introduction and demonstration

The demonstration programme for wind turbines consists of a 50 % investment subsidy aimed at installing about 4MW of generating capacity, corresponding to an output of about 10 GWh/year. The programme started in 1989 and will end in 1993. Then the whole wind energy programme will be reconsidered and possibly reorganized.

At present, ten Danish wind turbines with 2,9 MW rated power are connected to the Norwegian grid system. Eight of these are owned by utility companies and have been installed with support from the wind energy programme. The other two are privately owned and operated.

A group of three wind turbines, 3 x 400 kW, was installed at Vikna, north of Trondheim, in 1991. The wind farm will be enlarged with two additional units (2 x 500 kW) next year.

All the Norwegian wind turbines are located along the west coast, where warm and moist air meets cold and dry air during the winter. The lightning activity in these areas may be quite high, and this seems to bring about problems deserving more attention in the future.

Two of the wind turbines were damaged by lightning last winter. A 400 kW Vestas/DVT at Frøya was damaged in the end of December 1991, probably by a lightning stroke in the local grid. The generator end the control system were damaged. The renovation cost amounts to 23 % of the investment cost. However, all costs are not related to the lightning stroke, since some modifications and improvements of the control and hydraulic system.

The 300 kW Nordtank wind turbine at Smøla in the same region was damaged by lightning in February 1992. All blades were split and some parts of the blades were burned, see Figure 2.7 1. The lightning had probably struck the wind turbine during a period with high wind speed when the turbine was shut down, since no error messages were recorded. Fortunately, the wind speed sensor was also damaged, so that the control system did not try to restart the turbine.

The wind turbine at Smøla has been rebladed and put into service again. The cost of the damage is about 12 % of the totalinvestment cost.

Outlook

For the time being, the supply of energy to the national grid system is good, and a certain amount of surplus power is available at a low price. As a consequence, it may be unprofitable to install wind turbines in the grid system, at least for the next few years. Wind energy has to find its own niches in the supply system if it is to be utilized with economy. Fortunately, it appears that some small niches for wind turbines will exist in the Norwegian energy system in the coming years.

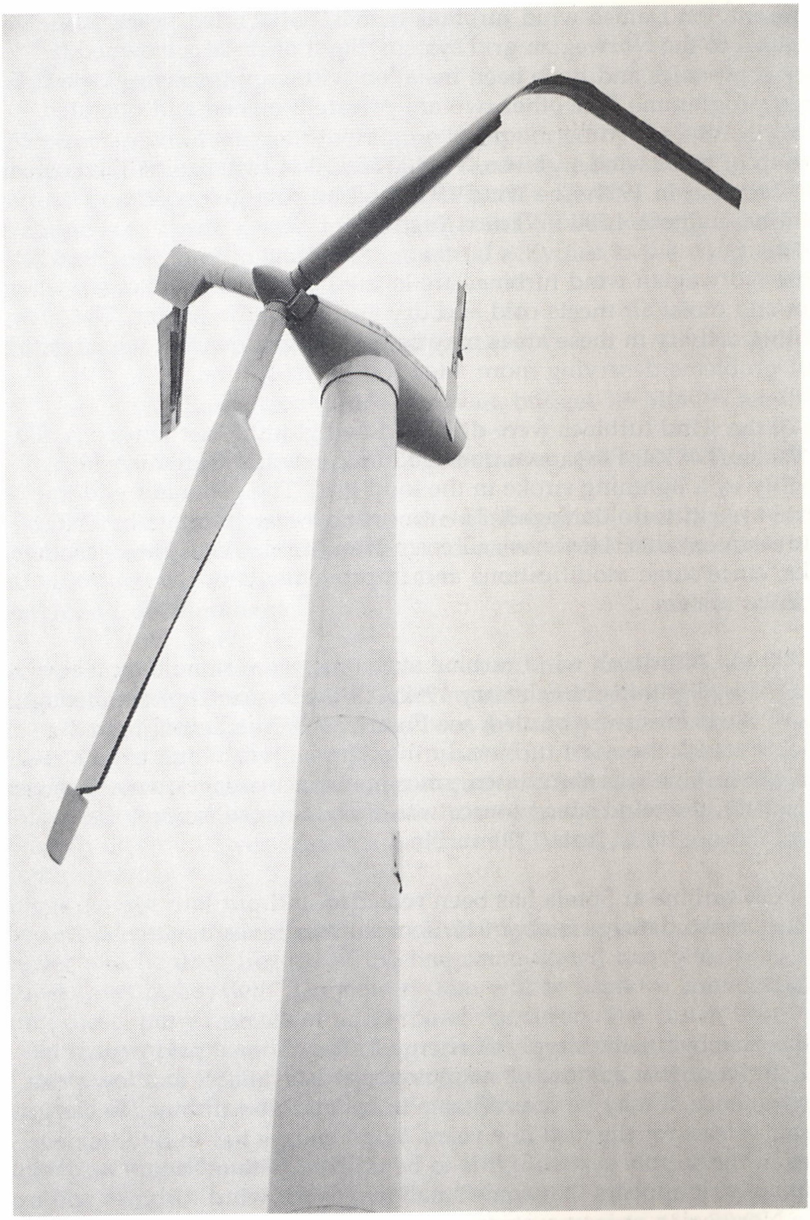


Figure 2.7.1 The wind turbine at Smøla (300 kW Nordtank) after the lightning stroke 25 February 1992.

2.8 Spain

Introduction

Spain has good possibilities for wind energy utilization due to the existence of several zones of high wind potential and the high availability of land in these areas which usually have low population density.

During 1992, a total of 233 wind turbines with a capacity of nearly 40 MW were installed in the mainland and in the Canary Islands. At the end of the year, Spain will have a total installed wind power capacity of 50 MW, see Figure 2.8 1.

New installations are in the planning stage, and several private and public initiatives from investor groups will guarantee a continued increase in the use of wind energy in the Spanish electrical system.

The national goal of having 100 MW of wind power installed by 1995 as expressed in the 1989 Renewable Energy Plan (PER-89) now appears to be amply fulfilled. The most optimistic predictions envisage more than 1000 MW of wind power installed by the end of the century.

This panorama, together with a prospering wind turbine manufacturing industry, makes the future for wind energy utilization very promising in Spain. During 1992, six wind turbine manufacturers have delivered about 300 units in sizes from 200 W to 300 kW at a total cost of about ESP 6000 million (60 MUSD). The development of new and larger prototypes, such as the Ecotecnia 24/300 and the Made 26/300, is continuing.

On the other hand, there is no specific national wind energy R&D programme in Spain. The PER-89 only considers Demonstration and Application renewable energy actions. The main center for R&D projects is the Instituto de Energias Renovables (IER) of CIEMAT, but there are also other public and private research centers working in wind energy, mainly in the framework of the JOULE I-II programmes of the CEC.

Installations

The rapid increase in the number of wind turbines and the rated power is shown in Figures 2.8.2 and 2.8.3.

Twelve wind farms are now in operation, details of which are listed in Tables 2.8.4 (capacity < 1 MW) and 2.8.5 (capacity > 1 MW). Also shown are wind farms in the planning stage as of 20 October 1992, Table 2.8.6.

The wind farms of PESUR (20 MW) and E.E.E. (10 MW) represent, together with Tarifa and Monte Ahumada, the largest concentration of wind turbines in Europe with a total of 272 machines and a rated power of 33 MW. The annual energy production is expected to be 100 000 MWh, equivalent to 175 000 barrels of oil.

In addition to the 4,5 MW wind farm at Cabo Villano (La Coruña) which is in operation, three wind farms are in the planning stage and will begin operation in 1993/94. Two are in the Canary Islands: the 10 MW Consorcio de Aguas de Fuerteventura and the 5 MW Inhalsa wind farm in Lanzarote. The third is the 3,9 MW Bajo Ebro wind farm in Cataluña (Tarragona).

The installation of new wind turbines is expected to continue during the coming years. Including the installations by private investors the total wind power capacity will be close to the target of 100 MW in 1995.

Industrial activities

The Spanish wind turbine manufacturers have been very active during 1992 due to the ongoing wind farm installations. During the period August 91 - August 92 the three main manufacturers, Made, Ecotecnia and AWP, have fabricated around 300 units rated between 100 and 150 kW.

At the same time new wind turbines have been developed, for instance the Made AE-25 with 25 m rotor diameter and 300 kW rating. The prototype started operation and testing in February 1992. The Made company is also developing a 500 kW, which is in a preliminary stage of design.

Ecotecnia is also testing a new prototype, which is an upscaling of its 20/150 model. It is rated at 200 kW and is known as Ecotecnia 24/200, see Figure 2.8.7.

Abengoa Wind Power (AWP) is manufacturing the U.S.Windpower 100 kW wind turbine in Spain, and Aerogeneradores Canarios S.A. (ASCA) the Vestas V-27.

In the area of small wind turbines rated around 1 kW, Bornay S.A. is continuing the manufacture of various models.

R&D projects

The national renewable energy plan, PER-89, only considers demonstration and application of renewable energy sources. R&D was included in the Energy Research Plan, PIE. However, there is no specific national R&D programme for wind energy.

Several R&D projects are carried out in public and private centers. University departments, such as at the Universidad Politécnica de Madrid and the Universidad Politécnica de Las Palmas, are working in different fields, for example wake effects, wind-diesel systems, composite blade materials, and assessment of wind characteristics.

