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COM/ENV/EPOC/IEA/SLT(2005)5

OECD ENVIRONMENT DIRECTORATE
INTERNATIONAL ENERGY AGENCY

INTERNATIONAL ENERGY TECHNOLOGY COLLABORATION AND CLIMATE CHANGE MITIGATION

Case Study 5: Wind Power Integration into Electricity Systems

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Organisation for Economic Co-operation and Development 2005
International Energy Agency
Organisation de Coopération et de Développement Economiques
Agence internationale de l'énergie

FOREWORD

This document was prepared by the OECD and IEA Secretariats in March 2005 at the request of the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC). The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy-makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

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ACKNOWLEDGEMENTS

This paper was prepared by Debra Justus, Organisation for Economic Co-operation and Development. The author would like to thank the following individuals for the comments and ideas they provided: Dennis Tirpak and Jane Ellis of the OECD; Richard Baron, Cédric Philibert, Lily Alisse, Lorcan Lyons, Piotr Tulej, Rick Sellers and Til Stenzel of the International Energy Agency.

Gratitude is expressed to the many individuals who contributed information and insights including: Tom Acker (Northern Arizona University, US), Thomas Ackermann (Royal Institute of Technology, Sweden), Nikos Hatziargyriou (Corfu Power, Greece), Gordon Mackenize and colleagues (Risø National Laboratory, Denmark), Elliot Mainzer (Bonneville Power Authority, US), Eri Nakajima (Ministry of Economy, Trade and Industry, Japan), Hiroaki Nishigami (Kansai Electric Power Company, Japan), Brian Parsons (National Renewable Energy Laboratory, US), Kurt Rohrig (Institut für Solare Energieversorgungstechnik, Germany), J. Charles Smith (Utility Wind Industry Group, US), Poul Sørensen (Risø National Laboratory), Harald Weber (University of Rostock, Germany).

Many thanks to Elizabeth Corbett and Barbara Ladeuille for assistance with manuscript preparation.

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Executive Summary

Wind power is undergoing the fastest rate of growth of any form of electricity generation in the world. The resource potential is large; with many countries having wind regimes that could serve as a significant energy source. Ambitious goals for wind power development have been set by many countries.

Rapid growth of wind power since the 1990s has led to notable market shares in some electricity markets. This growth is concentrated in a few countries with effective research, development and demonstration (RD&D) programmes and with policies that support its diffusion into the market place. The speed and depth of its penetration in those electricity markets has amplified the need to address grid integration concerns, so as not to impede the further penetration of wind power. Research on technologies, tools and practices for integrating large amounts of wind power into electricity supply systems is attempting to respond to this need. In recent years, existing international collaborative research efforts have expanded their focus to include grid integration of wind power and new consortia have been formed to pool knowledge and resources. Effective results are of benefit to the few countries that already have a significant amount of wind in their electricity supply fuel mix, as well as to the potential large markets worldwide.

This case study largely focuses on the challenge of bringing significant amounts of intermittent generating sources into grids dominated by large central generating units. It provides a brief overview of the growth of wind power, mainly since 1990, the technical and operational issues related to integration, and selected collaborative programmes underway to address grid integration concerns. It does not cover the many other areas of wind research collaboration, e.g., turbine developments or rotor aerodynamics, nor the history of international collaborative R&D in bringing wind technology to its current point in the commercialisation process.

Several observations emerge from this case study that may have relevance for other clean energy technology development and diffusion efforts:

- Government, industry and international collaborative RD&D, spurred on by the energy crises of the 1970s in some cases, resulted in major design improvements and increased technical and economic performance of wind turbines and related components. Subsequently, the successful and rapid diffusion of these technologies, in some countries, by a variety of incentives has revealed a new set of technical and operational challenges, namely those of grid interconnection. Since research programmes did not keep pace with the rapid deployment of wind power, this suggests that such efforts were either disconnected from deployment programmes or were not sufficiently well connected.

- Programmes and policies that aim to assist in building new markets and transforming existing markets must engage all stakeholders along the commercialisation chain in an integrated and pre-emptive fashion. Policy designers must understand the interests of those involved in the market and there must be effective communication with those stakeholders and the research community.

- The incentives for stakeholders to collaborate include the need to “learn” from technical and operational solutions and failed approaches of others, to improve the reliability of tools such as models for wind farm dynamics and grid operation, to develop standardised approaches across market areas, and to provide technical expertise for regulatory and standards setting processes.

- RD&D and market deployment programmes must take account of “learning effects”; i.e., go beyond the immediate needs of stakeholders and foresee technical requirements in anticipation of deployment, particularly when new infrastructure is required such as offshore wind farms.

- Responding to a challenge, such as the need to rapidly find technical and operational solutions to grid interconnection issues, can foster more co-operative research at national, regional and international levels. The benefits of international collaboration for emerging low-carbon energy technologies include: pooled resources, shared costs, harmonisation of standards, and strengthened national R&D capabilities.

- As an energy technology advances on the path from RD&D to commercialisation, costs and risks shift from government to industry. As illustrated by the collaborative groups profiled in this study, grid integration research includes participation and financial support from wind and electricity supply industries to a significant degree.

1. Context and Background

Mitigating climate change and achieving stabilisation of greenhouse gas atmospheric concentrations – the objective of the United Nations Framework Convention on Climate Change (UNFCCC) – will require deep reductions of greenhouse gases, including energy-related carbon dioxide (CO_2) emissions. Further development and dissemination of new or improved low-carbon energy technologies are needed. In addition to RD&D efforts, effective policies, regulations, market deployment strategies and economic tools need to be part of a comprehensive approach. Two previous AIXG papers have focused on possible drivers for a significant technological change: *Technology Innovation, Development and Diffusion* (Philibert 2003) and *International Energy Technology Collaboration and Climate Change Mitigation* (Philibert 2004).

