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THE INTERNATIONAL ENERGY AGENCY COLLABORATION IN WIND ENERGY

H.J.M. BEURSKENS
B. PERSHAGEN

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The Netherlands Energy Research Foundation ECN
Service Unit General Services
P.O. Box 1
NL-1755 ZG Petten
The Netherlands
Telephone: +31 2246 43 23
Fax : +31 2246 34 83

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H.J.M. BEURSKENS
B. PERSHAGEN*

* NUWEC ENERGIKONSULT, SWEDEN

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MASTER

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H.J.M. BEURSKENS, Netherlands Energy Research Foundation ECN
B. PERSHAGEN, NUWEC Energikonsult, Sweden

THE PROGRAMME

The International Energy Agency (IEA), founded in 1974, is the energy forum for 21 industrialized countries, all of which are members of the Organization for Economic Co-Operation and Development (OECD). An important objective of the Agency is to encourage collaboration among the member countries in energy research, development and demonstration (R,D&D). One such area is wind energy. Twelve international projects in wind energy have been organized since 1977 with participation from 15 of its member countries.

The IEA projects are set up under Implementing Agreements which define the commitments of the participants and establish a management structure; they also provide for the protection of information and intellectual property supplied to or arising from the projects. The contracting parties are either governments or parties designated by their respective governments. The IEA has no central funds to finance projects. All resources must therefore be supplied by the contracting parties either by cost-sharing or task-sharing.

Initially, there was a great need for basic know-how and a willingness to coordinate research efforts as well as a desire to cooperate in the planning and execution of the national programmes for large-scale wind turbines. Therefore, two Implementing Agreements were set up:

- A Programme for the Research and Development on Wind Energy Conversion Systems
- Co-operation in the Development of Large-Scale Wind Energy Conversion Systems

As wind energy technology developed into a more commercial stage, the character of the IEA activities also changed gradually. The contracting parties became reluctant in coordinating research which was considered of strategic importance for their industries. As a result th IEA efforts centers around the following type of work, still considered of common interest:

- basic research essential for the cost-effective implementation of wind turbine systems;
- pre-normative research such as the establishment of recommended practices for wind turbine testing and evaluation;
- collection and assessment of operational experiences from large wind turbine systems.

Because of the changed conditions for cooperation, there was no longer need for two Implementing Agreements. The Agreements were therefore merged, effective 1 January 1991. The large-scale WECS activities were incorporated in the R&D Agreement which was renamed "Implementing Agreement for Co-Operation in the Research and Development of Wind Turbine Systems", or IEA R&D WIND for short.

IEA R&D WIND has presently 16 contracting parties from 13 countries. The Agreement is of the umbrella type where individual Tasks are defined in Annexes to the Implementing Agreement. This offers the possibility of adding further Tasks under new Annexes as the project proceeds. The programme is controlled by an Executive Committee in which each contracting party is represented. So far, twelve Tasks have been initiated, nine of which have been successfully completed, see Table 1. Each Task is managed by an Operating Agent, designated by the participants in the Task. The participation in the current Tasks is shown in Table 2.

In addition to collaborative research projects, IEA R&D WIND provides for the exchange of information on national accomplishments, problems, issues and priorities. Topical expert meetings have been arranged since 1978. Joint Actions on technical issues of current interest are undertaken as needed.

The detailed results of the activities are documented in technical reports which are normally available only to the participants. General information on the progress of the programme is published in the Annual Reports from the Executive Committees to the IEA [1]. Overviews have been presented at earlier wind energy conferences [2]. This paper concentrates on the ongoing Tasks and other current activities.

OFFSHORE WIND SYSTEMS

A study of offshore wind systems (OWS) was started in 1983 to assess the viability of offshore wind power, to define design criteria for an OWS prototype, and to outline a plan for the design, construction and operation of a joint prototype. In pursuit of these objectives, five subtasks were initiated:

- Data collection and compilation (meteorology)
- Conceptual design of an OWS power station
- Development of design specifications
- Generic studies
- Structural dynamics study.