The utilities have several R&D projects in progress, ranging from short term prediction models of energy production to the development and testing of new prototypes. For example, Endesa is cooperating with Made in the development of the 300 and 500 kW prototypes. Union Fenosa is operating the large-scale prototype AWEC-60 and is cooperating with Heidelberg Motor GmbH of Germany on the development of the 1,2 MW H-Rotor vertical-axis wind turbine (see Table 2.3.1).

The main R&D center is the Instituto de Energias Renovables (IER) of CIEMAT, which has been working in wind energy since 1985. The IER wind department is involved in several projects, some of them in the framework of the JOULE I and II programmes of the CEC, and in cooperation with other R&D centers in Spain and CEC countries. the main areas of activity are:

- resource assessment
- environmental issues
- composite blade development and testing
- design, testing and certification of prototypes
- stand-alone plants and wind-diesel systems.

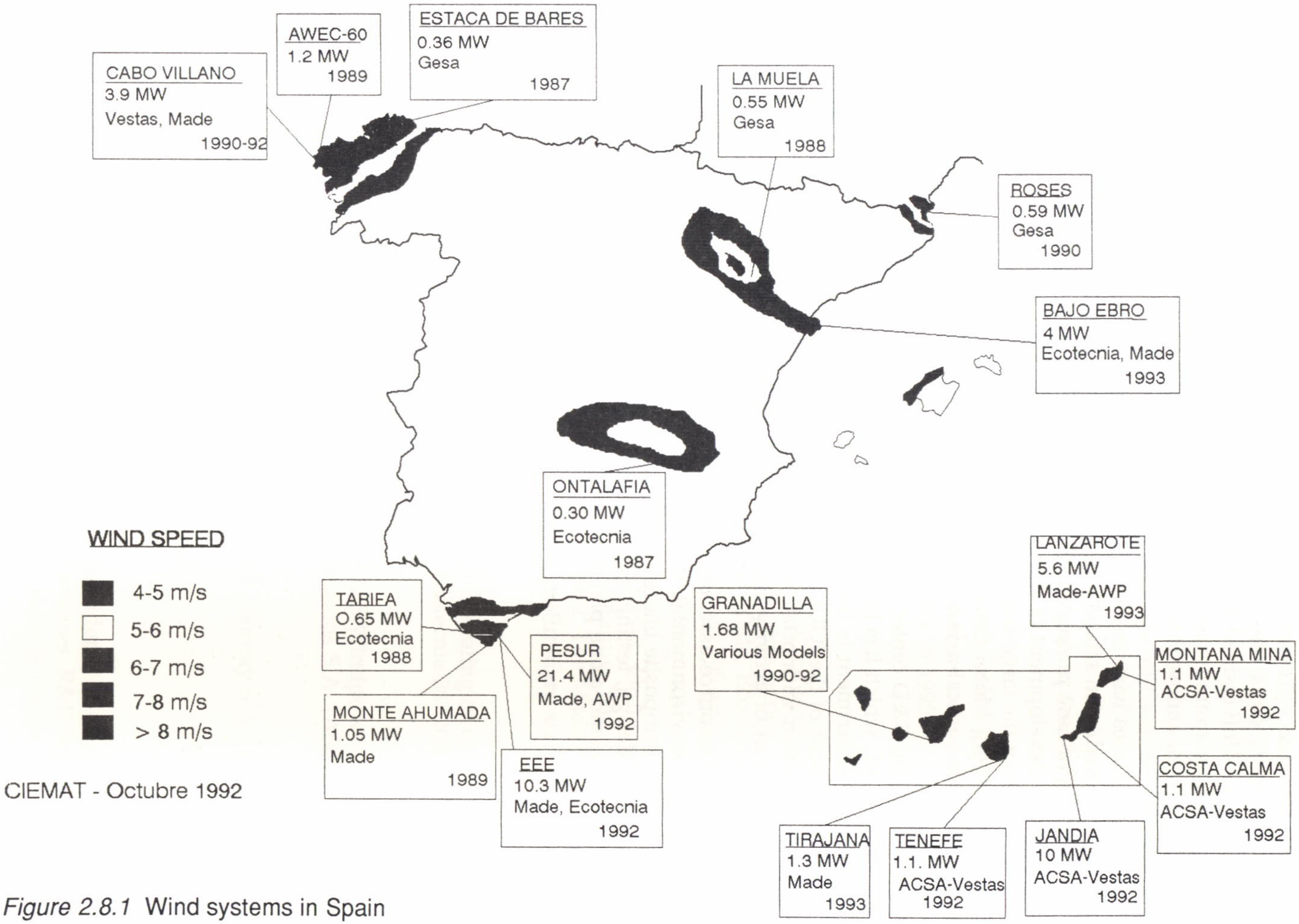
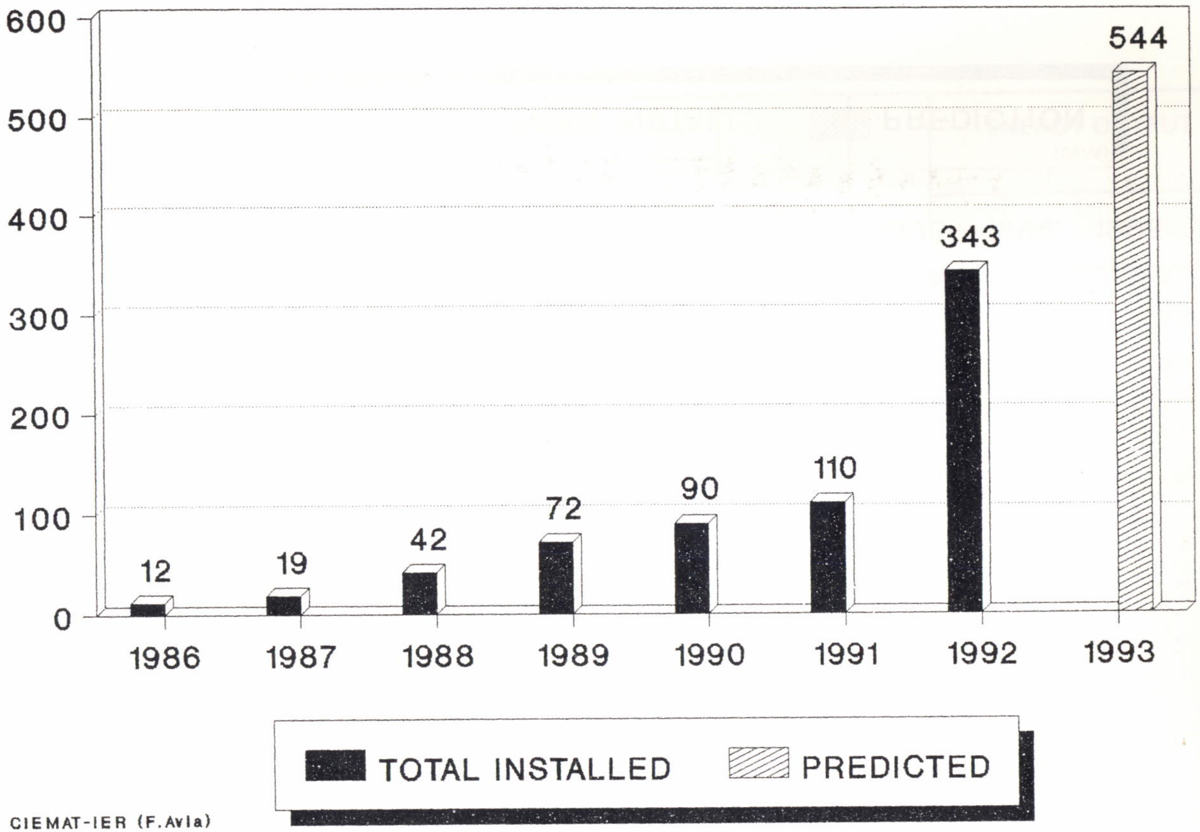


Figure 2.8.1 Wind systems in Spain



CIEMAT-IER (F.Avia)

