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European Wind Energy at the dawn of the 21st century

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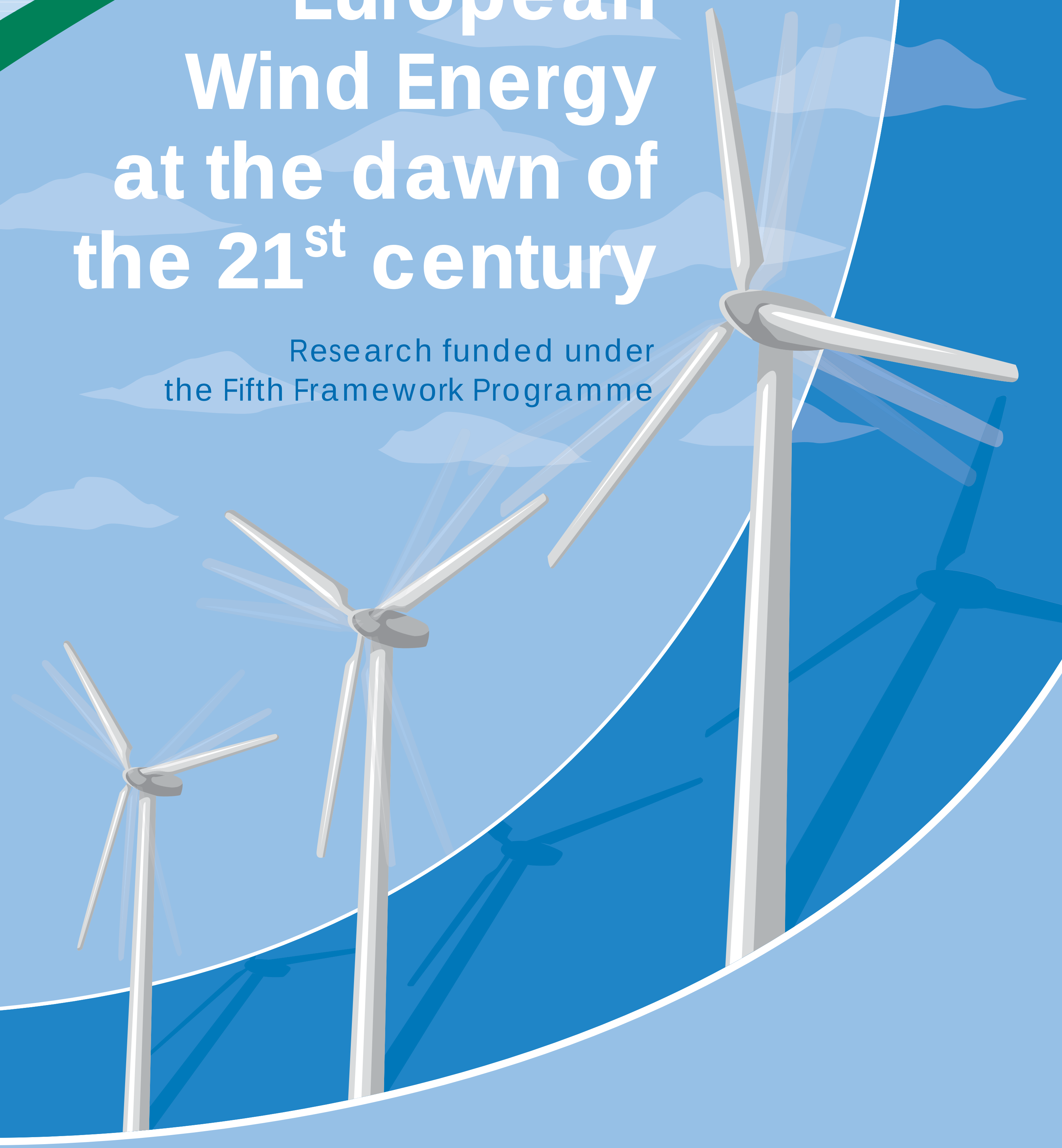

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2005

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Contents

Preface 5
Introduction 7
Wind energy developments, 1998–2004 9
Turbines 9
Blades and Rotors 10
Wind Resources – Forecasting and Mapping 13
Wind Farms 15
Integration of Wind Power 16
Demonstration Projects 18
Conclusions 23
Project Details 27

Preface

One of the objectives of the European Union for 2010 is to increase the share of renewable energy sources (RES) to 12 % of gross energy consumption and 21 % of electricity generation, from the 1995 levels of 5.3 % and 13.8 % respectively. These targets are set out in the White Paper for a Community Strategy and Action Plan: Energy for the Future – Renewable Sources of Energy (COM(97)599 final). In particular, this document also sets a target of 40 GW of wind turbine installations by 2010.

In 2005, the EU-25 has already reached an installed capacity of over 34 GW and the European wind sector leads the world in the technology and production of wind power, with 74 % of worldwide generating capacity and 90 % of the market for generating equipment. Germany, Spain and Denmark are the leading producers, and other Member States (Italy, the Netherlands and the United Kingdom) are substantially increasing their wind power activity. Over the last ten years the total generating capacity has grown by almost 30 % per year and wind power is estimated to have supplied more than 2 % of gross EU-15 electricity consumption in 2003.

This European success is an excellent example of what strategically focused research combined with motivated industrial innovation can achieve in a favourable political environment.

Wind energy research has continuously received the support of the European Union through its Framework Programmes. Currently, we have 30 projects in progress funded under the Fifth and Sixth Framework Programmes, while we are actively involved in planning FP7.

Wind energy has made enormous strides over the last five years: megawatt-plus machines are now the norm rather than the exception, and the kWh price has continued its downward trend. As a fast-growing industrial sector generating not only clean sustainable energy, but also employment, knowledge and wealth, wind power is contributing significantly to the realisation of the aims of the Lisbon Strategy.

It is timely to review the contribution EU-funded research has made to the recent progress in wind energy developments, and to consider what still needs to be done to enable wind to play an even more significant part in meeting Europe's energy needs in the coming decades.

Janez Potočnik
Commissioner for Science and Research

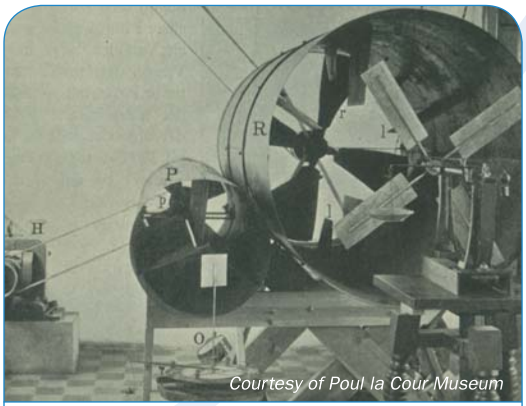
Introduction

Wind energy has been used for thousands of years for a wide variety of purposes; its early harnessing, via sails, as a means of ship propulsion played a significant role in the expansion of the early empires. When static windmills were first used on land is uncertain, but it has been suggested that the Babylonian Emperor Hammurabi used them for an irrigation scheme in 700 BC.

By the 18th century, what we commonly call the Dutch windmill was becoming a common sight across Europe, used not only for the milling of corn and similar products, but also for lifting water for irrigation purposes. The other prominent development was the wind pump which sprung up all over rural America, Australia, and elsewhere as a means of pumping water from deep boreholes for cattle grazing and farm irrigation. It is estimated that there were 5 million such machines in the USA around 1900. Many can still be seen functioning around the world, apart from their frequent scene-setting role in Hollywood movies.

Between 1900 and the oil crisis of 1973 there was no sustained development of wind energy, although the odd electricity generating wind turbine did appear from time to time. However, the basis for the modern wind turbine for electricity generation was set during that period by European inventors such as Poul la Cour and Johannes Juul in Denmark and Ulrich Hütter in Germany.

The USA was the first nation to invest heavily in wind energy, and in the early 1980s Californian wind farms served as a beacon to researchers and enthusiasts around the world. Activities increased in many western European countries but the falling back of oil prices tended to reduce the political and economic pressure for rapid progress.



Courtesy of Poul la Cour Museum

Poul la Cour's experimental wind tunnel circa 1900.

Various European countries continued to invest individually in the harnessing of wind energy for electricity production and, as this brochure will illustrate, rapid progress was made during the last quarter of the 20th century. The cost of wind-produced electricity from favourable sites is already competitive with fossil-fuel sources.

Today, wind turbines are gigantic rotating machines with blades up to twice the length of the largest plane wings. Nacelles with gearboxes and generators weighing more than a jumbo jet are erected on top of 120-metre masts, and rotors sweep an area the size of a football field. Wind technology can no longer borrow research from other sectors: it needs to forge ahead on its own.

This document highlights the contribution that more than 30 projects with funding of € 42 million under FP5 have made to the overall progress of wind energy in Europe. In this publication, the projects are grouped under six themes, and are described in further detail in the following sections.

The first area relates to wind turbines. More economic operation of wind energy installations can be obtained through larger wind turbines offering economies of scale and making better use of good sites. This includes the exploitation of high-wind-speed sites in complex terrains with robust, easy-to-transport and easy-to-install wind turbines, and the development of small and medium-sized stand-alone windmills with high efficiency, low cost and low environmental impact.

The second area deals with blades and rotors which are the most critical components of wind turbines. The aerodynamic properties of the blades can still be enhanced using experimental data from operating wind turbines and from wind tunnel measurements, leading to higher efficiency and lower noise. The dynamic behaviour of blades as well as the hub can be improved with skilful combinations of new materials, especially to reduce overall weight.

The third area examines forecasting and mapping of wind resources. A better knowledge of wind resources can significantly reduce the cost of wind power production by selecting the most appropriate sites (high wind and steady conditions). Better forecasting of power production increases dependability of supply and allows time for preventive actions to protect wind turbines from excessive wind loads.

Wind farms, i.e. groups of wind turbines installed at given sites, are presented in the fourth area. They offer economies of scale and make better use of the available sites. The funded projects aim to improve the management, monitoring and surveillance of such wind farms and to provide recommendations on how best to set them up.

The fifth area is integration of wind power. Wind is a source of electrical power which varies in time and is produced in a decentralised way (though modern offshore wind parks will soon have generation capacities comparable to conventional power plants). This creates special problems, especially if wind is to provide a high share of overall electrical power supply. These problems can be solved or at least alleviated by dedicated research efforts on the integration of wind power into local, national, and international grids.

The short-to-medium term wind energy RTD actions managed by the Directorate-General for Energy and Transport (DG TREN) are described in the sixth area. These projects aim to demonstrate, under realistic operating conditions, how integrating innovative technological solutions contributes to cost reduction. In particular, projects in the context of the growing market of larger machines and the emerging offshore market have been supported.

Wind energy developments, 1998–2004

Turbines

In order to make a substantial contribution to the achievement of the White Paper target of 40 GW for wind turbine installations in Europe for 2010, specific scientific and technological barriers or risks that hinder or slow down the wider use of wind turbines as a source of electricity must be addressed. Among these, the major problems with respect to wind turbines are as follows:

- Overcoming the bottlenecks that hinder the full exploitation of onshore wind energy and stimulating offshore exploitation using wind turbines that have a large capacity with improved performance, durability, availability and reliability, and with reduced environmental impact.
- Exploiting wind turbines as stand-alone energy generation systems for local power supply to optimise the available potential of wind energy in isolated rural conditions.
- Improving the design and performance of wind turbines by increasing energy capture, durability and operational life, which will contribute to overall system efficiency and cost effectiveness as applied to the costs of manufacturability, installation, operation, maintenance and end of life.

The achievement of a high penetration of wind energy in Europe is directly related to installing large wind turbines (>5 MW) in either onshore or offshore sites, especially when considering the densely populated northern countries where offshore seems the only viable solution for further significant and systematic wind deployment. Moreover, high penetration in the southern part of Europe, and also in some regions in Central and Northern Europe, will require the installation of large-capacity wind turbines in mountainous, complex terrain sites, usually with relatively poor infrastructure. It is anticipated that a significant portion of the 40 GW target for wind turbine installations will be developed on such sites.

Wind turbines in mountainous terrain.

In all cases, the successful expansion of offshore as well as complex terrain sites, and the shift towards larger capacities in the range of multi-MW machines, will require the development of new concepts, improved design methodologies as well as new manufacturing, installation and transportation techniques. Eventually, and in order to achieve the same levels of reliability as with the more conventional sites, new certification rules and standards need to be established and applied.

Furthermore, the exploitation of wind energy worldwide is strongly related to the development of smaller units, which can be easily installed and maintained in developing countries as part of stand-alone energy generation systems.

Four projects in the thematic area ‘Turbines’ attempt to provide answers to these critical issues and help the European wind industry to overcome the relevant problems. Each of them has been designed to contribute to the alleviation of one or more of the specific barriers to competitive wind turbine operation both onshore and offshore.

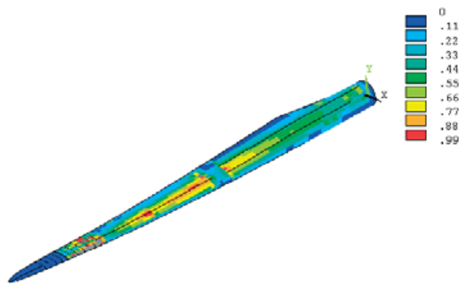
In particular, the 5 MW WIND TURBINE project aimed to set out the complete technical and economical platform for a future production version using new technical concepts. MEGAWIND sets out to formulate procedures to overcome the barriers to the transportation and erection of MW-sized machines in complex terrain, high wind speed areas with limited infrastructure, and to reduce costs through design optimisation and tailoring, with the results applied to the design and construction of a 1.3 MW prototype.

RECOFF aims to prepare reliable and robust guidelines and recommendations for the design and certification rules for offshore wind turbines and the safe development of offshore wind farms.

Within EXPLOREWIND, efficiency, cost reduction and environmental issues related to new wind turbine concepts for small non-grid connected power systems are investigated.

More specifically, these projects all contribute to alleviating the aforementioned barriers by meeting the set targets and providing answers in the following critical areas:

- A reduction in the kWh cost of electricity from large wind turbines: by reducing the expected extreme loads, through the reduction of nacelle weight to 30 kg/KW, of the rotor weight by 15 % and edgewise loads by 20 %, and by increasing the efficiency by 1-2 % through the use of new blade profiles, and through the careful design of a 5 MW wind turbine.
- The concept of direct conversion of output from a synchronous generator to High Voltage Direct Current has been shown to reduce power losses, remove the need for a low-voltage converter and perhaps also for slip rings in the power circuit.
- Improved compact design ideas, such as the split-blade concept and the composite material tower for easier/cheaper transportation and erection of large wind turbines, have been investigated and introduced at a MW size wind turbine, offering new possibilities to the wind energy community.



A finite element analysis of a split-blade design (Megawind).

- Guidelines and recommendations for the design and the certification of offshore wind turbines have been prepared which are expected to have a direct impact on the readiness to invest in offshore wind energy projects and cut objections related to project safety.
- Low-cost, easily scalable, stand-alone small wind generators have been researched making it possible to diversify into new applications powered by available ground-based mechanical drives (centrifugal pumps for running desalination systems, etc.).

Blades and Rotors

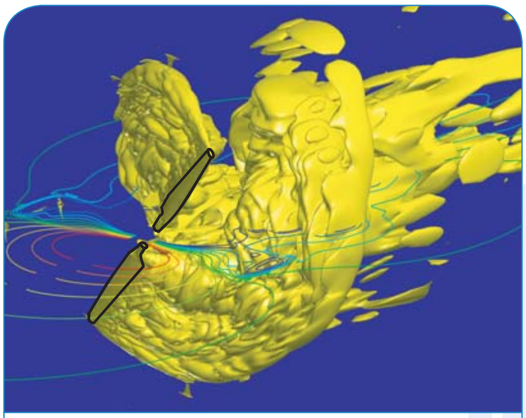
In 1997, the average nominal power of the wind turbines erected in Germany and Denmark was about 600 kW. By 2003, this average nominal power had grown to more than 1600 kW. The corresponding rotor diameter has increased from about 44 m to 70 m. Nowadays, the first prototypes of 5 MW turbines are being erected with rotor diameters of more than 120 m.

These large wind turbines are generally more economical, especially for offshore applications. However, although the generated power increases with the square of the rotor diameter, the mass of the blades increases to the third power of the rotor diameter if the dimensions are simply scaled up. In a continuous effort to fight this square-cube law, rotor blade design is becoming ever more critical as the size of the turbines increases. Furthermore, almost all the loads on the whole wind turbine are introduced through or from the rotor.

A reduction in the uncertainty in the design calculations and material properties will lead to a more balanced design, resulting in a weight reduction and a more reliable wind turbine and, consequently, reduced costs of wind power. In order to accomplish a more balanced and reliable design, designers must have a thorough understanding of all the aspects related to the material behaviour of the blades, the aerodynamics and the aero-elastic stability. On top of all this, they must have access to verified and qualified computer codes to perform detailed analyses of all load cases. The material properties should be consistent and well documented for all possible load situations and environmental conditions. To limit aerodynamic noise emission, the designer must also be aware of the coupling between the aerodynamic and acoustic properties of profiles and blade tips.

In order to fill some of the knowledge gaps faced by designers, a number of projects are being carried out within FP5. Key areas where much research is needed are aerodynamics, aero-elasticity and stability. The design tools currently available to the industry still contain a lot of uncertainties and, especially in the field of aero-elastic stability, the available models have limited capabilities.

The KNOW-BLADE project aims to reduce the uncertainties in the aerodynamic and aero-elastic analyses by applying Navier-Stokes solvers in place of today's more common BEM (Blade Element Momentum theory) solvers. The areas looked into in detail include 2D and 3D modelling, blade tip problems and aerodynamic accessories such as vortex generators and stall strips.



KNOW-BLADE: Vortex wake behind the NREL-Phase-VI rotor computed with the Detached Eddy Simulation technique.

Another important issue in this field is the verification and qualification of the aerodynamic design tools. In order to enable the wind community to improve, qualify and verify their aerodynamic design tools, an experimental database obtained under controlled and well-established conditions is needed. The MEXICO project aims to provide just such a well-documented database through a set of detailed wind-tunnel measurements in the German-Dutch DNW wind tunnel. An area closely related to this is the production of aerodynamic noise from wind turbines, which is still one of the major hindrances for the onshore exploitation of wind energy.