Building on those papers, case studies have been developed to provide insights on the role international technology collaboration can play to help achieve the objectives of the UNFCCC. This paper on wind power integration into electricity systems is one of five case studies. Case studies on concentrating solar power technologies (Philibert 2004a) and high-yielding crop varieties (Gagnon-Lebrun 2004) were published in 2004. Case studies on clean coal technology (Philibert and Podanski, 2005) and appliance energy efficiency (Guéret, 2005) have been prepared in parallel with this paper in the 1st quarter 2005. A synthesis paper drawing from the two papers and the five case studies is planned for 3rd quarter 2005.

2. Introduction

Grid-connected wind capacity is undergoing the fastest rate of growth of any form of electricity generation, achieving global annual growth rates on the order of 20 - 30%. Capacity has been doubling every three years for the last decade. The World Energy Council has stated that it is doubtful whether any other energy technology is growing, or has grown, at such a rate. Global installed capacity was 40 GW in 2003.[1] According to industry associations, global wind power capacity was 47.3 GW in 2004.[2]

Wind power is increasingly being viewed as a mainstream electricity supply technology. Its attractiveness as an electricity supply source has fostered ambitious targets for wind power in many countries around the world. Its benefits include:

- Very low lifetime emissions of harmful gasses, particularly CO_2

[1] This report uses installed wind power capacity and electricity generation data from IEA statistics (IEA 2004a), except where indicated.

[2] Global Wind Energy Council, press release. March 2005.

- Significant economically exploitable resource potential
- No cost uncertainties from fuel supply price fluctuations
- Increased diversity and security of supply
- Modular and rapid installation
- Opportunities for industrial, economic and rural development.

As wind power penetration rates have increased in electricity supply systems in a few countries in recent years, so have concerns about how to incorporate a significant amount of intermittent and non-dispatchable generation without disrupting the finely-tuned balance that network systems demand. Grid integration issues are a challenge to the expansion of wind power in some countries. Solutions such as aggregation of wind turbines, forecasting and modelling have been implemented to facilitate larger market penetration of wind power. Collaborations are increasingly addressing the integration and grid improvement matters.

This case study briefly summarises the growth of wind power since 1990, primarily in OECD countries, and takes a look at international collaboration underway to address grid integration issues. It does not cover international R&D co-operation that has supported wind technology for decades, nor the many other on-going areas of international research collaboration such as wind turbine performance.

3. Wind Power Overview

3.1 Outlook

Estimates of the global wind resource potential are large and geographically broad. The total technically recoverable resource is estimated to be 53 000 Terawatt hours (TWh).[3] To put this into context, in 2002 world electricity generation was 16 054 TWh. The IEA's 2004 World Energy Outlook estimates that by 2020 global electricity demand will be 25 578 TWh.

Ambitious targets for renewable sources in energy supply have been established in many countries to diversify supply for energy security, for economic development reasons such as job creation and for environmental reasons, including greenhouse gas emissions. Examples include:

- Japan has mandated that its power companies increase renewable sources in electricity supply, with a national target of 3 000 MW of wind power by 2010;
- A European Union (EU) Directive sets fixed percentage targets: the EU 15 have an overall target of 22% of electricity supply from renewable energy sources by 2010 and the EU 10 have a target of 11% by 2010;
- Germany's long-term target aims to produce 25% of the country's electricity from wind power by 2025;
- China aims to increase wind power capacity to 4 000 MW by 2010. It has a target of 10% of electricity supply from renewable energy by 2020.

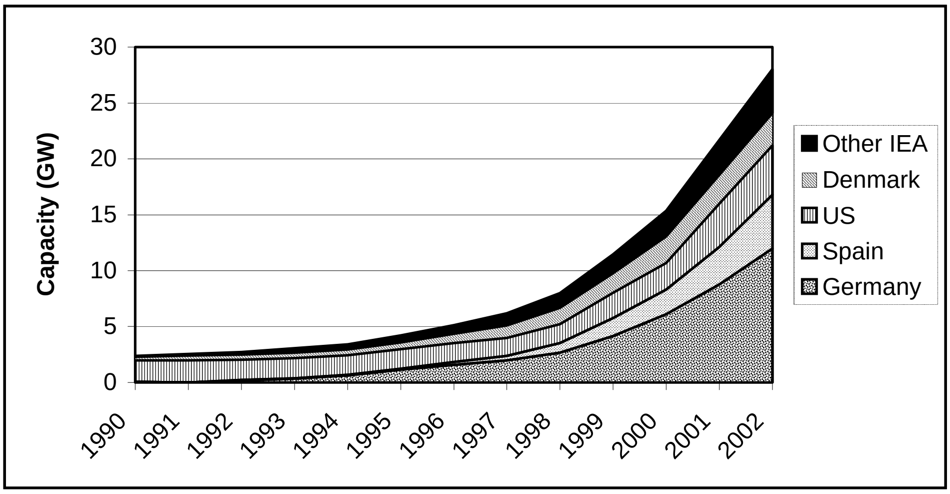
[3] Wind Force 12, European Wind Association and Greenpeace, May 2004.