Figure 2.8.2 Number of wind turbines in Spain

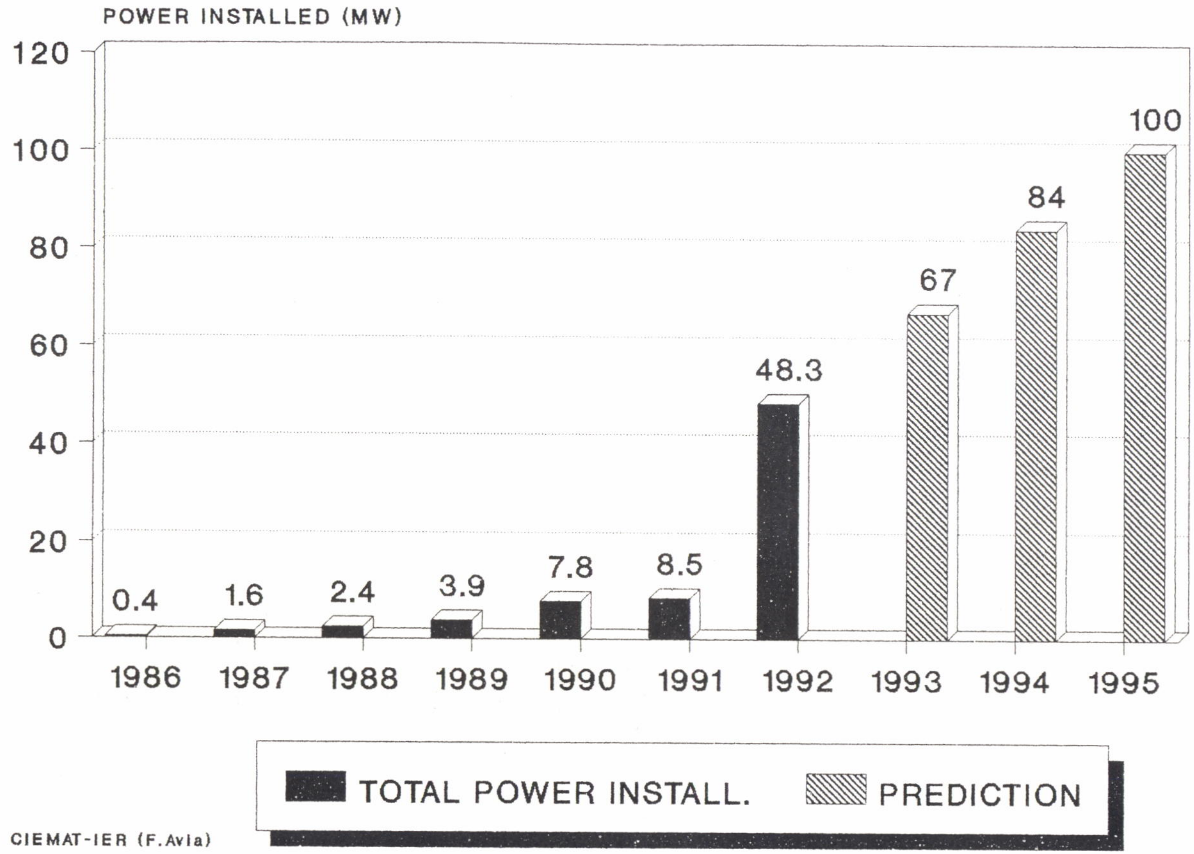


Figure 2.8.3 Installed wind power capacity in Spain

WINDFARM			WINDTURBINES			MACHINES Nº	YEAR	ENERGY OUTPUT (MWH)		
NAME	LOCATION	TOTAL POWER (MW)	MANUFACTURER	MODEL	RATED POWER (kW)			1990	1991	ACCUMULATED
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	238	1347
TARIFA	TARIFA (CADIZ)	0,65	ECOTECNIA ECOTECNIA ECOTECNIA	12/30 20/150 24/200	30 150 200	10 1 1	1988 1989 1992	783 442	708 488	3475 1098
CABO DE ROSES	GERONA	0,59	GESA GESA	AE 15 AE 18	75 110	2 4	1990	?	451	

Figure 2.8.4 Wind farms with rated power < 1 MW in operation in Spain as at 20 October 1992

WINDFARM			WINDTURBINES			MACHINES N°	YEAR	ENERGY OUTPUT (MWH)		
NAME	LOCATION	TOTAL POWER (MW)	MANUFACTURER	MODEL	RATED POWER (kW)			1990	1991	ACCUMULATED
GRANADILLA	GRANADILLA TENERIFE (CANARY ISLANDS)	1,68	MADE	AE-20	150	1	1990	28	376	404
			ECOTECNIA	20/150	150	1	1990	8	297	305
			W.E.G.	25/250	250	1	1990	-	216	216
			CENEMESA	FL-19	300	1	1990	-	111	111
			VESTAS	V 25	200	1	1990	76	590	666
			ENERCON	34	330	1	1991	-	168	168
			MADE	AE-26	300	1	1992			
								112	**1758**	**1870**
MONTE AHUMADA	TARIFA (CADIZ)	1,05	MADE	AE-20	150	7	1989	**2554**	**2200**	**4754**
CABO VILLANO (Phase 1st y 2nd)	CAMARIÑAS (LA CORUÑA)	3,9	VESTAS	V 25	200	1	1990	386	699	1085
			VESTAS	V 20	100	1		290	251	541
			MADE	AE-20M	180	20	1992	-	-	-
								676	**950**	**1626**

Figure 2.8.5 Wind farms with rated power > 1 MW in operation in Spain as at 20 October 1992

WINDFARM			WINDTURBINES			MACHINES N°	YEAR	ENERGY OUTPUT PREDICTED (MWH/year)
NAME	LOCATION	TOTAL POWER (MW)	MANUFACTURER	MODEL	RATED POWER (kW)			
PESUR	TARIFA (CADIZ)	21.1	MADE A.W.P.	AE-20 AWP-100	180 100	34 150	1992	68.000
E.E.E.	TARIFA (CADIZ)	10.3	ECOTECNIA MADE	20/150 AE-20	150 180	50 16	1992	32.000
COSTA CALMA	FUERTEVENTURA (CANARY ISLANDS)	1.1	ACSA-VESTAS	V 27	225	5	1992	3.400
TENEFE	GRAN CANARIA (CANARY ISLANDS)	1.1	ACSA-VESTAS	V 27	225	5	1992	2.800
MONTAÑA MINA	LANZAROTE (CANARY I.)	1.1	ACSA-VESTAS	V 27	225	5	1992	2.800

Figure 2.8.5 (continued) Wind farms with rated power > 1 MW in operation in Spain as at 20 October 1992

WINDFARM			WINDTURBINES			MACHINES Nº	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	225	45	1992	28.000
BAJO EBRO	TORTOSA (TARRAGONA)	4	ECOTECNIA MADE	20/150 AE-20M	150 180	16 9	1993	8.000
CABO VILLANO (Phase 3rd)	CAMARIÑAS (LA CORUÑA)	15	MADE	AE-26	300	50	1993	30.000
INALSA	LANZAROTE (CANARY ISLANDS)	5.6	MADE AWP	AE-20 AWP-100	180 100	9 40	1993	11.000
BARRANCO TIRAJANA	GRAN CANARIA (CANARY ISLANDS)	1.3	MADE	AE-20	180	7	1993	3.000

Figure 2.8.6 Wind farms in planning stage in Spain as at 20 October 1992

Figure 2.8.7 The ECOTECNIA 24/200 prototype

2.9 Sweden

Wind energy programme

Sweden has good wind resources and was one of the first countries to embark on a wind energy programme in 1975. About half of the electricity is generated by hydro power, which facilitates the integration of wind power but makes its introduction difficult due to the low price of electricity in the present system, about 0,25 SEK/kWh (≈ 0,034 USD/kWh) on the average.

At present the government is supporting the utilization of wind energy in three ways:

- A research programme, financed to 100 %, with a three-year budget of 41 MSEK (≈ 6 MUSD) for 1990-1993;
- A development and demonstration programme for the support of large wind system projects, at a maximum of 50 % of the cost;
- A market stimulation programme in which wind power plants are subsidized at 25 % of the investment cost. The subsidy will be increased to 35 % by 1 January 1993.

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, inlcuding wind systems, through the Swedish Energy Development Corporation (SEU). Vattenfall AB (formerly the State Power Board) has a substantial development programme of its own.

Private investors have been comparatively slow in utilizing wind energy because of insufficient incentives in view of the generally low costs of electricity. The installation rate of turbines in the 150 - 450 kW range increased after mid-1991, however, due to the 25 % investment subsidy.

Basic research

The 1992 allocation for wind energy research is 13 MSEK (≈ 1,8 MUSD). The research is mainly carried out at universities and national research institutes. The Aeronautical Research Institute (FFA) in Stockholm is performing studies in aerodynamics, structural mechanics, materials, advanced design methods, noise, control technology, safety and standards.

Basic atmospheric research is carried out at the Department of Meteorology, University of Uppsala (MIUU), for example on wake effects and boundary layer phenomena. Wind measurements and resource assessments are undertaken by the Swedish Meteorological and Hydrological Institute (SMHI), Norrköping.

A Swedish wind atlas has been compiled by SMHI. The best wind conditions are found on the west and south coast, around the two largest lakes and on the Baltic islands. The northern mountains have also good winds, which will be further investigated in the coming research programme.

Electric machinery and control technology for wind systems are studied at the Chalmers University of Technology, Gothenburg, who also operate the Wind Turbine Test Station at Hönö off the west coast near Gothenburg. A 40 kW wind turbine (Berewoud) is used at Hönö, mainly for testing power electronics. The turbine has recently been rebuilt for stall control and variable speed with a hub that can be fixed or teetered.

Integration of wind power into the electric grid is studied at the Department of Electrical Energy Systems, Royal Institute of Technology, Stockholm.

Development projects

The government is supporting wind energy development and demonstration projects at a maximum of 50 % of the cost through the Energy Technology Fund, established in 1988 and managed by Nutek. Priority is given to large-scale wind turbines of approximately 1 MW rated power or larger.

Maglarp

The 78 m, 3 MW wind turbine, installed in 1982, has operated well since the repair of the gearbox in 1991. By 31 December it had generated 34 049 MWh during 26 159 hours on line. The cumulated output is world-leading for a single turbine.

The wind turbine is operated by the Sydkraft utility; since 1 January 1992 without government support. Due to noise problem, the machine has a limited operation permit and is planned to be shut down in May 1993.

Näsudden

The 75 m, 2 MW wind turbine, originally erected in 1983, was dismantled during 1990/1991 to prepare for the installation of the Näsudden II machinery on top of the existing tower. The new unit was installed in October 1992, see Figure 2.9.1.