Courtesy of Technion

MEXICO: CAD drawing of model of wind turbine in the wind tunnel.

In the SIROCCO project, an aerodynamic/acoustic design method is being developed to be used in the design of silent aero-foils. These aero-foils will be applied to existing turbines and subjected to extensive measurement trials. As shown in the figure below, the main source of noise appears to be the outboard part (but not the tip) of the downward-moving rotor blade.

Courtesy of NLR

SIROCCO: Noise generated by wind turbine.

The STABCON project has been funded to improve knowledge in the field of aero-elastic stability and control of large wind turbines. Through the formation of a European Network on aero-elastic stability, this project aims to develop reliable design tools for aero-elastic stability analyses and the optimisation of large wind turbines.

Another innovative idea under investigation in the FP5 programme is the design and realisation of a fibre-reinforced hub as an alternative to the conventional cast-iron hub used in the present generation of turbines. The COMHUB project has demonstrated that it is practical to produce a composite hub with a significant weight reduction over conventional designs.

STABCON: Aero-elastic stability.

COMHUB: manufactured composite hub.

Another key area where progress is being made is in the understanding of the material behaviour of blades. In particular, the static and fatigue properties of fibre-reinforced blades is being investigated. As a part of this research, the OPTIMAT BLADES project is progressing with a detailed parametric study which will result in a comprehensive and consistent database for fibre-reinforced materials, for use by the industry. In addition to this database, design guidelines, ready to be implemented into the design standards, will be formulated.

At the intersection of material development and aero-elastic stability, research is being carried out on the development of damped composite blades. The DAMPBLADE project is focusing on using the benefits that can be gained from taking advantage of material damping properties in the design of large composite blades. As an additional result, the project will provide the wind industry with an analytical tool to incorporate the explicit modelling of composite structural damping in stability and fatigue analyses.

The future

After completing these projects, not all the problem areas and uncertainties will be solved. Further weight reductions can be achieved by the introduction of new materials, innovative and smart rotor designs, improved understanding of all the aerodynamic and aero-elastic phenomena, and supported by harmonised measurement and testing procedures. All this will be necessary to enable the industry to design the next generation of wind turbines aiming at enhanced reliability and efficiency and reduced environmental impact, and to make wind energy competitive with other energy sources. This next generation might well include turbines larger than 8 MW, introducing ever-more challenging demands for the designers and the tools available to them.

Wind Resources – Forecasting and Mapping

An enhanced knowledge of wind resources is expected to reduce the cost of wind energy production significantly by:

- selection of the most appropriate sites with high wind and steadier conditions
- better forecasting of power production a few hours to a few days ahead
- preventive action to protect wind turbines from excessive wind loads.

Tools for the estimation of onshore resources have been developed since the early stages of the wind industry. In recent years, factors such as public acceptability and the search for sites with high but smooth wind speeds have motivated the development of offshore wind parks. Accurate mapping of the offshore resource has emerged as a need and a challenge, not only for financial reasons due to the size of the necessary investments, but also for technical ones due to the need to evaluate the resource over large areas of several square kilometres for implementing offshore wind farms.

The aim of the WEMSAR project was to develop, validate, and demonstrate the potential of satellite-based Synthetic Aperture Radar (SAR), scatterometers and altimeters to map wind energy in offshore and near-coastal regions for potential wind turbine siting.

The main result from the project is the WEMSAR tool: a prototype satellite SAR wind retrieval and statistical analysis tool. The methods developed in the project could prove valuable for mapping coastal wind energy potential on a global scale. A cost-efficient method for mapping this valuable renewable energy source has the potential to be adopted by international organisations, governments as well as private companies.

In a global context, the advantage of SAR to the wind industry is expected to lie in combining this retrieved high-spatial-resolution wind data with in-situ measurements and models. This will improve the efficiency of forecasting and result in less costly planning and siting assessment of wind turbine parks.

At the operational level, the large-scale integration of wind power in any type of power system, interconnected or autonomous (i.e. islands), presents a number of difficulties in day-to-day management. This is due to the intermittent nature of wind production which operators have to balance – for example, by the allocation of spinning reserve. The requirement for secure and reliable operation of the power system acts as a limiting factor on wind penetration.

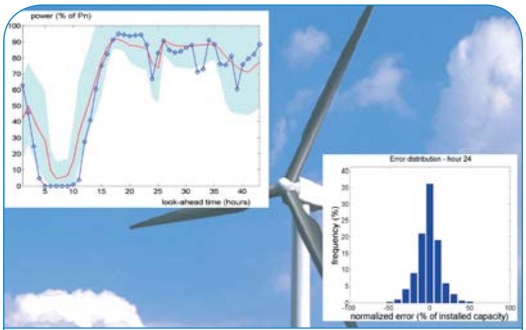
Experience from countries in which wind energy already makes a significant contribution shows that advanced tools are necessary to assist end-users in the management of wind-generated electricity. Systems that could accurately and reliably forecast wind production are widely recognised as making a major contribution to increasing wind penetration.

Moreover, European utilities today are experiencing restructuring in the areas of electricity generation, transmission and distribution. Deregulation is generally supported by appropriate frameworks that permit new actors to enter the electricity market. However, in the case of wind energy, the intermittency of the resource limits the competitive advantage of wind production compared to controllable conventional sources of electricity. Accurate predictions of wind production, a few hours ahead, would reduce the penalties in a spot market coming from errors in estimating production. As a consequence, the economic attractiveness and acceptability of wind power is increased. Higher financial and operational benefits would enable further investment in wind power installations.

The ANEMOS project aims to improve methods for short-term wind power forecasting substantially. It responds to the needs of different end-users through the development of approaches for single wind farms, for regional or national forecasting, and for different time scales ranging from a few hours to a few days ahead.

Emphasis is given to challenging situations such as complex terrain, extreme weather conditions, as well as to offshore prediction for which no specific tools currently exist.

New methods are being developed to estimate on-line the level of uncertainty of the predictions, as well as the expected risk based on ensemble weather forecasts.



Accurate predictions of wind power up to two days ahead is the objective of the ANEMOS and HONEYMOON projects.

A benchmarking process has been set up in which prediction systems are compared to physical and statistical models developed in the project using test cases covering various conditions (on-, near-, off-shore, flat to complex terrain, and interconnected and island systems). This comparison will permit an analysis of wind predictability as a function of the site characteristics, the type of weather predicted, etc.

The project is developing the ANEMOS prediction platform that integrates the various advanced models developed by the partners. The software will shortly be installed in six countries for on-line operation at onshore and offshore wind farms by end-users participating in the project. The benefits from wind prediction will be evaluated at national, regional, and single wind farm level.

Given that substantial improvement in wind power forecasting can be achieved by more accurate weather forecasting, the HONEYMOON project is developing an approach that focuses on identifying weather prediction errors and developing methods to reduce them.

An operational Numerical Weather Prediction (NWP) system is being enhanced through direction-dependent roughness parameterisation. To increase predictability of offshore winds, the air-sea interaction component of the NWP system has been improved by coupling the atmospheric model with wave and ocean models. The NWP model is then enhanced with modules able to provide predictions of wind power directly. The project aims to improve the accuracy of the predicted weather parameters used to compute the wind power and provide an uncertainty estimate of power predictions using ensemble predictions. The HONEYMOON system will be validated against end-user data while demonstrations of its on-line use are planned by the project’s end-users.

Future challenges

As the size of wind farms increase, together with wind penetration in Member States, the demands by end-users for reduced investment and operational risks become more and more intensive. Further R&D activities in the area of resource assessment and forecasting could significantly reduce these risks.

Challenges include better mapping in mountainous and cold climates, micro-siting in complex terrain, and improved methods for calculating annual energy yield. Increasing computer power is expected to enable new modelling opportunities. Techniques for data fusion from various sources (satellites, models, in situ) will permit better mapping of the offshore resource, while the projected large offshore farms will be a valuable source of data for validating theoretical developments. Synergy with research in meteorology will enable improved accuracy in the short-term forecasting of wind production. All temporal scales up to the level of climate change need to be explored.

Finally, in the ongoing liberalisation of electricity markets, a good understanding of the uncertainties related to the predictability of wind capacity at a European scale will be needed. For the economic management of wind generation, appropriate decision support tools, databases and services related to resource mapping and forecasting will be of primary importance.

Wind Farms

Wind turbines are typically erected in clusters, called wind farms, due to the economy of scale in purchasing larger numbers of turbines, the cost of electrical cables to take power to the grid, efficiency of maintenance and installation, and the best use of available sites. These advantages are compelling but there is one disadvantage of having turbines closely spaced (within 200–1000 m) which is that the reduction in wind speed and the increase in turbulence directly downwind of a turbine (called the wake) leads to a reduction in produced power and an increase in loads on any downwind turbines and their blades. This effect is particularly important offshore because wind farms are now being developed with 100 turbines and more, and also because lower ambient turbulence offshore may mean that wind speed in a wake does not recover as quickly as it does over land.

The project ENDOW undertook a comparison of state-of-the-art wake models using data from existing offshore wind farms. After the initial comparison, all models were improved and were subsequently found to show better agreement between themselves and measurements in high wind speed and turbulent conditions. This should lead to improved predictions of wake losses within wind farms before they are constructed, which will lead to a more optimal placing of wind turbines within the space available and better financing prospects.

Wind farm at Nysted.

Since wind farms are increasing in size and may be placed in remote areas (including but not exclusively offshore) where access is difficult, there is considerable advantage to be gained from closely monitoring individual turbines.

The project CleverFarm has developed a system which includes information on the current running conditions, short-term predictions of wind conditions and electricity production, video-camera surveillance of the wind farm, and wind turbine component fault predictions based on condition monitoring with vibration sensors. This combination enables the wind farm owner to effectively plan the maintenance of the wind farm and take into account the future weather situation.

CleverFarm: Outside mounted camera with pan, tilt and zoom. (Camera: Overspeed GmbH)

Two wind farms were instrumented in Denmark and Germany, the initial project software (CleverBeans) was installed, and the central servers and communication links were set up. One member of the consortium was able to report success from another wind farm where they could detect the future failure of a gearbox bearing one year before it occurred.

Economics of wind farms, both onshore and offshore, can be improved by better monitoring and prediction of wake losses.

To investigate whether a cost-effective integrated condition monitoring system could be realised in practice, the project CONMOW (Condition Monitoring for Off-shore Wind Farms) has extensively instrumented a single turbine, a GE 1.5S located at Zoetermeer, not only with condition-monitoring techniques but also with the more 'traditional' measurement systems. The main objective is to improve monitoring systems and to develop data processing techniques to create an early-warning system for component failure.

Selected condition monitoring techniques will then be applied in a five-turbine wind farm based on their added value, particularly for offshore wind turbines where major maintenance needs to be undertaken in the summer months since the turbines are inaccessible for long periods during winter.

Benefits of this research

A factor in the cost of electricity produced from wind turbines is the number placed in one location. Large wind farms typically produce power at a lower cost and make optimal use of the sites with good wind conditions. Optimising the power production by quantifying power losses from turbines placed at different spacings is a key part of the initial financing scheme. The best price for electricity is obtained by accurately forecasting the hour-to-hour variability of the power produced. Coupled with this is the need to reduce maintenance costs, particularly for offshore wind farms. By predicting component failures, advanced monitoring systems can help in maintenance planning thereby reducing costs and increasing the overall availability of each wind turbine.

Future work

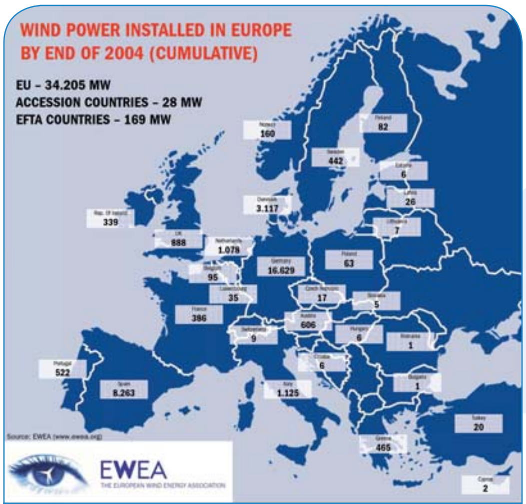
An increase in turbine availability has resulted from research over the past few years but more can still be done to predict component failure leading to lower costs of electricity produced from wind energy. More work also needs to be done to understand the optimal layouts of wind farms, particularly in an offshore environment. This is important for both power production and load prediction. If loads could be more accurately predicted, costly over-engineering could be avoided. Both issues are becoming increasingly urgent with the large-scale developments of offshore wind energy around the European shores.

Integration of Wind Power

Wind energy penetration levels in the electricity sector have reached 20 % in Denmark and about 5 % in both Germany and Spain. The north German state of Schleswig-Holstein has 1,800 MW of installed wind capacity, enough to meet 30 % of the region's total electricity demand, while in Navarra, in Spain, 50 % of consumption is met by wind power. Wind energy is now well established across parts of western and southern Europe, and installations are beginning to take off in the new Member States of central and eastern Europe, for example in Latvia (24 MW at the end of 2003) and Poland (57 MW). The figure below shows the installed capacities in European countries.

As part of the desire to increase the expertise in the former eastern European area, the FP5 RO-SWEET project is encouraging knowledge exchange on solar and wind energy systems between Romania and centres of excellence in the West.

If positive policy support continues to develop, EWEA has projected that wind power will achieve an installed capacity of 75,000 MW in the EU-15 by 2010. This would represent an overall contribution to electricity supply of 5.5 %. By 2020, this figure is expected to increase to more than 12 %, with wind power providing energy equal to the demand of 195 million European household consumers.



Wind power Installed in Europe (end 2004).

Transmission and distribution of wind electricity

A key strategic element in the successful penetration of wind power is its efficient integration into the European electricity transmission and distribution grid network. Technical, economic and regulatory considerations must be borne in mind when approaching this area. The three main issues are connection to the grid network, operating and upgrading of the network and planning for new generation capacity.

The rapid increase in penetration of wind power production into the grid raises a number of issues. Most are matters of utility attitude rather than engineering imperative.

The output from a wind farm fluctuates to a certain degree according to the weather. Wind farms are often located at the end of the distribution networks. Most European grids have been designed for large-scale electricity generation from a relatively small number of large plants, sending power outwards towards the periphery, rather than in the opposite direction.

The technical characteristics of wind generation are different to those of conventional power stations, around which the existing systems have evolved.

Intermittency issues require an understanding of variability and predictability. The variability of power output of a single turbine is small in the timescale of a few minutes and, for wind farms across a large area, is small in a timescale of hours. Although there has been progress in wind prediction techniques there is still room for significant improvements which would help firm up wind power for systems operators by reducing and specifying forecast error. Other techniques are likely to become increasingly significant as wind energy's penetration expands. These include forecasting, interconnections and electricity storage. Using such techniques, as well as reinforcement of the grid network itself, and increased geographical dispersion of wind power, it is feasible to have a very high level of wind penetration in the European electricity systems without affecting the quality of supply. The WILMAR project contributes to this through investigating a range of possibilities such as dedicated storage facilities and regional power exchanges.

Small networks

The vast majority of electricity consumers in Europe are connected to large networks. However, small isolated networks will continue to play their part, particularly because such systems are often located in rural or peripheral areas.

The integration of wind energy into smaller networks is technically more complex due, among other things, to:

- More constricted geographical area: all turbines in the system will be subject to the same weather pattern, whereas in a larger system poor wind speeds in one area of the system may be mitigated by positive wind conditions elsewhere.
- Sharp peaks and troughs in consumer demand: these are not ‘averaged out’ into a smoother curve, as is the case with larger systems.

For these reasons, the management of variability becomes particularly important in such systems, and consequently these systems may involve the use of one or other storage technology, to ensure smooth supply. With EU support, the FIRMWIND project has investigated the limits of exploitation paying particular attention to smaller, isolated grids and the potential for wind-diesel systems.

One project (RES2H2) is looking at the practicality of using hydrogen as a storage medium and is currently assembling equipment for two trial installations in southern Europe. Further support has been given through the MORE CARE project focusing on the operation of small grids and on-line security of supply.

Wind Energy R&D Network

The Wind Energy R&D Network organises industry-wide discussion on R&D needs with a view to establishing a strategy for wind research, assigning individual research tasks among public and private sectors. The network seeks to ensure that research tasks falling into the nine categories below are undertaken across the wind community, the objective being to achieve more optimal efficiency and a more aggressive development in the wind industry.

Priority R&D areas

- Economic, Policy and Market Issues, such as assessments affecting wind farm investments and market barriers
- Environmental and Social Impacts, enhancing local incentives, for example, by developing participation models
- Wind Turbine and Component Design Issues, including basic research in aerodynamics, structural dynamics, structural design and control
- Testing, Standardisation and Certification. Common accepted certification procedures for wind turbines and wind farms
- Grid Integration, Energy Systems and Resource Prediction, including the forecasting of wind resource
- Operation and Maintenance – for instance, advanced condition monitoring
- New Potentials in, for example, complex terrain and remote areas where satellite technology, among others, can be used in the formulation of wind atlases – showing the wind resource
- Offshore Wind Technology, including the control and efficiency of very large wind farms; more cost effective foundations; and transport and installation techniques
- Megawatt and Multi-megawatt Wind Turbines, for example the application of new materials with improved strength-mass ratio and development of lighter components.

Demonstration Projects

The nine projects discussed below represent a selection of demonstration actions funded under the Fifth and Sixth Framework Programmes of the EC DG TREN. Most of the projects are ongoing. All projects mentioned here have a unique innovative character and focus on the development of new markets for WEC implementation, such as (a) mountainous regions, (b) new Member States, and (c) the offshore application of wind turbines.

Wind power utilisation in mountainous areas

To improve turbine efficiency at alpine sites under icing conditions, a wind farm was erected at 1,835 metres above sea level within the framework of the Tauernwindpark project. This is a site in the Alps experiencing severe weather conditions.