3.2 Status of Wind Power Development

Market deployment policies, combined with reduced costs and improved technology, are driving unprecedented growth in wind power. Growth since 1990 is impressive. In 1990, OECD countries had 2 390 MW of installed wind power capacity. By 1995 it had expanded to 4 214 MW. In 2002, installed wind capacity was 28 089 MW. Electricity output was 7 349 GWh in 1995 and 47.6 TWh in 2002. Global wind power increased to 47.3 GW installed capacity and 54.2 TWh electricity production in 2004, according to wind energy associations.

While a number of OECD countries have significant potential based on wind resource assessments, in 2002 about 86% of the installed capacity was in only four countries (Figure 1). About 75% of total global wind power capacity is installed in Europe. Development has been concentrated in a few countries with effective RD&D and market support policies. In other countries, technology is imported and learning is shared across borders.

Figure 1: Installed Wind Power Capacity in IEA Countries, 1990-2002



Source: International Energy Agency, 2004.

Overall, about 8% of government energy RD&D budgets in IEA member countries have been allocated for renewable energy technologies since 1974 (Table 1).[4] Some countries apportion a higher share. In Germany, the world's wind power leader, about 10% of energy RD&D spending was for renewables in the 1974 – 2002 period, with 49% of this allocation for solar photovoltaic and 20% for wind.

Wind research has received about 1% of government energy technology RD&D funding across IEA countries since 1974 (Table 1). RD&D in wind technology appears to have a strong link with the development of markets and a supporting industry. In Denmark, Germany and the United States, significant RD&D funds were invested in the years preceding rapid market growth. In the 1987 – 2001

[4] IEA member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States. (IEA member countries do not include the OECD members: Iceland, Mexico, Poland, and Slovakia.)

period, seven countries accounted for 85% of total wind RD&D investments in IEA countries. Those seven countries had 94% of the installed wind power capacity in 2002.

In conjunction with RD&D, the deployment of wind power technology has been strongly supported in some countries by government incentives and policies such as feed-in tariffs and various forms of obligations such as renewable energy portfolio standards. Most countries have used a combination of policy instruments. Investment incentives such as capital subsidies and tax credits have been coupled with payment of premium prices for electricity produced. In recent years, premium prices are increasingly preferred to capital investment subsidies.

Table 1. Energy RD&D Budgets in IEA Countries by Technology

	1974-2001 Budgets (Million US$)	**Share in Energy RD&D 1974-2001**	**1974-1986 Budgets** (Million US$)	**Shares in Energy RD&D 1974-1986**	**1987-2001 Budgets** (Million US$)	**Shares in Energy RD&D 1987-2001**
Nuclear Fission	137 529	47.3%	84 866	53.6%	52 662	39.7%
Fossil Fuels	36 842	12.7%	20 559	13.0%	16 283	12.3%
Nuclear Fusion	30 562	10.5%	15 947	10.1%	14 615	11.0%
Other * Technologies	29 212	10.0%	10 598	6.7%	18 613	14.0%
Renewable Energy	23 550	8.1%	13 316	8.4%	10 233	7.7%
Solar Heating & Cooling	*3 024*	1.0%	*2 139*	1.4%	*885*	0.7%
Solar Photo-Electric	*6 353*	2.2%	*2 717*	1.7%	*3 636*	2.7%
Solar Thermal-Electric	*2 555*	0.9%	*1 889*	1.2%	*665*	0.5%
Wind	*2 910*	1.0%	*1 445*	0.9%	*1 464*	1.1%
Ocean	*754*	0.3%	*625*	0.4%	*128*	0.1%
Biomass	*3 578*	1.2%	*1 495*	0.9%	*2 083*	1.6%
Geothermal	*4 088*	1.4%	*2 867*	1.8%	*1 221*	0.9%
Large Hydro (>10 MW)	*92*	0.0%	*0.00*	0.0%	*92*	0.1%
Small Hydro (<10 MW)	*48*	0.0%	*0.18*	0.0%	*48*	0.0%
Conservation	23 479	8.1%	8 607	5.4%	14 872	11.2%
Power & Storage Technology	9 844	3.4%	4 344	2.7%	5 500	4.1%
Total Energy R&D	291 020	100.0%	158 240	100.0%	132 781	100.0%

* This category includes cross-cutting R&D that is not specifically related to one technology.

Source: Renewable Energy Market & Policy Trends in IEA Countries, OECD/IEA 2004.

