European Academy of Wind Energy

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Preface

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Courtesy of Nordex

The Academy:

Unique European Network of Excellence

The European Academy of Wind Energy aims at integrating the activities of the highest level academic and research institutes in Europe working on Wind Energy under a joint programme of long-term character. Particular attention will be paid in spreading excellence through joint education and training activities.

The benefits of past RTD in the wind energy sector have been clearly demonstrated by the increasing sizes of turbines and the lower prices per installed production capacity of electricity. Production costs of wind turbines have been reduced by a factor of four from 1981 to 1998. Today, wind energy is close to cost competitive with other forms of electrical generation at locations with a good wind resource.

At present, Europe is leading in the wind energy field, both with respect to the industry, installations and research. This is a unique position in a rapidly growing international market characterised by major development in technology, size and application.


Courtesy of Vestas Wind Systems A/S

To maintain the position and fully exploit the growth perspectives requires both continued technology development and education and training of a highly qualified workforce in Europe.

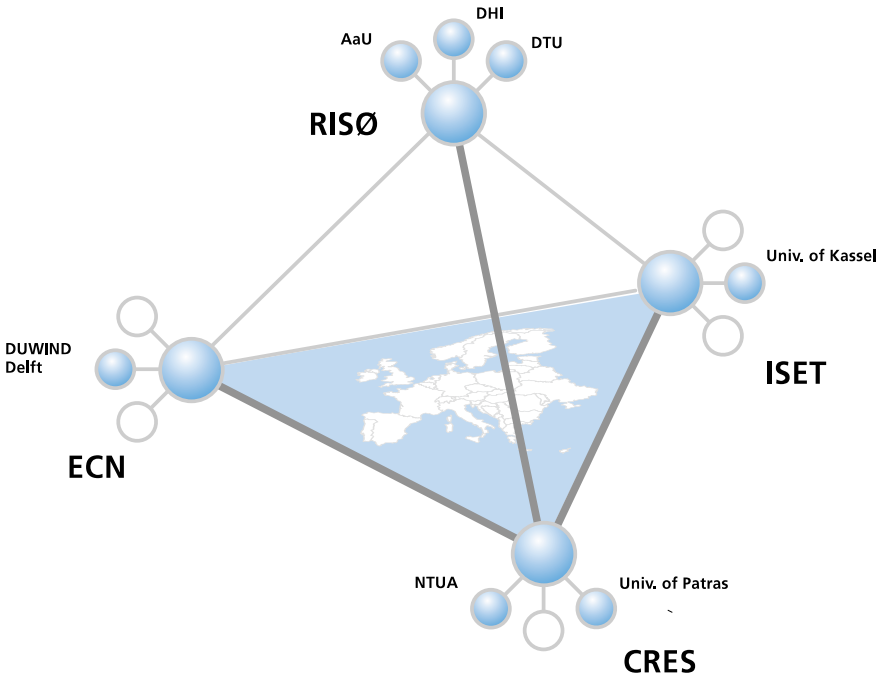
Continued R&D in long-term aspects is essential to provide further reductions in cost and uncertainty, strengthen acceptability and reliability and increase the overall value of wind power in order to realise the anticipated level of deployment.

The nature of the long-term research needed is highly multidisciplinary in the technological sense and trans-disciplinary in the implementation sense (different wind-climates, offshore-flat terrain-complex terrain, large scale integration - isolated island grids etc). It is the kind of research particularly well suited to be performed by a network of excellence at the European level..

If further RTD is one necessary component for the future success of Wind Energy, qualified human resource at all levels (technical and non-technical) is a second. High level education and training is a key issue for developing the human resource needed to support the anticipated wind energy market boom. But high level education and training also bespeaks for a living research web.

The Partnership

The core group of the European Academy of Wind Energy includes at present 11 entities, representing 4 EU countries and more than 80% of the long-term research activity in the field of Wind Energy. During the years, the group members have established strong links through a systematic collaboration under the European Framework Programmes and through common participation in human networks, including European and International Standardization and Certification bodies. All core partners have an outstanding position in their national Wind Energy research activities



The network will advance knowledge in the area of wind energy, by pooling a critical mass of competence and skills. The initial core group is structured with national nodes, represented by major wind energy research institutes with associated partners from universities or other research institutes. The national networks are well established through consortia or firm agreements of cooperation.

The core group of the proposed network includes the following entities with an outstanding experience in Wind Energy research:

- CRES, NTUA, University of Patras, Greece
- ECN, Delft University of Technology, The Netherlands
- ISET, University of Kassel, Germany
- RISØ, Technical University of Denmark, Aalborg University, DHI, Denmark

Integration activities

PhD-Exchange

In training better young European scientists, the Network of Excellence will contribute to bridge the gap it has with the Unites States and Japan in terms of density of researchers per inhabitant thus consenting businesses to hire personnel trained in high and new technologies.

Exchange of scientists

Short term exchange of scientist among the network's participants in order to promote integration of R&D, contribute to education of PhDs and preparation of dissemination activities.

Exploitation of existing research infrastructures

with a view of shared or complementary use, in particular for large, full scale, laboratories (WT test-stations, blade-testing rigs, wind tunnel facilities, atmospheric and sea-state field measurement systems etc.)

Long-Term research activity

The following thematic areas and topics are identified as first priority long-term RTD issues for EAWE's joint programme of activities:

Long-term Wind forecast	• Wind resources, • Micro-siting in complex terrain, • Annual energy yield, • Design wind conditions (turbulence, shear, gusts, extreme winds)
Wind Turbine Environmental Conditions	• Characteristics of wind regime and waves • Atmospheric flow and turbulence • Interaction of boundary layer and large wind farms • Prediction of exceptional events
Wind Turbine Technology	• Aerodynamics, aeroelasticity and aeroacoustics, • Electrical generators, power electronics and control • Loads, safety and reliability • Materials and composite structures, fracture mechanisms • Material characterization and Life Cycle Analysis • New wind turbine concepts
System Integration	• Grid connection and power quality issues • Short-term power prediction • Wind farm and cluster management and control • Condition monitoring, Maintenance on Demand • New storage, transmission and power compensation systems
Integration into Energy Economy	• Integration of wind power into power plant scheduling and electricity trading • Profile-based power output, Virtual power plants • Trans-national and –continental supply structures • Control of distributed energy systems

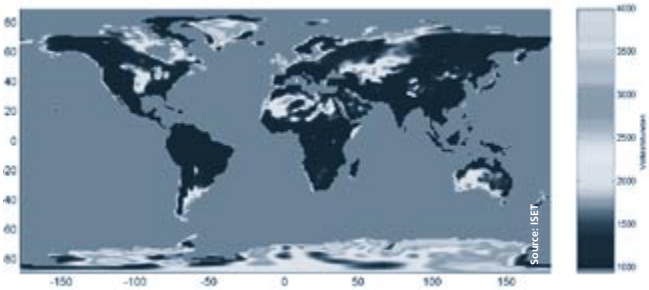
Activities of spreading the excellence

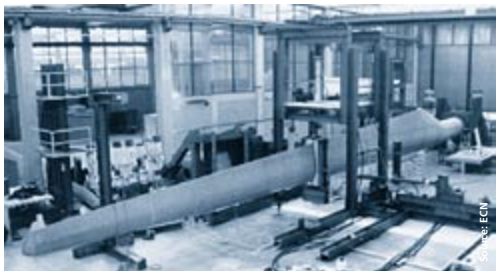
Development
of international training courses to provide a suitable vehicle for the training of researchers, students, engineers and industrial executives (in particular for SMEs), and of other potential users of the knowledge produced within the network. Such clearly identified training activities should contribute to the professional development of the persons concerned and incorporate a mobility aspect. The member institutes will create and perform joint-courses of different levels and durations. Practical training will be included. These courses will be offered to European and extra European customers.

Dissemination of knowledge
- Web site: public access to R&D outputs
- Intranetwork communication and partner meetings
- International seminars
- Summer schools for graduate and PhD-students

Services in support of technological innovation in SMEs
- Training courses for industry technical staff
- Development of computer software for technology development
- Targeted R&D news service

Standardisation
Specific R&D for preparation of proposals, evaluation and participation in CENELEC and IEC technical committees and working groups in the R&D fields of the network.





University of Kassel

ISET's Design Centre Modular Supply Technology

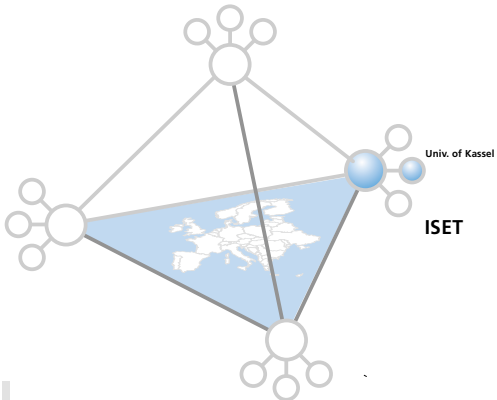
ISET

University of Kassel – Institut für Elektrische Energietechnik (IEE-EVS)

The "Institut für Solare Energieversorgungstechnik e.V." (ISET) was founded in 1988 as a non-profit research institute, associated with Kassel University. In order to realise a strong link to industry needs in the strategic R&D programme, about 50% of the scientific advisory board are representatives from the industry. Today, about 75 employees are working in ISET's facilities at Kassel and Hanau. ISET's activities in the field of wind energy range from theoretical investigations via experimental research and the execution of field tests and measurement programmes to the development of control, inverter and information systems.

For more than 20 years, the Institut für Elektrische Energietechnik (IEE-EVS), University of Kassel, has been working in the field of electrical power supply and wind energy research. The main topics of this work are the grid connection of wind turbines, grid control and supervision and generator systems.

ISET and IEE-EVS common R&D activities cover the following topics: technical and economical studies and system analysis; new models and tools for the dynamic simulation of wind energy converters and systems; development of new control concepts for reduced load impact and improved reliability; development of innovative generator systems and improved design tools for grid integration; development of information and energy management systems for large scale wind power integration; development of short term wind power forecasting systems; condition monitoring and fault prediction in wind turbines; development of new microprocessor technology in control and inverter systems; development of small wind turbines for application in hybrid systems.



ECN terrain

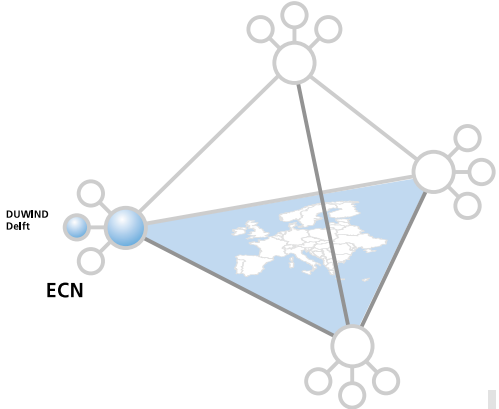
ECN

Delft University of Technology

ECN Wind Energy and the research institute DUWind of TU Delft have a close co-operation that has been built upon a history of many years of informal bilateral work as well as close collaboration on numerous European projects. Since 1996, the two institutions have collaborated under a national program, adapting their programs in order to facilitate collaborative re-search. Formal collaboration between the two entities was agreed in 2000, with an emphasis on collaborative research, staff exchange and the shared management of large -scale research and test facilities.

Together DUWind and ECN Wind Energy form one of the largest knowledge centres in the world focused upon the pursuit of fundamental knowledge of wind energy technology in general, and of offshore wind technology in particular. The collaboration offers a unique combination of renowned expertise and testing facilities including DUWind's open jet wind tunnel, its low speed low turbulence wind tunnel and its open-air research site. ECN facilities include its Multi-Megawatt (offshore) turbine testing facilities and mobile measurement systems. In 2003 DUWind and ECN have opened their joint full scale WMC testing facility for wind turbine blades, materials and constructions.

While both institutions focus upon fundamental R & D activities, DUWind maintains a stronger focus on fundamental R &D aspects while ECN focuses more so on applied R&D and testing. The collaboration is organized to keep the character of each institution, while maximizing the complementary and shared expertise areas. DUWind research staff number 27 including 10 Ph.D postitions. Another 16 Ph.D positions are currently planned in DUWind's strategic expansion program by 2004. ECN Wind Energy research staff number 45.