Eleven WEC of the VESTAS V66/1.75 MW type with a hub height of 60 metres were set in operation. Design parameters were determined and the turbines modified to fulfil the requirements. One research turbine had a special surface coating on the rotor. The efficiency of this surface coating was investigated in direct comparison with the production data of turbines with a standard rotor coating. Today, the overall WEC availability reached a level of 97 % and the project contributed to an advancement of cold climate technology for wind turbines. This project certainly was a milestone in the exploitation of wind energy in alpine regions. Nonetheless, research is still required into heated sensors, ice detectors, methods to forecast the influence of icing conditions, applying model calculations to determine wind currents in complex terrain and, last but not least, to develop measures for keeping ice off the rotor blades.

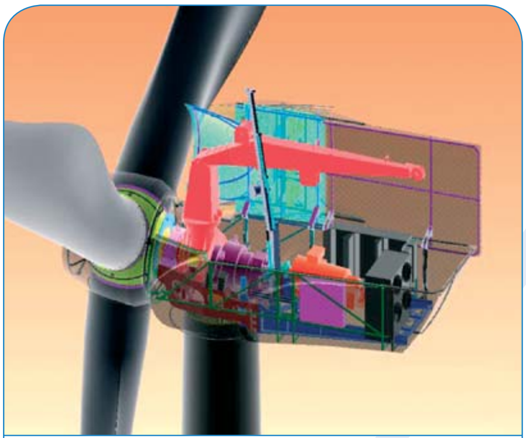
Vestas WEC at Tauernwindpark Oberzeiring (Coordinator Energiewerkstatt GmbH).

Foundations and power crane

Additional and external equipment needed for maintenance and repair actions is costly, especially for WEC which are installed at remote sites. Therefore, such costs should be reduced to a minimum to increase the economical viability of wind electricity generation.

A consortium around Nordex is developing a new crane concept – the power crane – for the Nordex N80 2.5 WTG WEC. With the availability of such a power crane, expensive mobile cranes are only needed during the initial installation process. During WEC operation, the power crane, which is part of the turbine, allows the replacement of major components, thus significantly reducing the down time (with related income loss) and the external crane costs. This concept will be demonstrated and tested in the framework of the Estonia 20 MW Wind Park project to be installed at Paldiski, the first wind park in Estonia.

In addition, three foundation types are being tested during this project and a comprehensive measurement programme will verify the concepts.



The Power Crane (Nordex).

According to EWEA, a total offshore capacity of 9 GW is planned and will be operational until 2006 in Europe. The further and vast exploitation of this promising market requires financially viable solutions for WEC foundations, for WEC transportation to the installation site and for WEC erection, as well as for power transmission to the onshore grid. Last not least, it demands highly reliable WEC which can be operated with a minimum maintenance effort.

Foundations

Since foundation costs amount to over 20 % of total installation costs, optimisation of the foundation is crucial. Within the framework of OPTIPILE, optimal monopile foundations for offshore wind turbines were developed for deep-water environments with sea bottom, wave and wind condition characteristics which are common in the North Sea and in other Atlantic continental shelves. The foundation technology was primarily developed for a 120 MW wind park (Q7-WP) located 25 km off the Dutch coast which is to be equipped with VESTAS wind turbines.

A validated scour design tool is the second important output developed by OPTIPILE.

Identification and removal of non-technical barriers in offshore wind energy deployment

Today, non-technical barriers make a significant impact on the time required for offshore the development of a WEC project. A Concerted Action for offshore wind energy deployment was established in the framework of the COD project. The objective of this project is to speed up the implementation of off-shore wind energy in the European Union by early identification and removal of non-technical barriers This target shall be achieved via a coordinated action of the energy agencies from seven North/Baltic Sea countries (NL, DK, UK, DE, SE, PO, and IE) representing >90 % of the technical offshore potential in the EU. COD will interact with NGOs such as EWEA, Seas-at-Risk, through a steering committee. The work will result in a proposal for uniform guidelines and best-practices for off-shore wind energy exploitation.

The relative costs for WEC installation, operation and maintenance, especially when going offshore, are very related to the number of WECs installed. WEC with high power outputs at comparable installation costs (in euro/kW) will have a significant advantage compared to standard WECs. Developing this market requires the development of suitable machines.

5 MW WEC (for offshore application)

A consortium around Enercon developed a 5 MW off-shore wind energy converter for pilot operation in the framework of the 5 MW offshore WEC project. This WEC will be the first offshore WEC to be installed in Germany. Its rotor has a diameter of 112 m. Start-up of the prototype has been planned for early 2005. This offshore version of the E-112 will be Enercon's first real offshore WEC with a steel tower, floating debarkation area, a steel-made suction bucket foundation (the largest ever built for a WEC), and an integrated and powerful dehumidification, heat exchange and cooling system. The experiences learnt from this WEC will be key in the further development and exploitation of the offshore market.

A first prototype with 'wet feet' was installed close to Emden/Germany in October 2004. The next prototype to be set up in the framework of the 5 MW offshore WEC project and installed offshore early in 2005. It will have a steel tower with floating debarkation area and will be grounded on a suction-bucket foundation.

INNOWT5000

INNOWT5000 is the name of a project aiming to design, manufacture and install a 5 MW wind turbine. This first REpower 5 M WEC prototype with a rotor diameter of 126 m has been designed for both onshore and offshore application. LM Glasfiber developed the blade which uses carbon-fibre-reinforced plastic. Non-locating bearings for the drive train are supplied by SKF. The first prototype was installed in October 2004 at Brunsbüttel in Germany and can be considered as a further milestone towards the future exploitation of offshore wind energy potential.

Prototype of RePower 5 MW wind turbine installed at Brunsbüttel, Germany. With a rotor diameter of 126 m, it is the largest wind turbine ever built.

42 MW offshore wind park

One of the largest offshore wind farms in the world and one of the first wind farms to be connected to a full-scale HVDC light system will be developed within the framework of CLOWEBS at Klasården. This 42 MW wind park will be sited some 2 km from the west coast of the Näs peninsula on the island of Gotland in the Baltic Sea and will be operational by 2006.

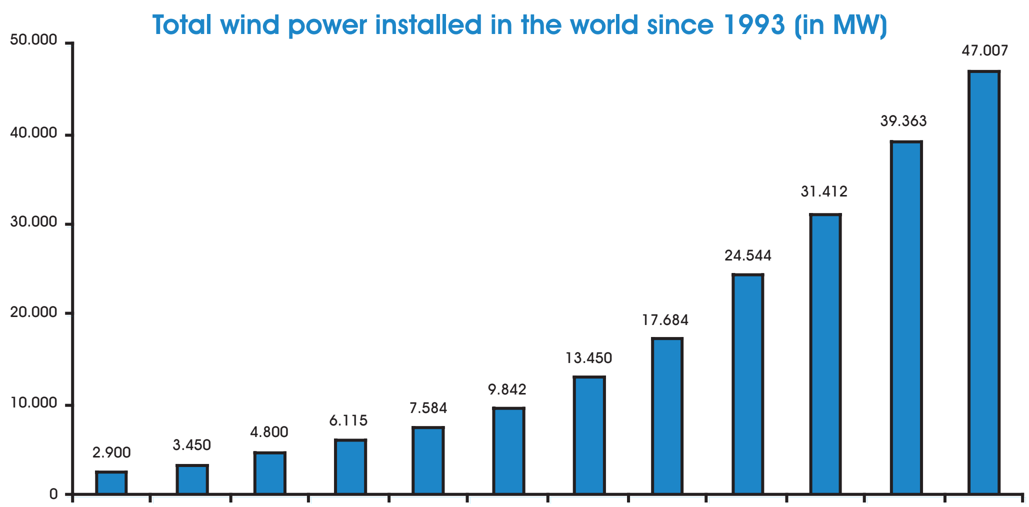
It will demonstrate that large amounts of wind-generated electricity can be fed into a comparatively weak or isolated grid via a full-scale HVDC light system. The project will consist of 16 machines from Vestas, type V-90, each rated at 2.6 MW, and will use innovative gravity foundation design.

Vestas V90-3MW Wind Turbines.

Conclusions

The aims of this document have been to highlight progress in wind energy developments over the last five years and to assess the contribution of FP5 projects to these advances.

Reviews of the individual areas have shown that significant progress has been made, and that wind energy, at least on good sites, can already compete with alternative forms of electricity generation without requiring any special support. By 1998, the EU-15 had an installed wind energy capacity of 6.5 GW; today this has risen to 34 GW. Europe's dominance in wind energy has strengthened, with its share of the world's capacity increasing from 64 % to 74 % in the same period.

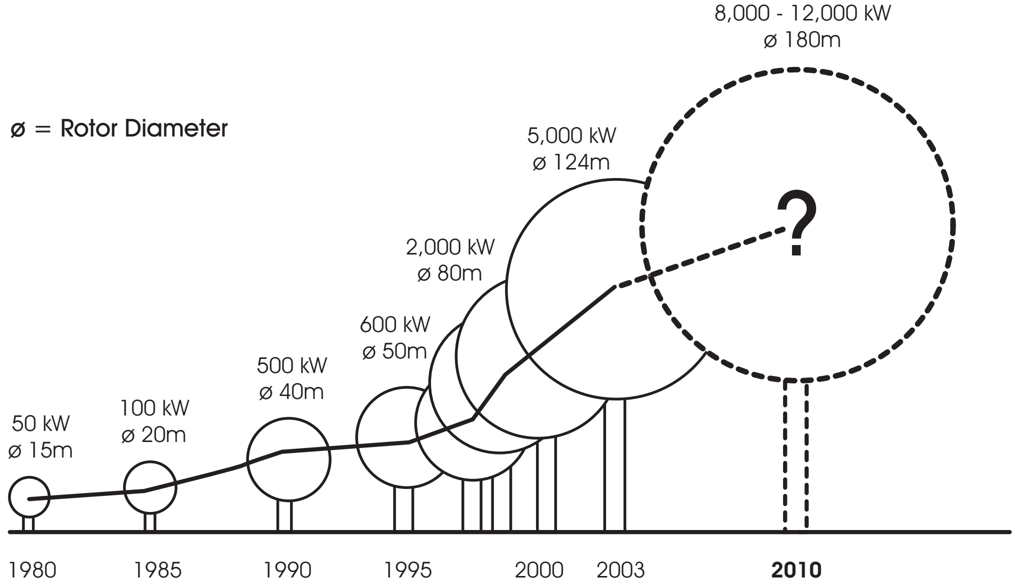


Growth in the installed capacity of commercial wind turbines.

Over this period, the size of the typical wind turbine has also grown dramatically. Towards the end of the last century, a typical wind turbine had a rated power of 0.6 to 0.8 MW; nowadays, most manufacturers' standard commercial machines are in the order of 1.5 MW, and prototypes of up to 5 MW no longer cause surprise. The cost of wind-generated electricity is strongly related to turbine size, and the doubling of the rated output of the 'standard' turbine has led directly to a fall of around 20 % in generation costs. Other benefits have come from more efficient and cheaper turbine designs associated with reduced maintenance costs due to increased reliability. All of these factors have been assisted not only by experience in the field but also by knowledge gained from research in the laboratory and on prototype turbines.

Although the paragraph above highlighted the quadrupling of installed capacity over a five-year period, the wide variation between the EU Member States should not be overlooked. Most of this growth can be attributed to just two countries, Germany and Spain, with Denmark continuing its steady progress. Furthermore, wind is almost completely unexploited in the new Member States. In many countries, environmental and other concerns continue to limit wind farm developments, and attention is moving to offshore sites where winds are higher and which may prove less contentious. Already, much of the current research considers this scenario: large machines are more attractive if sited offshore, while reliability becomes crucial given the increased installation, maintenance and repair costs.

One of the most common criticisms of wind energy is the unreliability of the supply. While it is obvious that wind turbines cannot produce electricity in periods of calm, research has shown that the



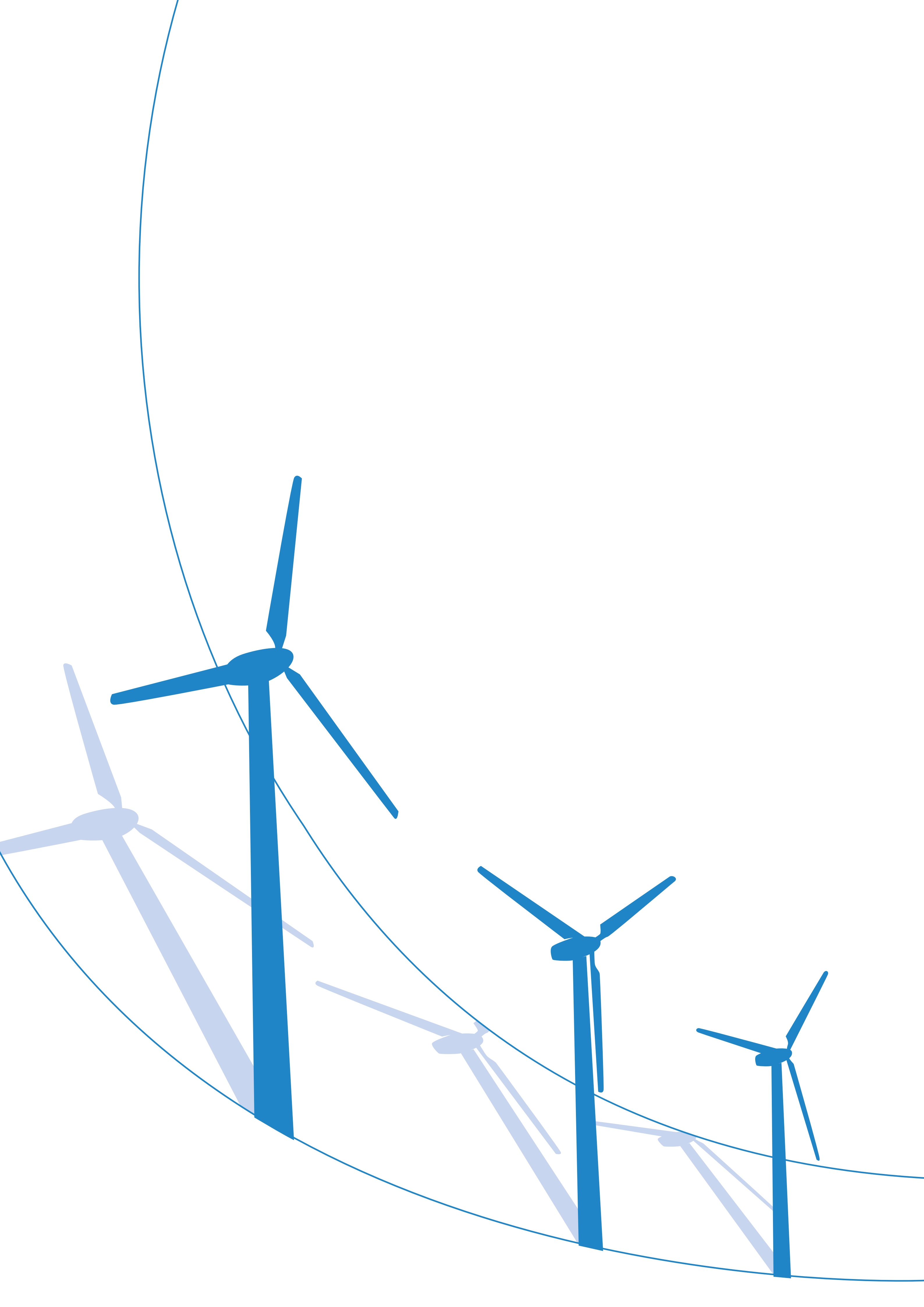
Growth in the size of commercial wind turbines.

supply can be smoothed somewhat by placing wind farms in diverse locations, and methods for predicting wind energy output from a given site have been further developed with increased reliability. As wind penetration increases, such work will be of growing importance.

Grid connection of wind farms is one of the major barriers today for a larger penetration of wind farms in isolated area and offshore. Investments in grid infrastructure are necessary to enable the full exploitation of wind resources. The development of distributed energy generation requires smart networks where wind power can be transmitted easily across large distances to where it is needed, mitigating against the intermittent character of the wind.

Overall, the last five years have seen dramatic progress in wind energy. However, it would be wrong to see it as a fully mature technology. Offshore wind energy is still barely in its infancy, and many questions remain unanswered. Even in terms of the fundamental technology, various options are still being debated, such as low speed, direct-drive generators versus high-speed generators and gearboxes, and two- versus three-blade rotors for offshore applications.

Ambitious scenarios are predicting a substantial share of total electricity generation for wind power (12.1 % by 2020). However, to tap the potential of wind energy to the full, and to achieve this target, more research and demonstration is essential to overcome both technical and non-technical barriers. The current FP6 programme provides continuity for short-term demonstration and longer-term research projects during the period 2002-2006.



TURBINES

Contract: ENK5-CT-2000-00300

Acronym: 5 MW WIND TURBINE

Title:
Research and Development of a 5 MW Wind Turbine

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Project start date: 01-01-2001

Duration: 42 months

Project summary

Objectives and problems to be solved

Several factors have stimulated the trend towards larger and larger wind turbines: economies of scale, scarcity of sites and offshore locations, and the learning curve of the technology. With new technical concepts and the availability of new materials, this project will establish the complete technical and financial platform for a later production of a 6 MW Wind Turbine (WT). The project aims to carry out all the research, development and engineering – including manufacturing, operation and testing. As such, the project is a design project and does not encompass the actual production of a complete WT. The expected data for a 6 MW WT are: hub height: 120 m, rotor diameter: 135 m, nominal output: 6 MW, mode of operation: variable speed, each blade with intelligent pitch control.

Description of work

The work will focus on the following R&D issues:
- Integrated drive train concept with a potential nacelle weight reduction of 25 % compared relatively to present 2 MW machines.
- Lightweight/rotor using composite materials and new (non-NACA) profiles; expected relative weight reduction of 15 %.
- Integration in a 6 MW WT with variable speed and intelligent pitch control.

Expected results and exploitation plans

The main result of the project will be the reduction of the cost of kWh produced. This will be achieved by reduced extreme loads, by the reduction of the nacelle weight to approximately 30 kg/kW, by a reduction of the rotor weight by 15 % and of edgewise loads by 20 %, and by an efficiency increase of 1-2 % due to the new profile.