3.2.1 Technology Developments

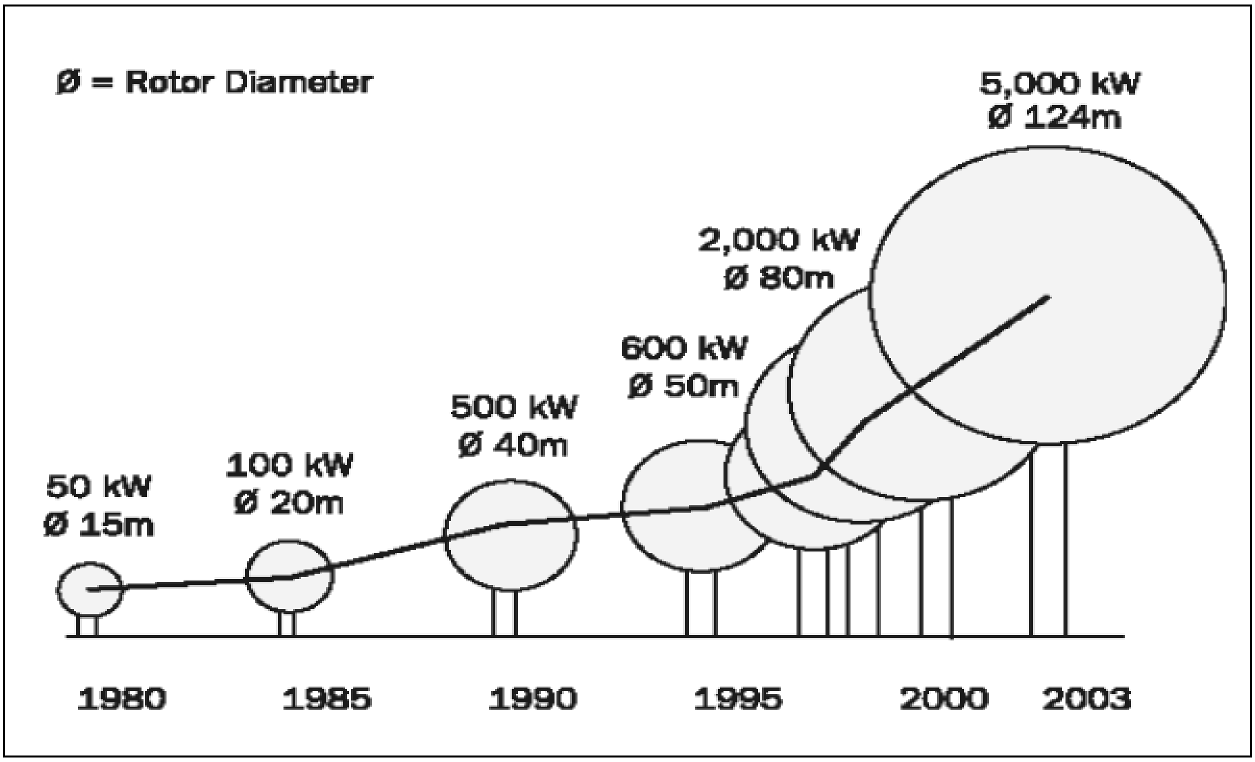
Major design improvements and increased technical and economic performance have resulted from government, industry and international collaborative RD&D. The cost per unit of wind electricity fell from

€15.8 cents to €5.7 cents per kWh between 1981 and 1995 due to improved turbine design and better siting, according to an evaluation of wind turbines in Denmark by the Risø National Laboratory.[5] New generations of larger and improved turbines have become the norm since then. Production costs have been cut by 50% over fifteen years. Wind industry cost estimates for state-of-the-art onshore wind turbines in 2003 were €804 per installed kW with a unit price of €3.79 cents per kWh.[6]

Enhanced performance and cost reductions have been closely related to increases in turbine size. Until the mid-1980s, turbines were typically less than 100 kW with rotor diameters of about 20 metres. This increased to a few hundred kilowatts by the mid-1990s, when turbine sizes began to range from 0.5 – 1.5 MW (Figure 2). New turbines deployed in 2002 averaged about 1 170 kW. In 2002, a large offshore demonstration project in Denmark was commissioned using 2 – 2.3 MW turbines, while in Germany, average wind turbine size reached 1.4 MW. The largest turbines being manufactured today are 4.5 MW capacity with a rotor diameter of 112 metres. A prototype 5 MW turbine with a 124 metres rotor diameter, the largest in the world, has been installed recently in Germany.

Wind technology has also benefited from RD&D on power electronics, variable-speed conversion systems, materials and resource assessment and modelling. Since the early 1980s, the power of a wind turbine has increased substantially. Variable-speed turbines can handle a broader array of wind speeds while reducing the effects on the structure.

Figure 2: Growth in Size of Commercial Wind Turbine Designs



Source: *Wind Power Technology*, European Wind Energy Association, 2004.

[5] Risø National Laboratory, www.risoe.dk

[6] Wind Force 12, European Wind Association and Greenpeace, May 2004.

Interest in the potential for offshore wind development has grown more or less in step with the up-scaling of turbines. In Denmark onshore wind development seems to be close to saturation in terms of sites with adequate wind regimes and problems of siting large turbines in densely populated areas. MW-size turbines can dominate the landscape, so offshore development appears to be a precondition for continued large-scale development of wind in Denmark. The situation is similar in Germany.

In 2002, a 160 MW offshore project was commissioned in Denmark. Other coastal countries such as Ireland, Netherlands, Sweden and United Kingdom are investigating or planning exploitation of offshore wind resources.

Offshore technologies are less well proven than onshore wind: the marine environment is more challenging, and it requires large fixed investments to develop the infrastructure – civil engineering, ships, platforms, installation technologies and transmission lines. The on-going development of onshore wind turbines and components is viewed by some as primarily the preserve of industry, because the technology is relatively mature. Both onshore and offshore wind power expansion face issues of grid integration, although the technical, operational and cost issues differ.

3.2.2 Profiles of Wind Development in the Five Leading Countries

The world's five leading countries in terms of installed wind power capacity are: Germany, Spain, United States, Denmark and India.

Germany: The installed wind power capacity was 48 MW in 1990. It increased to 12 GW in 2002, the largest amount of installed capacity in the world. According to industry associations, installed capacity increased to 16.6 GW in 2004.[7] Electricity production from wind turbines was 18.5 TWh in 2003, more than 3% of Germany's electricity production. Industry sources estimate electricity production at 22.6 TWh in 2004.

One-third of the world's installed wind power is in Germany. In 2002 there were about 16 000 wind turbines, mostly situated in northern Germany near the border with Denmark.

The impetus for the German wind power market was the 100 MW Programme initiated in 1989, which was expanded to 250 MW in 1991. This programme provided grants as well as remuneration under the Electricity Feed-in Law. The 1991 Feed-in Law is considered the driving force behind the rapid increase in wind power in Germany. It provided renewable energy producers up to 90% of the retail price of electricity for every kWh generated. The Renewable Energy Sources Act 2000 further strengthened market deployment by providing an incentive production payment for the first five years of operation followed by a decreasing output payment in subsequent years. Investment support provides up to 80% of total investment costs at low interest rates. Rapid deployment of wind power is also attributed to changes in codes that awarded wind farms the same legal rights as fossil and nuclear power plants.