Risø

Technical University of Denmark,

Aalborg University

DHI - Water and Environment

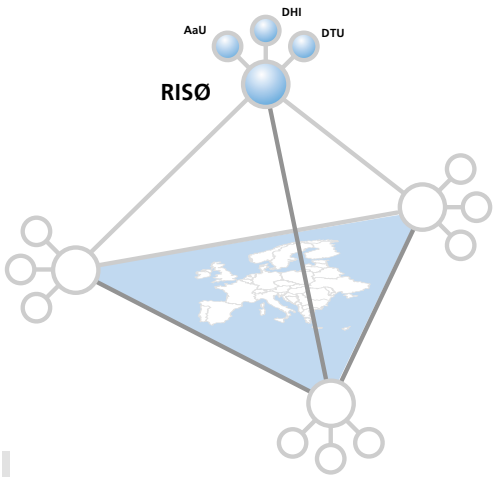
A Danish network in the form of a research Consortium in Wind Energy, dealing with research and education of researchers, has recently been formed with the four partners.

Risø National Laboratory, a national laboratory under the Ministry of Research and Information Technology, with its own board of governors. The major part of the wind energy R&D takes place in the Department of Wind Energy, which has six research programs: Atmospheric Physics, Wind Power Meteorology , Aeroelastic Design, Wind Turbines, Elec-tric Design and Control and Wind Turbine Diagnostics. In addition the department performs commercial and technical support services such as blade testing at the centre at Sparkær, wind turbine testing in the field and international consulting on wind energy. The System Analysis Department is involved in wind energy through their programs energy systems analysis, energy, environment and development planning, UNEP Centre, safety, reliability and human factors and technology scenarios, while the Materials Department does research on materials for wind turbines, in particular composites.

Aalborg University (AAU) was inaugurated in 1974 as the fifth Danish university with now more than 12,000 registered students. Research within the field of wind energy is carried out by the Institute of Energy Technology, Institute of Mechanical Engineering, Department of Civil Engineering and the Department of development and planning under the Faculty of Engineering and Science. The wind energy research comprises power electronics and generators, grid integration, energy system analysis and socio-economic evaluatiuons as well as wind turbines structures and foundations, fluid dynamics and materials.

The Technical University of Denmark (DTU) is a self-governing national university with about 5000 students and a permanent scientific staff of about 450. Research within the field of wind energy is at DTU focussed on aerodynamics and aero-elasticity (Section of Fluid Mechanics, Department of Mechanical Engineering), stochastic modelling (Department of Informatics and Mathematical Modelling) and power electronics (Department of Electric Power Engineering).

DHI Water & Environment is an independent, self-governing research and consultancy organisation affiliated to the Danish Academy of Technical Sciences. Fields related to offshore wind are: Offshore structures and pipelines, Ports and coastal structures, Coastal hydraulics, Water environment and ecology, Coastal zone management, Environmental impact assessment, Laboratory services, Institutional capacity building and training, Water and environment informatics.



CRES

NTUA

University of Patras

University of Patras

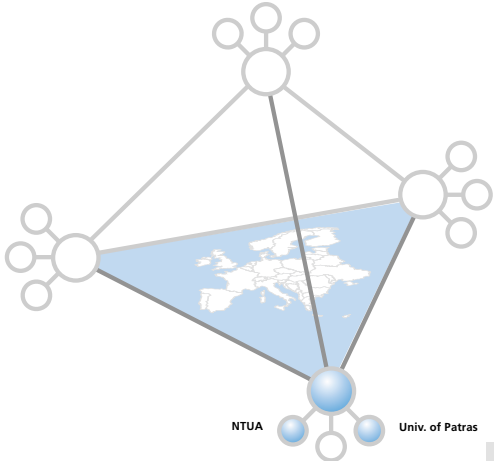
CRES, entrance to main facilities

The Centre for Renewable Energy Sources (CRES) is the national organization for the promotion of the renewable energies and energy saving in Greece, supervised by the Greek Ministry of Development. The Wind Energy Department of the Renewable Energy Sources Directorate of CRES is mainly involved in applied R&D in various aspects of the wind energy field having accumulated a notable experience since 1990. Key areas of R&D are: wind assessment and characterisation, wind turbine and component development, aerodynamics, aeroelasticity and CFD modelling, wind turbine and component testing and assessment, wind desalination and integration in autonomous power systems, standards and certification.

The National Technical University of Athens (NTUA) is actively involved in two research areas concerning wind energy, namely in rotor aerodynamics and the wind energy integration in the electrical grid. The Electrical Engineering Department of NTUA is actively involved in the field of wind energy since the beginning of the 80's, in issues relating with the technical constraints and problems in the integration of wind power into the electrical grids, the management and control of isolated power systems with increased wind power penetration, the issue of electricity tariffs for dispersed renewable generation, issues of power quality of wind turbines and wind parks, as well as with the design of electrical components for variable speed machines, such as electrical generators, including permanent magnet synchronous generators, power electronics converters and controls, and lightning protection of wind turbines and wind parks. On the other hand, the Fluids Section of the Mechanical Engineering Department of NTUA has a long-term RTD experience in covering following fields of wind energy: wind potential assessment, aerodynamic and aeroelastic design of wind turbine blades, design of machine components, certification, wind park design and assessment, noise and environmental impact assessment and hybrid systems.

The Applied Mechanics Laboratory of the University of Patras (AML/UP) has accumulated systematically experience in wind energy technologies related to design, manufacturing, testing and certification of rotor blades since 1990. Application focus expands in the following areas: structural design, optimisation and dynamics of composite wind turbine rotor blades, fatigue failure prediction of multidirectional laminates under combined stress state and variable amplitude loading, fatigue characterisation of composite materials using conventional and Non-Destructive testing, structural damping and vibration testing.

CRES, NTUA and AML/UP form a strong R&D team in the Wind Energy field in Greece, maintaining close cooperation. CRES focuses on applied R&D and testing, while the universities are concentrated more on fundamental R&D, thus, all three together forming an integrated group covering most aspects of Wind Energy. Moreover, since CRES maintains strong links to industry it often acts as a communication link bringing universities closer to the industry.



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ISET's building in Kassel

ISET in the Technologiepark Hanau with R&D-division Energetic Use of Biomass

The "Institut für Solare Energieversorgungstechnik e.V." (ISET) was founded in 1988 as a non-profit research institute, associated with Kassel University. In order to realise a strong link to industry needs in the strategic R&D programme, about 50% of the scientific advisory board are representatives from the industry. Today, about 75 employees are working in ISET's facilities at Kassel and Hanau.

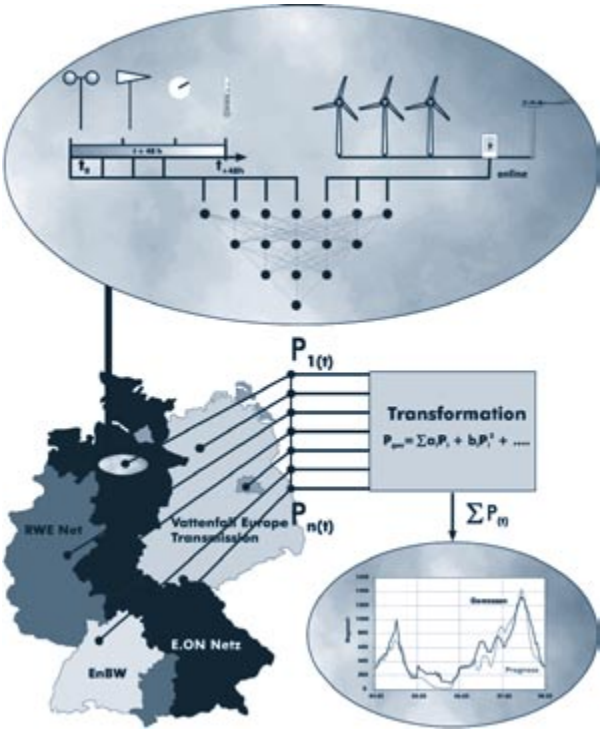
ISET's activities in the field of wind energy range from theoretical investigations via experimental research and the execution of field tests and measurement programmes to the development of control, inverter and information systems. The main focus is on the electrical and systems engineering aspects of wind power applications which arise both on component and grid integration level.

Facilities & Characteristics

wind energy remote measurement network	data acquisition for online monitoring of wind energy converters, wind measuring network with 80 selected sites in Germany
laboratories for software development	specific dynamic simulations, controller design and plant rating, hardware-in-the-loop system, PLC development environment
generator / inverter laboratory	hard- and software simulation environment for wind turbine drive trains and control concepts
power electronic and converter laboratories	set up and measurements of electronic circuits and converters, circuit layout system
EMC laboratory	accredited in accordance with IEC 17025, CE certifications, equipment for investigations of the electromagnetic compatibility, EMC measurement chamber
battery laboratories	dynamic battery testing field up to 2000 A and 400 V, climatic cabinets, H_2/O_2 analysers for hybrid applications
fuel cell laboratory	H_2/O_2 gas supply system, fuel cell measuring fields up to 10 kW, PEM experimental system with 2 x 1.5 kW electrical power
water pumps laboratory	water pumps laboratory for specific supply tasks, e.g. powered by wind turbines

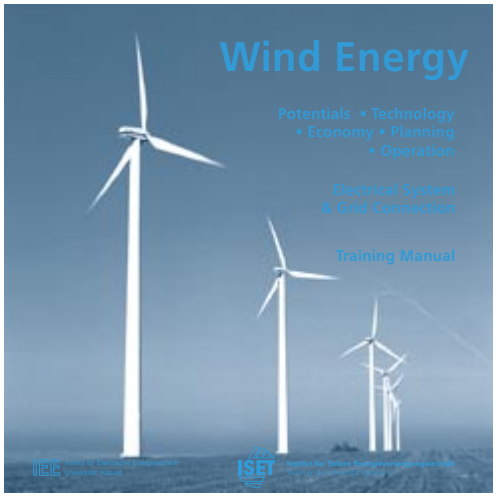
Research Focus

The main objectives of ISET's activities are to promote and execute applied research and pre-industrial development in the area of renewable energy sources, efficient use of energy and water treatment. These include the acquisition of knowledge for designing environmentally friendly energy systems, the development of methods and procedures for designing and controlling decentralised energy supply systems, the support of Know-how transfer between research and industrial applications, the design of courses for engineering students and external experts, in co-operation with universities, research institutes and the industry.



Wind power forecast: ISET's model for prediction with artificial neural network and online model for current wind power feed-in

R&D programme



Basic and current cognitions of R&D flow into specific teaching aids for international seminars

ISET's short to medium term wind power R&D programme covers the following subjects:

- technical and economical studies and system analysis for further development of wind power technology and application,
- development of new models and tools for the dynamic simulation of wind energy converters and systems
- development of new control concepts for reduced load impact and improved reliability,
- development of information and energy management systems for improved integration of large scale wind power into electrical networks,
- development of prognosis systems for wind power forecasting
- condition monitoring and fault prediction in wind turbines as a basic for wind farm supervision and maintenance/repair scheduling
- development of new microprocessor technology in control and inverter systems,
- development of small wind turbines for application in Hybrid systems,
- design and execution of measurement programmes, operation and further development of remote measurement networks,
- planning, supervision and execution of development and pilot projects,
- execution of trainee courses and further education measures.

Research groups involved

ISET is organised in four different research and development (R&D) divisions, two of which are directly involved in wind power activities with a total manpower capacity of 15 scientists and technicians.

The R&D division information and energy economy mainly deals with technical and economical aspects regarding an increasing use of renewable energy sources. This also refers to the associated energy economy field, which shows more and more elements of distributed power generation. Therefore, a main emphasis is put on wind power applications. The R&D projects cover technical and economical studies and system analysis for further development and application of wind power in energy systems, information and energy management systems for improved integration of large scale wind power into electrical networks, prognosis systems for wind power forecasting and the development and execution of further education measures in the field of wind energy.

The field of work of the R&D division for energy conversion and control engineering

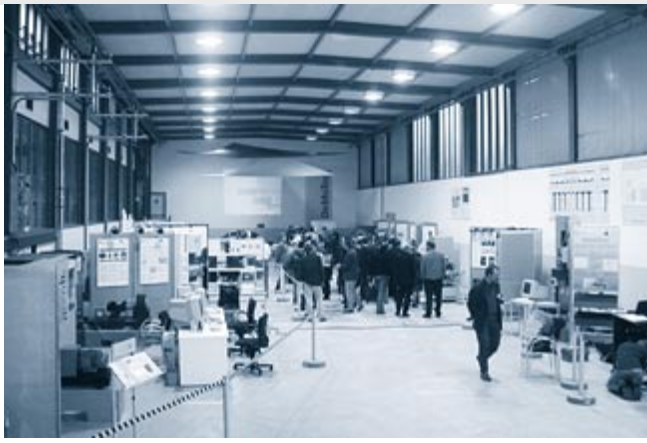
World-wide project of EXPO 2000: Wind energy in the 21st century – regional and national aspects of energy supply with high wind penetration, demonstration of a central control unit in DeMoTec

covers the optimal usage of renewable energies as well as the rational use of limited energy resources. Besides the technical and economical investigation of subsystems of different energy supply technologies, such as wind power, the division improves design and layout of complete systems. In addition to technological and constructive progress, this requires in particular the application of a modern control and system engineering approach. In particular this division has been involved in the development of advanced control systems for megawatt wind energy converters and commercially available modern fault prediction or condition monitoring units.