Näsudden II has been developed in cooperation with German partners and is the sister unit of Aeolus II, erected in August 1992 near Wilhelmshaven, Germany. The rotor diameter is 80 m and the rated power 3 MW. The blades are made of a carbonfibre and glassfibre composite. The turbine technology is based on Näsudden I with an upwind two-speed rotor, a stiff hub, and full-span pitch control.

Näsudden is operated by Vattenfall. Kvaerner Turbin AB supplied the machinery and Messerschmidt-Bölkow-Blohm (MBB), Germany, the blades. The cost of the Swedish part of the Näsudden II/Aeolus II project is about 100 MSEK (≈ 14 MUSD) and is financed by Vattenfall/SEU/Nutek in the proportion 50/25/25, which means that the government subsidy is 25 %.

Vattenfall operates a monitoring and evaluation programme, to be reported in 1995, including a comparison with the performance of Aeolus II. The evaluation programme is funded 50/50 by Vattenfall and Nutek.

During 1992 Vattenfall, Kvaerner Turbin AB and MBB have completed a study for defining the design basis of a third generation 3 MW wind turbine.

Risholmen

The 750 kW Howden wind turbine was installed by KVAB in 1988 on the island of Stora Risholmen in the outer harbour of Gothenburg. The crack in the blade tip actuator, discovered in September 1991, was repaired in January. The machine operated with high availability until June, when it lost a blade tip during starting operation. The incident is being investigated in cooperation with the manufacturer.

NWP 400

Vattenfall has installed two medium-sized wind turbines at Basteviks-holmarna near Lysekil on the west coast in a project, called the Lyse Wind Power Station. One of turbines has an advanced design by Nordic Wind-power AB and the other one is a standard Bonus machine. The intention is to compare the standard three-bladed technology and the new flexible two-bladed technology in turbines of about the same size and at the same location.

The 450 kW Bonus was erected in June and the 400 kW NWP 400 in August, see Figure 2.9.2. A testing programme will continue until Spring 1993. If all tests are satisfactory, Vattenfall will take over operation and maintenance. After take-over, a two-year evaluation programme will follow.

NWP 400 is designed to minimize loads due to fatigue and extreme wind speeds at standstill. The parking loads are minimized by the small projected area of the unit. Short term wind speed variations due to wind shear and turbulence are decoupled from the machine by the teetering hub and the yaw control. The 35 m rotor is upwind and stall-controlled, and the blades are made of glassfibre-reinforced polyester.

The NWP 400 weighs only 28 tons as compared to 46 tons for the Danish machine. This will hopefully contribute to cost effectiveness and competitivity in serial production. The machine is now being certified by the Norske Veritas.

Nordic Windpower is studying the design of a 1000 kW version, called NWP 1000, which will be developed in cooperation with some European manufacturers.

Zephyr WTS 28.250

Zephyr is a 250 kW two-bladed, passively pitch-controlled wind turbine with individually flapping blades. The pitching of the outer part of the blades is aerodynamically controlled with the blade parts working against a torsional spring, see Figure 2.9.3. The rotor has 28 m diameter and two rotational speeds at 55 and 37 rpm. The machine has been designed by Zephyr AB, based on a Swedish invention.

The project is funded by the local utility of Falkenberg on the west coast and Nutek. The utility has ordered two units, the first of which was installed during Summer 1992 at Falkenberg A first prototype of the same concept has operated at the site since 1990.

Market stimulation

The government has allocated 250 MSEK (≈ 35 MUSD) over a five year period, starting 1 July 1991, for supporting the installation of wind power plants. The subsidy is 25 % of the investment cost for plants larger than 60 kW rated power. The support should correspond to around 100 MW of installed capacity by 1996.

To qualify for support, the wind turbine must be certified. A certification procedure has been set up. The project must obtain all local permits before receiving the support, and the owner/operator must participate in an evaluation programme of plant performance.

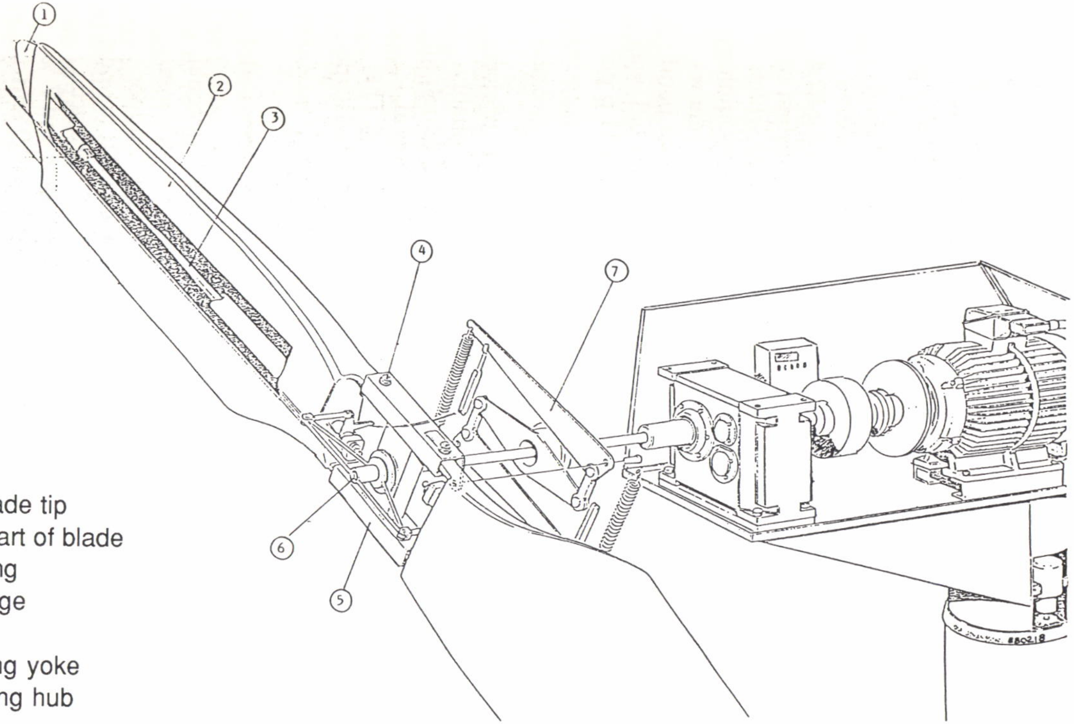
Several provinces have initiated planning activities as a result of the market stimulation programme. In particular, this involves a more detailed documentation of the wind resource than is possible in the national wind atlas.

As a result of the market stimulation programme, the number of wind turbine installations has tripled in 15 months. By September the number was 89 with a total rated capacity of 16 MW, excluding the large prototype machines. The installation rate has been less than expected, however, which is the reason why the government has increased the investment subsidy to 35 % from 1 January 1993.

The performance of the small and medium-sized wind turbines is reported monthly since 1989. A three-year summary was published in September 1992, showing, for example, that the capacity factors varied from 6 to 33 %. All of the machines except two are Danish. The average investment cost, including grid connection, was 9200 SEK/kW (≈ 1250 USD/kW).

Figure 2.9.1 The 3 MW Näsudden II. Rotor diameter 80 m

Figure 2.9.2 NWP 400 at Basteviksholmen near Lysekil



1 Pitchable blade tip
2 Inner fixed part of blade
3 Torsion spring
4 Flapping hinge
5 H-hub
6 Synchronizing yoke
7 Torque limiting hub

Figure 2.9.3 Zephyr WTS 28.250 hub principle

2.10 United Kingdom

Large scale generation

Wind farms (reported by D I Page)

In November 1991 the second renewable order of the Non-Fossil Fuel Obligation was issued covering 122 projects totalling 457 MW Declared Net Capacity (DNC) of which 49 were wind energy projects totalling 82,4 MW DNC (192 MW rated capacity). For this tranche a "bid-in" system of pricing was used with each developer having to state the price at which he was prepared to supply his nominated capacity. Six separate technology bands were established to allow adequate demonstration of each renewable technology. The proposals with the lowest bid-in price in each band were offered contracts. A single price, that of the highest accepted bid, was applied to all contracts in a single band; for wind energy this was 11 p per kWh, reflecting the short period of the contracts due to the 1998 constraint.

The response to planning applications submitted for 2nd tranche projects has been much more positive than to those of the 1st tranche, probably due to greater awareness and understanding of the problem, although all projects in NFFO 1 have now received planning consent. In general, planning permission is granted subject to a number of conditions. The main concerns of the planners are still noise intrusion, loss of landscape value and electromagnetic radiation (both reflected and emitted). Assessment of visual intrusion, being largely subjective and non-quantifiable, are causing particular difficulties.

In the agreements reached, there are some common elements (e g tonal noise), but in general planners and developers have arrived at different details (e g noise levels and distances) depending on their own judgements and the particular character and sensitivity of each site. To the best of the auther's knowledge, by march 1992 43 % of the NFFO 2 projects (totalling 89 MW rated capacity) had received planning consent and 7 % had been refused; these numbers had increased to 49 % (109 MW) and 31 % (50 MW) by September 1992. Table 2.10.1 shows details of wind farms in operation or where construction has started.

Clearly there is a need to obtain information on existing developments by a monitoring process to help assess proposed projects. It is the intention to monitor all the NFFO projects to gather data on their technical, environmental and economic performance. This monitoring is being undertaken at three levels: universal, independent and full technical monitoring.