Wind turbines are largely connected to the grid at low and medium voltages. With the advent of the feed-in tariffs in 1991 and the spurt of wind developments that followed, the transmission system operators had concerns about grid integration reliability and cost issues. They looked to the government for a solution. The Renewable Energy Sources Act 2000 consequently provided for a burden sharing between all network operators and allocation to their customers. This solution is estimated to currently add about €12 per year to the average household electricity bill. The significant growth of onshore wind power led to collaboration between the transmission system operators and German research institutions to develop advanced

[7] Global Wind Energy Council, press release. March 2005.

forecasting and modelling tools for wind power. Subsequently, the expected extension offshore led to a more fundamental review of grid extension and upgrade needs, which culminated in a joint research effort between German research institutions, grid operators and the electricity supply industry. German researchers are also significantly involved in international and European research programmes on grid integration matters.

The German Government has a target of 20% share of renewable energy in electricity generation between 2015 and 2020. Most of this is expected to come from wind power. Concerns about network integration and infrastructure capacity to accommodate some 37 GW of wind power by 2015 were the impetus for a federal government and industry joint-financed report released in February 2005, "Energy Planning for the Integration of Wind Energy in Germany on Land and Offshore into the Electricity Grid".[8] It finds that reinforcement and extension of the grid and technical solutions for reliability are preconditions for achieving the envisaged wind power development and avoiding 20 to 40 million tons of CO_2 emissions in 2015. It would entail about 850 kilometres of new high-voltage lines and 400 km of grid upgrades at an estimated cost of €1.1 billion. The study cautions that implementation could be stymied by the planning and legal authorisation process for transmission lines. The study suggests that the additional cost for the expansion of wind power will be 0.39 – 0.49 € cents per kWh in 2015 for a residential consumer.

Spain: The installed wind power capacity was 2 MW in 1990. It increased to 4.8 GW in 2002, the second largest in the world. According to industry associations, installed capacity increased to 8.2 GW in 2004. Electricity production from wind turbines was 11.5 TWh in 2003. Industry sources estimate electricity production at 14 TWh in 2004, about 4% of Spain's electricity production.

Strong growth is attributed to local manufacturing of turbines and policy support through feed-in tariffs and low-interest loans. An important impetus has come from regional governments that support the construction of factories and the creation of local jobs. Three Spanish companies are among the world's ten largest manufacturers of wind turbines. Favourable lending arrangements, in which banks guarantee the cash flow of the project thereby reducing risks, have been very effective in increasing wind power.

The incentive structures have favoured large wind developments that are connected to the high voltage transmission network. Weak grid infrastructure in some areas has inhibited the development of wind farms. This led to a comprehensive review of transmission and distribution requirements by the grid operator, which is concerned about system impacts from more large-scale wind farms and the costs of integration. At present, Spain's transmission system interconnections with neighbouring countries are weak so opportunities afforded through power pools are limited.

United States: The installed wind power capacity was 1 911 MW in 1990. It increased to 4.4 GW in 2002, the third largest in the world. According to industry associations, installed capacity increased to 6.7 GW in 2004. Electricity production from wind turbines was 11.5 TWh in 2003.

Wind power experienced two distinct periods of growth in the United States. The Public Utility Regulatory Act (PURPA) in 1978 required utilities to offer long-term power purchase contracts to private power developers that were based on the utilities' avoided generation costs. There were also federal and state tax incentives. Most of the early development occurred in California where utilities had high marginal costs.

In the late 1990s there was a second period of growth spurred by a combination of federal tax incentives and policies adopted in several states, e.g., renewables portfolio standards. The new generation of wind

[8] Deutsche Energie-Agentur, 24 February 2005, www.dena.de

turbine technology available by then further supported the interest of utilities. In Texas nearly 1 000 MW of wind power development were installed in 2001, in part to meet the state's renewable energy portfolio standard. Voluntary green power marketing programmes have also encouraged wind power developments, which represent a significant share of the green power sold in the United States. One of the federal incentives, the production tax credit (PTC) dating back to 1992, has been allowed to expire several times. Its on-again - off-again nature has resulted in boom-and-bust cycles for new installed capacity. The PTC was revived late in 2004 and set to expire at the end of 2005, which therefore is expected to be a record year for newly installed capacity.

To date, intermittency, per se, has not been an obstacle to wind projects in the United States. Wind power developments have been largely in remote areas and connected to high voltage transmission networks. However, access to transmission networks and pricing for intermittent resources has been a hurdle. In 2004, the Federal Energy Regulatory Commission proposed modifications in the wholesale electricity market structure that would eliminate penalties associated with wind's variable output when it does not result in increased costs to the system. This proposal is currently under consideration.

With significant growth anticipated, the wind energy and electric power industries, research institutions and the federal government are working collaboratively to address issues related to the integration of larger amounts of wind power, including co-joining wind farms with hydropower plants. As an example of this type of innovation and integrated resource management, in 2002 the Bonneville Power Administration (BPA) undertook an extensive R&D effort to evaluate the costs and opportunities associated with integrating wind energy into the federal Columbia River hydropower system. In May 2004, BPA launched two new services that will use the flexibility of the hydro system to integrate wind energy into its control area on behalf of electric utilities in the US Pacific Northwest region.