Advanced research techniques

- Advanced data acquisition and processing tools to calculate power output of widely dispersed wind turbines summarised in defined clusters and supply areas
- Advanced data base systems with calculation and evaluation tools for operational data of about 1500 wind turbines over a time span of 10 years and wind measurement data from up to 250 stations
- Spacial extrapolation model to calculate the total wind power feed into the German transmission and distribution networks
- Artificial Neural Networks for short term wind power prediction up to 48 hours based on weather forecasts from meteorological services
- Modelling and simulation tools for renewable energy system components, e.g. wind turbines or grid components
- Hardware in the loop test facilities with real time component simulation for development and testing of measurement and condition monitoring hardware
- Developed and field tested condition monitoring systems including hardware and software components for fault prediction tasks in wind turbines

External collaborations



DeMoTec – Design Centre for modilar Supply Technology, area for demonstration and experimentation of approx. 600 m²

ISET is a member of numerous national and international research associations, such as the German "Forschungsverbund Sonnenenergie (FVS)". FVS is a co-operation of non-university research institutes with the goal to develop and to investigate new technologies for the use of renewable energy sources. The institutes principally co-ordinate their research programmes. Furthermore, ISET scientists are participating in IEC and IEA working groups for wind power and inverter technologies. Regarding large scale integration of wind power into electrical networks, ISET co-operates closely with the German transmission network operators E.ON and Veag. Finally, ISET is the co-ordinator of the EC funded project "Distributed Generation with High Penetration of Renewable Energy Sources (DISPOWER) with 37 partners from 11 European countries and strong industry involvement from utilities and component manufacturers.

Education and training activities

Wind energy training in Brazil for PETROBAS engineers, March 2003

ISET offers training courses "Wind Energy Utilization – Potentials, Technology, Economics, Planning, Operation", which are tailored to the special demands of industry, utilities and organizations for international capacity building.

The training activities reach from 1-day seminars to 4-months programmes in-house and abroad.

In co-operation of the Kassel university groups "Electrical Energy Supply Systems", "Efficient Energy Conversion"and ISET, a special topic of study concerning Renewable Energies and Efficient Energy Conversion was established at the University of Kassel:

- Providing support to course work and diploma theses, as well as to trainees and graduate assistants
- Qualification of staff through limited, multi-year work at ISET and through the opportunity to write their doctoral thesis

Universität Kassel

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resolution allows only this size

Institute building

For more than 20 years, the Institut für Elektrische Energietechnik (IEE) at the university of Kassel works in the field of electrical power supply and wind energy research. The institute has ca. 20 employees. The research fields of the institute are, power conditioning, PV hybrid systems and wind energy technology. The main topics in these fields are; the electrical grid formation, the control and supervision of feed-in and storage systems, the grid integration of wind energy turbines, photovoltaic systems, diesel aggregates, phase shifters and battery units and the accompanying inverter technology. Additionally, the research activities the institute introduce regular and advanced lecturers in the field of renewable energy, which include wind energy converters, control and integration of wind turbines, solar energy.

Control and communication laboratory

Facilities & Characteristics

Power converter laboratory for prototype production incl. test field
Photovoltaic laboratory incl. PV-experimentation platform
Battery laboratory incl. inspection station for long- and short-time tests
Development environment for simulation- and processor systems
Two machinery test facilities, specially qualified for variable rotation speed in the power range of 50 kVA and 400 kVA
Development of components for system configurations and system simulations in conjunction with autonomous power supply units (test facility for pumps)
Laboratory for modular system technology incl. hybrid plant for the power supply of island grids
Demonstration and test Centre DeMoTec

University of Kassel – Germany

Test bench for wind converter drive train development

Research Focus

Extensive research are exists in the design and development of power supply systems based on renewable converters, mainly PV and wind generators. In this context control, supervision, dynamic investigations supported by simulation and measurement programmes are basic part of the research activities. Researches concerning grid formation, grid control and supervision, grid integration of wind energy converters and photovoltaic systems and the accompanying inverter technologies, and modelling and simulation of renewable components and storage systems are the core issue of the institute's activities. Designing of decentralised power supply structures and development of operational control of stand-alone and bonded systems are of the basic institute activities.

R&D programme

The R&D programme of the institute includes several points of interest for the next half decade. Such R&D activities are:

- Power electronics (power converter technology) as the connection between power supply components and systems: Development of decentralised power electronic components and devices, accompanying analysis concerning the electromagnetic compatibility (EMC) during the development of power electronic components and devices
- Structuring of complex systems: Microcomputer (micro controller, digital signal processors) and it's application for controlling and managing electronic supply systems
- Conversion and utilisation of decentralised and regenerative energies: Dynamic and quasi steady-state modelling and simulation of components and systems, controlling and grid integration of components and systems (virtual power plant / distributed generation), grid quality, development and technical realisation
- Study of grids and grid branches: Simulation and power flow calculations, design, measurements

Software environment for power system analysis

Research groups involved

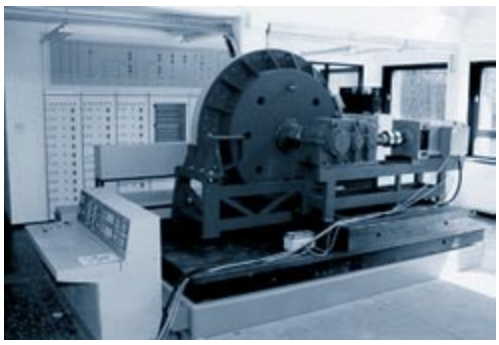
The institute of energy supply technology (EVS) at the university of Kassel has worked in the wind energy research and teaching fields since 20 years. The institute staff is organised in two research and development (R&D) divisions:

The first R&D division of "supply systems, communication and power electronic" concentrates their work on the control and management of power supply systems and components and communication technology. Therefore, security functionality, lifetime and cost-effectiveness are the basic aspect that are considered. Further point of interest of this division is the development of power electronic units such as converters and inverters.

The second R&D division "wind energy technology, grid Integration and grid calculation" works not only with wind turbines but also with component development, grid quality investigation and design of wind farms. Furthermore, in cooperation with software companies simulation programmes are developed for the investigation of the positive characteristics of the wind energy converters and analysing of different power supply systems. Also, these programmes are used to study the control, tracking and stability of grids.

Advanced research techniques

- Build-up and maintenance of measurement equipment (e.g. wind, load and grid data) incl. data remote inquiry and data evaluation
- Modelling / Programming
- Grid calculations
- System dimensioning and optimisation
- System control
- Implementing Knowledge-based and artificial intelegence systems for operation and diagnoses



Machine test laboratory, 400 kVA

External collaborations

The institute has developed cooperation partnership in the field of the wind energy with several national and international universities, research institutes and the industry, for example: aerodyn Energiesysteme, ALSTOM, avacon, EAM, SIEMENS and SMA in Germany, in Germany, IIT Delhi in India, CRES in Greece, ITER Tenerife in Span, Petrobras, CEPEL, CHEFS, Uni. Federal de Pernambuco, Energias Renovaveis da Brasil in Brazil, EMD in Germany and Denmark, EDF in France and EIBA. NRC Cairo in Egypt and EUREC in Brussels.

Education and training activities

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ECN premises

ECN, WMC and WTW in the province of Noord-Holland

The Energy research Centre of the Netherlands is a non-profit organisation and develops technologies for a safe, efficient, reliable and environmentally benign energy supply. Wind energy is one of the 8 priority areas of ECN. The unit ECN Wind Energy is active in this area since 1975. It is positioned between universities and industry to form a bridge between fundamental research and application.

Main activities cover all stages of wind energy projects (resource assessment, environmental aspects, technical and economical risk assessment, wind farm design and control, operation and maintenance, performance evaluation) and of turbine development (aerodynamic and aeroelastic design, structural design and analysis, design of control algorithms, trouble shooting). Moreover, the unit organises international training courses and contributes to national and international policy development.

Facilities & Characteristics

WMC Knowledge Centre (joint activity of ECN and Technical University Delft)	Software development and support for the engineering design and testing of structural wind turbine components, especially blades
ECN Wind Turbine Test Farm Wieringermeer (ECN WTW)	Test site with 4 locations for (prototype) testing of large wind turbines up to 6 MW and 120 m diameter. Test wind farm consisting of 5 turbines of 2.5 MW
ECN test site	Test site for small wind turbines (up to 300 kW)
Environment for turbine control development	Software and process simulator for the design and implementation of wind turbine feedback control algorithms and for the design and testing of turbine controls
Software	Wide palette of (partly in-house developed software) ranging from codes for turbine simulation to aeroelastic analysis, from electric load flow calculations to optimisation of offshore maintenance, from farm design to cost analyses of off-shore wind energy
Measuring equipment	Hardware (and software) for measuring performance, mechanical loads and vibrations, noise, power quality and wind characteristics In-house developed robust mobile equipment for data acquisition and communication
Accreditation	MEASNET for power performance and noise measurements. ISO 17025 for calibration and testing laboratories. ISO 9001 and 14001 (all ECN activities)

Research Focus

ECN Wind Energy contributes to the achievement of national and international targets for wind energy by R&D aiming at:

- increasing the value to cost ratio for wind energy,
- removal of barriers for implementation of wind power,
- exploration and development of new sites for wind turbine application,

To this end the research is focused on:

- phenomena that determine the (dynamic) behaviour of wind energy systems, sub-systems and components within their periphery and during the full life-cycle
- integration of technical, economical, environmental and social aspects
- design and operation of large offshore wind energy turbines and power plants
- support of national policy development regarding wind energy

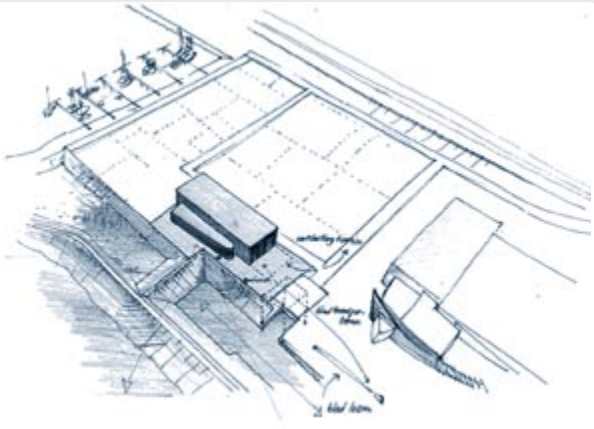
Stall Flags, in-situ flow visualisation

WMC blade testing laboratory

R&D programme

In the coming years the R&D program of ECN Wind Energy will emphasise:

- Detailed modelling of large wind farms with respect to performance and loads. Innovative approaches in farm design and operation. Field and wind tunnel validation
- Adapting existing monitoring systems for application in offshore wind turbines. Optical techniques for stress and strain measurements, bird collision detection and lightning impact localisation
- Expert systems for momentary decision making aimed at low cost operation and maintenance of offshore wind farms. Input from continuously updated failure information, wind and sea-state forecasting and residual lifetime estimates for structural and wear sensitive parts
- Aeroelastic code development. Increased reliability and accuracy by improved fluid dynamic models for blade and rotor aerodynamics, coupling to detailed structural dynamics models
- Structural reliability techniques for wind turbine design. Statistical description of all external conditions and material properties and detailed dynamic response on combinations of extreme conditions



Artist impression of the new WMC blade testing lab

Research groups involved

ECN Wind Energy is active in the area of wind energy for nearly 30 years. The permanent staff consists of 50 members, mainly scientists. At present the unit is divided into four market orientated research groups:

- Wind Farm Design (7 staff)
- Wind Farm Operation (9 staff)
- Wind Turbine Technology (11 staff)
- Experiments (10 staff)
- Special Project Staff (6)

Advanced research techniques

- Blade flow diagnostics: Stall Flag measurements, a patented technique for visualisation and analysis of the flow behaviour along the blades of full-scale turbines in operation. Unique and quick diagnostic method for performance enhancement and trouble shooting.
- Wind speed measurement: SODAR, a remote sensing technique for average wind speed and direction based on Doppler shift of sound waves.
- Bird collisions: WT-BIRD, innovative system for the detection and registration of bird collisions (or lightning strikes) on blades
- Stress and strain: fibre optics techniques for the measurement of stress and strain.
- CFD modelling: Computationally efficient fluid dynamics methods applied to rotating systems
- Turbine simulation: TURBU, frequency domain simulation of linearised, complete turbine systems including wind and wave loading, detailed feed back control and structural dynamics
- Wake modelling: turbine scale models for wind tunnel validation of wake models at various power, axial thrust and bade pitch angle.
- O&M costs: model for the optimisation of O&M schedules for off-shore wind farms based on probabilistic quantification of the costs