Achievements to date

A turbine with a nacelle weight approximately 25 % lower relative to a 2 MW nacelle has been obtained. A new blade has been developed and tested successfully, and is the first of a new generation using carbon as a main structural material. A competitive drive train system has been developed, a system which, at present, indicates a weight reduction of approximately 25 % relative to a 2 MW.

Contract: ENK5-CT-2000-00328

Acronym: MEGAWIND

Title:
Development of a MW scale wind turbine for high wind complex terrain sites

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- NECSO Entrecanales Cubiertas SA – NECSO - ES
- Geobiologiki SA – GEO - EL
- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas – CIEMAT - ES
- Joint Research Center – JRC - IT
- Foundation for Research and Technology Hellas – FORTH - EL
- University of Patras – UP - EL
- National Technical University of Athens – NTUA - EL
- Newcastle University – NU - UK

Project start date: 01-01-2001

Duration: 54 months

Project summary

Objectives and problems to be solved

The high penetration of wind energy mainly in the Southern part of Europe but also in some regions in Central and Northern Europe is directly related to installing large-capacity turbines in mountainous-complex terrain sites. It is anticipated that nearly 25 % of the 40 GW target for wind turbine installations in Europe by 2010 will be developed in such areas. In this connection, the challenge for the European industry is twofold: to develop procedures which circumvent the barriers to transport and erection of MW-size machines in areas of limited infrastructure, and to reduce costs by means of design optimisation and tailoring. MEGAWIND sets out to formulate such procedures and apply them to the design and construction of a 1.3 MW prototype for high wind sites.

Description of work

The conventional wind turbine design procedure is revised and adapted in the following four aspects: i) The geometry of the blade is optimised for maximum energy capture under high wind speed conditions. The structural design follows a split-blade concept. ii) On-site manufactured towers, featuring composite material shells and concrete or other core material kernels are introduced. iii) The gearbox is specifically designed for high wind high turbulent conditions aiming at developing a highly reliable, low cost, low weight, low noise emission geared drive system. iv) The introduced compact design concept (split-blades, on-site tower construction, lightweight components) will facilitate machine transportation and erection under reduced infrastructure requirements. The wind turbine design is conducted according to the IEC 61400-1 standard using state-of-the-art tools, extensively validated in complex terrain applications. The performance of the prototype components will be evaluated through systematic testing.

Expected results and exploitation plans

The introduction of new materials and design options in the wind energy industry will impose favourable socio-economic impacts in Europe by enhancing industrial competitiveness, supporting employment, and promoting social cohesion by regional industrial development. MEGAWIND has been designed to overcome the bottlenecks that hinder the full exploitation of large capacity machines in complex terrain. In particular, the MW-size technology will be applied to complex terrain, a MW-size machine will be designed for high wind speed, the compact design concept will be introduced for easier and cheaper transportation, and the erection of large wind turbines and the construction of the prototype components will verify the design approach.

Achievements to date

The design of the rotor blade, the composite material tower, and the transmission system have been finalised, and extensive sub-component testing has been undertaken to verify the design at the early stages. Moreover, the prototype 30 m split-blade has been manufactured and its laboratory testing is under preparation. The full-scale composite material tower is under construction and its installation for full-scale testing is in preparation.

Contract: ENK5-CT-2000-00322

Acronym: RECOFF

Title:
RECommendations for design of OFFshore wind turbines

Project coordinator:
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Partners:
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- Germanischer Llyod Windenergie GmbH – GL WIND - DE
- Garrad Hassan and Partners Ltd. – GH - UK
- Energy Research Center of the Netherlands – ECN - NL

Project start date: 01-01-2001

Duration: 44 months

Project summary

Objectives and problems to be solved

The objective has been to prepare guidelines and recommendations for the design of offshore wind turbines. The main intended use of the project results has been the provision of recommendations for European and national standards for offshore wind turbines and the development of certification rules for such turbines. The success of the project will be marked by the delivery of reliable and robust design methods and certification rules needed for the safe development of offshore wind farms. This will have direct impact on the readiness to invest in offshore wind energy projects and reduce objections relating to project safety.

Description of work

Readily available information has been reviewed and used, as far as possible. In several areas, a need for research was identified and generic results were obtained. Specifically, we emphasise the following subjects where recommendations have been obtained

- **External conditions:** review of existing standards, regulations and literature resulting in recommendations for good practice;
- **Analysis methods:** methods for lumping, mainly with respect to wave loading, of fatigue load cases;
- **Analysis methods:** principle of synthesising load cases for different wind directions, wind speeds, and sea states in order to obtain extreme response during normal operation;
- **Design load cases:** drafting, partially based on project results, proposals for a suitable, i.e. limited and representative, DLC table for offshore turbines;
- **Probabilistic methods:** review of general methods and application of probabilistic calibration methods to the combined action of wind and wave loads in the storm event.
- **Structural integrity:** based on discussions about reliability levels onshore and offshore and on comparisons with current practice, proposals for safety factors in fatigue and extreme load events are given;
- **Operation and maintenance:** documents have been prepared on recommendations regarding labour safety and monitoring of turbine performance.

Expected results and exploitation plans

The RECOFF project has run in parallel with a working group (TC88-WG03) set up by the IEC (International Electrotechnical Commission), and was assigned the task of preparing a separate international standard for design of offshore wind turbines. Several of the RECOFF partners are members of the IEC-TC88-WG03, which has caused a strong interaction with current international standardisation work, and a rapid implementation of the findings of the RECOFF project in terms of obtaining the status of being standards' material. Once the IEC standard has been accepted it will soon become a European CENELEC one as well, thereby achieving the intended aim of the project.

Achievements to date

The project has been finalised – see above.

Contract: ENK5-CT-2002-30034

Acronym: EXPLOREWIND

Title:
Exploring new concepts for small and medium-sized wind mills with improved performance

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SMEs

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- GEA srl - IT
- Solaris - PL

RTD Performers

- SINTEF Energiforskning A/S - NO
- Labor - IT
- Canary Islands Institute of Technology - ES

Project start date: 01-01-2003

Duration: 24 months

Project summary

Objectives and problems to be solved

EXPLOREWIND is expected to investigate the efficiency, cost reduction, and environmental issues found in new wind turbine concepts for small non-grid-connected power systems.

Description of work

The work plan has been built around the following objectives:

- Development of a downwind turbine with basic new aerodynamic design for the purpose of achieving increased efficiency
- Improving performance by:
  - New design of top mast section to eliminate mast turbulence to the downwind turbine
  - Test set up with direct drive of ground-based pumps, generators, etc. connected to the turbine by bevel gear and mechanical mast transmission, exploring how gyro forces may affect the turbine through the bevel gear
  - Attention to developing a tidy package for transport and to simple mounting and rising solutions.
- Achieving manufacturing and installation costs of less than € 8 000 for a 5 kW wind mill, or 1 kW at a total cost of € 4 500, by means of:
  - Components modularity
  - Design and manufacturing for ease of transportation and installation.

Expected results and exploitation plans

EXPLOREWIND is expected to provide future life for downwind technology, creating a family of low-cost, easy-scaleable, stand-alone small wind generators. This family is expected to address directly the market segment of stand-alone applications, existing in Europe and mostly in the third world countries, where there are many areas in which the connection to a power grid is expensive or unreliable. The research proposed in this project will be ideal for use in small communities located in remote areas, in third world countries, and wherever it is necessary to produce energy close to where it is consumed, making it possible to implement easily new applications powered by the available ground-based mechanical drive (e.g. centrifugal pumps for the purpose of running desalination systems, etc.).

Achievements to date

The design phase has been completed, and full computational fluidodynamic investigation has been performed. A prototype is available and testing is expected to start in early October 2004. The prototype is prepared with three different sets and lengths of turbine blades. Tests will be made with different mixes of three and six blades.

The turbine diameter with long blades is 4 metres. With small blades, the diameter is 2.4 m and 2.2 m, respectively. The test set up with registration of flow and pressure from the pump will give a wide documentation of the turbine efficiency from low to high wind speeds.

BLADES AND ROTORS

Contract: ENK6-CT-2000-00320

Acronym: DAMPBLADE

Title:
Wind Turbine Rotor Blades for Enhanced Aeroelastic Stability and Fatigue Life Using Passively Damped Composites

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Partners:
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- Foundation for Research and Technology Hellas – FORTH - EL
- Geobiologiki SA – GEO - EL
- University of Patras – UP - EL
- Danmarks Tekniske Universitet – DTU - DK

Project start date: 01-01-2001

Duration: 48 months

Project summary

Objectives and problems to be solved

The development of damped composite wind-turbine blades and direct prediction of composite damping into future blade design practices are the main objectives of the project. Additional goals are the development of missing critical analytical technologies enabling explicit modelling of composite structural damping and a novel ‘composite blade design capacity’ enabling direct prediction of aeroelastic stability and fatigue-life; development and characterisation of damped composite materials; and evaluation of new technology via design and fabrication of damped prototype blades and full-scale laboratory and field testing.

Description of work

These objectives will be attained through many research and validation tasks. Unique composite damping mechanisms are being exploited: tailoring of laminate damping anisotropy, damping layers and damped polymer matrices. Novel composite damping models and damping finite elements, aeroelastic tools, and fatigue-life models are being developed. New higher-damping polymers have been engineered and extensive characterisation of new damped composite materials and laminates has been conducted to establish a complete database with elastic, damping, strength and fatigue-life data. A unified blade design capability is being established enabling direct improvements in aeroelastic performance. Two prototype-damped-blades are being designed, fabricated and tested. A rotor is being manufactured and will be field tested to demonstrate aeroelastic improvements. The project will provide unique aeroelastic and life prediction capabilities by providing missing composite damping models. Damped blades will contribute towards the development of large W/Ts by helping to overcome current ‘bottleneck’ problems relating to aeroelastic stability.

Expected results and exploitation plans

Significant results are: verified damping elements, the material databank, a verified stability tool, ‘blade design capacity’, damped blades, and measured laboratory and field data. The project will have significant impact on increasing the durability and operational life of current blades.

Achievements to date

With the exception of the rotor field testing, all tasks have been successfully completed. Lab. testing of a redesigned damped glass-polyester blade yielded more than 80 % damping capacity improvement, in both (first) flap and lead-lag modes, compared to the original blade.

Contract: ENK6-CT-2001-00503

Acronym: KNOW-BLADE

Title:
Wind Turbine Blade Aerodynamics and Aeroelasticity: Closing Knowledge Gaps

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- Totalförsvarets Forskningsinstitut – FOI - SE
- Danmarks Tekniske Universitet – DTU - DK
- National Technical University of Athens – NTUA - EL
- Vrije Universiteit Brussel – VUB - BE
- Foundation for Research and Technology Hellas – FORTH - EL
- LM Glasfiber A/S – LMG - DK

Project start date: 01-12-2001

Duration: 36 months

Project summary

Objectives and problems to be solved

The objective of the project is to fill in important knowledge gaps in the wind turbine community by applying Navier-Stokes (NS) solvers to a series of unsolved aerodynamic and aeroelastic problems. Focus is put in particular on the following four topics:
- Improving the power prediction capability of existing 3D Navier-Stokes solvers
- Introducing models for aerodynamic accessories, vortex generators, stall strips, etc., in existing Navier-Stokes solvers
- Aeroelastic modelling in two and three dimensions with Navier-Stokes aerodynamics
- Investigation of industrial flow details: tip shapes and loads during standstill.

Description of work

The task of improving the prediction capability of NS solvers has been concentrated on implementing laminar/turbulent transition in the codes, and investigating the potential of advanced Reynolds Averaged Navier-Stokes turbulence models and Detached Eddy Simulation (DES) techniques. The activities around aerodynamic accessories have been following two paths, one group has used 2D simulations to investigate phenomenological models, changed surface geometries, and special boundary conditions. Another group has investigated vortex generators in 3D either by directly resolving the vortex generators, using kinematic boundary conditions, or by introducing vorticity directly in the domain. The aeroelastic work has concentrated on developing a full 3D aeroelastic NS tool, and using 2D aeroelastic NS tools to investigate the damping properties of airfoils equipped with aerodynamic devices. Finally, work has been done on industrial details, investigating several different tip shapes and load cases for rotors during standstill for two different blade geometries.

Expected results and exploitation plans

As the project is nearly finished, several of the results have already been achieved, some of which are listed below; the main method of exploitation is through direct interaction with industry using the methodologies developed and through publication in journals.

Achievements to date

During the project, several laminar/turbulent transition models have been implemented indicating a potential for improving the power prediction capability. In addition, the first DES of a full wind turbine rotor has been performed in the project.

The work on aerodynamic devices has shown that the simple 2D models can give some insight into the qualitative behaviour of the devices both aerodynamically and with respect to their aeroelastic behaviour, but that they are not accurate enough to give quantitative values. A full 3D NS aeroelastic model has been implemented, and can be used for predicting aeroelastic stability of rotors. Finally, a series of different tip shapes has been studied aerodynamically during rotational conditions and loads for rotor blades during standstill have been computed providing high-quality data.

Contract: ENK6-CT-2000-00309

Acronym: MEXICO

Title:
Model Experiments in Controlled Conditions

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- Delft University of Technology – DUT - NL
- Israel Institute of Technology – TECHNION - IL
- Risø National Laboratory – RISOE - DK
- Danmarks Tekniske Universitet – DTU - DK
- Aeronautical Research Institute of Sweden – FFA - SE
- Centre for Renewable Energy Sources – CRES - EL
- National Technical University of Athens – NTUA - EL

Project start date: 01-01-2001

Duration: 60 months

Project summary

Objectives and problems to be solved

With the growing size and investment costs of wind turbines, there is an equally growing demand for more reliable design methods. This is specifically, but not exclusively, the case for offshore designs, where it is now estimated that rotor diameters of between 150 and 200 m may be reached. At present, uncertainties in design calculations are between 10-20 % in performance prediction and up to 30 % in dynamic loads. The main contribution to these uncertainties stems from the aerodynamic modelling.

The objective of the MEXICO project is to reduce these uncertainties significantly by providing an experimental database of detailed aerodynamic quantities, both of surface pressure distributions and external flow field data, from experiments in a large wind tunnel, hence under known conditions. This database will be used to improve present engineering models for aerodynamic load calculations (short term) and serve as a reference validation tool for the upcoming area of Navier-Stokes-based design calculations (longer term).

Description of work

The project is divided into four phases:
1. Design of a wind turbine model and measurement system;
2. Construction and instrumentation of the model;
3. Performance of measurements in the DNW LLF and data processing/interpretation;
4. Possible adaptation of BEM models based on improved insight and knowledge.

Expected results and exploitation plans

Pressure distributions on the rotor blades will be measured with a total of 140 high-frequency response electronic pressure sensors, distributed over five blade sections. Mechanical blade loads are measured through strain gauges, and the total turbine loads are recorded through a six-component balance in the supporting structure. The flow field will be measured with PIV (Particle Image Velocimetry) techniques which will give both flow visualisation and quantitative vectorial flow speed information. The test matrix for the tunnel entry has been completed. Dynamic effects will be obtained by operation in yaw and with pitching actions.

The results of the measurements will be organised in a database which will eventually become available to the wind energy community. The project partners will use the results during the last year (2005) for possible adaptation of their engineering design codes based on BEM (Blade Element Momentum) methods.

Achievements to date

At present, the first phase has been finished and the second phase has almost come to an end, while the tunnel test (phase 3) is scheduled for January 2005. The rotor is a three-bladed 4.5 m diameter configuration designed to run a maximum tip speed of 100 m/s to obtain a sufficiently high Reynolds number. The blades can be pitched at sufficient speed for dynamic inflow effects to occur. The electrical system consists of a variable speed electrical generator, allowing for fast start-up and controlled operation at different tip speeds. The experiments will be performed in the 9.5*9.5 m^2 open test section of the DNW LLF.

A very significant effort has gone into understanding and finding corrections for the tunnel environment, as compared to free stream conditions. A dedicated pilot tunnel test has been performed for this, together with sophisticated Navier-Stokes simulations and quasi 1D models, to obtain practical correction methods.

Contract: ENK6-CT-2001-00552

Acronym: OPTIMAT BLADES

Title:
Reliable Optimal Use of Materials for Wind Turbine Rotor Blades

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- Knowledge Centre Wind turbine Materials and Constructions – WMC - NL (Technical Coordinator)
- Deutsches Zentrum für Luft- und Raumfahrt e.V. – DLR - DE
- Deutsches Windenergie-Institut GmbH – DEWI - DE
- Council for the Central Laboratory of Research Councils – CLRC - UK
- Risø National Laboratory – RISOE - DK
- Centre for Renewable Energy Sources – CRES - EL
- Vrije Universiteit Brussel – VUB - BE
- University of Patras – UPAT - EL
- Technical Research Centre of Finland – VTT - FI
- Germanischer Lloyd WindEnergie GmbH – GL WIND - DE
- Det Norske Veritas Danmark A/S – DNVD - DK
- LM Glasfiber A/S – LMG - DK
- Polymarin Beheer BV – POLYMARIN - NL
- Nordex Energy GmbH – NORDEX - DE
- Gamesa Eólica SA – GAMESA - ES
- GE Wind Energy GmbH - DE
- Vestas Wind Systems A/S – VESTAS - DK

Project start date: 01-01-2002

Duration: 52 months

Project summary

Objectives and problems to be solved

The project aims to provide accurate design recommendations for the optimised use of materials within the next generation of wind turbine rotor blades and to achieve improved reliability. This considers the design of new blades, but also the prediction of the residual strength and life. To achieve this overall objective, the project will investigate the structural behaviour of the composite material under the unique combination of conditions experienced by rotor blades, such as variable amplitude loading, complex 3-D stress states, extreme environmental conditions, thick laminates and their possible interactions. For life extension, condition assessment and repair techniques will be developed.

Description of work

The fundamental research is being carried out in five task groups investigating the effects of variable amplitude loading, complex stress states, extreme environmental conditions, thick laminates and repair, and residual strength and condition assessment. The task group leaders, together with the certification bodies, will form task group 6 which has the job of implementing the results into design recommendations. The work is divided into two main phases. During the first phase, the work will concentrate on one reference material. During the second phase, new materials expected to be used for future blades and the interactions of the phenomena investigated during the first phase will be addressed.