Large scale demonstration wind turbines (> 500 kW)

WEG LS-1 3 MW turbine on Orkney (Scottish Hydro-Electric - reported by W G Stevenson)

A twelve month monitoring period started on 28 February 1992.

Machine generating statistics from 28 February to 23 October were:

Running time	2345 hours
Energy production	3042 MWh
Availability	68,1 %
Load Factor	17,8 %

Since commissioning, total running time has been 6348 hours and energy production 8441 MWh.

HWT-1000 1 MW turbine at Richborough (PowerGen - reported by A Boston)

The turbine has been out of commission since December 1991 with generator phase to earth failure. The generator has been completely rewound. This has been carried out to "Class F" insulation standard as before but the windings have been doubly dipped. The generator manufacturer (Laurence Scott) states that failure was due to the ingress of moisture and recommended the installation of a baffle in the cooling air intake on the underside of the nacelle. This has been done.,

In July a similar machine in Sweden suffered a failure of the tip brake. The tip became detached during operation. Howden advised PowerGen not to run the Richborough until further notice. However contact was made with the Swedish utility. It appeared that the cause of the failure was probably loose or fractured capscrews which hold the tip in place. After thoroughly checking these screws it was decided that it would be safe to run the machine.

The return to service of the machine was delayed by vibration problems. Initially it was thought that these were caused by water entering the blades. However, although the vibration was reduced by draining water from one of the blades, it is now thought that the main cause of instabilities is inadequate yaw brakes. Windharvester are exploring options for adapting the yaw mechanism. The machine was eventually recommissioned on 27 October 1992 but the cut-out wind speed was reduced to about 12 m/s to reduce yaw system loads until the difficulties are overcome.

The last figures available for running time and energy production are:

Running time	4722 hours
Exported energy	1722 MWh

HWT-750 kW turbine on Shetland (Scottish Hydro-Electric - reported by W G Stevenson)

A new blade tip has been manufactured and the blade tip to blade attachement set bolts on all three blades have been increased from M12 to M14. The stop dogs have been redesigned. The cumulative effect of the modifications is estimated to be a 3:1 improvement. The actuator lever radius has been increased slightly to reduce actuator loads and utilise a larger stroke. The cylinder rod diameter has been increased from 25 mm to 30 mm.

The site assembly work was completed by the end of October. Tip alignement problems were experienced due to sticking hydraulic units. After corrective action the machine was available again in in-November.

VAWT-850 500 kW (VAWTL - reported by N Hall-Stride, ETSU)

Since the failure of a blade on the machine in February 1991, Slingsby Aviation (the blade designer and manufacturer) and VAWTL have been engaged in re-design work with a view to re-comission the machine. However, higher priority work due to the rapid developments in the UK wind farm activities has delayed the work. VAWTL in conjunction with the sponsors (National Wind Power LTd, CEC and DTI) are reassessing the need to conclude the monitoring of the machine in light of the substantial amount of technical and economic data already acquired.

Government funded R&D activities

DTI R,D&D programme (managed by Energy Technology Support Unit, Harwell)

Technology development (reported by K F Mc Anulty)

The backbone of UK technology development programme for wind energy consists of design studies funded by the Department of Trade and Industry, and which are being carried out by Wind Energy Group, Renewable Energy Systems, and Windharvester Ltd. These studies are supplemented by projects in specific branches of wind technology such as aerodynamics, control, materials etc. Since the implementation of wind power on a large scale raised questions of how a scattered and diffuse source such as wind energy can be collected and delivered to users, a programme of studies is being planned to clarify the technical issues which might limit the amount of wind energy that could reasonably be accomodated on the electrical distribution network.

(i) Design studies

Wind Energy Group is in the early stages of a project to design a two-bladed machine of about 45 m rotor diameter. This machine will be generically related to previous WEG designs while incorporating both experience gained from MS-3, and the uprated version of MS-3, known as the WEG 400 and findings emerging from the Department of Trade and Industry's technology development programme over the past decade.

The design and cost definition study of a 1 MW rated horizontal-axis wind turbine being carried out by Renewable Energy Systems Ltd will apply the results of technology development activities in the Uk to the realisation of a three-bladed, fixed hub HAWT capable of generating electricity at a competitve cost.

Windharvester Ltd is combinig Howden technology with recent advances in aerodynamics and control, to arrive at amachine which will be suited to wind farm applications in the UK and abroad.

Each of the design studies has an assessment of its market potential associated with it.

(ii) Wind turbine technology

Work continues in the DTI programme to reduce the cost of electricity by further developing the technology underlying wind turbine design.

Wind tunnel studies of the mechanism of stall on rotation blades has continued in support of the decision to retrofit a stall regulated rotor to a WEG MS-3 at Myres Hill. Flow visualisation has come to play an important part in this work and the recently developed technique of particle image velocimetry (PIV) is being investigated with a view to applying the technique to studies of the behaviour of flows over stalled rotors.

The field evaluation of advanced control algorithms has been completed and a report will be published in December 1992. Further studies of the relationship between machine configuration and control system performance has commenced. The control strategies appropriate to the control of stall regulated rotors when used with variable speed drives are to be evaluated in a study that is now in the opening stages. Control system studies have been augmented with work to investigate the dynamic and aerodynamic properties of new control devices.

Interest in structural dynamics has centered around extending the understanding of yaw loads and their effects. Some work has been done to establish the feasibility of improving wind turbine control characteristics by incorporating compliant elements in the drive train and nacelle mounting.

A substantial project to determine the factors contributing to gearbox life and rating by carefully controlled shop testing is well advanced and will report in mid 1993. Further studies of the feasibility of direct drive generators using utilising permanent magnet technology have commenced.

A list of wind energy contractors' reports issued by ETSU since October 1991 is given in Table 2.10.2 and a list of new R&D contracts offered since the same day is given in Table 2.10.3.

Commercialisation and exploitation of the resource (reported by H G Parkinson)

(i) Regional resource and planning studies

These studies are being undertaken with Regional Electricity Companies (RECs) and County Councils and cover all main renewable energy technologies. Collaboration with the County Councils is valuable because it introduces the perspactive of physical planning and it is likely that planning considerations will be one of the key constraints on wind energy development. Defining the availability of suitable connection points to the local electricity distribution network ia a valuable outcome of the collaboration with the RECs. At the moment there are five regional studies with RECs underway and five with County Councils.

(ii) Supporting R&D on non-technical barriers to exploitation

Supporting R&D work continues looking at the topics specific to wind energy, mainly environmental impact. Other topics such as integration with electricity distribution network local planning and financing are mainly being tackled either through regional studies or through cross-renewables projects.

Recent work in the area of visual intrusion includes a study of the impact of wind farms on the landscape in Dyfed using a land classification system. This gave general guidance on the siting of wind turbines in Dyfed and a detailed assessment of ability of the landscape to absorb wind turbine developments of different sizes.

Much new work has recently been commissioned lookong at all aspects of wind turbine noise and its impact. This includes projects covering the prediction and reduction of both mechanical and aerodynamic nois at source, noise propagation and measurement, background noise levels and their variation with time and the assessment of audibilitity and annoyance of noise. It is hoped that the work in hand will enable more quantitative and relevant guidelines to be drafted over the next 18 months regarding the assessment and control of noise impacts from wind turbines.

Recent work undertaken as part of the DTI programme obtained measurements in both the UK and Denmark on the effect of wind turbines on broadcast signals. Another project looked at the radiation emitted by a wind turbine and concluded it would cause no problem to sensitive radioa antennas used by international telecommunications traffic.

Several general surveys of public attitudes have been carried out and recently both before and after construction surveys have been undertaken at some of the sites of NFFO projects (Delabole and Cemmaes). This type of survey is valuable for demonstrating any shift in public opinion resulting from the availablility of information arising from actual experience of the project.

Science and Engineering Research Council R&D programme (Rutherford Appleton Laboratory - reported by J A Halliday)

SEC is responsible for funding academic research in engineering and science in Higher Education Institutes. It operates a Wind Test Site at its Rutherford Appleton Laboratory (RAL). Both graduate students and research associates from universities make use of the facilities on a day to day basis, indeed some are seconded for long periods to the Enegry Research Unit at RAL. Currently, some eight universities have ongoing projects involving the RAL Wind Test Site. During the last year, new funding has been obtained from SERC for the following projects:

PIV stage II

This work, in which a sheet laser is used to illuminate the airflow and measure velocities around moving airfoils, has been demonstrated most successfully under wind tunnel conditions. SERC have just announced thatthey are going to fund a further period od work involving Professor Grant of Heriott-Watt University and Dr Infield of RAL's Energy Research Unit, to carry the work forward towards an ultimate application of the technique to open air conditions.

Non-Destructive Testing (NDT) using infra-red imagery

A new and fairly novel technique is being applied to wind turbine blade testing. The programme is collaborative, between Professor Clayton of Nottingham University and members of the Energy research Unit. The early work has shown that "hot spots" can be detected at points of weakness of blades under fatigue testing well before the actual moment of failure. A newly announced SERC grant will wnable the work to be extended to new materials and new situations, the ultimate aim being to develop a technique that can be used in the field.