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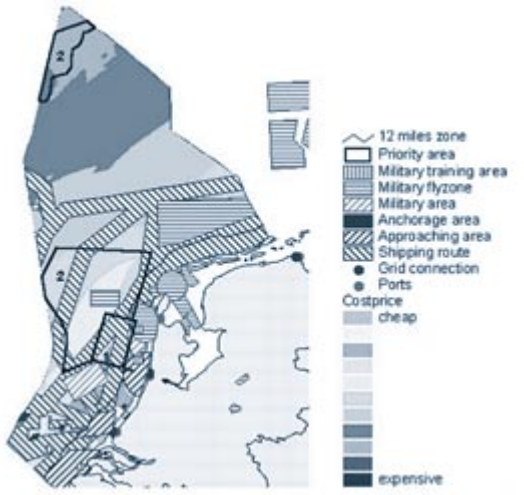

External collaborations

Subject and Partners:

- Offshore wind energy technology: NEGMicon (DK); Ballast Nedam (NL), Van Oord ACZ (NL); LM (DK/NL)
- Wind turbine rotor design: DeWind (G); Jeumont (F)
- Hydro-dynamic loads on offshore turbines: EDF (F)
- Fibre Optic measurement techniques: FOS (F)
- Blade Materials: 9 universities; 6 manufacturers; 2 certification institutes
- Certification: Det Norske Veritas; Risø (DK)
- Aero-acoustics of wind turbine rotors: National Aerospace Laboratory (NL)
- Basic rotor aerodynamics: German Dutch Wind Tunnel Facility DNW (NL); NASA Ames (USA)
- CFD boundary layer modelling : University Twente (NL)
- Condition Monitoring: Siemens (NL): Prüftechnik (G)
- Wind energy implementation: ERA (Costa Rica); CWET (India); NUON, ESSENT (NL)
- Offshore measurements: NSW (NL); 3E (Bel)

ECN Wind Energy has a formal co-operation agreement with the research institute DUWind of TU Delft, with an emphasis on collaborative research, staff exchange and the shared management of large-scale research and test facilities

Education and training activities

ECN Wind Energy regularly organises tailor made "in-house" training courses for industry and authorities. It is well known for its annual international two-week course 'Implementation of Wind Energy'. Training of Trainers programs and renewable energy training centers are also designed and executed by ECN staff as part of overseas wind energy projects. The ECN Wind Energy business unit also hosts university students on an ongoing basis for the practical training components of their studies and promotes doctoral study activities carried out by unit staff or by university based students.

DUWind

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Wind energy research at Delft University of Technology started more than 25 years ago at its faculty of Aerospace Engineering. Nowadays the wind energy research programme of TU Delft covers many aspects of modern wind turbine technology, and is undertaken across four faculties. Each of the research groups at these four faculties has its own specific expertise. However an increasing number of research problems require a multi-disciplinary research approach. This gave rise to the establishment of DUWind, an interfaculty research organization covering the wind energy research over the different faculties.

DUWind, the Delft University Wind energy research institute, comprises 8 sections with an equivalent of approximately 30 full time researchers. The focus of DUWind's research programme is on the development of offshore wind turbine and wind farm technology, ranging from basic research through to design support for the industry. DUWind also stimulates renewable energy course development, participated in several (inter) national educational activities and provides courses for M. Sc. students and for professionals in the wind energy industry.

The experimental turbine for rotor research, with a tiltable tower to have easy access to the blades

Facilities & Characteristics

Open Jet wind tunnel	The Open Jet Wind Tunnel is dedicated to wind energy research. It has a circular open jet with a diameter of 2.2 m and a wind speed up to 15 m/s. The section Wind Energy operates this wind tunnel since 1980 and it is used for several types of experiments. In the early days, experimental verification of the physical principle of power augmentation by tip-vanes was performed here. Later the research shifted towards the analysis of the general flow field and around horizontal axis wind turbine model rotors. Emphasis in this research was given to velocity measurements in the near wake of the rotor. Recently experimental research on vertical axis wind turbines and on the use of wind power in the built environment has been performed in this facility.
LSLT wind tunnel	The low speed low turbulence wind tunnel is mainly used for the development of new aerofoil for wind turbine blades. It is a closed loop wind tunnel with a test section of 1.25 x 1.80 m with a contraction ratio of 17.6:1. Over the last decade a complete set of wind turbine aerofoils, ranging from the 18% DU 95-W-180 until the 30% DU 97-W-300 were developed and tested in this wind tunnel. These aerofoils are now commonly used on a number of modern rotor blades. More recent research is performed on aerofoil behaviour at large angles of attack and aerofoil behaviour under unsteady conditions.
Open-air Rotor Research Facility	The open-air rotor research facility is situated on a 1-hectare sized outdoor research site. The site is equipped with several foundations for wind turbines. The facility has a tower, which can completely be tilted by a winch to enable easy maintenance and modification of the instrumentation and the rotor. It can be equipped with rotors up to 16 m diameter and can run with any pre-set rotor speed between 10 and 180 rpm. Its yaw angle is controlled manually. Most of the recent research was dedicated to determination of detailed load distributions and to three dimensional aerofoil behaviour. For this research the facility was equipped with a 10 meter two bladed rotor, one of them completely instrumented with 240 pressure taps.
WMC fatigue testing laboratory	In the WMC laboratory (formerly called the Stevin II laboratory) mechanical fatigue testing is accomplished on full-scale rotor blades, blade components and material coupons. Blades tested over the past 20 years ranged from 4 to 50 m long. The lab has tested most blades manufactured in The Netherlands and a significant amount of blades from other countries a.o. from Germany and Denmark. For realistic results the laboratory applies multi-axial loads on the specimens, both in static and fatigue loading. In 2003 a new facility has been realized in a joint venture with ECN, where blades up to 60 m length can be tested.

Research Focus

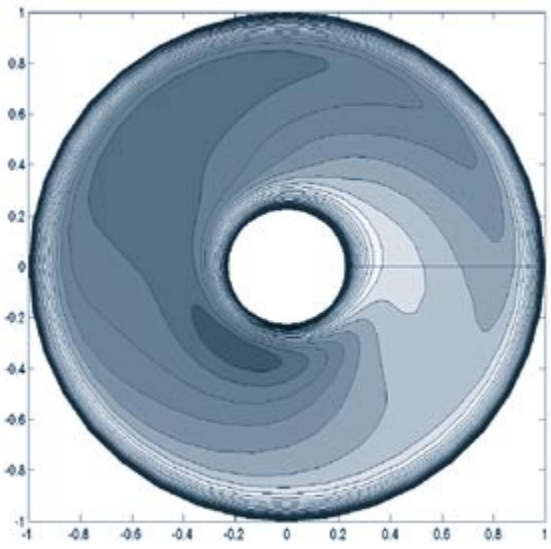
The long term R&D programme of DUWind focuses upon the technical demands of large-scale application of offshore wind energy. Future large-scale offshore wind farms will consist of a large number (100 or more) of turbines, each with an installed power of at least 5 MW. The wind turbines for such wind farms will be significantly larger than the current wind turbines onshore, and will be comparable in size with at least the „the London Eye", (the Millennium Wheel of 135 m diameter). The design and installation of wind power plants or -stations at sea require a large input of Civil engineering knowledge (environmental and site conditions: wind and wave loading, remote sensing; foundation aspects; planning of infrastructure; etc.) of Aerospace knowledge (rotor aerodynamics, dynamics, light-weight construction), of Electro-technical knowledge (electric conversion process, local grid layout, connection onshore) and of Control knowledge (control of the individual turbines as well as the control of the entire wind power station).

R&D programme

The research programme of DUWind is driven by the following three objectives:

- To maximise the reliability of wind turbine and wind farm operation (through development of accurate design tools)
- To minimise the loads on the structures (on both the rotors and support structure)
- To optimise the entire energy supply chain (wind, wind turbines, grid layout and onshore connection, integration into the main grid).

The research programme focuses on long-term research efforts, which will be performed mainly as PhD research projects. The character of this research will be fundamental, oriented on pioneering technology and/or serving the demands for the future large-scale application of wind power. The DUWind research programme is divided into 4 programme lines, covering 16 new PhD positions in total. These four major areas are:



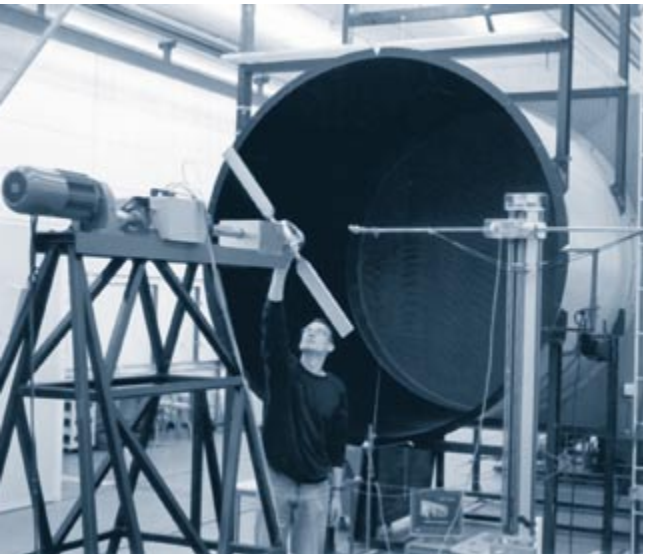
The axial load distribution for a rotor in yaw, calculated by the DUWind code PREDICDYN®

- Unsteady aerodynamic loads
- Smart dynamic control (smart structures)
- Offshore design methodology
- Concepts and components

Evidently some of the projects belong to two of these programme lines.
Examples are Aero-elasticity of large wind turbines; Advanced control of modern wind turbines, and integrated design methodologies. A number of these topics will be covered in cooperation with ECN; mainly regarding issues regarding rotor aerodynamics, design of smart structure rotors, structural reliability design and fatigue load prediction as well as large-scale integration into the electricity supply system and offshore site conditions.

Research groups involved

Faculty of Civil Engineering and Geosciences
- Wind Energy: Aerofoil design, rotor aerodynamics, turbine design, offshore technology, integrated design, offshore O&M, design tools, wind field description.
- Offshore Technology: Offshore design tools, support structures.



A model of a rotor placed in front of the open jet wind tunnel of Duwind

Faculty of Information Technology and Systems
- Electric Power Processing: Electric conversion systems, direct drive generators, electrical layout of offshore wind parks
- Electrical Power Systems: Wind power plants as part of renewable energy systems, integration of renewable energy in the grid, stand-alone systems.
- Systems and Control Engineering: Intelligent modelling, fault-tolerant control.

Faculty of Design, Engineering and Production
- Production Engineering & Industrial Organisation: Mechanical engineering, mechanical design.
- Systems & Control Group: System identification, design and testing of turbine control systems.

Faculty of Aerospace Engineering
- Flight Mechanics & Propulsion: Rotor dynamics, aero-elastic stability.
- Production Technology: Composites, fibre metal laminates (GLARE), production techniques, adhesion technology, and design of advanced lightweight structures.
- WMC laboratory: Full scale blade testing, component testing, composite materials and design tools

Advanced research techniques

Evidently DUWind as a university research institute is strongly focussed upon the development and application of advanced technologies for wind power application. In the smart structures programme line, as well as in the development of very large rotor blades for future offshore application the use of advanced materials will be investigated. The realisation of the new WMC rotor blade testing facility is one of the key elements in further material research.

Within the sections cooperating within DUWind a number of analysis and design codes have been developed. Amongst them are SWING: a numerical 3-d wind simulator; RFOIL, a wind turbine aerofoil design code, PREDICHAT and PREDICDYN: codes for the determination of aerodynamic loads on wind turbine rotors, DUWECS: a wind turbine dynamics and control code, FOCUS: a rotor blade structural loads design tool and CONTOFAX: an O&M simulation tool for offshore wind farms.

The section EPP has been heavily involved in the development of direct drive generators for wind turbines; as well into the development of AC-DC AC conversion systems.

External collaborations

ECN Wind Energy and the research institute DUWind of TU Delft have a close co-operation that has been built upon a history of many years of informal bilateral work as well as close collaboration on numerous European projects. Since 1996, the two institutions have collaborated under a national program, adapting their programs in order to facilitate collaborative re-search. Formal collaboration between the two entities was agreed in 2000, with an emphasis on collaborative research, staff exchange and the shared management of large -scale research and test facilities.