Denmark: The installed wind power capacity was 343 MW in 1990. It increased to 2.9 GW in 2002, the fourth largest in the world. Wind turbine capacity represented 21.8% of Denmark's electricity supply in 2002. According to industry associations, installed capacity increased to 3.1 GW in 2004, but only 2 MW were added that year. Offshore capacity was 214 MW in 2002, up from 50 MW in 2001.

Electricity production from wind turbines was 5.5 TWh in 2003, about 16% of Denmark's electricity production. Industry sources estimate electricity production at 6.6 TWh in 2004, about 19% of electricity production. In Denmark, each MW of capacity produces an average of 2 129 MWh a year – much more than the world average.

Denmark has successfully and flexibly employed both demand pull and technology push policy instruments to achieve its wind power targets. For example, the Risø National Laboratory established a test station in 1978 for wind turbines that was responsible for type approvals that were a precondition for obtaining plant and production subsidies. Risø functioned as a technological service centre for the nascent Danish wind turbine industry, whose individual companies at that point did not have the resources to undertake technological development. Government RD&D has been directed towards basic research rather than actual turbine or component development and had enjoyed a relatively stable level of support.

The technological developments led to significant growth in demand for wind turbines in the 1990s in both domestic and export markets. Within Denmark, the technological advances were coupled with market deployment strategies building on a policy combination of feed-in tariffs and subsidies for installation costs. Utilities were required to connect private wind turbines to the grid. An agreement was established between utilities, government and wind turbine owners in the early wind power development period. Among other features, it established the grid connection rules, and particularly who should pay. Grid integration costs are paid by the network and allocated to all customers.

The Danish Government supported wind to help achieve energy goals and other policy objectives, e.g., industrial development and rural employment. Investments were made in RD&D and learning in a niche market to improve technology cost and performance. Through the development years, the Danish state financed the additional costs involved. Following liberalisation of the electricity market and reflecting the maturing of the wind power technology, the economic commitment shifted to consumers. The support scheme is being reorganised and following a transition period, wind turbines will have to produce on market terms, but with a bonus that capitalises on the environmental and societal benefits of wind power.

Denmark has the highest penetration of wind power in its electricity supply systems of any country. About 93% of the wind generation is fed into the distribution networks. Wind farms in Denmark are generally small clusters in the 10-20 MW range and are widely dispersed across the country, which means lower volatility of output in the short-term and therefore less need for balancing power. With this profile, the variations in output are less than for very large and isolated wind farms and therefore more manageable for network operators. In addition, wind power in combination with combined heat and power generation, which is widespread in Denmark, provides some of the needed power regulation flexibility as the district heating systems can be used as a short-term energy buffer. As well, the Danish transmission system has strong interconnections with Germany and the Nordic countries and participation in the Nordpool power market is an important means for selling excess capacity and purchasing additional balancing power as and when needed. Danish network operators, utilities, government and research institutions are active in international and European collaborative research on grid integration matters.

India: According to the India Wind Association, the installed wind power capacity was 30 MW in 1990. It increased to 2 117 MW in 2002, the fifth largest in the world. Installed capacity increased to 3 000 MW in 2004.

The first wind power development was a government supported demonstration plant in 1986. India had notable wind power developments by the late 1990s, largely due to incentives such an accelerated depreciation allowance of capital costs and exemptions from excise duties and sales taxes, and regionally administered feed-in tariffs. A tax rebate of 80% on the income from power generation for the first ten years of operation has encouraged commercial investment, as has the attraction of power supply for use in businesses. Since the first demonstration plant, some 2 052 MW of installed wind capacity has been developed by commercial interests. In some cases they are not well integrated as the wind turbines produce more power that the weak distribution system can handle.

The government Centre of Wind Energy Technology (C-WET) in Chennai is a specialised institution for research and development, standardisation, testing and certification, along with resource assessment. Risø National Laboratory provided technical assistance for its establishment.

With rapid growth in wind power development in the 1990s, the capacity of the grids in the wind farm regions in Tamil Nadu and Gujarat was insufficient to accommodate the wind power. It caused frequent outages of the grid and reduced the return from the wind farms. In 1998, Risø and C-WET collaborated on a research project to study wind power integration in weak grids in India.

India has developed indigenous wind energy equipment manufacturing with a capacity of about 1 000 MW per year.

3.3 Challenges: Integration into Electricity Systems

- Grid integration concerns have come to the fore in recent years as wind power penetration levels have increased in a number of countries as an issue that may impede the widespread deployment of wind power systems. Two of the strongest challenges to wind power's future prospects are the problems of intermittency and grid reliability.

Electricity systems must supply power in close balance to demand. The average load varies in predictable daily and seasonal patterns, but there is an unpredictable component due to random load variations and unforeseen events. To compensate for these variations, additional generation capacity is needed to provide regulation or set aside as reserves. Generators within an electrical system have varying operating characteristics: some are base-load plants; others, such as hydro or combustion turbines, are more agile in terms of response to fluctuations and start-up times. There is an economic value above the energy produced to a generator that can provide these ancillary services. Introducing wind generation can increase the regulation burden and need for reserves, due to its natural intermittency. The impact of the wind plant variability may range from negligible to significant depending on the level of penetration and intermittency of the wind resource.

The intermittent profile can affect grid reliability and is a new dimension that transmission and distribution network operators have not traditionally had to manage on any significant scale. Consequently as wind power has become more than a novelty in electricity supply, the electricity system planners and operators have been increasingly concerned that variations in wind plant output may adversely affect grid reliability and increase the operating costs of the system as a whole.