A considerable number of major reports and papers were contributed to the study. The final summary report was published in 1988 [3].

The study tentatively established a range of generating costs. Costs at the lower end of the range could be an economic alternative to other forms of electricity generation, but this would not be the case for costs at the upper end of the range. However, it is important to note that the costs were derived for wind turbines which are not of the latest design. There is evidence to show that the capital costs of the latest machines are substantially lower than was envisaged when the study was started.

The original objective to outline a plan for a joint OWS prototype was abandoned since none of the participating countries was ready to commit itself to the plan for a prototype at the time. Since then, national projects for offshore installations have been launched in three of the participating countries. In Sweden, an offshore medium-sized wind turbine was installed in the summer of 1990. The first Danish offshore wind farm will be ready for commissioning in 1991. It consists of 11 wind turbines, each rated at 450 kW. A site for an offshore demonstration machine has been selected in the UK. A feasibility study to outline design and cost a machine is being considered.

WIND-DIESEL SYSTEMS

In recent years the main application of wind energy has been to provide supplementary power to main electricity networks. However, many millions of people in the world have no access to electricity from large grids, and it is on them that wind-diesel systems could have an immense impact. Therefore, in 1985, a programme of work was initiated as Task VIII.

The formal technical aims of the programme 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.
- To apply and further develop models suitable for analysing the performance of wind-diesel systems, and to obtain a sound technical basis for planning and designing wind-diesel systems.

At subsequent meetings it was agreed to produce a guidebook on wind-diesel technology including site assessment techniques. The purpose of the book is twofold. For the interested researcher it sets out the state-of-the-art in simple terms, and it disseminates knowledge to the wider non-expert community who may wish to consider wind-diesel for remote applications. The authors comprise experts from ten countries who by discussion and information exchange have agreed on the contents. Currently, a contract for publishing the book is being negotiated [4].

The book covers the following items:

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

The economic viability of a wind power system depends, more than anything else, on the wind climate of the site. The report gives a comprehensive overview of the techniques which can be used to assess a site's wind conditions. A methodical approach to wind appraisal is proposed. The technical design considerations include the choice of generator, diesel engine, wind turbine, dump or auxiliary heat load, storage, system control, protection and safety, and load management. Substantial modelling will be required for optimising the configuration and control of a wind-diesel network.

The report indicates how the economics of a particular system can be assessed using standard economic appraisal techniques. Based on the presented design considerations and modelling techniques, the best configuration can be established. Alternatively, having decided at the outset on a particular system, the performance can be assessed and the resulting power production estimates used as input to the economic calculations.

WAKE EFFECTS

Wind tunnel tests of wind turbine wake effects were pioneered in the late 1970's by the Department of Fluid Dynamics of MT-TNO, Apeldoorn, the Netherlands, as a subtask of Task I [5]. An extension of this work was carried out as Task V in co-operation between the Central Electricity Research Laboratory, Leatherhead

(UK) and the MT-TNO with six other participants. In addition to the laboratory-scale tests, this work included field measurements as well as the development of predictive models [6].

At the close of Task V a reasonable understanding had been gained of single wake behaviour and estimates made of the array losses in large wind farms. The wind farm efficiency estimates had not been validated against full scale data, however, nor was the flow environment for a wind farm known sufficiently well to enable blade load and fatigue calculations to be undertaken with confidence. A continued study was therefore initiated in 1985 as Task IX. The primary objective was to obtain a better understanding of wake interactions within wind farms. The work was carried out as a task-sharing collaboration of seven participants with the UK Central Electricity Generating Board (now National Power) as the Operating Agent [7].

Data on wakes from single wind turbines and pairs of interacting turbines were collected from wind tunnel investigations and six wind turbines in the field. This data included ambient meteorological parameters, mean windspeed deficits and turbulence intensities and spectra. Data on the performance of wind farms were collected from nine installations in six countries. These measurements included ambient meteorological parameters and wind turbine power output. In addition, masts within the wind farms were in many cases available to give data on the wind speeds, turbulence levels and spectra. In some cases, power deficits, power fluctuations and blade loads were also measured.