DUWind cooperates with NREL (USA), MEL and Mie University (Japan) and a number of European universities and research centres, under the umbrella of the International Energy Agency IEA. This cooperation mainly involves wind turbine rotor aerodynamic topics.

DUWind coordinated two major offshore projects: Opti-OWECS (technical and economic optimization of offshore wind energy technology) and CA-OWEE, the Concerted Action on Offshore Wind Energy, establishing the state of the art on offshore wind energy. In the latter project partners of almost all European countries with a shoreline took part. DUWind also coordinated and continues to do so some major European projects on blade materials and blade testing. The expertise gained in these projects serves as input in several working groups of the IEC on the drafting of standard on several topics of wind energy.

Education and training activities

TU Delft is the largest technical university in The Netherlands. More than 12000 students follow a B.Sc. or a M.Sc. educational programme in 14 different faculties. At present 11 international M.Sc. programmes are offered. A wind energy course is provided in the first phase of M.Sc. programme, and can be chosen by M.Sc. students in all faculties. Apart from that there is a course Offshore Windf Farm Design within the M.Sc. pogramme offshore engineering. The course programme will be extended with a few more courses the next two years in order to present a complete Wind Energy M.Sc. Course programme in 2005. Furthermore training courses are provided each year on Wind Energy Technology and Offshore Wind Energy Technology.

At present 10 PhD students are working within the DUWind programme on a number of different technical issues such as aerodynamics, aeroelastics, smart rotor design, generator design, grid control issues, support structure design, long term fatigue damage calculation etc. A large expansion programme foresees in another 16 PhD positions by 2004.

CRES

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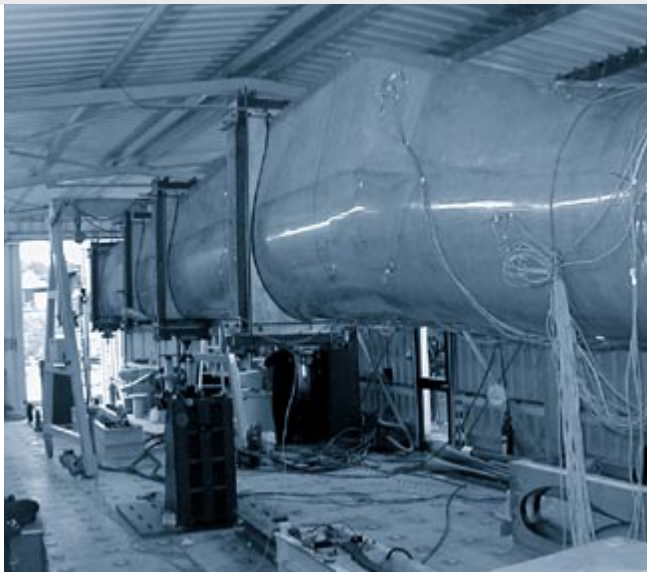
CRES, entrance to main facilities

CRES was founded in 1987 and since 1994 is the Greek national coordination center for Renewable Energy Sources and Energy Saving. CRES is supervised by the Ministry of Development, enjoying, however, financial and administrative independence. The Wind Energy Department of CRES has accumulated a notable experience through its participation in numerous wind energy related national and international projects, covering all aspects of wind energy, including wind energy potential assessment, wind turbine and wind turbine components design, testing and assessment, wind powered desalination and integration in autonomous power systems.

CRES in cooperation with other authorities is developing the National Wind Turbine Certification System, participates in relevant activities in the European and International level (CENELEC, IEC) and is a founding member of the MEASNET network. Moreover, within the Wind Energy Department the Laboratory for Wind Turbine Testing provides high quality measurement services, accredited according to ISO 17025, covering the whole aspects of wind turbine systems and their components, as well as wind potential measurements and analysis.

Facilities & Characteristics

Laboratory for wind turbine testing	Services include Wind Turbine Power curve & Power quality measurements, Load & Noise measurements, Wind Resource Assessment
W/T Blade testing Laboratory	Full scale modal, multi-axial static and fatigue testing of wind turbine blades up to 20m with suitable servohydraulic equipment.
NDT for Wind Turbine Blades	Non Destructive Testing of composite materials including Acoustic Emission and Ultrasonic applications and blade geometry quality control
Mechanical Testing of materials	Static and fatigue experiments of blade materials and components with a servohydraulic MTS 250kN testing machine
Wind Tunnel	Anemometer calibration in the wind speed range 4m/s to 16m/s with calibration uncertainty better than 0.5% in a measuring section of 0.8x0.8m^2
Test site & Demonstration wind farm	Complex terrain test site for R&D and certification of Wind Turbine systems. Demonstration wind farm comprising 5 medium sized wind turbines
Hybrid Wind-Diesel Laboratory System	Simulation of small autonomous grid operation. System is equipped with a 45kW diesel generator, a 30kW wind turbine simulator, control and monitoring systems.
Measuring equipment	Hardware and software for measuring mechanical loads and vibrations, noise, power quality and wind characteristics. Mobile equipment for data acquisition and communication
Software	In-house developed software ranging from CFD modeling to remote monitoring and control of wind turbine operation
Accreditation	Laboratory for wind turbine testing and W/T blade testing facility accredited according to ISO 17025. MEASNET member



CRES laboratory for full-scale wind turbine blade testing

Research Focus

One of the main purposes of the Wind energy Department is to support national and international policies through R&D to decrease the cost of energy production from wind and increase the penetration of wind power systems in the total energy balance. To this end, the research is focused on:

- Wind assessment and characterization
- Wind Turbine and component development, testing and assessment
- Aerodynamics, aeroelasticity and CFD modeling
- Development and integration of wind turbines in autonomous power systems such as desalination and hybrid systems
- Standardization and certification
- Support of national industry regarding wind energy applications

R&D programme

Wind Energy Department of CRES has an ambitious long-term R&D program in support of the wind energy development, aiming to achieve following in the short to medium period:
Characterization of the main features of complex or mountainous sites, affecting both the power performance and the loading of different types of wind turbines operating at such environments

- Development of wind turbines for installation in hostile environments of limited infrastructure
- Improvement of damping characteristics and thereof aerodynamic stability of wind turbine blades
- Development of new techniques for power quality measurement and assessment
- Contributing know-how to Wind Turbine standardization procedures
- Developing blade-testing techniques including non destructive testing
- Understanding generic aeroelastic performance of WT blades through CFD techniques
- Developing cost-effective micro-siting techniques for complex terrain topographies
- Developing new techniques for wind speed and direction measurements
- Improving characterization of composite material 3D fatigue life and residual strength through experiments for enhancing reliability of wind turbine blades

Partial view of CRES demonstration wind farm

Research groups involved

The wind energy department of CRES has a scientific staff of 20 highly experienced and specialized scientists, engineers and technicians. Their activities can be divided in following major research groups:

- The technical support group, which is responsible for equipment issues (purchase, maintenance, calibration), design and development of measuring systems, preparation, testing and installation of complete measuring systems for testing purposes.
- The group of the laboratory for wind turbine testing, which is responsible for execution of tests within the services provided by the wind energy department of CRES
- The quality assurance group, which is responsible for the execution of projects under the quality specification required by the accreditation scope of the laboratory for wind turbine testing.
- The numerical tools development group, which is responsible for the implementation of the theoretical findings in the design and analysis software used for wind energy applications
- The standardization and certification group, which deals with the relevant issues as part of the national development of standardization code, as well as the harmonization of the different wind turbine certification systems used in the EU.

Advanced research techniques

- Aeroelastic code: ALKYONE, an in-house developed, blade element based numerical code used for the design, analysis and certification of horizontal axis wind turbines
- Navier-Stokes solvers: 2-D, Quasi 3-D and 3D in-house developed solvers are available for applications such as micro-siting, blade section analysis and blade aeroelasticity.
- 3-D Boundary Layer model: A method, which is based on a viscous-inviscid interaction scheme, used for atmospheric flow modeling.
- Optimization techniques: used for the aerodynamic optimization of profiles and blades
- Measurement techniques: Used for wind turbine and component testing including power curve and quality measurements, noise and load measurements, anemometer calibration, resource assessment, full-scale blade testing, etc.
- Data acquisition and analysis: In-house developed software used for efficient data acquisition during measurement campaigns and fast and reliable analysis of experimental data.
- NDT techniques: especially developed for the evaluation of structural integrity of wind turbine blades are implemented during blade testing
- SMS and WAP techniques: in-house developed, used to monitor and control wind turbine and measurement systems operation remotely.

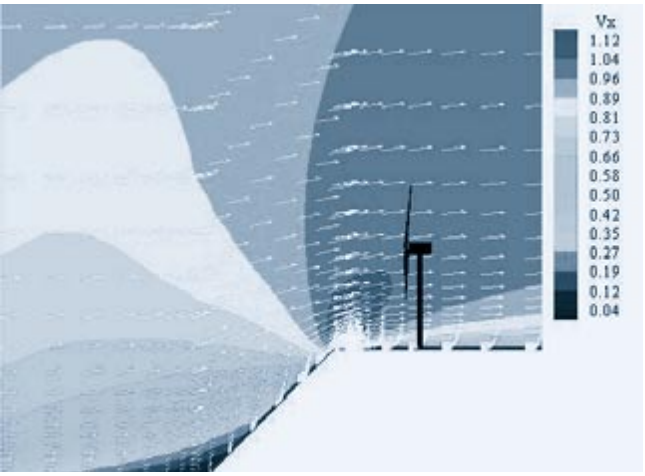
External collaborations

The Wind Energy department of CRES has a long standing cooperation with NTUA; the National Technical University of Athens and University of Patras. Moreover, CRES has established a good collaboration in the field of wind energy exploitation with many European Universities and Research Institutes, mainly in the frame of European funded projects but also due to the support in academic research and professional training, CRES is providing to academic students taking part in European programs like SOKRATES/ERASMUS. On the other hand, CRES is the contracting party for Greece of the International Energy Agency implementing agreement for cooperation in the R&D of Wind Turbine systems and is collaborating with standardization organizations such as CENELEC, IEC, ELOT (the Hellenic Standardization Organization).

Moreover, CRES is a founding member of European MEASNET network of measuring institutes acting in the wind energy field.

Education and training activities

Wind Energy department of CRES in support of academic research has created strong links with universities on a national basis. CRES researchers are taking part in consulting committees during PhD preparations with subjects relative to wind energy. Moreover professional training is taking place in the laboratory for wind turbine testing for students of National Technological Institutes. On a European level CRES supports programs like SOKRATES/ERASMUS, while CRES researchers are invited speakers for courses such as EUREC master course program. CRES also provides its testing facilities for academic research in support of PhD or master thesis preparations, as well as for hands-on trainings during master courses on subjects relevant to wind turbine and wind turbine component design, testing and construction. In general CRES is very supportive of educational activities covering the needs from the elementary school, allowing for example educational visits to its premises, to the higher academic level, amongst others offering a 3-year scholarship on PhD candidates with relevant subjects.



Navier-Stokes solver

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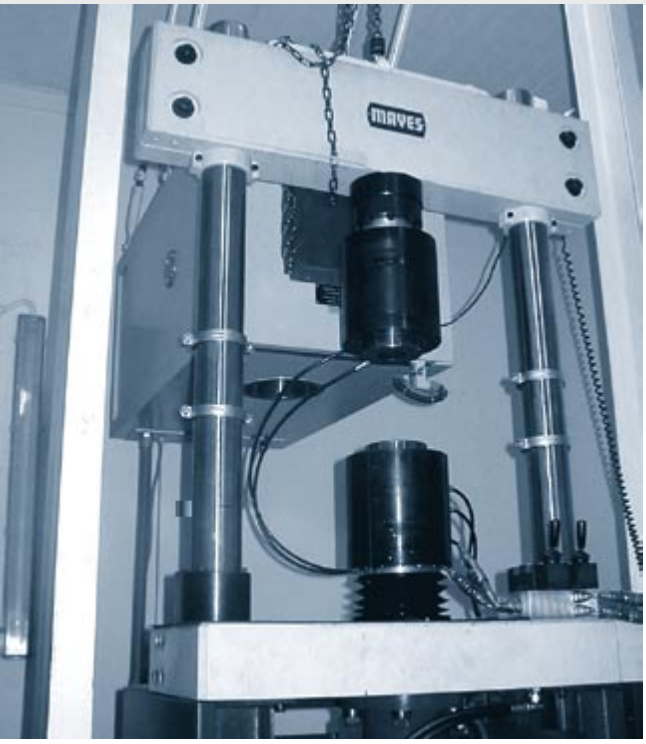
University of Patras, administration building

Applied Mechanics Laboratory, Dept. Mechanical Engineering and Aeronautics of the University of Patras (AML/UP) is in operation since 1980 and deals mainly with the general field of materials & structures, giving emphasis in the science, technology and the applications of composite materials. Since 1990 AML/UP has accumulated systematically experience in wind energy technologies related to design, manufacturing, testing and certification of rotor blades. AML is associated with industry through consultancies, by participating in the technical committees of several corporations and in numerous national and EC-funded research projects. Since 1990, AML has been involved in private, national or EU R&D projects involving Greek industries and public organizations, aiming at the design and manufacturing of composite rotor blades or assessment of their structural integrity. AML/UP as a part of an educational institute provides courses about mechanics of composites, non-destructive testing techniques, finite/boundary element analysis methods in graduate and postgraduate level.