- The conventional management of transmission and distribution operation is challenged by electricity market restructuring, security of supply concerns and the integration of newer generation technologies such as wind power.

Yet some developments of market restructuring such as increasing network interconnections can improve grid integration and management of variable generation sources. It can provide opportunities for market design that reduce costs for balancing power. In some countries the transmission and distribution networks are aging or are at capacity limits. Infrastructure replacement and upgrading is an opportunity to re-examine design and operation parameters including integrating wind power generation as a key part of the overall network strategy. This will require network system operators to develop active network management – a radical shift from the traditional central control approach.

- Offshore wind development presents a lower level of technological maturity and higher risks than onshore wind power developments.

While R&D advances and market learning are observed in the areas of turbines, base structures, operation and maintenance and communication relays for offshore development, all need further attention. Development offshore will entail transmission line construction. In many cases it is expected to be High Voltage Direct Current (HVDC) technology, which comes at increased expense but offers additional functionality for grid integration and low line losses. Offshore turbines are expected to be in the multi-megawatt range for development in the near term thereby bringing larger amounts of intermittent resources into the generation mix and increasing the need to find near-term solutions to the integration challenges.

- Transmission availability can be a barrier to wind power development. Favourable wind locations are often in areas distant from existing transmission – offshore areas in Europe and rural areas of North

America. Building new transmission lines can be difficult due to planning barriers, land use rights and costs.

- Internationally accepted standards for power performance, safety, noise and other environment-related conditions are needed to reduce market barriers, as well as administrative and installation costs.

3.4 Strategies to Tackle the Challenges

The electricity industry worldwide is undergoing a period of unprecedented change: implementing new generation, transmission and distribution technologies; opening and integrating power markets and a new range of market players. Considering national/regional targets for the growth of renewable energy technologies, it is likely that they will account for a significant and increasing proportion of total generating capacity in the years ahead. Wide scale deployment of new generation technologies can pose significant technical and regulatory challenges for the networks to which they are connected as well as for the entire electricity system. Yet, wind integration issues will vary with the geographical region over which the wind power is installed, and the structure and fuel mix of the electricity system into which it is to be integrated.

Technical challenges and opportunities include the role and future architecture of networks, control, data exchange and provision of security services across the transmission/distribution network boundary, quality of supply, reliability and network resilience, together with issues such as dynamic stability and intermittency seen at a system level.

The costs imposed on the system for intermittent renewables and markets for balancing power are of increasing concern to grid operators and policy-makers alike. The analytical techniques and their application are in the early stages of development. As the use of wind power increases around the world, there is increasing interest in the impacts on power system operation and costs. The development of better forecasting tools for wind can be valuable to traders, schedulers and dispatchers. Although forecasting tools are becoming more accurate, integrating large-scale wind power plants into the grid can still pose challenges.

Strategies to tackle the challenges of wind power grid integration include:

- Both RD&D and new management techniques (network planning and operation);

- RD&D to increase the value of wind by facilitating electricity production forecasting;

- Standardised certification and testing procedures for entire wind power systems. The type approval and certification system help to mitigate market barriers, e.g., the European network of tests centres with mutually accepted test certifications.

- Long-term: turbine and infrastructure to interact in closer co-operation; intelligent wind systems to interact with other power sources in a network; electricity storage technologies.

4. International Technology Collaboration: Grid Integration

Research on technology, tools and practices for the integration of wind power into electricity systems has lagged its explosive growth. The issues related to grid integration have gained more attention in the last few years as large amounts of wind power have been developed and ambitious targets or obligations for renewable energy for electricity supply have been adopted at regional, national and state levels.

4.1 Current Focus

In general, most of the international collaborative work specifically concerned with wind power and distributed generation integration into electricity supply systems now underway has a near- and medium-term focus. It can be categorised into four main areas:

1. Wind power prediction tools to improve forecasting for electricity production.

The intermittent nature of wind power and its non-dispatchability present relatively new challenges to grid system operators who must ensure that supply and demand are always in balance. Better forecasts for wind power production potential mean fewer network system imbalances. Analysis is also directed at how the costs for this balance management should be allocated: what is the value of the societal benefit of wind power; grid operators remit to treat all producers equally versus priority dispatch for renewables in some countries. Improved forecasting techniques are also relevant to increasing the value of wind power generation in liberalised markets where power is bid into a pool in day-ahead or other advance timing arrangements with affiliated costs for non-attainment.

2. Modelling and grid simulation studies to develop management tools and practices to ensure grid system optimisation.

3. Investigations and planning of designs to reinforce and extend the grid.

In some countries wind turbines have been developed in rural areas necessitating transmission to areas with higher demand. As well, the oldest and thus smallest turbines that are located at the favourable wind sites are being replaced by new ones with ten times the capacity, which can put strain on existing infrastructure.

Offshore wind developments will be large and require high voltage transmission capacity. New design parameters for incorporating distributed generation in grids are being investigated. Studies are also pointing out the need for better integration of wind power development and grid infrastructure needs as wind power can be developed very quickly, even in large quantities, but planning, licensing and construction of grid infrastructure can be a long-term process.

4. Analysis and development of grid access rules, technical code requirements and international standards.

In the early years of wind power development the technical aspects of grid connection were largely a matter of local concern with utilities and grid operators. With growth in wind power, grid operators become more concerned with wind turbine effects on grid safety and reliability. Currently most grid operators have their own technical requirements for interconnection. This imposes additional costs on turbine manufacturers as they have to adapt their products to local requirements. The need for certified testing procedures and additional international standards are being addressed in several collaborative efforts.