Expected results and exploitation plans

The main result of the project will be accurate and reliable design recommendations, allowing for the design of reliable blades with optimised use of materials. Together with the application of condition assessment and repair, this will result in:
- Reliable blades
- Reduced use of material
- Life extension of blades
- Less waste of material
- Larger availability of wind turbines
- Larger turbines possible

All these aspects can contribute to the reduction of costs for wind energy. The increased reliability and weight reduction of the blades will stimulate further the offshore exploitation with large capacity wind turbines.

Achievements to date

- Establishment of a general geometry usable for both uni-direction and multi-direction fibre reinforced materials, for tests on static tension, static compression, fatigue (all stress ratios), and residual strength
- Establishment of fatigue testing procedures including load levels and frequencies for the reference material and some procedures for establishing testing for other materials
- Development of tubular and cruciform geometries for bi-axial tests
- A material database with about 1 500 tests from the project has been generated
- A number of publications have been written.

Contract: ENK5-CT-2002-00702

Acronym: SIROCCO

Title:
Silent Rotors by Acoustic Optimisation

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- National Aerospace Laboratory – NLR - NL
- Gamesa Eólica SA - ES
- GE Wind Energy GmbH - DE

Project start date: 01-01-2003

Duration: 36 months

Project summary

Objectives and problems to be solved

Wind turbine noise is still one of the major hindrances in the widespread use of wind energy in Europe. For modern large turbines, aerodynamic (in particular trailing-edge) noise is considered to be the dominant noise source. In a number of European and national projects during the last decade, the understanding of aerodynamic noise from wind turbines has increased significantly, and new noise-reduction concepts have been developed.

The principal objective of the SIROCCO project is to obtain significant noise reduction on full-scale modern wind turbines, without a reduction in power performance, by improving the aerodynamic flow at the trailing edge of the wind turbine blade airfoils. Such noise reduction has a large potential regarding increased public acceptance and the consequent growing implementation of wind energy in Europe.

Description of work

- A combined acoustic/aerodynamic design methodology will be developed to design low-noise airfoils. The method is validated by means of wind tunnel experiments
- The low-noise airfoils are being used on two wind turbines and the aerodynamic and acoustic performance is being validated. This validation is done with a new measurement technique that provides the location and quantification of acoustic noise sources on wind turbine blades.

Expected results and exploitation plans

The final result from SIROCCO will be the delivery of two sets of validated low-noise rotor blades for the baseline turbines, with comparable performance. With that a validated integrated design methodology will become available which enables manufacturers to design silent but efficient rotor blades. These results are being accomplished through a number of intermediate results, such as a validated design methodology for low-noise airfoils, and a proven acoustic measurement technique for location and quantification of rotating noise sources.

The research institutes within SIROCCO will exploit the low-noise airfoil design methodology and acoustic measurement techniques in their consulting activities for wind turbine and other industries, such as aeronautics. Finally, the understanding of fundamental noise mechanisms will be further improved.

Achievements to date

In summary, the following achievements can be reported (September 2004):

- Boundary layer measurements on airfoils are made in the wind tunnel. The results are being used in the development of the design methodology
- The combined acoustic/aerodynamic design methodology has been developed and utilised to design a first round of acoustically optimised airfoils. These designs have been tested in the wind tunnel. A second round of airfoils has been designed using insights from the first round. These airfoils will be measured in October 2004
- Acoustic measurements on one of the chosen turbines have been carried out successfully.

Contract:	**ENK5-CT-2002-00627**
Acronym:	**STABCON**

Title:
Aeroelastic Stability and Control of Large Wind Turbines

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- National Technical University of Athens – NTUA - EL
- Danmarks Tekniske Universitet – DTU - DK
- Universität Stuttgart– USTUTT - DE
- Delft University – DELFT - NL
- NEG Micon A/S – NEGM - DK

Project start date:	01-11-2002
Duration:	48 months

Project summary

Objectives and problems to be solved

The main objective of the STABCON project is to form a European Research Network on the aeroelastic stability of wind turbines with active control. This is a fundamental issue in the development of large megawatt-size wind turbines. The project consortium develops reliable design tools for analysis and optimisation of large wind turbines with respect to aeroelastic stability and active control.

Description of work

Part 1 concerns the aeroelastic stability of wind turbines that have active power regulation but no active aeroelastic control. All types of aeroelastic wind turbine instabilities are being considered including stall-induced vibrations and classical flutter. New stability tools are being developed and used to predict the stability limits for an existing 2.75 MW turbine. The project utilises 3D CFD to assist the modelling and understanding of instability mechanisms. The predicted damping characteristics of the test turbine are measured in the field using newly developed experimental methods.

Part 2 concerns the active aeroelastic control of wind turbines. A morphological study of possible wind turbine control systems is being performed. Collective and individual blade pitch and other concepts to control power and loads are considered, including a controller for active damping of vibrations. Aeroelastic codes and stability tools are being refined to include these new control systems, and optimisations performed for each of the three objectives (independently and by conditional weighting): instability suppression, turbulence and gust alleviation, and power enhancement.

Expected results and exploitation plans

Derived guidelines describe how to:
- Identify important parameters for aeroelastic stability, and optimise them for increased damping to passively suppress instabilities and reduce loads
- Identify the potentials of active aeroelastic control to reduce loads by suppressing instabilities and alleviating gusts, and to enhance power production
- Perform integrated design studies of active-stall and pitch-regulated turbines to allow control of lifetime consumption and adaptation to specific conditions.

Achievements to date

Currently in progress is the development of several tools for the prediction of aeroelastic stability limits for wind turbines. These tools are based on different aeroelastic modelling approaches and different linearisation techniques. Three tools have been completed and another three tools are well under way. An experimental investigation has been performed on a 2.75 MW turbine. The pitch control system of the turbine was used to excite turbine vibration modes and the aeroelastic damping was estimated. The experimental results are currently being used to validate the stability tools.

Contract: ERK6-CT-1999-00008

Acronym: COMHUB

Title:
Innovative composite hub for wind turbines

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- NOI-Rotortechnik GmbH – NOI - DE
- Technisher Überwachungsverein Nord E.V. – TÜV - DE

Project start date: 01-04-2000

Duration: 36 months

Project summary

The objective of the COMHUB project was the development of a glass fibre-epoxy composite hub. Traditional cast-iron hubs are expected to be a bottleneck in the development of the emerging industry of large wind turbine generators as they are heavy and because of limitations in volume of production and size. Due to its low specific weight and easy manufacture, a composite hub is expected to overcome this problem and enhance the production of large wind turbines (larger than 2 MW). In particular, the lightweight, enhanced swept area and corrosion resistance of a composite hub will facilitate wind energy exploitation in offshore sites.

In this project, a pitch-controlled 800 kW wind turbine was chosen for the design (according to wind class IEC II a) and subsequent installation of the composite hub prototype.

The structural design of such a composite part has involved different steps. The constraints for the composite hub design from both the wind turbine and rotor blades side have been thoroughly identified. An iterative process to define an optimum conceptual design has been followed. Attention has been paid to the standardisation of hub flanges in order to ensure their adaptability to standard blades. Specific geometries for hub-blade and hub-rotor joints have been developed. The structural design has been developed by means of the finite element methods in which several user sub-routines have been implemented for fatigue calculation, delamination analysis, etc. A major issue has been the modelling and data analysis of thick shell composite materials and the fatigue and fracture analysis. An original methodology for the lifetime estimation of thick composites under complex load states has been developed and implemented in FEM codes. The design has obeyed the compromise between low weight, high structural stiffness and the maximisation of material property usage. In parallel with the numerical modelling tasks, an experimental investigation of the static and fatigue properties of the lay-outs to be used has been performed.

The composite hub was designed with a 4 m diameter. Pitch flanges to the blades were 1.400 mm in diameter. The interface to the main shaft was designed following the criteria of exchangeability of the composite hub to a traditional cast-iron hub.

The production of the first composite hub has been successfully finished within the present project. The resin injection mould technology that had been chosen for the prototype production can also be considered adequate for large-series productions. Thus, the production of the first composite hub for wind turbine is an innovative step for the further development of lightweight rotor systems.

The potential user is widespread. On the one hand, turbine manufacturers are looking for a technical and economical solution for the weight reduction of the rotor for new turbine designs. On the other hand, wind farm operators are looking for an option in order to increase energy capture with a larger swept area using a composite hub by substituting a cast-iron hub. But mainly, a composite hub may represent a diversification of business activities for blade manufacturers with high-level know-how in composite parts production.

BLADES AND ROTORS

WIND RESOURCES FORECASTING AND MAPPING

Contract: ENK5-CT-2002-00665

Acronym: ANEMOS

Title:
Development of a Next Generation Wind Resource Forecasting System for the Large-Scale Integration of Onshore and Offshore Wind Farms

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- ARIA Technologies – SA ARIA - FR
- Universidad Carlos III de Madrid – UC3M - ES
- Centro de Investigaciones Energeticas, Medioambientales y Technologias – CIEMAT - ES
- Technical University of Denmark – DTU - DK
- Meteo France – METEO-FRANCE - FR
- Overspeed GmbH and Co. KG – OVERSPEED - DE
- Council of the Central Laboratory of the Research Councils – CCLRC - UK
- Risø National Laboratory – RISOE - DK
- Institute of Accelerating Systems and Applications – IASA - EL
- University of Oldenburg – Univ-Oldenburg - DE
- Electricité de France – EDF - FR
- Corporación Energía Hidroeléctrica de Navarra SA – EHN - ES
- Elsam A-S – ELSAM - DK
- National Grid, Electricity Supply Board – ESB - IRL
- EWE Aktiengesellschaft-Abteilung HV-BE – EWE - DE
- Public Power Corporation SA – PPC - EL
- Red Eléctrica de España – REE - ES
- Instituto para la Diversificación y Ahorro de la Energía – IDAE - ES
- National Technical University of Athens – NTUA - EL
- Ecole Nationale Supérieure des Mines de Paris-Centre d'Energétique – ENSMP - FR
- Centro Nacional de Energías Renovables – CENER - ES

Project start date: 01-10-2002
Duration: 48 months

Project summary

Objectives and problems to be solved

Accurate forecasting of wind power production up to two days in advance is recognised as a major contribution towards reliable large-scale wind power integration. Prediction tools enhance the position of wind energy compared to other forms of dispatchable generation, especially in a liberalised electricity market. The ANEMOS project aims to develop advanced forecasting models that will significantly outperform current methods. Emphasis is being given to challenging situations such as complex terrain, extreme weather conditions, as well as to offshore prediction for which no specific tools currently exist.

Description of work

In the initial stage, the prediction requirements are defined in collaboration with end-users (utilities, transmission system operators, etc.). The project aims to develop advanced prediction models based on both physical and statistical approaches. Research on physical models is putting emphasis on techniques for use in complex terrain and the development of prediction tools based on CFD techniques, model output statistics, or high-resolution meteorological information. Statistical models (for example, those based on artificial intelligence) are being developed for downscaling, power curve representation, and upscaling for prediction at regional or national level. Methods to estimate on-line the uncertainty of wind forecasts are being developed. The performance of purely meteorological forecasts, but also long-term wind predictability up to seven days ahead, are being evaluated in detail. Appropriate physical and statistical prediction models are also being developed for offshore wind farms, taking into account advances in marine meteorology such as interaction between wind and waves and coastal effects. Finally, a next generation forecasting software, ANEMOS, is being developed to integrate the various models.

Expected results and exploitation plans

The project is developing a prediction platform that will integrate the advanced models developed by the partners. The ANEMOS software is enhanced by advanced Information & Communication Technology functionality and can operate both in stand-alone or remote mode, or be interfaced with standard energy management systems. The software will be installed for on-line operation at onshore and offshore wind farms by the end-users participating in the project, and the benefits from wind prediction will be evaluated at national, regional or at single wind farm level. The ANEMOS consortium is committed to the exploitation of the developed software and models.

Achievements to date

Advanced prediction models have been developed as well as models for on-line uncertainty assessment. A benchmarking process was set up which enabled detailed evaluation of the performance of the developed models and a comparison to be made between them and existing models, using a number of representative case studies. The main modules of the ANEMOS prediction software have been developed and their integration into the common platform is ongoing. For more information see: **http://anemos.cma.fr**

Contract: ENK5-CT-2002-00606

Acronym: HONEYMOON

Title:
High Resolution Numerical Wind Energy Model for On and Offshore Forecasting Using Ensemble Predictions

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- Danish Meteorological Institute – DMI - DK
- Meteorological National Institute – INM - ES
- E.ON UK - Power Technology – EPT - UK
- Espace Eolien Développement – EED - FR
- Réseau de Transport d'Electricité – RTE - FR
- E.ON UK Renewables – EDL - UK
- EWE AG – EWE - DE
- Eltra a.m.b.a. - DK

Project start date: 01-01-2003

Duration: 24 months

Project summary

Objectives and problems to be solved

The experience with most real-time wind power prediction systems is that the ultra-short-term predictions (< 6h) for larger groups of wind farms are often of good quality. Serious forecast errors frequently occur mainly for prediction horizons greater than the ultra short range. These experiences suggest that the major source of the wind power prediction errors can be found in the prediction of basic weather parameters that are used to calculate the wind power, rather than the calculation of the wind power itself. The project is designed to identify these errors and, if possible, reduce them.

Description of work

The work is split into four work packages:

WP1 contains the central Honeymoon prediction system, which is linked to meteorological centres, where the required input data are retrieved. WP2 contains the NWP ensemble prediction system and utilities that are required to use the ensemble forecasts. For wind power predictions, the utilities convert the ensemble predictions into a probability distribution function for a particular location or area. WP3 contains the power curve analysis tool and an improved wind power parameterisation. In WP4, the Honeymoon model system is validated with end-user data.

Expected results and exploitation plans

The combination of real-time data and an on-line historical forecast archive for efficient generation of power curves will allow new end-users fast and easy access to high-quality forecasts. The end-user will not need to deal with many subtasks, such as the wind to power conversion utility, its maintenance, the required input data from a meteorological centre, etc. The Honeymoon system is a self-contained system which, in addition, provides an uncertainty estimate of the forecasts to the end-user.

Achievements to date

The first 18 months of the project have been used to develop and set up the Honeymoon system and test it in off-line mode. The off-line simulations have been running since the second half of 2003. They have been used for monitoring the Honeymoon system and to create a forecast archive for the generation of power curves.

The work on the model system has been spread over three areas. The surface stress parameterisation and the air/sea interaction in the model system have been improved and an uncertainty estimate of the wind power predictions developed.

The consortium has agreed upon and designed the model system such that the central Honeymoon system will deliver forecasts of wind power in real time, and wind power relevant atmospheric variables such as wind speed and direction in different heights in off-line mode. The demonstration phase will start in autumn 2004.

Contract: ERK6-CT-1999-00017

Acronym: WEMSAR

Title:
Wind Energy Mapping Using Synthetic Aperture Radar

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- Risø National Laboratory – RISOE - DK
- NEG Micon Project Development A/S - DK
- Terra Orbit AS - UK

Project start date: 01-03-2000

Duration: 36 months

Project summary

Objective

The overall objective was to develop, validate, and demonstrate the potential of satellite-based Synthetic Aperture Radar (SAR), scatterometer and altimeter to map wind energy in offshore and near-coastal regions for potential wind turbine siting.

Background

An important aspect of wind turbine siting includes the potential for offshore wind turbine parks. Several parks have already been constructed, and many more are in the planning phase. Many countries lack suitable land-based wind turbine sites, and moving the wind turbines offshore is therefore more appropriate. Just as important is the fact that wind speeds are often higher offshore than onshore – differences of 20 % within a small area on/offshore are not uncommon. An important aspect in mapping coastal wind-energy areas from satellites is the advantage of combining the continuous spatial coverage with equally spatial continuous data sets of ocean bathymetry, i.e. ocean depth. Obviously, offshore wind installations will need to be located in relatively shallow areas to keep the construction costs as low as possible.

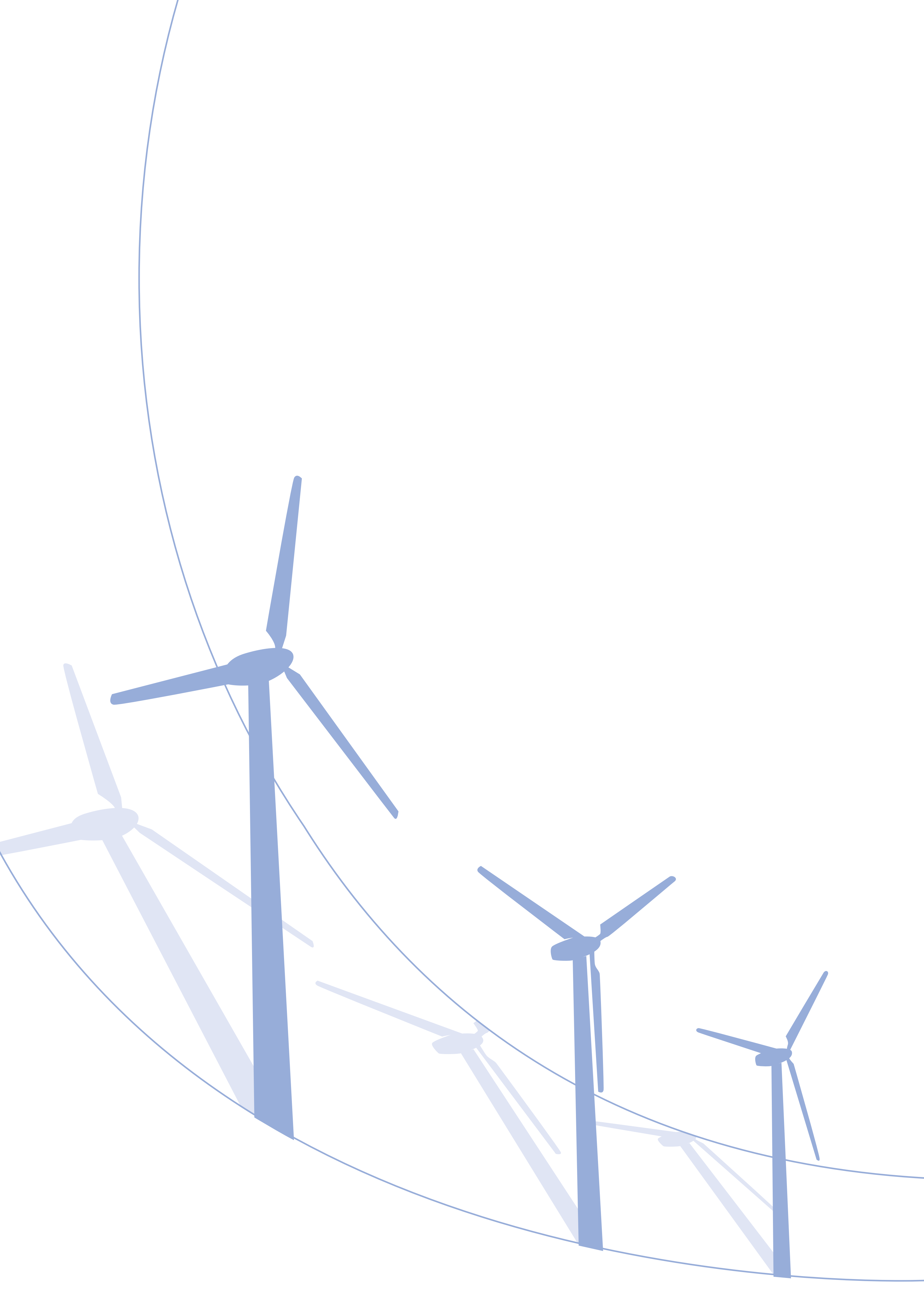
Description of work

The project comprises the following work packages:
- Implementation of existing algorithms for wind data retrieval from satellite radars, based on a literature search
- Satellite data from SAR, altimeter and scatterometer will be collected, processed and analysed, and wind information obtained. Validation of SAR wind-energy retrieval
- The micro-siting model will be tuned for optimal integration in the WEMSAR tool
- Development of an integrated WEMSAR tool for optimum data synergy for maximum site selection efficiency
- WEMSAR validation
- Production of a marketing plan, including a cost/benefit assessment for identifying potential customers and where they operate, and the time frame of their projects. This task includes planning and initiation of product exploitation.