Facilities & Characteristics

Mechanical testing of materials	Hydraulic Universal Denison-Mayes Testing Machines (100 kN) for fatigue testing, equipped with oven for working from sub-ambient temperature to 5000 C 2 Quasi-Static Universal Testing Frames 25 kN Dynamic and Thermal Analysis DuPont 2000 Equipment with 9900 Programmer
Data acquisition systems	Various multi-channel Data Acquisition Devices Multi-channel high-speed dynamic data acquisition & spectral analyser Dynamic acceleration, strain, force and temperature measurements
Non-destructive testing	NDT Equipment (pulse generator, resonant and broadband piezoelectric transducers, angle beam sensors, pre-amplifiers) USIP 11 Krautkraemer pulse generator and C-scan peripherals with bath size 1200x1000 mm for Ultrasonic Testing Ultrasonic System dedicated to the characterization of the stiffness matrix of anisotropic materials and the anisotropic damage developed under thermo-mechanical fatigue conditions. The necessary software (developed in-house) is included 6-channel SPARTAN 2000 (PAC) for Acoustic Emission 4-channel MISTRAS (PAC) for Transient Acoustic Emission Analysis 2-channel MISTRAS custom boards (PAC) for High-Frequency AE Analysis
Fractographic analysis	Nikon Thermo-camera system Nikon-Optiphot 66 Microscope equipped with CCD and video recorder
Conditioning chambers	Conditioning chamber for humidity and temperature control Conditioning chamber for bellow zero temperatures
Software	Nastran, Nike, Patran, NISA, ANSYS and LS-DYNA3D Finite Element codes, Franc 2-D and 3-D for Fracture Analysis Warp3D Analysis code for advanced plastic and viscoplastic analysis Several in house developed codes for advanced FEM, BEM and Statistical Pattern Recognition

University of Patras – Greece



Servo-Hydraulic testing machine

Research Focus

Application focus of the AML/UP expands in the following areas:

- Anisotropic Material Property Characterization
- Structural Design, Optimisation and Dynamics of Composite Wind Turbine Rotor Blades
- Fatigue Failure Prediction of Multidirectional Laminates under Combined Stress State and Variable Amplitude Loading
- Probabilistic Methods in the Design of Composite Structures
- Fatigue Characterization of Composite Materials using Conventional and Non-Destructive Testing
- Development of Numerical Tools (FEM and BEM)
- Mechanics for Composite Materials & Structures with Embedded Actuators and Sensors
- Structural Analysis & Finite Element Methods for Smart Composites and Structures
- Structural Damping (Passive & Active Vibration Control)
- Vibration Testing

R&D programme

The research group of AML/UP dealing with rotor blade structures has a long-term research plan on different aspects of composite materials applications for wind energy industry, aiming to achieve the following in the next 4 years period:

- Optimized design procedures using advanced FE modeling techniques to improve rotor reliability. This includes the efficient 3D anisotropic material strength & stiffness experimental characterization, the introduction of structural damping tensor as a design parameter and the development of 3D fatigue life and residual strength computational procedures
- Detailed 3D stress analyses (analytical & numerical) of structural joints such as T-bolts for very thick (>30 mm) composites and development of efficient life prediction procedures, including stochastic modeling of material property and loading
- Development of damage tolerant design techniques for composites used in the wind turbine industry introducing the use of NDI methodologies for assessment of blade structural integrity and composite repair efficiency in specific life intervals
- Development of real-time data processing methodologies and NDT monitoring procedures including smart materials such as shape memory alloys, piezoelectric actuators and sensors for active damping control and assessment of blade dynamic response

Composite materials workshop

Research groups involved

AML/UP has a staff of about 25 members; 5 academic, 2 post-doctoral, 3 laboratory assistants and 15 PhD students. Their activities cover the following three major research areas:

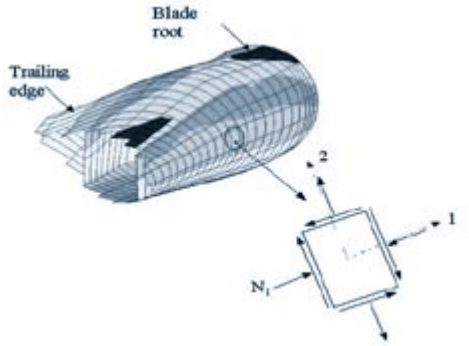
- Structural analysis, Design of composite structures, Mechanics of composites, Smart materials
- Development of numerical tools for design of composites (FEM, BEM etc)
- Condition monitoring, NDT, Adaptive structures.

Advanced research techniques

AML/UP, produces advanced techniques that concern mechanics of composite materials, design with composites and smart materials.

- In-house developed and commercial computational tools for advanced 3D stress analyses of thick composite structures (FEM, BEM), stochastic and reliability analyses
- In-house developed pattern recognition codes based on either conventional algorithms or neural networks for classification problems of data emanating from NDT measurements
- 3D experimental characterization of damage accumulation in thick composite samples using through-transmission ultrasonic testing and dedicated, in-house developed, S/W
- Acousto-Ultrasonic and AE NDT methods to assess structural integrity of new or repaired blade structures
- Characterization of composite damping properties and measurement of structural damping, Passive & Active vibration control

Acoustic Emission and Acousto-Ultrasonic devices



Complex stress state analysis

External collaborations

Major external research collaborators of the AML/UP are CRES; the Centre for Renewable Energy Sources of Greece and NTUA; the National Technical University of Athens, Greece.

However, during the last 10 years, in the frame of EC funded research projects, AML/UP has established a good cooperation with European Universities(Delft University, VUB Brussels, University of Rome "La Sapienza" etc) and Research Organizations (ECN, DLR, RISOE, CCLRC/RAL etc.)

Education and training activities

University of Patras is the third largest University in Greece and the fastest growing one, with more than 14000 under- and post-graduate students. Its 4 schools and 22 departments cover various sectors of science, engineering, health sciences, humanities and economics. The school of engineering is composed of 7 departments, one of which is that of Mechanical Engineering and Aeronautics. The section of Applied Mechanics provides for the last 3 semesters of the 5-year diploma a course program on composite materials and structures with emphasis on structural analysis, mechanics and Non Destructive Testing. At present, more than 15 PhD students of the Applied Mechanics Laboratory are activated in various research fields: (a) fatigue failure prediction of multidirectional laminates under combined stress state and variable amplitude loading, (b) probabilistic methods in the design of composite structures, (c) residual strength and fatigue damage characterization of composite materials using wave propagation techniques (d) smart composites and structures and (e) structural damping, passive and active vibration control (f) Progressive damage mechanics in multi-layer composites, development of numerical tools FEM, BEM

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NTUA

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The National Technical University (NTUA) is the oldest and most prestigious educational institution of Greece in the field of technology, and has contributed unceasingly to the country's scientific, technical and economic development since its foundation in 1836.

The Electric Energy Systems Laboratory (EESL) has been actively involved in research in the areas of Power System Analysis, Planning and Control, since 1978. Research on Wind Power dates since 1980. Since that time it has developed significant experience in issues relating with the technical constraints and problems in the integration of wind power into the electrical grids, the management and control of isolated power systems with increased wind power penetration, the issue of electricity tariffs for dispersed renewable generation, issues of power quality of wind turbines and wind parks, as well as with the design of electrical components for variable speed machines, such as electrical generators, including permanent magnet synchronous generators, power electronics converters and controls, and lightning protection of wind turbines and wind parks.

In the last 10 years, the Electric Energy Systems Laboratory has participated in several R&D projects funded by the EU, PPC, EAC, the General Secretariat for Research and Technology, CRES, INESC and various private companies including ALSTOM, Groupe Schneider, INTRASOFT, AMBER, etc. It is the coordinator of the EC projects CARE (JOR3-CT96-0119), MORE CARE (NNE5-1999-00726) and MICROGRIDS (ENK-2002-610).

EESL is also associated with industry through consultancies and by participating in the technical committees of several international committees and working groups.

Facilities & Characteristics

Software	EESL is equipped with several commercial software packages for the analysis of Wind Power integration issues and their effects on stability and power quality. These codes include the packages: EUROSTAG, EMTP, EMTDC, MATLAB/SIMULINK, etc.
	Code has been developed capable to analyse power quality issues caused by Constant Speed and variable Speed Wind Turbines.
	Control software for the operation and management of isolated power systems with increased penetration of Wind Power has been developed (within the CARE and MORE CARE projects).
	CYMGRD for the Grounding Systems analysis and has developed specialized code for the analysis of Wind Turbine and Wind parks Grounding Systems for Lightning Protection.
Real Time Digital Simulator	EESL is equipped with a Real Time Digital Simulator (RTDS) capable to model power networks and test external devices and control circuits via digital and analogue inputs. The RTDS hardware comprises a digital processor that uses advanced parallel processing techniques to achieve real time performance. The software includes detailed models of several power system components and a powerful user-friendly interface that allows an easy set-up of study cases and analysis of the results. It is particularly useful for the study of Wind Turbine effects on power quality.
Model Microgrid The model Microgrid is used to study isolated (islanded) and interconnected operation. It includes the following components:	Photovoltaic generator with 10 Modules in series - Single crystal Si, 110 W, 12 V per module and an 1100 W Inverter
	Lead-acid, vented type batteries, 30 cells, 2 V, 250/370 Ah connected through an 3.3 kVA Inverter:, bidirectional, suitable for grid-connected and islanded operation
	Grid: Connection to local building distribution (lab switchboard), MCB for protection - Contactor for control
	Load: Passive (switchable resistive, inductive, capacitive), Lighting (incandescent, CFL), Small motor and other available appliances.
	1 KW controllable Wind Turbine will be installed next year.

Research Focus

MicroGrid Components

- Investigation of the effects of connection of increased wind power penetration in medium and low voltage distribution networks.
- On-line control for the secure and economic operation of island power systems and distribution networks with increased wind power penetration. Operation and control of Microgrids.
- Quantitative assessment of the economic benefits from the integration of dispersed renewable generation, primarily wind, in the distribution grids.
- Lightning protection systems for Wind Turbine and Wind Parks with emphasis on effective grounding.
- Wind Power Prediction
- Control systems for variable speed wind turbines.

R&D programme

The research group of EESL/NTUA has a long-term research plan on different aspects of the integration of wind energy in the electrical grids and in the next 4 years period:

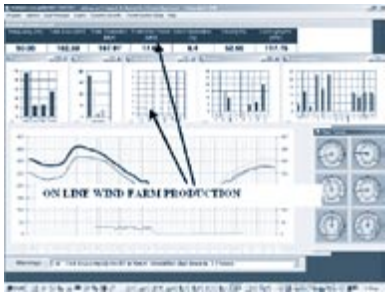
- Extension of simulation tools for the investigation of the effects of increased wind power penetration in medium and low voltage distribution networks. These tools include steady-state (load flow type), dynamic analysis (angle and voltage stability) and power quality analysis (flicker, harmonics, etc.). Extension of probabilistic tools for the investigation of the above phenomena.
- Extension of on-line control tools for the secure operation of isolated power systems with increased wind power penetration. These tools incorporate advanced software routines for short-term and medium-term forecasting, economic scheduling (unit commitment and economic dispatch) and dynamic security assessment.
- Development and extension of simulation tools to quantify the economic benefits from the integration of dispersed renewable generation in the distribution grids. These benefits include reduction of power losses due to the proximity to loads and deferral of investments in the Transmission, Distribution and Thermal Generation system. Based on these benefits objective decisions on fair tariffs can be developed.
- Development and extension of analytical and experimental tools for the design of lightning protection systems for Wind Turbine and Wind Parks Grounding Systems, Wind Turbine Blades, etc.
- Contribution to the development of grid codes and connection criteria for wind power plants.
- Development and extension of laboratory equipment related to prototype Wind Turbines and other forms of Dispersed Renewable Generation and Storage. This equipment include the development of an experimental ”micro-grid” that operates autonomously and interconnected to the main power supply.
- Research on effective control systems for variable speed wind turbines in order to provide constant active power and voltage support at the connection points.