Two benchmark exercises were held towards the end of the Task, one to compare computer codes with single wake data from the Swedish Näsudden wind turbine, and one to compare predictions of array efficiency with measurements from the Taendpibe wind farm in Denmark. The calculations on Näsudden generally tended tooverestimate the velocity deficit to some degree, although the results indicate that current models are capable of providing acceptable estimates of wake decay rates. The calculations on Taendpibe showed that all models have a tendency to overpredict the power level of turbines deep within the wind farm.

The results generally indicate, however, that the understanding of the wake from a single wind turbine is now good and appropriate models are available to provide estimates of mean velocity and turbulence intensity for a single wake. The understanding of wind farm performance has not advanced to the same stage. The models give reasonable estimates of wind farm power production, but further work will be required if the details of the flow are to be predicted with confidence.

RECOMMENDED PRACTICES FOR WIND TURBINE TESTING

In response to a widely recognised need for a set of standard procedures for testing and evaluating the performance and other characteristics of wind turbines, a series of documents are published as a subtask of Task XI. The recommendations are updated as needed when experience is obtained from their application. The preparation and updating of the documents are carried out by ad hoc groups of experts from the participating countries. The activities are planned and evaluated by a Standing Committee, appointed by the IEA R&D Wind Executive Committee. A list of the documents published so far is shown in Table 3.
The Operating Agent is the Department of Fluid Mechanics of the Technical University of Denmark.

JOINT ACTIONS

The activities of Task XI include Joint Actions as agreed by the Executive Committee. A Joint Action represents a looser form of cooperation than a Task but may develop into a Task if necessary. So far three Joint Actions have been initiated in the areas of aerodynamics, fatigue and offshore wind systems.

In the Joint Action on aerodynamics, symposia are arranged with invited participation of experts from the member countries. To date four symposia have been held with contributions on topics of current interest, such as new airfoil sections, theoretical and experimental studies of rotors in yaw, and three-dimensional flow through rotors. Proceedings are published by the Department of Fluid Mechanics of the Technical University of Denmark.

In the Joint Action on fatigue, a group of experts has agreed on a reference load spectrum with variable amplitude for wind turbine blade fatigue testing. The spectrum is known as WISPER (WInd turbine load SPEctrum Reference). The spectrum is used in variable amplitude fatigue testing of blade materials among others in a programme co-sponsored by the Commission of the European Communities.

The IEA R&D WIND participants which are already committed to or actively planning to install offshore wind systems, are cooperating in a Joint Action for the exchange of information on specific problems, such as support structures.

EXPERT MEETINGS

Topical expert meetings have been arranged under the IEA wind energy agreements since 1978. The subjects reflect the progress of wind technology during the past ten-year period, see

Table 4. Proceedings are edited and published by the German contracting party, the Research Centre Jülich.. The topical expert meetings with a limited number of attendants and where participation is by invitation have proved to be a very effective means of communicating research results and discussing programme plans.

EXPERIMENTAL WIND TURBINE

UNIWEX (Universal Wind Turbine for Experiments) is a computer-controlled, two-bladed experimental wind turbine of 16 m rotor diameter installed at the Ulrich Hütterr Wind Test Field near Schnittlingen, Germany, Figure 1. The objectives of Task XII, which is a follow-on project to the former Task IV (see Table 1), are to study experimentally the aerodynamics, operational behaviour, load spectra and control strategies of various advanced wind turbine configurations, as well as to validate computer codes. UNIWEX allows the simulation of different hub concepts (rigid, teetering, individual flapping, flexible blade attachment, etc), upwind and downwind operation, variation of tower stiffness and geometry, mass of the rotor blades and other design parameters.