Achievements to date

The main result from the project is a prototype satellite SAR wind retrieval and statistical analysis tool called the WEMSAR tool. The tool is an add-on tool to the widely used Wind Analysis and Application Programme (WAsP) for wind turbine siting. Following a literature review, it was decided to use the commonly accepted and validated C-band algorithms. SAR images from test sites in Norway, Denmark and Italy was analysed to derive wind speed using, whenever possible, SAR-retrieved wind direction, and new model simulations of the wind fields in the test sites was carried out. Based on the work on comparison of the model, satellite and in situ observations, the WEMSAR tool was defined and developed.

The methods developed in the WEMSAR project could prove valuable for mapping coastal wind energy potential on a global scale. A cost-efficient method for mapping this valuable renewable energy source has the potential to be adopted by international organisations, foreign governments as well as private companies.



WIND FARMS

Contract: ERK6-CT-1999-00006

Acronym: CLEVERFARM

Title:
Advanced Management and Surveillance of Wind Farms

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- Carl-von-Ossietzky University Oldenburg - DE
- Projektierungsgesellschaft für regenerative Energiesysteme mbH – Projekt - DE
- Danish Meteorological Institute – DMI - DK

Project start date: 01-04-2000

Duration: 45 months

Project summary

Objectives and problems to be solved

The idea behind the CleverFarm project was to take the many advanced techniques developed for optimising and enhancing the performance of wind farms, integrate them into one system and implement the system at a number of wind farms. The techniques include remote measuring of the status and production of the wind farm, short-term prediction of the expected power output from the wind farm, models for wake calculations, remote control of wind farm production, and so on. By combining these techniques, the wind farm would seem intelligent to an outside viewer. For example, the wind farm can send immediate warnings to the maintenance crew if something goes wrong. It will also send e-mails to the electrical utility (and power brokers) containing its expected production over the next two days, it will suggest optimal periods for preventive maintenance, it will give the wind farm operator real-time images from the wind farm, etc.

The group participating in this project is a unique combination of industry (condition-monitoring system manufacturers and electric utilities), wind-farm operators, consultancy, and research, making it possible for the first time to carry out such work successfully. The group comprises expertise in implementation of power-prediction systems, remotely controlled condition monitoring and fault-prediction systems, wind-turbine control, maintenance, and wind-farm operation.

Description of work

After a phase of identifying and making an inventory of the different approaches and needs, a Danish wind farm was chosen to host the first installation of the system. Two turbines were instrumented with two different drive train vibration monitoring systems, one with an additional camera, and a common wind farm PC hosting the central CleverFarm® system (database and jsp server). The system developed was built on a Linux server in the wind farm, running the CleverFarm system written in Java. The CleverFarm system is modular, through the use of CleverBeans which encapsulate the actual working code. After some initial tests and development, another turbine in Germany was instrumented. The results of first-year experiences have been detailed in the final report.

Expected results and exploitation plans

A general system was developed which can be used to enhance a SCADA system with knowledge of the current status of the wind farm and its components. Since the system is not quite real time, it is not considered able to replace the wind turbines own controller, but rather to support it as a kind of SuperSCADA. With the current state of the system, and the resources each partner can contribute towards its further development, it seems bound to remain a research platform. As such, it is already being used in two further EU-funded research projects (ConMow and OffShoreM&R). To prevent the group's efforts from going to waste, it was decided to make the code accessible as open source (except for the individual CleverBeans). Some partners also use it inhouse.

Contract:	**ERK6-CT-1999-00001**
Acronym:	**ENDOW**

Title:
Efficient Development of Offshore Wind Farms

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- Energi E2 A/S - DK
- Elsamprojekt A/S - DK
- NEG Micon Project Development A/S - DK
- Energy Research Center of the Netherlands – ECN - NL

Project start date:	**01-03-2000**
Duration:	**36 months**

Project summary

Objectives and problems to be solved

Europe has large offshore wind energy potential that is poised for exploitation to make a significant contribution to the objective of providing a clean, renewable and secure energy supply. Using experience gained through the demonstration projects currently operating offshore, this project aims to reduce uncertainties in estimating power production resulting from wake effects in large offshore wind farms, particularly those operating in areas affected by coastal discontinuity where the atmosphere is not at equilibrium with the surface. The major objectives are to evaluate wake models in offshore environments and to develop and enhance existing wake and boundary-layer models accounting for complex stability variations, in order to produce a design tool to assist planners and developers in optimising offshore wind farms.

Description of work

The proposed work is divided into five areas:

1. Evaluation of current wake models and production of standardised databases of observations from offshore wind farms to be used in their initialisation. These case studies were used as the basis for evaluation of six different wake models varying in complexity from engineering solutions to complex computational fluid dynamics codes
2. Development and enhancement of wake and boundary layer models for use in offshore areas, and construction of a model interface to link these models. The performance of the models under different atmospheric conditions was utilised to develop consistent model evaluation specifications and define criteria for model improvement
3. The performance of the coupled models was evaluated based on simulations for existing databases and also results from an offshore wind farm experiment designed to offer direct measurements of the wake influence on downstream profiles of meteorological parameters and power output. During this experiment, SODAR measurements provided additional vertical resolution
4. Based on the experience gained, a design tool was developed for use in offshore wind farm planning. This is based on enhancements to existing commercial software currently used by the wind energy industry, and is modular
5. Demonstration of the design tool in different offshore environments. The demonstration projects represent offshore areas of Europe, and include different wind speed and stability regimes and different water depths.

Expected results and exploitation plans

The project focuses on maximising industry input to enhance existing wind farm design tools. The design tool allows wake impacts on power output from large offshore wind farms to be minimised. A module for minimising grid connections was also incorporated to provide selection criteria for optimal wind farm design. These tools were rigorously evaluated for both scientific/technological and computing performance prior to their demonstration in the design of three planned offshore wind farms. Significant improvements in the state of art of wake and marine boundary-layer models and a thorough evaluation of wake models were achieved. The design tool will ensure that both turbine and wind farm developers have the capability to more accurately design and predict power output from large offshore wind farms.

Contract: ENK5-CT-2002-00659

Acronym: CONMOW

Title:
Condition Monitoring for Offshore Wind Farms

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Partners:
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- Risø National Laboratory – RISOE - DK
- Garrad Hassan and Partners Ltd. – GH - UK
- Pall Corporation - ES
- GramandJuhl APS - DK
- Prueftechnik CM GmbH - DE

Project start date: 01-11-2002

Duration: 48 months

Project summary

Objectives and problems to be solved

This project aims at developing techniques for diagnostics and condition monitoring of wind turbines (and farms) at remote areas, and selecting and demonstrating a suitable set of techniques. The objectives are fourfold:

1. Development of new algorithms for data processing through a case study of a turbine with variable speed and pitch control
2. Improvement of currently available condition-monitoring techniques and SCADA systems to the specific wind turbine needs, to ensure they will meet the newly developed wind turbine communication standards as being developed, for instance, in IEC TC88 WG 25
3. Investigating and demonstrating the benefits of condition-monitoring techniques and generic SCADA systems in a wind farm, and assessing the added value in the operation of large wind farms at remote (offshore) locations
4. Implementing the selected procedures and techniques for condition monitoring into the O&M plan for the offshore wind farm, with the aim of changing from preventive and corrective maintenance to condition-based maintenance.

Description of work

The project is separated into two main phases:
In the first phase, one single turbine will be instrumented extensively, not only with condition- monitoring systems but also with 'traditional' measurement systems like load measurements in the blade root, torque of main shaft, pitch system parameters, rotor speed, etc. An extensive measurement campaign on this turbine under normal and faulted conditions will be carried out. Interrelationships will be determined between various turbine parameters and condition- monitoring results. The condition-monitoring techniques will be assessed on their added value for wind farm operation. If desired, the most suitable techniques will be improved.

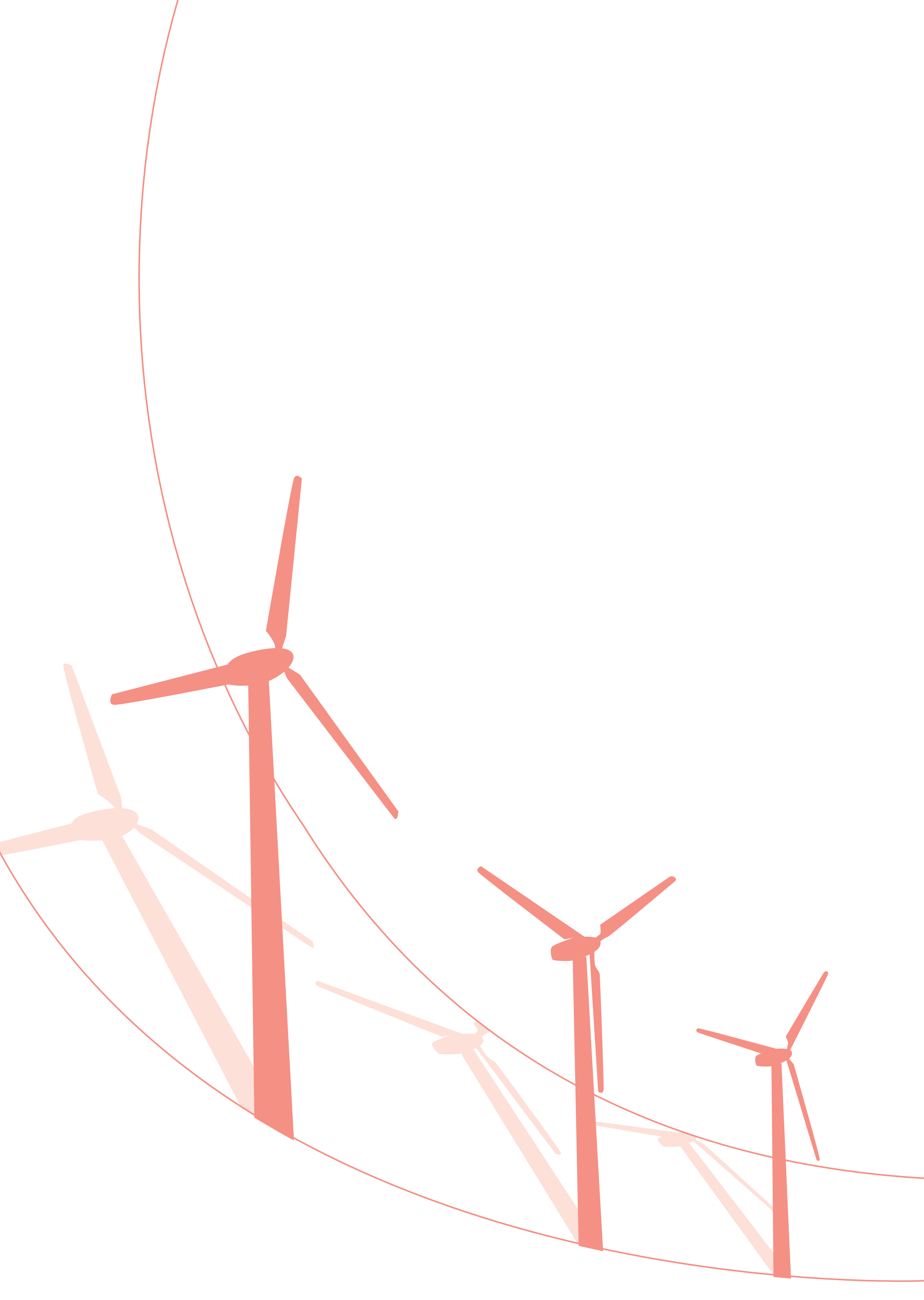
In the second phase, the selected and improved methods will be applied on a larger scale (four to six turbines) in a wind farm. The systems will be tested over a longer period of time. A generic SCADA system will be used to collect and store the data and to make it accessible to various users. In this testing phase, both the condition-monitoring techniques and the SCADA system will be improved continuously. Experiments will be done with automated surveillance.

Expected results and exploitation plans

The main result expected from this project is a set of condition-monitoring techniques with recommended practices for use in offshore wind farms, the added value of which is demonstrated for a group of wind turbines with variable speed and pitch control. Furthermore, new algorithms and adjusted hardware and software for early failure detection and an improved generic SCADA system, implemented at a wind farm, will become available.

Achievements to date

The single turbine has been instrumented and the traditional measurements have been ongoing since mid 2002. The configuration of the vibration-monitoring systems and the installation of oil-monitoring systems are nearly complete. Furthermore, the data processing has started.



INTEGRATION OF WIND POWER

Contract: ENK6-CT-2001-20401

Acronym: WIND ENERGY NETWORK

Title:
Wind Energy Network

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Partners:
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- Pauwels - BE (representing component manufacturers)
- Investitionsbank Schleswig Holstein - DE (representing financiers and insurers)
- Energy Research Centre of the Netherlands – ECN - NL (representing R&D, Testing and certification Centres)
- Risø National Laboratory – RISOE - DK (representing R&D, Testing and certification Centres)
- Bundesverbands WindEnergie – BWE - DE (representing end-users: turbine Owners)
- Renewable Energy Systems Ltd. – RES - UK (representing end-users: developers)
- Elsam A/S - DK (representing utilities and end-users other than developers and owners)

Project start date: 01-12-2001

Duration: 42 months

Project summary

Description of work and objectives

The Wind Energy Thematic Network's overall aim is to ensure that EU-funded wind energy R&D meets the needs of the European wind industry – to maintain and increase its competitiveness in EU and external markets; and to develop to meet European Commission and national targets for renewable energy use and greenhouse gas reductions from energy generation, amongst other Union policy objectives.

Up until now, the wind industry has not had a coherent R&D strategy. With a view to further R&D under the FP7 technology platforms, such a strategy is becoming increasingly important. This Network provides the opportunity for the wind energy sector to contribute fully to the European Research Area: through better coordination of EC-funded and Member State R&D; the promotion of a common industry view on R&D needs; coordination of industry inputs to R&D and policy discussions; and by providing the European Commission with rapid access to this information.

Activities are organised around key themes for the industry. Examples include socio-economic, policy and market issues, environmental impact, design issues, standardisation and certification, integration into Energy Systems, O&M issues, unconventional sites, offshore developments, and multi-MW turbines.

Network objectives include:
- Establishing industry discussion groups to promote information exchange and networking within the industry, including networking between different sectors in the industry
- Promoting discussion on indicators to track wind technology development to feed into policy
- Evaluating R&D requirements to maintain EU leadership of the wind energy sector
- Undertaking a structured, regularly reviewed programme of strategy development, responding to new external influences, resulting in a final strategy for future EU R&D, divided between public and private sectors
- Establishing and reviewing existing support to wind energy R&D in EU Member States.

Achievements to date

An active network of over 300 participants has been established, 200 of which are registered users of the project website.

To date, five strategy workshops have been held, yielding detailed R&D requirements, which have been woven into the strategy. The sixth (and final) workshop will be held in Brussels in the spring of 2005 before the strategy is finalised.

Alongside these strategy workshops, five updates of the strategy have been developed, and five updates of national support for wind energy R&D. January 2004 saw the successful public launch of the strategy.

Contract: ENK5-CT-1999-00016

Acronym: FIRMWIND

Title:
Towards High Penetration and Firm Power from Wind Energy

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- Sintef Energiforskning A/S – SINTEF - NO
- Econnect Ltd - UK
- Proven Engineering Products Ltd - UK
- Bremen Institute of Production Technology and Applied Work Science - DE

Project start date: 01-05-2000
Duration: 36 months

Project summary

Objectives and problems to be solved

Due to variability, wind energy within an electrical distribution system has a limited capacity credit. This limits exploitation, particularly in remote weak grids, in island grids and in rural electrification schemes. FIRMWIND has investigated innovative measures to increase wind energy's realisable capacity credit.

Description of work

The project has looked at holistic, energy management control of the distribution system, including generation plant, consumer loads, storage devices and the import/export feed link. The project has selected and analysed real situations in Europe, one in Iceland and one in Scotland. The analysis has been based on load-flow analysis methods used by utilities but has extended the concept of dispatching to all elements of the network. There has been major concentration on modelling storage and on developing storage-dispatching philosophies which are the key to conferring improved capacity credit. The analyses have been at a techno-economic and logistic level but have fully recognised real network topology and limits. The feasibility of the solutions has been reviewed in the context of deregulated market mechanisms.