Non-steady aerodynamics for a 60 kW HAWT

Professor Graham of Imperial College together with RAL has recently been awarded a major SERC grant to install an extensive set of pressure transducers on the RAL Windharvester 60 kW wind turbine, and to study its aerodynamics under open air wind conditions.

Autonomous wind/diesel systems in new configuration

The pioneering work of Imperial College and RAL in wind/diesel /flywheel studies has continued. Work has just been completed to build and test a large scale diesel system using the 60 kW wind turbine at the RAL site. A key feature of the work has been the introduction of an electrical variable speed drive in the system. The drive control was developed at Leicester University by ateam led by Dr Smith. SERC has also recently announced funding for a study concerning the benefits of introducing flywheel storage to reinforce weak grid lines. The syudy partners include Dr Freris of Imperial College and Dr Bleijs of Leicester University.

The above list summarizes some of the major activities at the RAL test site. It should be emphasized that SERC funds many other projects which are based in universities and that the above list is by no means exhaustive.

DTI standards and certification programme (managed by National Engineering Laboratory - reported by G Elliot)

International standards activities

The BSI committee has submitted its comments on the draft standards document to the IEC and the IEC Working Group discussed comments from all participating countries at a meeting in Rotterdam on 6 - 7 October. An agreed draft standard is expected for grid connected wind turbines exceeding 12 m in diameter is expected to be issued by the end of 1992.

The IEC have set up another Working Group to consider standards for small wind turbines (less than 12 m diameter), but a draft standard is not expected until 1993.

Discussions have started between CEC member countries about the possible need for a Special Directive from the CEC relating specifically to wind turbines.

UK certification activities

Certification procedures for the UK continues to be addressed by DTI aided bu consultation between NWTC at NEL and other European test centres.

Table 2.10.1 NFFO Wind Farm Operational or Under Construction as at 1 September 1992

Developer	**Site of project**	**Manufac-turer**	**Num-ber**	**Rated MW**
Blythe Harbour/REGEN	Blythe, Northumberland	HMZ	9	2,7
Carter Wind Turbines	Orton Airport, Cumbria	Carter	10	3,0
EcoGen	Llidiartywaun, Powys	Mitsubishi	60	18,0
EcoGen	Penrhyddlan, Powys	Mitsubishi	43	12,9
EcoGen	Rhyd-y-Groes, Anglesay	Bonus	24	7,2
National Wind Power	Cemmaes, Powys	WEG	24	7,2
National Wind Power	Cold Northcott, Cornwall	WEG	21	6,3
National Wind Power	Llangwyryfon, Dyfed	WEG	20	6,0
Perma Energy	Taff-Ely, Mid Glamorgan	Nordtank	20	9,0
Renewable Energy Systems	Carland Cross, Cornwall	Vestas	15	6,0
Renewable Energy Systems	Coal Clough, W Yorkshire	Vestas	24	9,6
Windcluster	Haverigg, Cumbria	Vestas	5	1,1
Windelectric	Delabole, Cornwall	Vestas	10	4,0
Windstar	Werfa Mynydd, Glamorgan	Windharvest	20	0,5
Yorkshire Water	Chelker, Yorkshire	WEG	4	1,2
Yorkshire Water	Ovenden Moor, Yorkshire	Vestas	23	9,2
		Totals	**332**	**103,9**

Table 2.10.2 List of Wind Energy Reports Issued by ETSU since October 1991

No	Title	Contractor
6018	Investigation of torque control using a variable slip induction generator	WEG
6022	Feasibility study of a teetered, stall-regulated rotor	WEG
5046	Fatigue evaluation of wood laminates for the design of wind turbine blades	Bath University
5078	Aerodynamic performance predistion for the stalling HAWT rotor	Cranfield
5122	Directly coupled slow speed wind turbine alternators	NEI - IRD
5132	Dynamic and aerodynamic loads on a stall-regulated VAWT	VAWT
6041	Effect of blade root geometry on the stalling of a rotor	Imperial College
6014	Fatigue tests on fillet welded joints under variable amplitude loading	Welding Institute
5092	Site development costs for wind farm sites	WS Atkins
6015	Theoretical investigation of impact of control systems on fatigue of WTs	Garrad Hassan
6042	Influence of advanced pitch control algorithm on turbine fatigue loads	Garrad Hassan
6043	Report on the passive control of horizontal axis wind turbines	Garrad Hassan
6056	Effects of turbines on VHF television reception field tests in Denmark	Perma Energy
5059	Desin and dynamic analysis of flexible wind turbines	City University
5084	Fatigue strength assessment of weld details	WEG/BAe
6027	Wind farm balance of plant costs	WEG
6101	Control of horizontal axis wind turbine generator by leading edge spoilers	WEG
5108	Wind turbine control systems modelling and design Phase I +II	U Strathclyde

Table 2.10.3 List of Wind Energy R&D Contracts Offered by ETSU since October 1991

No.	Contractor	Title	£k	Start
248	U of Strathclyde	Dependence of control systems on WTG configuration	48	920601
274	U of Manchester	Permanent magnet direct drive generator for WTGs	170	911001
275	Wind Energy Group	Design and test of an aerodynamic tip brake	221	911111
276	Ren Energy Syst	Estimating the true energy output of a wind farm	93	911216
278	U of Strathclyde	Strategies for the control of variable speed WTGs	79	920501
284	Flow Solutions Ltd	Assessment and prediction of wind turbine noise	65	911201
287	U of Bath	Optimization/fatigue design of wood composite blades	120	920301
343	Windelectric	Measurement of noise levels at Delabole wind farm	15	920501
281/01	Nat Wind Power	Ecological studies at Cold Northcott	5	920401
281/02	Nat Wind Power	Full scale flow measurements in wind turbine arrays		920401
348	U of Strathclyde	Non-linear control of HAWTGs		920801
350	Garrad Hassan	Monitoring and analysis of Carter 200/30 WTG		921001
262	Ren Energy Syst	Assessment of the prospects for Darrieus wind turbines	157	920101
289	Windelectric	Technical performance monitoring of Delabole - phase I	223	920117
302	CSM Associates	Technical performance monitoring of Delabole - phase I	146	920513
346	Westland Helicopt.	Wind turbine drive train soft mounting system	16	920706
300	Dulas Engineering	Impact study of Cemmaes wind farm	117	920429
301	Ren Energy Syst	Yaw behaviour of upwind turbines	96	920401
270	Imperial College	High lift aerofoils for HAWTGs	39	920901
292	Herriot Watt Univ'y	Flow measurement on a full scale stall regulated rotor	56	920801
341	Imp Coll Consultants	Induction generators with asynchronous links	10	920701
347	U of Strathclyde	The effects of yaw on a 9 m diameter wind turbine	28	920401

2.11 United States

Introduction

Wind energy conversion in the United States in 1992 was particularly notable for progress in the two areas of legislative initiatives and Department of Energy (DOE) program initiatives. In the former area, much debated federal energy legislation was signed into law authorizing a tax credit of USD 0,015 per kilowatt-hour for wind plants installed beginning in 1994. The energy bill also authorized transmission access for third-party wind developers. In addition, some important initiatives favourable to wind were proposed and in some cases implemented on the regional and state levels in 1992.

Industry status

Although 1992 was a landmark year for progress on new energy legislationand research, new wind installations were down when compared to recent years. By the end of the year, new wind capacity was expected to amount to less than 10 MW. This is attributed in large part to the continuing phase-out of Standard Offer 4 power purchase contracts, begun in California in the early 1980s. Also retirements of outdated turbines were expected to be slightly greater than new installations in some regions. As shown in Figure 2.11.1 the total installations will remain approximately the same, about 1600 MW. Energy production is expected to be up slightly from prior years due to improved performance of new turbines. Rapid growth in new installations in 1993/94 is expected to result from the new market incentives and advanced turbine developments.

A setback for wind energy occurred when Hawaiian Electric Industries announced October 6 that it had decided to shut down its wind farm at Kahuku due to losses from operations and continuing mechanical problems. Hawaiian Electric Renewable Systems, the unregulated, non-utility subsidiary, was formed in 1985 to develop wind power and other alternate energy sources. The company's main wind farm at Kahuku on the island of Oahu consists of two projects: the fourteen Westinghouse wind turbines, rated at 600 kW each, and the 3,2 MW Mod-5B wind turbine. The decision to shut down the wind farm came after one of the 600 kW turbines was destroyed following a hydraulic pitch change system failure, resulting in an overspeed runaway. These machines have now operated over 160 000 hours and produced 36 384 MWh, but are still considered prototype machines in need of some upgrading. Operation of the Mod-5B turbine is continuing until a disposition decision is made. As of the end of September, the machine had run a total of 20 561 hours and produced 26 776 MWh.

Energy policy and market development incentives

A major step forward for wind and other renewable energy systems was the passage of the Energy Policy Act (EPACT) by the U.S. Congress in October of 1992. This new law provides wind energy production incentives, access to transmission lines, and other programs helpful to wind energy development. The new law provides a tax credit of 0,015 USD/kWh for wind energy and "closed loop" biomass facilities for a 10 year period at facilities placed in service between 1 January 1994 and 1 July 1999. The credit is phased out as a reference price exceeds 0,08 USD/kWh.

Renewable energy production incentive payments of 0,015 USD/kWh are also authorized to publicly owned (e g municipal, cooperatives and public utility districts that do not pay federal taxes) and qualified renewable energy facilities. A qualified facility is one which generates electricity using solar, wind, biomass or geothermal energy.