Seven institutions from three countries (Germany, Netherlands and Sweden) are participating in the Task, which is operated by the Institute of Computer Applications at the University of Stuttgart. For a programme description, reference is made to conference papers at EWEC'89 [8,9]. After the recommissioning of the wind turbine, the first measurement campaigns for power control by yawing started in early 1990. The experimental results are being compared with theoretical predictions using advanced dynamic codes.

COOPERATION ON LARGE WIND TURBINE SYSTEMS

At the end of 1990, a total of 39 large wind turbines with a rated power equal to or larger than 500 kW were installed in the IEA R&D WIND member countries, corresponding to a total capacity of 45 MW. A substantial increase of the installed capacity is expected during 1991 as shown in Table 5, which illustrates the history of large wind turbines, including abandoned units.

Ten parties from Canada, Denmark, Germany, Italy, Norway, the Netherlands, Spain, Sweden, United Kingdom and United States are cooperating in Task XIII for the exchange of information and coordination of action in their national large-scale wind turbine programmes. Task XIII is administered by the Solar Energy Research Institute (SERI), USA, who is developing a computerized design and performance data archive on large wind systems in the participating countries. SERI will also operate an incident/accident report system and publish an Annual Report reviewing the national activities in the member countries.

CONCLUSIONS

The IEA wind energy agreements have provided a useful framework for international cooperative efforts during more than thirteen years. Nine comprehensive research Tasks have been successfully completed and three Tasks are currently in progress. The sharing of research and information has clearly contributed to the development of wind technology, has eliminated unnecessary redundancy in national programmes, has encouraged utilisation of the most efficient approaches to solve common problems, and has created a co-operative spirit among the professional groups that seems to be unique.

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[8] K.A. Braun, A Finkel; Numerical Aeroelastic Simulation of the Two-Bladed Test Wind Turbine UNIWEX, EWEC '89, Glasgow, UK, 10-13 July 1989.
[9] M. Müller; Experimental Investigation with the Universal Test Wind Turbine UNIWEX, EWEC '89, Glasgow, 10-13 July 1989.

Table 1
IEA R&D WIND Tasks

No.	Title	Operating Agent	Duration
I	Environmental and Meteorological Aspects of Wind Energy Conversion Systems	National Swedish Board for Energy Source Development	1978-81
II	Evaluation of Models for Wind Energy Siting	Battelle Pacific Northwest Laboratories, USA	1978-83
III	Integration of Wind Power into National Electricity Supply Systems	Kernforschungsanlage Jülich GmbH, Germany	1977-83
IV	Investigation of Rotor Stressing and Smoothness of Operation of Large-Scale Wind Energy Conversion Systems	Kernforschungsanlage Jülich GmbH, Germany	1977-80
V	Study of Wake Effects behind Single Turbines and in Wind Turbine Parks	Netherlands Energy Research Foundation	1980-84
VI	Study of Local Flow at Potential WECS Hill Sites	National Research Council of Canada	1982-86
VII	Study of offshore WECS	Central Electricity Generating Board, UK	1983-88
VIII	Study of Decentralised Applications for Wind Energy	National Engineering Laboratory, UK	1985-90
IX	Intensified Study of Wind Turbine Wake Effects	Central Electricity Generating Board, UK	1985-90
X	Systems Interaction	US Department of Energy	Postponed
XI	Base Technology Information Exchange	Department of Fluid Mechanics, Technical University of Denmark	1988-
XII	Universal Wind Turbine for Experiments (UNIWEX)	Institute for Computer Applications, University of Stuttgart, Germany	1988-
XIII	Co-Operation in the Development of Large-Scale Wind Turbine Systems	Solar Energy Research Institute, USA	1991-

Table 2
Participation per country in ongoing tasks

Country	Task XI	Task XII	Task XIII
Austria			
Canada	x		x
Denmark	x		x
Germany	x	x	x
Italy	x		x
Japan			
Netherlands	x	x	x
New Zealand			
Norway	x		x
Spain	x		x
Sweden	x	x	x
United Kingdom	x		x
United States			x