Research groups involved

The academic staff of the Electric Energy Systems (EES) Laboratory comprises 5 Professors, 2 Associate Professors and 1 Lecturer. Many of the research activities of this group involves wind energy studies, mostly related to their effects on the power system network. The wind energy research group also includes 12 PhD students and several undergraduate students working on their diploma thesis.

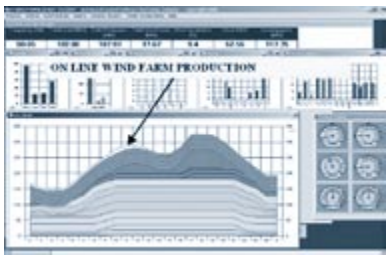
Advanced research techniques

Modelling and Simulation: Detailed models of the various electrical components of Wind Turbines have been developed. These include the types of electrical machines, the power electronic interfaces and their controls. In addition, various models of conventional machines and power network components are available. These can be used to assess the effects of wind park connection in distribution networks of interconnected and isolated systems.



Main Screen of the MORE CARE Software

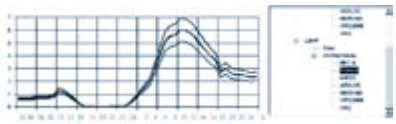
The effects of increased wind power penetration on the economic and secure operation of isolated systems can be also assessed.



MORE CARE 24-hour ahead Unit Commitment for Secure Wind Power Penetration

A Real-Time Digital Simulator (RTDS) and various laboratory models of power system components and micro-machines are also available.

Optimization strategies have been developed for wind turbine components based on deterministic and artificial intelligence approaches.



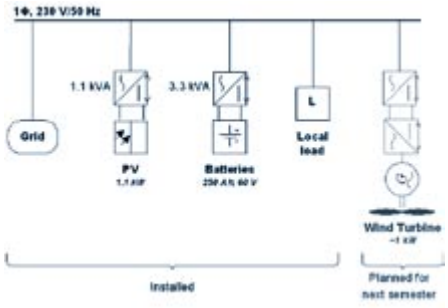
MORE CARE Wind Power Forecasting Screen

External collaborations

The EESL of NTUA has developed a continuous cooperation with many European Universities and Research Institutes, in the field of wind energy integration (INESC-Portugal, UMIST- UK, ARMINES-France, RAL-UK, ISET-Germany, Univ. of Catalunya-Spain, Univ. Carlos III Madrid-Spain, SINTEF-Norway, etc.). It has also close contacts with various Power Utilities (PPC, ESB, EEM, EDA, EDP, EDF, National Wind Power, etc.) and Industrial partners. The Electric Energy Systems Laboratory is actively involved in the activities of international Committees within CIGRE, CIRED and IEEE. Members of EESL represent Greece in the CIGRE and IEEE Working Grops related to Wind Energy and Distributed Generation, in general.

Education and training activities

The total number of undergraduate students at the The National Technical University of Athens is about 8500 and the graduate students 1500. The Electric Energy Systems laboratory (EESL) covers the educational and research activities in the area of Electric energy systems, in the broad sense. The EESL offers various degrees of experimental training of students, as part of the relevant courses of Power System Analysis, Power Generation, Power System Control and Stability, Transmission Systems, Renewable Energy Sources, Protection Schemes, Distribution Networks and Digital Techniques in Power Systems. It also affords the experimental and computational facilities necessary to carry out diploma theses and research work for doctoral and other research projects. Each year EESL offers 14 courses related to the Power System area at graduate level, 5 courses at postgraduate (PhD) level and numerous courses and seminars to practising engineers. One of the undergraduate courses is devoted to Wind Energy technologies. The Department of Electrical and Computer Engineering directs the Interdepartmental Postgraduate course "Energy Production and Management" that offers advanced graduate studies related to energy systems. One of the two directions of the programme is renewable energies, prominently wind power.



Single line Diagram of Model MicroGrid

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Risø National Laboratory and Risø Wind Energy Centre
Risø is a national laboratory under the Ministry of Science, technology and innovation. Risø carries out research in science and technology, providing Danish society new opportunities for technological development.
The research creates new opportunities for Danish industry. It contributes to the development of environmentally acceptable methods for agricultural and industrial production as well as for the generation of the energy necessary for modern. Risø Wind Energy Centre encloses all wind energy activities at Risø National Laboratory. Risø National Laboratory employs totally 750 and Risø National Laboratory Wind Energy Centre employs 130.
Organisation of Risø Wind Energy Center.
Risø Wind Energy Centre is an organisation of Risø's wind energy activities in the departments Wind Energy, Material Research and System Analysis.
The Wind Energy Department of Risø is steadily growing and employs year 2003 a permanent staff of 120 persons, of which 2/3 are scientists and engineers.
The department is organised in research programs with attached commercial and technical services. Around 90 % of the activities in the department are in the wind energy area.
The System Analysis Department do have research related to wind energy (economics, energy marked, life cycle analysis and reliability for wind turbines) and the Department for Materials Research do both have materials research connected to application in wind energy and testing of materials used in wind turbines.

Facilities & Characteristics

Danish Research Consortium for Wind Energy: A cooperation between Risø National Laboratory, Danish Technical University, Aalborg University and DHI - Water end Environment about research and education in Wind Energy.
Danish Wind Energy Center at Risø National Laboratory with about 130 employed working with wind energy research, mearurements of windturbines, blades, materials etc. , consultanty assistance and sales of dedicated software for application in the wind energy sector, certification.
Høvsøre Test Station For Large Windturbines (west cost of Jylland)
Sparkær Blade Test Facility (Fatigue and ultimate test of blades up to 50 meter
Test station for Wind Turbines at Risø National Laboratory
Integrated stand alone test facility (wind turbine, diesel, storage, pv, load simulation etc.)
Test laboratory for materials

Research Focus

Risø's Wind Energy Centre aims to meet the need for new knowledge in wind energy. The overall objectives of the research are:

- To develop new opportunities and technology for the exploitation of wind energy
- To advance the competitiveness of wind energy
- To further the global application of wind energy
- To advance the atmospheric physics basis on wind effects

R&D programme

The key areas of scientific expertise in the department are boundary layer meteorology, aerodynamics, aero-acoustics, fluid and structural mechanics, electrical design and control as well as machine and construction technology. The scientific expertise is advanced through field tests, laboratory tests and numerical modelling.
The Wind Energy Department works within strategic and applied research in most themes of wind power meteorology, wind turbine technology and applications of wind energy, such as research in:

- Meteorology (wind resources - wind atlas, design conditions, forecast)
- Aerodynamics and airfoil design (Numerical wind tunnel)
- Aeroelasticy (aerolastic modelling and verification)
- Structural dynamics
- Structural design (structural modelling and verification)
- Load and safety (for land and offshore)
- Electrical design and power quality assessment
- Wind power integration in the electrical power system
- Hybrid systems and high wind energy penetration
- Test methods (meteorology, wind turbine testing, blade testing, power quality, safety)

The Materials Department works with materials research for wind turbine blades and the System analysis Department works with research in the technical and economical integration of wind energy in the electrical supply system.

Research groups involved

The Department for Wind Energy has the following research programmes
Meteorology:

Experimental and theoretical boundary layer meteorology applied for:
- Models for real-time estimation of dispersion from point sources
- Modelling and measurement of surface exchange

Wind power meteorological methods for estimation of:
- Wind resources
- Short time wind prediction
- Wind characteristics and
- Wind loads

Aeroelastic Design
Aeroelastic methods for estimation of:
- Interaction between aerodynamics and the structure's elastic deformation and application for design of conventional and new concepts for wind turbines

Wind Turbines
Methods for wind turbine design basis and application studies:
- Probabilistic and empirical estimation of loads and safety
- Structural design and testing of components
- Assessment of performance, risks and feasibility
- Wind turbine certification

Wind Energy Systems
Methods for estimation, optimisation and design in relation to:
- Control, adjustment and function monitoring
- Integration of wind power in supply systems and interaction with the power supply system
- Electric machines
- Hybrid systems

Risø WindConsult
- International Consultancy

For more information please contact:
Test and Measurements
Experimental methods for estimation of the characteristics of wind turbines:
- Efficiency
- Loads
- Structural dynamics
- Stability
- Aerodynamics
- Acoustic emission

Sparkær Blade Test Centre
Improvement and application of research-based methods for estimation of:
- Static structural strength
- Fatigue strength
- Vibration modes

Wind Turbine Testing
Research-based and internationally certified testing of wind turbines in relation to:
- Type approval
- Documentation and
- Support to industrial development

Advanced research techniques

- WAsP code to determine wind ressources
- WAsP-Engeneering determines wind design conditions
- Aerolastic code HawC.
- Advanced wind speed measurements
- Advanced blade test methoeds
- Advanced wind turbine test methoeds
- Advanced wind farm simulation models
- Advanced electrical simulation models
- Advanced models simulation integrated energy systems
- Advanced material models

External collaborations

Risoe Wind Energy Center collaborates internationally with Wind turbine manufactures, Developers, Electrical Utilities, The Danish Energy Agency, other Danish and forign state organisations fx. aid organisations, research institutes etc. Nearly all wind energy activities is carried out in collaboration with other actors in the sector.

Education and training activities

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e-mail: windacademy@
example-institute.de

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The Technical University of Denmark (DTU) is a self-governing national university with about 6000 students and a permanent scientific staff of about 700. Wind energy research has taken place at the Technical University of Denmark since the oil crisis in the early 1970s. In the beginning most of the research was focussed on basic unsolved engineering problems related to aerodynamics, structural mechanics and safety. Today, research and education in wind energy are focussed on aerodynamics, aero-elasticity, aero-acoustics, stochastic modelling, wind power prediction and power electronics. In 2002 the world's first international M.Sc. in Wind Energy programme was created at DTU and together with the other partners of the Danish Research Consortium in Wind Energy a Ph.D. research school has recently been established.

Facilities & Characteristics

Fluid Mechanics laboratory:	The fluid mechanics laboratory is equipped with all instruments needed to analyse basic fluid flows. This includes small wind tunnels; CTA hot-wire; Two-component LDA and Particle Image Velocimetry (PIV) equipment; Laser sheet visualization; Image analysis.
High Performance Computers:	The High Performance Computing (HPC) Centre at DTU consists of a system of 120 parallel connected SUN computers, partly donated by SUN in order to carry out research on interval analysis, dynamic systems simulation and wind energy.

Research Focus

In the coming years the R&D programme of DTU's activities within wind energy will emphasise:

- Further development of in-house CFD codes to cope with massive separation and 3-dimensional transition modelling.
- Development of fully coupled CFD/structural aero-elastic code.
- Development of complex aero-acoustic tools for noise predictions.
- Development of control to converter systems, analysis of converter parameters for control systems and series connection of power semiconductors.
- Development of models and methods for short-term meteorological predictions.
- Development of stochastic models for regulation and control of Development of stochastic methods to predict extreme wind conditions.

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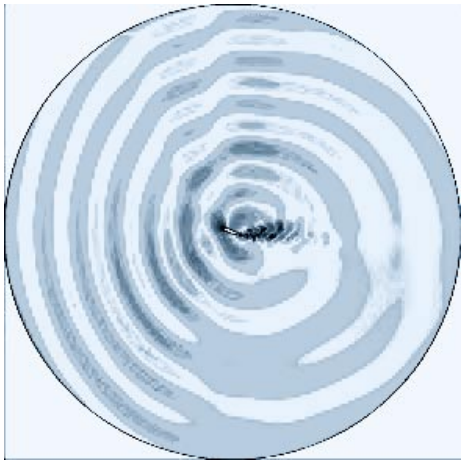
R&D programme

Present research activities are focused on the following key areas:

- Aerodynamics: Basic engineering modelling, development and application of CFD tools.
- Aero-elasticity: Complete wind turbine modelling, further development of the FLEX5 code.
- Aero-acoustics: Development of advanced numerical acoustic simulation algorithms.
- Wind data: Maintaining the IEA wind database.
- Power electronics: Power supply, switch mode techniques, grid connection and converter systems.
- Wind energy prognosis: Short term meteorological predictions, stochastic modelling of power production and control in wind parks, multivariate and multiple forecasting of wind energy, methods for ensemble forecasting of wind energy.
- Dynamic converter modelling: Converter parameters are found with converter models including non-linearity in components and modulation of pulse pattern.



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Research groups involved

- Department of Mechanical Engineering:
  Aerodynamics, aero-elasticity, aero-acoustics, Computational and experimental fluid mechanics, off-shore engineering, structural dynamics.

- Department of Informatics and Mathematical Modelling:
  Models and methods for predicting wind power, ensemble forecasts of wind power production, advanced model based predictive controllers, combined forecasting and use of multiple MET forecasts, extreme value modelling and wind energy.