Other new EPACT procedures provide for transmission access (including enlargement of transmission capacity necessary) for wholesale transactions that would otherwise be in the public interest, but that would not reasonably impair the continued reliability of the affected electric systems. In addition EPACT implements programs designed to encourage the use of wind systems through training and education. A wide range of other energy issues are also covered by the new law.

Federally-funded research and development

The U.S. Department of Energy (DOE) is supporting the development of wind energy primarily through an expanding R&D program. The goals of the program are to: assist utilities and industry in developing new markets and to develop advanced wind turbine technology. The DOE Wind Energy Program funding increased from USD 11,1 million in fiscal year 1991 to 21,4 MUSD in FY 1992, and 24 MUSD in FY 1993. The increase is primarily to begin government/industry cost-shared development of advanced wind turbines for markets in the mid to late 1990s.

Advanced wind turbines

The Advanced Wind Turbine (AWT) program is a collaborative venture with utilities and industry with the goal of assisting industry efforts to incorporate advanced wind technology in to commercial machines in the near term and to develop next generation of utility grade wind turbines. Figure 2.11.2 illustrates the program structure.

The AWT program has two major parts: the development of improved turbines incorporating incremental refinements into existeng designs by the mid-1990s and the development of next-generation technology for deployment during the late 1990s. Conceptual design studies began in late 1990 and were concluded in 1992. The Near-Term Product Development phase of the program is currently being funded, with three contracts awarded so far in 1992, and two more being negotiated. The specific goal of the Near-Term Product Development activity is to develop wind turbine systems to be commercially available in the 1994-95 time frame that produce electricity for 0,05 USD/kWh at 6,5 m/s wind sites.

Both near-term and next generation turbines may incorporate advanced and innovative concepts. For instance, the advanced turbines will incorporate blades with advanced airfoils designed specifically for the turbines, based on aerodynamics research performed at the DOEs National Renewable Energy Laboratory. In field testing these airfoil families have demonstrated energy capture up to 30 % greater than that produced by current commercial machines. For one near-term design, a single piece generator housing is being used, to reduce long-term manufacturing costs. In another near-term design, movable surfaces are being used for aerodynamic control of rotor speed. Variable speed operation, with associated power electronics, is being considered for the next generation turbines.

Utility integration program

The wind program has initiated a series of activities to help address the concerns that electric utilities have expressed about their ability to integrate wind systems into their normal operations. Two of these programs, both of which were started during 1992, are the Utility Performance Verification activity and the Power Marketing Administration initiative.

The Utility Performance Verification activity is being performed in conjunction with the Electric Power Research Institute. The goal of this major new activity is to deploy and evaluate commercial/prototype wind turbines in typical utility operating environments. This technology demonstration is a bridge between current advanced turbine development activities and when utilities begin large-scale purchases of wind turbines. The activity seeks to establish deployment and evaluation projects with at least two host utilities by mid-1993 and will document the experience from these tests over the period 1993-1997. The projects will involve a statistically significant number of turbines (nominally 20 at each host utility or approximately 6 MW). Funding for these activities will come primarily from the host utilities, with additional funds from EPRI and DOE. In addition, NREL, DOE, EPRI and vendors will provide technical support as required. A second phase is also being contemplated which would evaluate the next generation technology from the AWT program in the late 1990s.

The DOE Power Marketing Administration initiative is pursuing, in parallel with the EPRI project, a program of testing and validation of wind turbines as a source of electricity supply for the Northwest and Midwest areas of the country. These organisations predominate in those regions of the country which have a large percentage of the national wind resource. Further, since they came under the direct control of DOE, they offer a chance for close collaboration work with the Advanced Turbine program.

Collaborative Wind Technology Program

Activities under the Collaborative Wind Technology Program respond to the needs of the industry for assistance in research to maintain current competitiveness, as well as help with aspects of system development not addressed in other programs. These include the need for things as diverse and practical as manufacturing process advances and access to turbine and component testing facilities.

The Cooperative Wind Technology Applications activity assists the wind industry in seeking near-term commercial opportunities, both domestic and international, for wind energy. The activity's primary objectives are: 1) to enhance the performance, efficiency, and reliability of current wind farms; 2) to encourage regional diversification; and 3) to define new applications.

Seven companies received awards under the initial round of this activity. These cooperative cost-shared research activities are assisting the industry in the design, development, testing, and analysis of solutions to current operational problems. Specific problems being addressed include, but are not limited to, verification testing of existing, new, or improved wind turbines; design, development and testing to verify new technology components or subsystems; site engineering optimization; control and utility interconnection optimization; and application demonstrations in new operational environments (for example hybrid systems using small machines).

A Value Engineered Turbine (VET) effort was initiated in 1992 to asist the U.S. wind industry in developing near-term commercial wind turbines for both the domestic and international marketplace. The focus of this activity is on re-engineering and/or re-manufacturing conventional wind turbine configurations. Many of these designs have proven to be suppliers of electricity in California and Europe. However, the cost of energy achieved by these machines has been above the goals that have been set for wind energy. The VET will support, on a cost-shared basis, value analyses, manufacturing, and commercialization of these machines.

Finally, a National Wind Technology Test Center was recently announced which will provide the U.S. with a complete wind energy research and development center. This facility is located at Rocky Flats, Colorado (see Figure 2.11.3). It will provide specialised component test facilities, computer modeling facilities, and a turbine test capability for use by industry on a user facilitiy basis. This facility will support a wide variety of activities including the development of performance standards, and will significantly enhance industry's ability to compete worldwide.

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 conceptual design studies.

Aerodynamics 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 blade 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 and located at their test facility at Rocky Flats., Colorado (Figure 2.11.3).

Aerodynamic investigations on vertical axis turbines are being undertaken at Sandia National Laboratories (SNL). Much of SNLs efforts, in support of all areas of applied research, have been conducted on the 500 kW, 34 m vertical axis wind turbine test bed in Bushland, Texas.

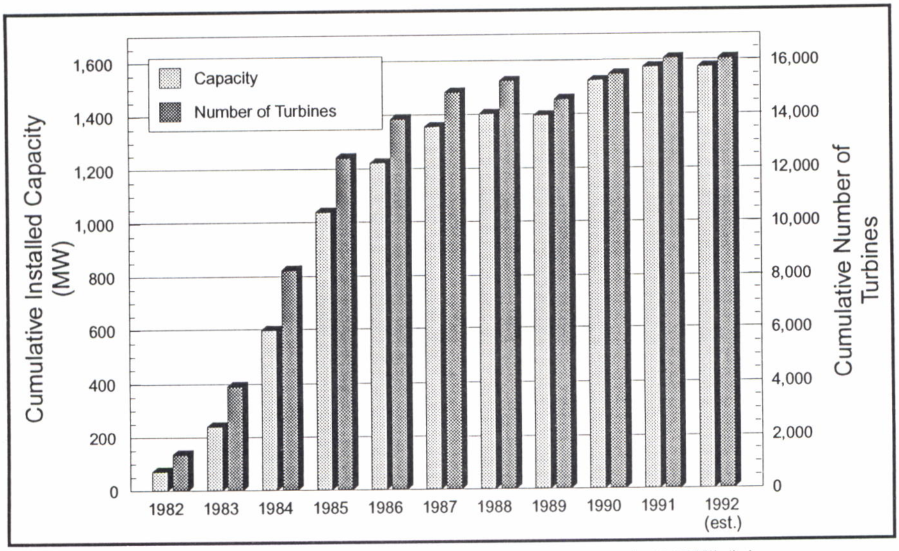
A new structural test facility, located at NREL, has been developed to perform static and dynamic tests of wind turbine components, such as blades. Static tests will determine ultimate strength limits and weak points in the components designs for later detailed investigation. Dynamic tests using hydraulic 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 control issues. The goal of activities in this area is to define electrical characteristics and controls that will eliminate undesirable power fluctuations and maximize the energy contribution that wind turbines can make to a utility grid.

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

In summary, 1992 produced few new commercial installations. Installed capacity is expected to grow substantially in 1994 as a result of new, more efficient designs and financial incentives. The DOE program continued to focus on applied research, advanced turbine development, and utility integration.

WIND SYSTEM INSTALLATION IN THE U.S.



Note: Numbers include replaced/retired turbines. 1989 reflects the net installation due to approximately 200 MW retired.