Table 3
Documents in the series of Recommended Practices for Wind Turbine Testing and Evaluation

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

Table 4
IEA Wind Energy Expert Meetings

No	Title	Date	Venue
1	Seminar on Structural Dynamics	12 Oct 78	Munich, Germany
2	Control of LS WECS and Adaption of Wind Electricity to the Network	4 Apr 79	Copenhagen, Denmark
3	Data Acquisition and Analysis for LS WECS	26-27 Sep 79	Blowing Rock, N Carolina, USA
4	Rotor Blade Technology with Spectral Respect to Fatigue Design	21-22 Apr 80	Stockholm, Sweden
5	Environmental and Safety Aspects of the Present LS WECS	25-26 Sep 80	Munich, Germany
6	Reliability and Maintenance Problems of LS WECS	29-30 Apr 81	Aalborg, Denmark
7	Costing of Wind Turbines	18-19 Nov 81	Copenhagen, Denmark
8	Safety Assurance and Quality Control of LS WECS during Assembly, Erection and Acceptance Testing	26-27 May 82	Stockholm, Sweden
9	Structural Design Criteria for LS WECS	7-8 March 83	Greenford, UK
10	Utility and Operational Experience from Major Wind Installations	12-14 Oct 83	Palo Alto, California, USA
11	General Environmental Aspects	7-9 May 84	Munich, Germany
12	Aerodynamic Calculation Methods for WECS	29-30 Oct 84	Copenhagen, Denmark
13	Economic Aspects of Wind Turbines	30-31 May 85	Petten, 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 Turbins into Utility Power Systems	11-12 Apr 89	Herndon, Virginia, 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 90	London, UK
20	Wind Characteristics of Relevance for Wind Turbine Design	7-8 March 91	Stockholm, Sweden

Table 5
Cumulated capacity of large wind turbines unit size ≥ 500 kW

Country	Model/ Location	Capacity (kW) in year of first rotation													
		1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
CAN	AQUILO/AWTS							600							
	EOLE/Cap Chat										4000				
DK	Tvind	2000													
	Nibe		630	630											
	Windane 40/Masnede									5x750					
	Tjæreborg										2000				
D	GROWIAN/Kaiser Wilhelm Koog						3000				-3000				
	Monopteros/Jade											640	2x640		
	WKA 60/Heligoland													1200	
	WKA 60/Kaiser Wilhelm Koog														1200
	HSW 750 Husum														750
	AEOLUS II/Jade														3000
ESP	AWEC 60/Cabo Villano												1200		
	Endesa/Cabo Villano														600
I	GAMMA 60/Alta Nurra														1500
NL	NEWECS 45/Medemblik								1000						
	NEWINCO/Maasvlakte												600		
	Windmaster/Bergen op Zoom												600	500	
	Holec/near Urk													600	
S	WTS 3/Maglarp					3000									
	WTS 75/Näsudden						2000							-2000	
	Howden/ Hisholmen											750			
	Näsudden II														3000
UK	WEG LS-1/Burgar Hill										3000				
	Howden/Burgar Hill											750			
	Howden/Richborough												1000		
	VAWT 850/Carmarthen Bay													500	
USA	Mod 1/Boone		2000			-2000									
	Mod 2/Goldendale			2500	6000					-7500					
	Mod 2 Medicine Bow			2500						-2500					
	Mod 2/Solano					2500					-2500				
	WTS 4/Medicine Bow				4000										
	WWG 0600/Kahuku Pt										14x600				
	VAWT Test Bed/Bushland										600				
	Mod 5B/Kahuku Pt											3200			
Cumulative (kW)		2000	4630	10260	19260	22760	27760	28260	29260	23010	35410	40150	45230	44330	(54930)