Expected results and exploitation plans

The project has demonstrated that wind energy capacity credit at the local distribution level is zero, at least at locations where wind is driven by weather systems. Wind, therefore, will not decrease capital requirements for infrastructure and conventional generation. It has been shown that the key to reducing such requirements is not to increase the capacity credit of wind directly, but to diminish the capacity required of the grid feed. This means managing the net loads on the system (net of wind) using storage wisely. The most important aspect is to reduce the capacity-determining peak net loads, and this means ensuring that there is sufficient storage capacity to cope with such events. Identifying the optimum interrelationship between storage (capacity, charge rate and discharge rate) and wind capacity is fundamental to the success of the approach. Successful implementation depends on good operational, logistic-level decisions but also on co-ordinated system-level investment planning. The deregulated markets are not always helpful in this process.

Achievements to date

The major achievements of the project have been the substantial and successful development of a simple load flow generation optimisation package into a complex time domain dispatching software package capable of handling storage and loads. In addition, 'cost-function' based control philosophies that are effective in raising capacity credit have been developed and demonstrated. Supplementary achievements have been the development of a wind speed synthesis routine that is realistic in both time and space, and the clear demonstration that there is an economic justification for implementing the case study schemes.

Contract: ERK5-CT-1999-00019

Acronym: MORE CARE

Title:
More Aadvanced Control Advice for Secure Operation of Isolated Power Systems with Increased Renewable Energy Penetration and Storage

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Partners:

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- Association pour la Recherche et le Développement des Méthodes et Processus Industriels – ARMINES - FR
- Public Power Corporation SA – PPC - EL
- Empresa de Electricidade da Madeira - PO
- Instituto de Engenharia de Sistemas e Computadores do Porto – INESC PORTO - PO
- Aristotle University of Thessaloniki - EL
- Council of the Central Laboratory of the Research Councils – CCLRC - UK

Project start date: 01-03-2000

Duration: 36 months

Project summary

Objectives and problems to be solved

Isolated and weakly interconnected power systems are presently affecting and limiting the economic development of more than 12 million European citizens, not taking into account Great Britain and Ireland. Penetration of renewable energy sources in such situations can substantially increase their quality of life, if advanced control tools are available to the operators of these systems. The main objective is the development of an advanced control software system aimed at optimising the overall performance of isolated and weakly interconnected systems in liberalised market environments. This will enable an increase in the share of wind energy and other renewable forms. The main features of the control system comprise advanced software modules for load and wind power forecasting, unit commitment and economic dispatch of the conventional and renewable units and on-line security assessment capabilities integrated in a friendly man-machine environment.

Description of work

The proposed work comprises collection and analysis of renewable, electrical and operating data and identification of the needs for the following developments of on-line control functions:

- Improved wind power forecasting modules for short-term (0-8 hour) and medium-term horizons (4-48 hours)
- Hydropower forecasting functions
- Unit commitment and economic dispatch modules that take into account the availability of hydro-storage, liberalised market conditions, and increased security conditions
- On-line security modules to provide both preventive and corrective advice in case of predetermined disturbances
- Installation of the enhanced and new forecasting, operational planning and security modules on three selected EU sites. The aim of these pilot installations is to test the system functions under the new operating conditions with very high wind power penetration.

A number of alternative technologies have been applied for the update and development of new software modules providing flexibility for their adaptation in island systems with increased renewable penetration.

Expected results and exploitation plans

MORE CARE advanced control functions will be developed and installed on the islands of Crete, Ireland and Madeira with the active co-operation of the local utilities. Socio-economic impacts will then be assessed. Results should demonstrate the effectiveness of the proposed approach and provide valuable feedback for the dissemination of MORE CARE in other EU and developing countries.

Achievements to date

The MORE CARE software system with advanced forecasting, operational planning and security modules has been installed in Crete and Madeira, in order to tackle effectively new operating conditions characterised by high wind penetration. Advanced wind power forecasting modules have been installed in Ireland. Evaluation during the first months of operation on Crete has shown clear economic gains from improved operational planning and timely warnings about potentially insecure operating conditions. Further installations are under negotiation.

Contract: ENK5-CT-2002-00663

Acronym: WILMAR

Title:
Wind Power Integration in a Liberalised Electricity Market

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- Kungliga Tekniska Hoegskolan - SE
- Danmarks Tekniske Universitet – DTU - DK
- Elkraft System a.m.b.a. - DK
- Universität Stuttgart – USTUTT - DE
- Nord Pool Consulting AS - NO
- Technical Research Centre of Finland – VTT - FI

Project start date: 01-11-2001

Duration: 36 months

Project summary

Objectives and problems to be solved

A rapid introduction of large amounts of intermitting renewable power production as wind power can cause technical and economic problems for power systems. These problems might arise due to the unpredictability of wind power or because of an imbalance between local power demand and intermittent power produced, causing grid instabilities. The main objective of this project is to investigate these problems and to develop a modelling tool which can be used to simulate alternative solutions providing a firm basis for decision-making by system operators, power producers and energy authorities. The opportunities for integrating fluctuating power production by optimising the interaction of the existing units in a given electricity system, the possibilities lying in power exchange between regions, and the performance of dedicated integration technologies such as electricity storages are all evaluated.

Description of work

The modelling and simulation efforts can be divided into two parts. One part consists of an investigation into the issue of system stability, i.e. the wind integration aspects connected to the fast (below ten minutes) fluctuations in wind power production. Secondly, the wind integration ability of large electricity systems with substantial amounts of power trade in power pools is being investigated. Starting with existing models, a planning tool is being developed and will be used to investigate the technical and cost issues of integrating large amounts of wind power into the electricity system. The model will cover the two power pools: Nord Pool and European Power Exchange, i.e. Germany, Denmark, Norway, Sweden and Finland.

Expected results and exploitation plans

The final planning tool will be made publicly available so that organisations outside the project consortium can benefit from the work. Analysis based on the tools developed in the project will be used to provide an estimate of the costs connected to the integration of wind power, and to provide recommendations about the usefulness and performance of different types of integration measures.

Achievements to date

The development of the planning tool has made good progress. A linear, stochastic, optimisation model, with hourly time-resolution and covering several regions interconnected with transmission lines, has been developed. One crucial input to this modelling tool is wind power production forecasts for each region in the model. A wind speed forecast model has been developed which incorporates the correlations between wind speed forecast from one time step to the next and the correlations between wind speed forecasts in different regions. A stepwise power flow model used to study frequency changes from minute to minute in a Nordic power system as a function of changes in load and available production capacity has been developed as well as the availability of regulating power in the system. This model provides a suitable level of modelling in order to study basic problems related to primary and secondary control and provision of reserves.

Contract: ENK5-CT-2001-00536

Acronym: RES2H2

Title:
Cluster Pilot Project for the Integration of RES into European Energy Sectors using Hydrogen

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- Instituto Nacional de Técnica Aeroespacial - ES
- OWK Umwelttechnik und Anlagenbau GmbH - DE
- Solantis Energy - PT
- Unión Eléctrica de Canarias - ES
- Compañía Transportista de Gas Canarias - ES
- Integral Drive Systems - CH
- Centre for Renewable Energy Sources - EL
- Frederick Institute of Technology - CY
- Electricity Authority of Cyprus - CY
- C. Rokas - EL
- Planungsgruppe Energie und Technik GbR - DE

Project start date: 01-01-2002

Duration: 60 months

Project summary

Objectives and problems to be solved

The objective of RES2H2 is the clean production of hydrogen through exploitation of a renewable energy source, such as wind power (although solar energy or biomass could also have been considered). The aim is to overcome, on the one hand, the problem of storing surplus energy (so frequent with renewable energy sources) and, on the other hand, to produce clean hydrogen that effectively meets the demands of sustainable development.

The project will include the design, construction and assessment of two self-sufficient energy systems, allowing the use of wind power to generate hydrogen, electricity and water. These systems could be implemented, in the more or less near future, in any region with a high renewable energy potential (i.e. wind power), to produce and commercialize hydrogen in order to meet demands for electricity and water (independent water and renewable energy networks).

Description of work

A total of fourteen partners are participating in this project. In Greece, an eletrolyzer within the 25 to 100 kW range will be connected to a 500 kW wind charger. The hydrogen thus produced ("green hydrogen") will be stored in a metallic hydride tank (up to 50 Nm^3). It will subsequently be compressed in a series of cylinders in a filling station. This compressed hydrogen can potentially be put on the traditional hydrogen market, as a first step to familiarising the industrial sector with, and helping them gain confidence in, hydrogen as an energy vector.

In Spain, several ITC wind power generating facilities on the islands of Gran Canaria (Pozo Izquierdo) and Fuerteventura (Punta Jandia), were first considered as alternatives. A new possibility which has recently been considered is that of using a turbine in Barranco de Tirajana Thermal Power Station. Hydrogen and water will be produced and stored in Spain, as mentioned above. An electrolyzer and a reverse osmosis seawater desalination plant (production of hydrogen and water, respectively), will be connected directly to a wind farm of up to 450 kW, at an isolated installation. The produced and stored hydrogen (500 Nm^3, under pressure) will likewise be used to feed a Polymer Electrolyte Membrane (PEM) fuel cell of some 40 kW to produce electricity when wind resources are unavailable.

Achievements to date

The technology development stage has already been completed and four documents have been prepared, with each document being related to a different technology. The conceptual design and simulation of the systems is near completion. There are reports available on the characteristics of the wind chargers to be used, as well as on the simulation of their behaviour (data on output obtained based on the wind data for the site), and a study of the components to be revised/modified in order to integrate them with the electrolyser system. Likewise, a first report on the feasibility of the integration of some of the different components is expected to be available in the near future, in particular electrolyser engineering, fuel cell and interfaces, and configuration of the reverse osmosis desalination plant.

Contract: ENK5-CT-2002-80667

Acronym: RO-SWEET

Title:
Solar and Wind Technology Excellence, Knowledge Exchange and Twinning Actions Romanian Centre

Project coordinator:
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Project start date: 01-11-2002

Duration: 36 months

Project summary

The overall aim of the project RO-SWEET is to increase the liaisons between the Romanian Centre and similar organisations from the European Union, to stimulate knowledge exchange and the twinning of common research activities, and to correlate the Romanian methods and research strategies with other research organisations from the EU. The target is to enhance the level of Romanian research in the field of solar and wind technology and to integrate Romanian efforts into a common European Research Area.

Objectives and problems to be solved

- Increase the linkage with EU research area in the field of photovoltaic, solar-thermal and wind systems
- Develop common actions together with partnership organisations to improve the existing design methods for isolated solar systems
- Enhance the level of knowledge of the Centre's staff in the field of grid-connected photovoltaic applications
- Provide technical solutions for photovoltaic grid-connected applications for Romanian conditions
- Promote the applications developed by the Centre.

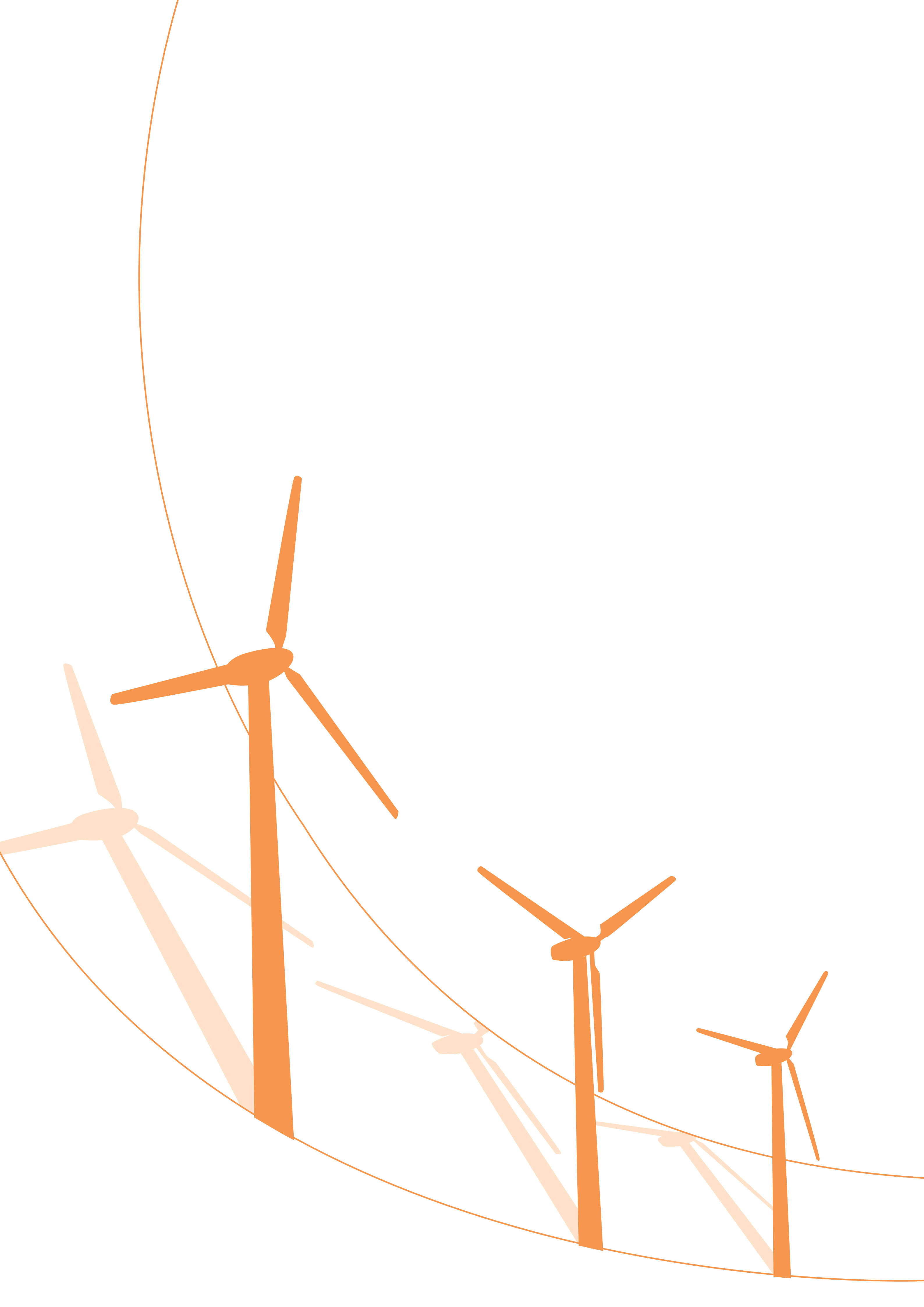
Description of work

The work was organised in a set of five work packages aimed at different yet correlated tasks:

1. Reinforcing the research capabilities of the Centre in the field of photovoltaic, solar-thermal and wind
2. Enhancement of the Centre's knowledge level in the field of building integration of solar (PV and thermal) systems
3. Increasing the technological and knowledge level of the Centre in the field of stand-alone hybrid (PV and wind) systems and micro-grids for rural electrification and tourism
4. Organisation of an annual technical conference (at European level) in the field of photovoltaic and wind energy
5. Dissemination of the results and identification of new research opportunities.

Achievements to date

- R&D and innovative research for new components and systems
- Study visits/training activities
- Two types of PV/hybrid systems have been identified as suitable for stand-alone and rural electrification
- Organisation of a technical workshop on 'New technologies for cost reduction of stand-alone PV and wind systems for rural remote households and social objectives'
- The annual conference 'SWIC – 2003', 'Solar and Wind International Conference and Workhop', was organised at ICPE – Agigea Test Site Facility, on the Black Sea coast, between 15-24 September 2003
- RO-SWEET members are taking part in several research projects in the framework of the National Research, Development and Innovation Programme (PNCDI).



DEMONSTRATION PROJECTS

Contract: NNE5-1999-629

Acronym: TAUERNWINDPARK

Title:
Tauernwindpark Oberzeiring, Wind Energy at Alpine Sites with Severe Weather Conditions

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- Finnish Meteorological Institute – FMI - FI
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- Vestas Deutschland GmbH - DE

Project start date: 01-06-2000

Project end date: 30-05-2003

Project summary

Objectives and problems to be solved

The aim of the project was to erect a wind farm at 1,835 metres above sea level at a site in the Alps enduring severe weather conditions. The main objective was to improve turbine efficiency at alpine sites under icing conditions. The problems involved were access to the site via a 12-kilometre long winding road, construction of the grid connection to the transformer station 21 kilometres away, and operation of the turbines under icing conditions.

Description of work

After thorough planning, it was decided that 11 WEC of the type VESTAS V66/1.75 MW with a hub height of 60 metres should be erected at the site. Design parameters were determined and the turbines modified to fulfil the requirements. Originally, it had been planned to install a blade heating system on the turbines but it turned out that this system was still in the production stage and not ready for installation. As an alternative, VESTAS constructed the research turbine with a special surface coating. The efficiency of this surface coating was investigated by comparing the production data of the turbine with the coating to a research turbine without the coating. Icing on the rotor blades was observed by special web cams installed for this purpose. In order to learn more about the wind conditions at the site, a 50 metres mast was erected, alongside a heated wind-speed sensor and ice detector with web cam which were also installed nearby. SODAR measurements were carried out to research the influence of the complex terrain on the wind conditions. Load measurements were taken on the research turbines to analyse the effect icing had on their performance and life span. A special vehicle was designed for transporting the large turbine pieces up the mountain.

Expected results and exploitation plans

The project improved knowledge of the construction and operation of wind turbines at alpine sites. The ice and load measurements supplied valuable information for designing wind turbines for severe weather sites and making the operation of wind turbines safer and more reliable. The optimisation of turbine technology allows the exploitation of new sites in alpine regions for wind energy production. Results of the project are being exploited at international conferences, on the internet and by the project partners.

Achievements to date

The concept for the construction at this difficult site was carried out without any major problems. After initial difficulties with the technical availability of the turbines, the availability reached a level of 97 % by the end of the first year in operation. The project contributed to an advancement of cold climate technology for wind turbines but research is still needed as regards heated sensors and ice detectors, forecasting the influence of icing conditions, the utilisation of model calculations for determining wind currents in complex terrain, and measures to keep ice off rotor blades.