ANNUAL ENERGY PRODUCED BY WIND SYSTEMS

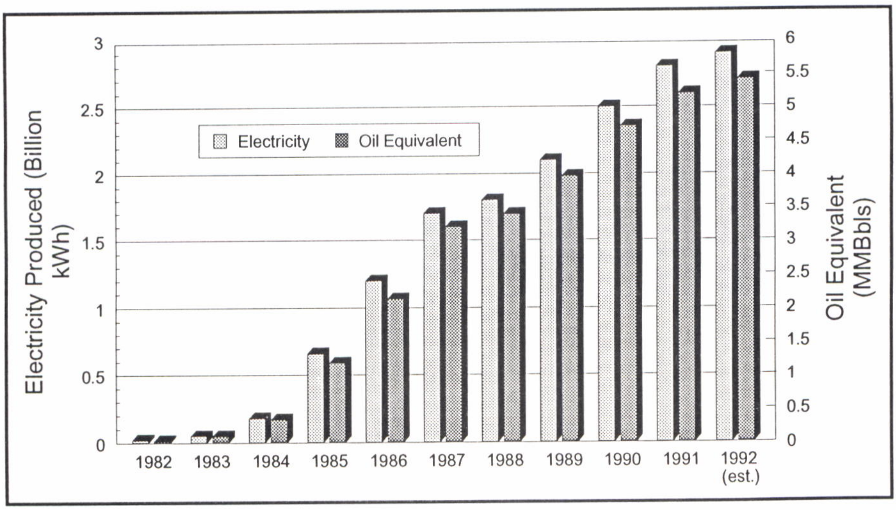


Figure 2.11.1 Wind system installations and energy production

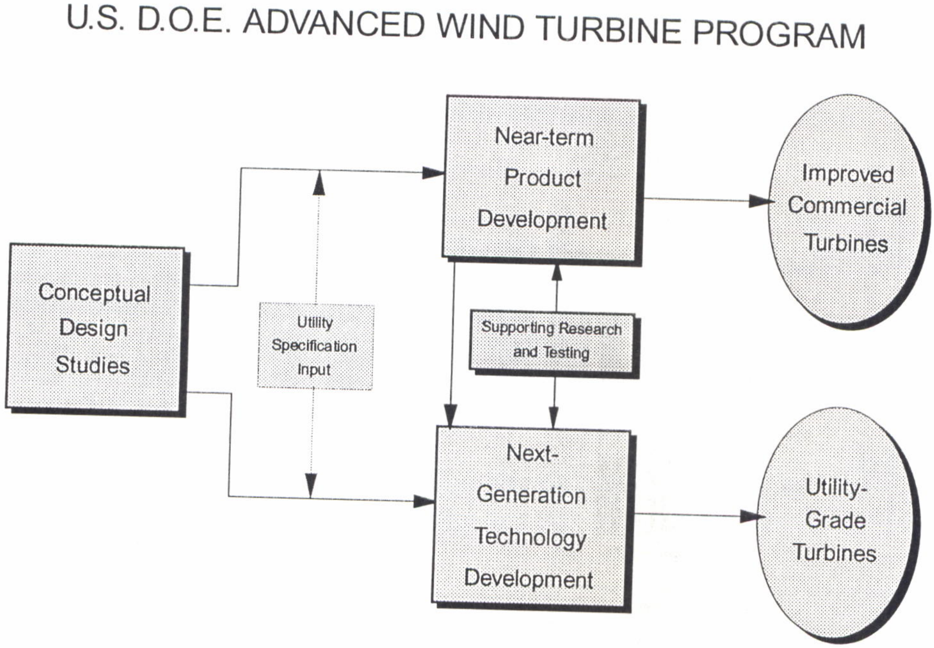


Figure 2.11.2 U.S.DOE wind energy program structure

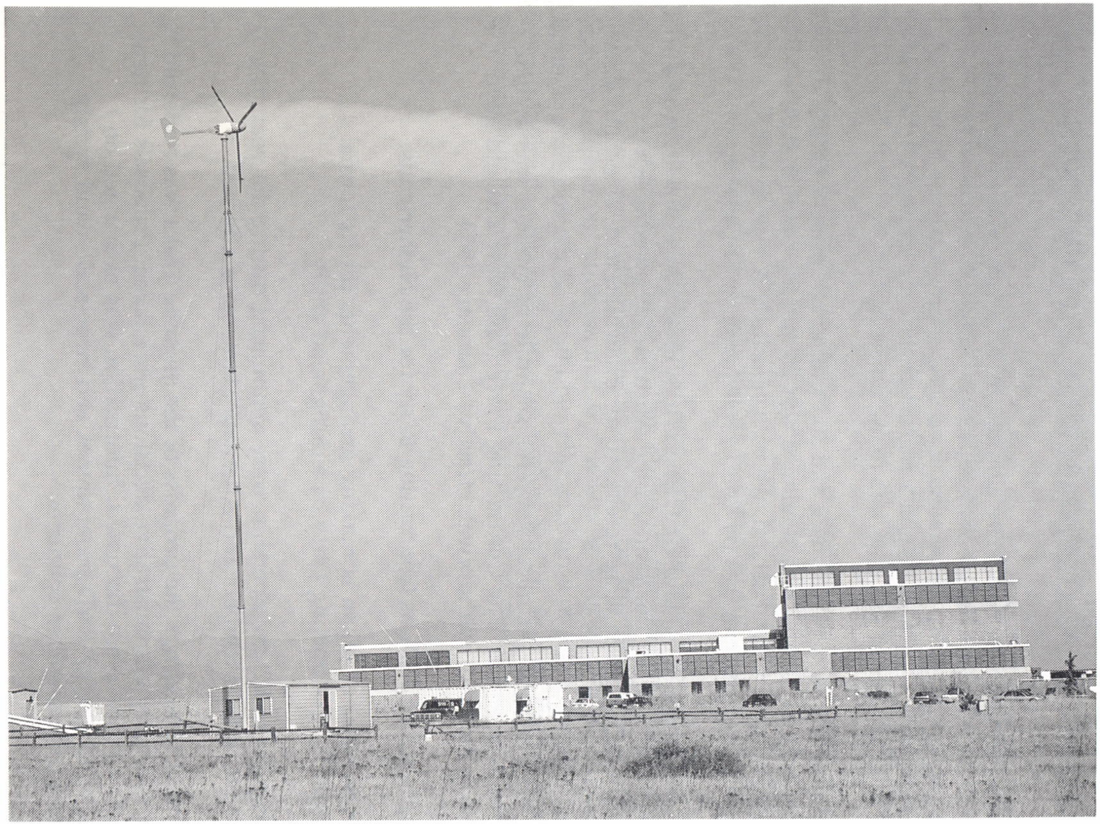


Figure 2.11.3 Test facility at Rocky Flats, Colorado

Executive Committee activities

The 29th meeting of the Executive Committee (EC) was held on 28 and 29 April 1992 at Windtest Kaiser-Wilhem-Koog GmbH, Germany. The meeting was attended by 24 persons, including representatives from 11 of 13 member states, Operating Agents and observers, see Figure 3.1. A visit to wind turbine sites in the area was made on 30 April.

The 30th meeting took place on 29 and 30 October at Carlos V Hotel, Alghero, Sardinia, Italy. The attendance was 25 and all member states, except Austria and New Zealand, were represented. A visit to the Alta Nurra wind test site, operated by ENEL, was made on 31 October.

Mr W G Stevenson (UK) and Dr E Sesto (Italy) served as Chairman and Vice-Chairman during the year. At the Autumn EC meeting Mr Stevenson and Dr Sesto were re-elected as Chairman and Vice-Chairman for 1993.

During the year, the Technical Research Institute of Finland was invited to join the Agreement. The Contracting Party from New Zealand gave preliminary notice of withdrawal, effective 1 January 1993.

NOVEM replaced ECN as Contracting Party for the Netherlands.

The Government of Japan is making arrangements for its formal replacement as Contracting Party by a designated entity .

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

During the EC meetings the progress of the ongoing Tasks was reviewed and the necessary administrative decisions were taken. Proposals for new cooperative action were discussed. Information was exchanged on national wind energy R&D programmes and large-scale wind system activities in the member countries.

A draft Annex XIV on Field Rotor Aerodynamics was prepared and discussed during the year. The objective is to improve the design basis for stall-controlled rotor blades by means of a coordinated measuring programme in order to obtain a data bank for design code verification. The measurements will be performed at the participants' field facilities in a task-shared effort. Coordination of planning, performance and evaluation will be made by the Operating Agent on a cost-shared basis. Prospective participants include Denmark, the Netherlands, UK and USA.

The second issue of the Wind Energy Newsletter appeared in October 1992, reviewing the progress of the cooperative Tasks and the national wind energy activities in the member countries. The EC acts as an editorial board for the Newsletter which is edited by R J Templin (Canada) and produced by NOVEM, the Netherlands.

Observers from Finland and six Eastern European countries were invited to the Spring EC meeting. The aim was to exchange information and explore the possibilities of closer cooperation. While all countries responded, only Finland and Estonia were able to send representatives to the meeting. Both countries reported on their national wind programmes. The problem with the others was apparently principally due to difficulty with finance. The efforts to establish contacts will continue.

At the Autumn EC meeting an ad hoc committe was set up to draft a strategy document for consideration at the Spring 1993 EC meeting. The strategy document will contain information on the objectives of the Agreement and its Annexes and the means and time schedules for achieving the objectives. It will be rolling document to be updated at certain intervals, and will serve as a reference for regular review and evaluation of the achievements under the Agreement.

Figure 3.1.1 The 29th Executive Committe Meeting at Windtest Kaiser-Wilhelm-Koog, Germany, 28 -29 April 1992

Appendix

IEA R&D Wind Executive Committee

(M = Member, A = Alternate Member)

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IEA Wind Energy
Annual Report 1992

Wind energy stands out as one of the most promising renewable energy sources in the near term. The deployment of wind energy is promoted by national programmes for advanced technology research and market incentives 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 1992 and highlights the national wind energy activities in the member countries.

By the end of the report period about 22 000 grid-connected wind turbines were in operation in the member countries, representing an installed power of around 2450 MW. The rate of increase is presently about 300 MW per year.

The average rated power was 200 kW in new units and is increasing. Commercial machines in the 500 kW range were put on the market during the year. Prototype megawatt-sized wind turbines are in operation or under construction in the lead countries.

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