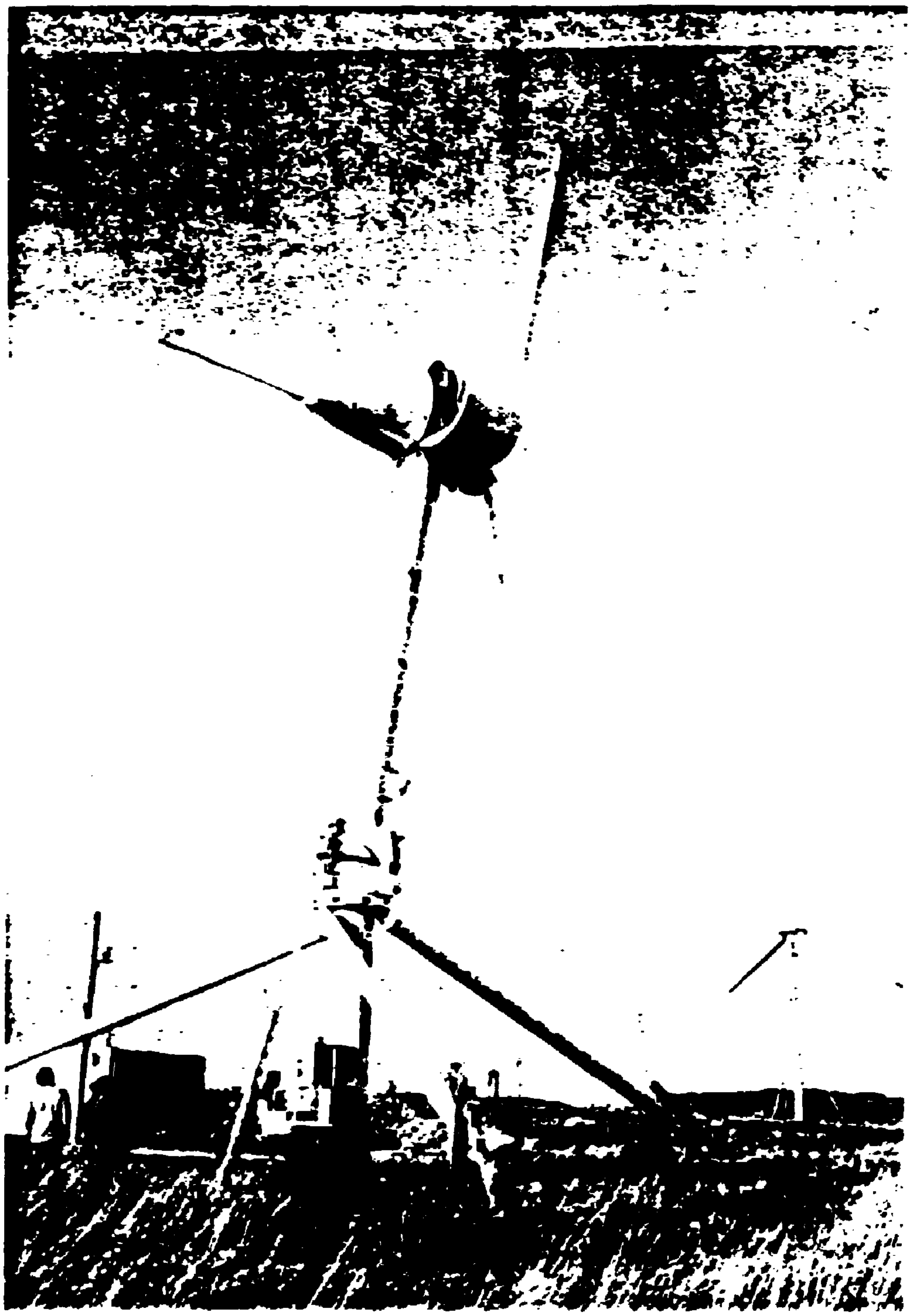

Figure 1. The Universal Test Wind Turbine UNIWEX at the Ulrich Hutter Wind Test Field near Schnittlingen, Germany