- Electric Power Engineering (HCØ):
  Power electronics, grid connection and supply systems.

Advanced research techniques

- CFD modelling: Flow fields about complete rotor configurations are computed using the in-house (in collaboration with Risø) developed CFD code EllipSys

- Aero-acoustic modelling: A full 3-dimensional aero-acoustic model for noise prediction of turbulent flow fields are developed and integrated into EllipSys.

- Aero-elastic modelling: The aero-elastic computer programme FLEX5, which is the most wide-spread design code in use by industry, is developed at DTU.

- Wind power prediction: In collaboration with Risø, a series of advanced wind power prediction tools have been developed.

External collaborations

DTU has, through the newly established consortium Danish Research Consortium in Wind Energy, a formal cooperation agreement between Risø, Aalborg University and DHI Water & Environment. Within the field of wind energy DTU cooperates with a large number of universities and research organizations all over the world.

Education and training activities

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Aalborg University

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Wind energy research at Aalborg University (AAU) is organized in WEST, which is a virtual center for Wind Energy Structures and Technologies with participants from several departments at the university. WEST was established in 2001, but wind energy research was previously organized individually at the different departments.

The activities of WEST are to coordinate research and teaching within the fields of wind energy at the Faculty of Engineering and Science at Aalborg University, to strengthen the collaboration between wind energy research at the different research environments at the university, to increase the visibility - internally and externally - of the university's research and teaching on wind energy, to initiate research and development activities and to coordinate activities related to the test wind turbines.

Foundation for off-shore wind turbine

Facilities & Characteristics

Offshore wind turbine in Aalborg:	2.75 MW offshore wind turbine placed at Aalborg harbour used for research and education. A meteorology mast is placed close to the wind turbine.
Offshore wind turbine in Frederikshavn:	3 MW wind turbine with bucket foundation placed in Frederikshavn. The bucket foundation is 12 m in depth and 12 m in diameter and is instrumented.
Power electronic and converter laboratory:	Facilities with generator-set, power device test bench, power converters and grid simulator, DSPACE, AC drive systems, inverter-systems for fuel cell and photovoltaic
High Voltage and Power System Laboratory:	Equipment for insulation test, high voltage AC and DC, Power Quality, Dynamic Voltage Restorer, Lightning

Research Focus

The main objectives of WEST are to perform and promote research and education within wind energy. The problems related to development of the wind energy area cover a wide spectrum - from the social and marketing related significance and control of wind turbine produced energy via design and analysis of the technically rather advanced wind turbine components to control and electronics related problems. Several of these problems require an interdisciplinary research approach across the established research structure at AAU, where research and teaching within this area have been conducted for more than 10 years.

The research is focused on wind energy and wind turbines in the following areas: energy planning, power electronics, generators, electrical drives and power systems, power quality control, analysis and design of composite structures, structural dynamics and analysis, foundation engineering as well as loads and safety.

Wind turbine for test. NEG-MICON 2.75 MW

R&D programme

- Energy Planning: Research on technical, economic, and institutional possibilities and barriers for advancing a sustainable development of the energy systems. The focal points of the research in wind power is the integration of the fluctuating power generation into the energy system as well as the economic and institutional conditions that assure a good integration. Research furthermore targets the geographic distribution of wind power and the impacts on transmission needs at different integration approaches.

- Power Electronics, Electrical Drives and Power Systems: Research activities in wind turbine and wind turbine systems: simulation platform is being developed where models of generators, power converters and the control system are established with different simulation tools (Matlab, Digsilent, Saber, EMTDC and HAWC), variable Speed wind turbines, advanced monitoring and diagnosis of electrical and mechanical wind turbines. Simulation of wind power plants and new power converters for wind turbines are researched. Power system stability with high penetration of wind energy, equipment to stabilize the power system at distribution and transmission level including energy storage. Development of small wind turbines in stand-alone mode and grid operation.

- Control: Research on stability and performance of Pitch Regulated Variable Speed wind turbines including new advanced control methods.

- Analysis and Design of Composite Structures: Research activities related to wind turbines are especially concerning analysis and design of lightweight composite and sandwich structures. Based on analytical methods within solid mechanics and finite element methods, the projects focus on the mechanical behavior of composite structures, adhesive bonded joints, micro mechanics, structural design of wind turbine blades, modeling and simulation of the moulding process for wind turbine blades, and multidisciplinary analysis and design optimization of problems involving fluid-structure interaction.

- Structural Dynamics: Research within global dynamics and mechanics of wind turbines, including the interaction between rotor, transmission system, tower and foundation.

Research groups involved

WEST at Aalborg University is organized in 8 research groups from the following departments at the Faculty of Engineering and Science:

- Department of Development and Planning: Energy planning
- Department of Energy Technology: Power Electronics, Generators, Electrical Drives and Power Systems
- Institute for Electronic Systems: Control
- Department of Mechanical Engineering: Analysis and design of composite structures
- Department of Civil Engineering: Structural Dynamics
- Department of Chemistry and Applied Engineering Science: Structural Analysis
- Department of Civil Engineering: Foundation Engineering/ Geotechnics
- Department of Building Technology and Structural Engineering: Loads and Safety
- Aalborg University has more than 30 people working with wind energy including 10 Ph.D. students.

Advanced research techniques

- Access to large offshore variable speed wind turbines equipped with sensors and data acquisition
- Advanced electrical simulation platforms for simulation, optimisation and design of wind turbines and wind farms
- Control concepts for small stand alone systems
- Hardware for real-time simulation and implementation in power converters

External collaborations

Aalborg University has a formal cooperation with DTU, Risø and DHI within wind energy and wind turbine technology including a graduate school (Danish Academy of Wind Energy).

Researchers at Aalborg University have numerous collaborations with external partners, e.g.:

- Wind turbine manufacturers and suppliers in Denmark (NEG-Micon, Vestas Wind Systems, Bonus, LM, Mita-teknik, Gaia, Bladt Industries)
- The utilies (ELSAM, E2, ELKRAFT, ELTRA, ELFOR, SEAS, NESA, HEF and other smaller utilities)
- Research groups at universities and research institution

Education and training activities

Aalborg University has three faculties with more than 12,000 students enrolled. The faculty of Technical and Natural Sciences has about 4000 students and offer more than 25 internationl M.Sc. programmes. The most relevant Master Programmes related to wind energy are Sustainable Energy Engineering, Power Electronics and Drives, Electrical Power Systems and High Voltage Technology and Environmental Management. Furthermore WEST is planning of Master course in Wind Energy, which may be held either at the university or on-site in a company.

About 10 Ph.D. students are working with wind energy related topics at Aalborg University and they are also related to the graduate school Danish Academy of Wind Energy (DAWE).

The university offers training courses on-site related to wind energy like simulation of wind turbines, advanced control of electrical drives, materials, foundation and optimization.

DHI

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DHI main office and test facilites

DHI Water & Environment is an independent, self-governing international research and consultancy organisation, established in 1964. DHI has been authorised as an Approved Technological Institute by the Danish Minister of Science, Technology and Innovation. DHI's objectives are to build competence and promote technological development in areas relevant to water and environment in the fields of ecology and environmental chemistry, water resources, hydraulic engineering and hydrodynamics as well as other related fields.

DHI's competencies include numerical modelling, environmental laboratories and physical modelling test facilities, field surveys and monitoring programmes, and institutional capacity building and training. The Institute has a total staff of approximately 470, the majority of whom are professional engineers and scientists with post-graduate qualifications – 35% have a PhD – and several years of consultancy and R&D experience.

Facilities & Characteristics

Test Facilities	Wave and current basin, 25 by 35 m, 0.8 m deep Wave basin 32 m by 30 m, 0.45 m deep Wave basin 30 m by 30 m, 0.75 m deep Wave and current basin 30 m by 20 m, 3 m deep Wave flume 28 m by 0.74 m, 1.2 m high Wave and current flume 35 m by 5.5 m 0.8 m deep Facilities are used for determination of loads and response of installation vessels, foundations (fixed or floating), and for scour and scour protection. All facilities are equipped with sensors and data acquisition and analysis hardware and software.
Field Survey	A wide range of field survey instrumentation is available at DHI for measurement of the hydrodynamics (waves, currents) and the physical, biological and chemical environment. Instruments include ADCP's, current meters, wave riders, echosounders, sensors for temperature, salinity, turbidity etc.
Laboratory Facilitie	Microbiological, Biological, Solid waste, Chemical, C-14, Water and Waste Water Treatment laboratories.
Numerical Models	MIKE 21 HD: Water levels and currents (operational and design). Modules include water quality and sediment transport MIKE 21 SW, BW, EMS, PMS: Wave models for operational criteria, design parameters and loads MIKE 3: 3-dimensional current model LITPACK: integrated modelling package for simulation of sediment transport and morphology NS3: CFD code for fluid-structure interaction

R&D programme :

A large part of DHI's research is directly relevant to offshore wind mills, although offshore wind farms are not the sole objective of the R&D. The areas include:

- Model system for forecasting of water levels, currents and waves
- Assessement of loads from combined action of wind-waves, wind-ice.
- Improvement of numerical tools for enhanced realism in simulation of natural processes (hydrodynamics, morphological, wave-structure interaction, use of FEM and Navier-Stokes engines)
- Development of data assimilation and on-line tools for integrated modelling and monitoring systems.
- Introduction of statistical elements in deterministic methods (risk analysis, forecasting).
- Improvement of meteomarine forecasting methods (data assimilation, Artificial Neural Networks, computational speed)
- Coupling of models (physical/numerical, large scale/refined flow field)
- Data management from field and laboratory sensors to application in modelling and design processes.
- Development of next generation of numerical ecological and sedimentary. The models will help to enhance and optimise environmental investments both in the public and the private sector.
- Test and development of our modelling systems for evaluating impact from climate change.

Scour protection at wind mill foundation

Base line studies for the environment

Research Focus

DHI's involvement in research for wind energy is related to offshore wind mills. The research activities of relevance to offshore wind mills include:

- Development of state-of-the-art wave and hydrodynamics models
- Wave models for kinematics and loads in shallow and deeper waters
- Development of refined flow models for local flow, loads and erosion at foundation units
- Design of scour protection
- Models for fatigue damage due to wave/current/wind (ice) action
- Operational aspects and collision risk analysis for installation and service vessels
- Models for sediment transport and long term morphological changes
- Measurements and modelling of the environment including biological and chemical aspects
- Methods to assess impact on migrating birds
- Methods to assess impact on cetaceans and fish
- A total of 80 researchers work within these groups. Some research is directly related to offshore wind power, some is more generic with potential for application in offshore wind power related projects.

Research groups involved

The main activities at DHI in relation to offshore wind mills are conducted within the Marine and Coastal Division. This division has a staff of 80 people. The following research groups are involved in research acitivities relevant to offshore wind mills and farms:

- Ports & Offshore Technology
  (Physical and numerical modelling of waves, operational and design data, hydrodynamic load and response of vessels and foundations, scour and scour protection).

- Coastal and Estuarine Dynamics
  (Wave-current-sediment transport modelling, morphological modelling, water quality modelling).

- Ecology and Environment
  (Modelling of water quality, physical, biological and chemical aspects).

- Marine Software
  (Develoment of software models for waves, currents, water levels, transport of sediment etc).

- Key research personnel:
  Dr. Erik Asp Hansen, Dr. Ole Sørensen, Dr Julio Zysserman;
  Dr. Hakeem Johnson, Dr. Hanne Kaas, Dr. Jørgen Birklund

Advanced research techniques

Offshore Wind Mills

- Wave and current basins (load, response, erosion, scour protection) fully equipped with sensors and data acquisition

- CFD for fluid-structure interaction. In-house code, NS3, developed at DHI

- Extensive field survey equipment including ADCP's for current and wave measurements

- Recognized numerical models for waves and water flow (MIKE 21 and MIKE 3), incl sediments

Installation vessel for offshore wind mills

External collaborations

DHI collaborates with the technical universities in Denmark. In particular, the Danish Reseach Consortium for Wind Power is a collaboration between Risoe National Laboratorium, Technical Univeristy of Denmark, University of Aalborg and DHI.

DHI is designated as the Collaborating Centre for WHO and UNEP and as a resource centre for the Global Water Partnership.

Formalised collaboration agreements (not restricted to wind energy) are in place with University of Utrecht, Asian Institute of Technology, National Institute of Oceanography, India, University of Iowa, University of Idaho, and National University of Singapore.

Furthermore, DHI has subsidiaries and branch offices and project offices in 15 countries including Sweden, Germany, Australia and USA.

Education and training activities

DHI cooperate with the universities and assist in both lecturing, training and tutoring of students on MSc and PhD levels.

European Academy of Wind Energy

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