Contract: NNE5-1999-703

Acronym: CLOWEBS

Title:
Klasorden 42 MW; A Demonstration of Cost-Optimised Large Scale, Offshore Wind Energy in the Baltic Area

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- NEG Micon A/S - DK
- Aeronautical Research Institute of Sweden – FFA - SE

Project start date: 01-07-2000

Project end date: 31-12-2004

Project summary

CLOWEBS, Klasården, 42 MW, is an offshore wind energy project sited some 2 km from the west coast of the Näs peninsula on the island of Gotland in the Baltic Sea. Näs is home to approximately 100 onshore wind turbines and five offshore wind turbines.

The project will consist of 16 machines (Vestas V-90) each rated at 2.6 MW, use innovative gravity foundation design and, above all, state-of-the-art technology for connection to the regional grid. The machines are of the so-called 'doubly fed induction' type and will be connected to one of the first full-scale HVDC light® systems in the world. The HVDC system will bring the power from Näs to the city of Visby some 60 km to the north. By using this system it is possible to connect larger-scale wind farms to comparatively weak or isolated grids.
Financing of the project is planned for the first six months of 2005 while construction of the grid network may begin in late 2005. The construction of the foundations and wind turbines is scheduled for 2006.

Objectives and problems to be solved

The main objective of the project is to increase the cost efficiency of offshore wind energy. This will be done by implementing an innovative turbine and foundation design. Furthermore, the project is sited in waters with significant ice and wave loads. Its value as a demonstration project is very high given that three new EU Member States, Estonia, Latvia and Lithuania, all hold considerable off-shore resources with similar seabed, wave and ice conditions.

The problems to be solved are mainly of an engineering nature and relate to optimising the installation and construction techniques for the newly designed foundations. Another challenge is the financing of the project. In Sweden, few than expected larger-scale wind energy projects have been achieved so far so no tradition for project financing currently exists. Thus, the consortium needs to find investors capable of raising large amounts of equity. This process has started and there are currently a number of European utilities which have expressed an interest in the project.

Description of work

The work packages cover several areas, such as project coordination, EIA; financing, insurance; surveys: seabed, wind, wave, ice; technical innovations: turbine, foundation, construction and installation; procurement; transport and installation; grid connection; and monitoring and evaluation.

Expected results and exploitation plans

The main expectation is to demonstrate a reduction in price per produced kWh compared to previous projects. Production costs of 0.044 euro/kWh are expected. It is planned to replicate the concepts designed and tested in the Klasården project in other areas of the Baltic. In particular, projects in the Baltic states will be targeted.

Achievements to date

So far the following has been achieved: full geotechnical analysis; wind, ice and wave studies; grid connection design; securing planning permission; design of the foundation and wind turbine.

Contract: NNE5-2000-412

Acronym: 5 MW off shore WEC

Title:
5 MW Wind Energy Converter for Off-shore Application

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- SIME Industrie - FR
- Centre for Renewable Energy Sources – CRES - EL
- Skanska Sverige AB - SE
- National Technical University of Athens – NTUA - EL
- Wobben Research and Development GmbH - DE
- Bladt Industries A/S - DK

Project start date: 01-06-2001

Project end date: 30-05-2005

Project summary

Objectives and problems to be solved

The objective is to develop a 5 MW offshore wind generator for pilot operation. This project is focused on the prototype for offshore applications, which differs considerably from land-based concepts. Within this project, the goal is to develop the actual hardware and to install and operate the prototype for offshore applications. The consortium will verify the generator performance in a pilot operation with the aim of preparing basic development which will then be used for further industrial exploration.

Description of work

This new generation of multi-megawatt wind turbines requires considerable research and development efforts in order to keep component weight down. Simple upscaling of current machines was not the way to succeed since components would have become too heavy and static and dynamic loads would be beyond acceptable limits (rotor diameter 112 m). Resolution of this problem required new design approaches, modelling and testing efforts. Particular challenges entailed: (a) the development of the offshore specific items, such as a specific blade design (narrow rotor blades with new profile and long-term protection coating, preventing the ageing process), (b) newly developed pitch bearings (three ring-double row), (c) azimut tracking at a very high yaw moment, (d) direct drive generator to be supplied and operated in four parts (diameter = 10 m), (e) off-shore specific tower foundations, (f) transport logistics, and (g) operation and maintenance procedures for a safe and reliable operation and many other components in order to exploit the vast wind energy potential of offshore operations along Europe's coasts and elsewhere. The project is accompanied by a thorough economic assessment, monitoring, and evaluation of the performance figures of the prototype in order to formulate new certification standards for the European wind industry in 5 MW class, and to assess and verify specific energy costs of such machines.

Expected results and exploitation plans

Developing a new class of machine, and putting it offshore simultaneously, is a major contribution towards securing the sustainable leadership of Europe's wind energy industry. It is expected that this WEC will be Enercon's first real offshore WEC and a WEC for future implementation in large-scale offshore wind parks.

Achievements to date

While the offshore WEC development has been finalised and the first WEC components manufactured, it was a major challenge for Enercon to obtain a construction permit for the turbine. Several installation sites were developed in parallel and a decision on the definite site could only be taken in July 2004. Thus project implementation has been delayed but the installation is secure.

Some other outstanding developments which are specific for this WEC type are: a suction bucket steel foundation (largest ever built), a movable platform for landing vessels, and the dehumidification, heat exchange and cooling system.

Contract: NNE5-2000-142

Acronym: ESTONIA 20MW WIND

Title:
8 x 2.5 MW Wind Turbines with Crane-free Erection to be Implemented in Estonia

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- Global Green Energy ApS - DK
- Paldiski Town Government - EST
- Tallin Technical University – TTU - EST
- Garrad Hassan and Partners Ltd. – GH - UK

Project start date: 01-10-2001

Project end date: 30-09-2005

Project summary

Objectives and problems to be solved

Several factors have stimulated the trend towards bigger and bigger wind turbines: economies of scale, scarcity of sites and offshore locations, and the technology learning curve. These factors are still very much in play. Stimulated by new technical concepts, a combined research and demonstration project was initiated which aims to develop and demonstrate a new crane concept (the power crane) for a newly developed 2.5 MW wind turbine, whereby expensive mobile cranes are only needed during the initial installation process. Within the remaining life-time of the wind farm, the site-present power crane will be able to carry out all replacements of major components, thereby reducing the down time (with related income loss) and the external crane costs significantly. Besides this, three foundation types in combination with the power crane concept are being tested, and a comprehensive measurement programme will verify the concepts. Furthermore, a large effect on demonstration is expected by introducing the first large-scale wind farm in Estonia. The target for reducing the cost of energy is from about 0.040 euro/kWh at present to about 0.035 euro/kWh.

Description of work

The work focuses on the following issues:

- Development, installation, test and measurement of the ‘power crane’ concept (life-time maintenance and replacement of major components without mobile cranes)
- Design, construction, test and measurement of different foundations (standard square, star and rock adaptor)
- Demonstration of the new concepts by implementing a 20 MW wind farm at Paldiski, Estonia, based on a competitive large-scale state-of-the-art wind turbine
- Implementation of a full-scale measuring and verification programme
- Dissemination of wind energy know-how in Estonia, the Baltic states and the EU.

Expected results and exploitation plans

The main aim of the project will be to demonstrate a significant reduction in energy production costs, to be achieved by:

- Large, site-optimised wind turbines (enhanced Nordex N80 2.5 MW WTG to N90 2.3 MW WTG)
- No external cranes used during life-time operation;
- Low foundation costs
- Demonstration effect of the large wind turbines as the first MW-scale wind farm project in Estonia.

Exploitation of the results will be done mainly via dissemination of the achievements and the widespread use of the demonstrated technology at comparable sites worldwide in future projects.

Achievements to date

Although the project has been delayed, mainly as a result of waiting for amendments to the Estonian Energy Act, the following results have been achieved:

- The power crane concept has been designed, developed and initially tested;
- The wind turbine design has been altered in order to adapt to the power crane;
- The measurement programme has been redesigned;
- The wind farm is under construction.

Contract: NNE5-2001-245

Acronym: OPTIPILE

Title:
Optimisation of Monopile Foundations for Offshore Wind Turbines in Deep Water and North Sea Conditions

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- Smit Maritime Contractors - NL
- Germanischer Lloyd WindEnergie GmbH – GL WIND - DE

Project start date: 01-04-2001

Project end: 31-03-2004

Project summary

Objectives and problems to be solved

The OPTIPILE objective is to develop optimal monopile foundations for offshore wind turbines in deep water with sea bottom, wave and wind conditions characteristic of the North Sea and other Atlantic continental shelves. Offshore wind energy is a key element in the EU renewables target of 10 % contribution of renewables in 2010. The target for offshore wind energy can only be reached when resources in both shallow and deep water can be developed. Since foundation costs amount to more than 20 % of total installation costs, optimisation of the foundation is crucial for economic feasibility of deep-water wind farms. Detailed knowledge of soil characteristics and scour behaviour is needed before a design optimisation can be carried out.

Description of work

The project is part of the development process of a 120 MW wind farm (Q7-WP) located 25 km off the Dutch coast in sea water varying in depth from 20-24 m. The problems addressed in the project cover a number of blank areas (soil characteristics, scour) and the problem of how to perform an actual design optimisation for monopile foundations in deep water (>20 m) in North Sea conditions. The project consists of a number of preparatory work packages (in particular, soil investigations and scour modelling/protection), followed by the actual design optimisation and certification of the Q7-WP offshore wind farm and by generalisation to other representative sites. Soil investigations are carried out because for most of the North Sea/Atlantic area existing knowledge is not sufficiently accurate for the type of analysis needed. Detailed knowledge of scour behaviour is required for design optimisation, so laboratory testing of scour and scour protection methods is included.

Expected results and exploitation plans

1. An optimised cost-effective design for the foundations of the VESTAS wind turbines for the Q7-WP wind farm
2. Design-optimisation and cost-reduction of scour protection of monopiles in sandy sea bottoms
3. Data on foundation optimisation for other deep-water offshore wind farms
4. Improved design and certification rules for offshore turbines.

Exploitation will be through direct use by project partners E-Connection Project, VESTAS Wind Systems, and Germanische Lloyd WindEnergie.

Achievements to date

OPTIPILE ended on 31 January, 2004 with the achievement of the project objectives mentioned above. Of particular interest is the development of a general design tool for scour around offshore wind turbine monopile foundations, to be used for prediction of scour depth and scour pattern for unprotected piles and design of optimal scour protection. The semi-empirical model is based on hydraulic tests on a 1:47 scale model.

The overall finding is that OPTIPILE showed that steel monopiles are the most cost-effective foundation solution for offshore wind turbines in the North Sea up to at least a water depth of 25 m.

Contract: NNE5-2001-633

Acronym: COD

Title:
Concerted Action for Offshore Wind-energy Deployment

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- The Swedish National Energy Administration – STEM - SE
- South Western Services Co-operative Ltd. – SWS - EI
- Department of Trade and Industry – DTI - UK
- Technische Universität Berlin – TU-Berlin - DE
- EC Baltic Renewable Energy Centre – EC BREC - PL

Project start date: 01-01-2003

Project end: 31-12-2005

Project summary

Objectives and problems to be solved

The objective of this project is to speed up the implementation of offshore wind energy in the European Community by early identification and removal of (non-technical) barriers: legal, administrative, policy, environmental and electrical infrastructure issues. These are preconditions to enable offshore wind energy to contribute to the EC's strategic goals and Kyoto objectives. The proposal aims to provide guidelines and best practices for a harmonised European offshore wind energy deployment, environmental impact analysis, consent procedures, and grid integration for offshore wind farms.

Description of work

COD is an intracommunity network comprising two working groups and an advisory board. The first working group is concerned with policy (chaired by Michel Verhagen, Dutch Ministry of Economic Affairs) with representatives from the Departments of Energy in the EU Member-States. The second is a working group with representatives from the Energy Agencies (co-ordinated by the Dutch SenterNovem - Ruud de Bruijne). The advisory board is chaired by EWEA's Christian Kjaer and formed by representatives from ETSO, WWF, SAR and Greenpeace.

COD was established in 1998 (UK, DK and NL). COD research activities for the period 2003-2005 are being financed by the European Commission within the framework of this project. At the moment, Belgium, Denmark, Germany, Ireland, the Netherlands, Poland, Sweden and United Kingdom are participating in COD. All other Member States have access to the results and meetings.

The COD working method involves: collecting all available and relevant data, studies, facts and figures; making the data accessible through internet databases; analysing the collected information, publishing benchmarks and overviews on the internet; and drafting guidelines, best practices and proposals for harmonisation.

Expected results and exploitation plans

1. A common information base with a commonly accessible website with up-to-date information on environmental, legal and grid issues concerning offshore wind energy: **www.offshorewindenergy.org/cod**
2. Proposal for uniform guidelines and best practices for environmental impact assessments.

Contract: NNE5-2001-710

Acronym: OFFSHORE M&R

Title:
Advanced Maintenance and Repair for Offshore Wind Farms Using Fault Prediction and Condition Monitoring Techniques

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- Overspeed GmbH and Co. KG – OSPEED - DE
- Gram and Juhl ApS – GJ - DK
- DMT Deutsche Montan Technologie GmbH – DMT - DE
- Risø National Laboratory – RISOE - DK

Project start date: 01-01-2003

Project end: 31-12-2005

Project summary

Objectives and problems to be solved

The main scientific and technical objective of the project is to lay the foundations for technical and economical optimised maintenance and repair (M&R) strategies for wind energy converters in offshore wind farms. This can be realised by integration of condition monitoring, fault prediction and M&R scheduling hardware and software into the technology of the individual wind energy converters and the entire wind farm. Wind turbine technology is based mainly on rotating components. Therefore, data evaluation algorithms using digital spectral analysis will be investigated. Suitable existing algorithms will be adapted for use in the field of wind energy converter condition monitoring and fault prediction. Furthermore, new algorithms for specific monitoring, fault prediction and M&R scheduling tasks for wind turbines will be developed and approved.

Description of work

The developments carried out in the course of the project should be understood as 'plug in' components for existing or currently developed offshore wind farm management and surveillance software products. To achieve an optimised integration ability for these products, existing industrial standards (e.g. IEC61400) will be used. It is also possible that parts of the project's results will contribute to the revision of these standards or will help to form new standards in the field of M&R strategies for offshore wind farms.

Expected results and exploitation plans

Expected results of the project will be:

- Concept for a technical and economical optimised hardware/software to perform condition monitoring, fault prediction and maintenance and repair scheduling actions in wind energy converters and wind farms
- Concept for standardised communication protocols based on international standards
- Data base concepts including storage optimisation, data file management and back-up management
- Experience from integration of condition monitoring in wind park management systems
- Influence on existing international standards and extension of standards.

Since the project consortium consists mainly of commercial companies, dissemination of the project's result on an industrial level is ensured within the consortium itself. Some results with a more general character will be made available to the public.

Achievements to date

Papers are currently being produced as a basis for discussions on further development of the above-mentioned concepts. The principle network configuration for internal data exchange was defined. Contacts were made to different user groups regarding the project results. A major activity of the consortium is the formation of an international work group for definition of an IEC standard for condition monitoring and maintenance and repair items in wind energy converters. It is quite likely that this will result in a new part or sub-part of the IEC61400 standard.

Contract: NNE5-2001-710

Acronym: INNOVT 5000

Title:
5 MW Innovative Wind Turbine Suitable for on Land and Offshore Installations

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- Offshore Wind Technologie GmbH – OWT - DE
- Center For Renewable Energy Sources – CRES - EL

Project start date: 01-01-2003

Project end: 31-12-2005

Project summary

Objectives and problems to be solved

INNOWT5000 aims to cover the following objectives:

1. To design, manufacture and install a 5 MW wind turbine for offshore and onshore application
2. To develop products and procedures to overcome the barriers of transport and erection of MW-class wind turbines
3. To respect the environment by adopting a different philosophy and increasing the use of new and environmentally friendly materials
4. To reduce the electricity production costs by optimising the design to competitive levels.

The problems to be solved are mainly caused by the size of the turbine. With an installed capacity of 5 MW and a targeted rotor diameter of 126 m, it is actually the largest wind turbine ever built. For this reason, the development of the components was a major challenge. A lot of innovative components and elements are necessary to achieve an economically viable turbine. Using many innovations means taking a lot of risks, the number of which are reduced by receiving subsidies from the EC.

Expected results and exploitation plans

It is expected that the 5 MW wind energy converter 'REpower 5 M' will enable the construction and economic operation of large offshore wind farms. A step-wise approach towards the offshore installation is planned, with initially a small number of turbines installed onshore in 2004 and 2005. At the start of the series production of the onshore machine in 2006, a first small offshore project is planned, followed by larger projects in 2007 and 2008. This will allow for a learning curve and enhancement of the turbine.

Achievements to date

All of the components for the machine have been developed and manufactured from a range of suppliers. The rotor blades are ready for delivery, as well as the nacelle and the hub. A workshop test of the nacelle with the hub mounted has been successfully performed and both components are ready for delivery to the onshore installation site. With the crane also installed at the site, everything is ready for the installation of the wind converter.

Innovative materials and components have been used in almost all major components. A range of new materials have been used for the blade, made by LM Glasfiber A/S, e.g. the main laminate, the highly loaded support structure, is made of carbon fibre reinforced plastic (CFRP). Furthermore, the drive train was based on a new innovative concept to overcome the massive weight increase and also to improve the availability of the gearbox. The solution was to use a cast iron, hollow rotor shaft in two bearings, separate from the gearbox. The non-locating bearing is a new development made by SKF, the so-called CARB™ -Bearing. Other examples of innovative elements include pitch drives fixed outside the hub.

European Commission

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This brochure provides an overview of research in the field of Wind Power, describing the current state of the art and the results achieved in EU-funded research and demonstration projects under the Thematic Programme 'Energy, Environment and Sustainable Development' of the Fifth Framework Programme (1998-2002). The projects, which have been compiled into six research areas, from turbine technologies to demonstration of wind power applications, are summarised giving the scientific and technical objectives and achievements of each, plus contact details for the participating organisations.

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