4.2 Collaborative Research Groups

As wind power penetration levels have grown and the technical complexities of incorporating large amounts of intermittent resources have increased, along with restructured electricity markets in some countries, the scope for collaboration has expanded. As well, a need to redress the lag between adaptability of traditional electricity supply systems and the influx of wind power generation at average annual rates exceeding 20% in some countries, have fostered more co-operative research at national, regional and international levels.

A number of groups conduct research and share experiences related to several of these priority topics. Table 2 summarises the nature of selected collaborations. Profiles of the organisations and consortiums are included in the appendix to provide additional information on the nature, objectives and participation in the research efforts.

The **International Energy Agency Wind Implementing Agreement** (IEA Wind) has been active in international collaborative RD&D for more than a quarter of a century. IEA Wind includes 19 countries and the European Commission. Wind power forecasting and modelling for grid system optimisation are the focus of a research task initiated in 2002. The task is a co-ordinated effort to develop and validate models for evaluating dynamic and transient stability. The aim is to provide the basis for a best practice guideline on grid connection of large wind farms. Eight European countries and the United States participate through their representative organisations in this task. The project runs from 2002 to 2005 and the combined labour contributed may amount to about 20 person-years of effort over the period. Results are to be shared among participants and disseminated in international fora.

The **Risø National Laboratory** has been a key institution that has undertaken basic and applied wind RD&D since 1977. Currently Risø, in co-operation with scientific centres in five countries and industry partners, is co-ordinating a project titled, “Wind Power Integration in Liberalised Electricity Markets”. Its aim is to develop a planning tool for grid integration of large amounts of wind power and economic analysis of the costs of grid integration in electricity markets. The project was launched in 2002 and results are expected in October 2005.

The **Institut für Solare Energieversorgungstechnik** e.V. (ISET) is engaged in applications-oriented research and development in the areas of renewable energy and decentralised power supply engineering. ISET is a technical institute that collaborates with other research groups and industrial partners around the world. Forecasting and balance management are focus areas for the research. General research results are available in publications and project partners have access to details. In 2003, an ISET initiative established the European Academy of Wind Energy among leading R&D institutes.

Dispower is a consortium of research institutes, industry and government in eleven European countries that is concerned with grid reliability for networks with a high penetration of distributed generation. Started in 2001, it aims to develop equipment and systems to ensure effective and economical grid operation, adapt test centres and provide training. In 2003, it adapted a wind power prediction tool for market-based trading in an electricity pool. It is available to wind farm operators, grid system operators and energy traders on a licence basis. Generally, results are made available in publications and project participants have access to details.

The **Utility Wind Interest Group** (UWIG) started as a wind power educational and experience-sharing forum for utilities and has evolved to include research and analysis of wind technology for utility applications. Membership has been predominately US utilities with associated members from industry, government and academic institutions, however, Électricité de France and ESB National Grid (Ireland) recently joined. UWIG has conducted studies on the costs of ancillary services (reliability services of regulation and reserves) for wind developments and compared results with other domestic and international studies that use various analytical approaches. This has led to additional grid integration studies. Results are available to UWIG members along with technical assistance.

Network operators increasingly in collaborative modes are examining grid reinforcement and extension design and planning, and network operation with wind and other renewables generation. An example is the **European Transmission System Operators** (ETSO), founded in 1999, as an association that represents the transmission system operators in continental western and central Europe. It aims to facilitate the European market for electricity investment and solutions of scientific and regulatory issues in areas such as wind power integration and related grid infrastructure. It also conducts research and provides recommendations for interconnection rules for large-scale wind power plants.

In addition to ETSO and several other groups, the **International Council on Large Electric Systems** (CIGRE) is a network that supports work on the development of internationally accepted standards and benchmarks for wind power systems. CIGRE provides for an exchange of information on research projects and best practices and a forum for disseminating technical information to a targeted audience in 80 countries. It conducts analyses in order to provide recommendations for grid access rules.The results of work conducted as part of the 2002-2006 strategic plan on distributed generation are available to members and are published in technical documents that are available to the public.

The **International Electrotechnical Commission** (IEC), is an international body that develops standards through its working groups. Research institutes, associations and insurers in Europe and the United States, lead the working groups for wind turbine standards. Risø National Laboratory participates in six IEC working groups on wind power standards. Risø's technical expertise has significantly influenced the development of standards and test certification procedures for wind technology around the world.

4.3 Observations of Collaboration on Wind Power Grid Integration

While this survey of collaborative efforts related to wind power grid integration does not portend to be exhaustive, several trends can be observed:

- Research and technical studies, collaborative or otherwise, on electric power grid integration, reliability and infrastructure issues for large amounts of intermittent and distributed generation generally have lagged the rapid deployment of wind power.

- Current research underway on wind power integration into electricity systems is focussed on near-term issues, e.g., grid optimisation, wind power prediction tools.

- Strategic longer-term R&D priorities for grid integration of wind power have been identified by research consortia and industry associations, but the bulk of research activities address near-term issues.

- Government support for RD&D has played a critical role in wind turbine and system component technical advancements and deployment, as well as resource assessment. It continues to do so in a number of areas. However, governments' role in grid integration research is not as predominate.

While government institutions support and participate in grid integration related research, there is a wider circle of electric power and wind industry, and grid operators actively involved. This reflects the growing maturity of the technology (onshore wind). The pattern is similar to large hydropower, a mature renewable energy technology, where RD&D has been provided by utilities, turbine manufacturers and other industries related to electricity system infrastructure. It reflects the usual progression that as a technology advances on the path from R&D to commercialisation, there is a shifting of costs and risk from government to industry.

- The incentives for research groups, governments, electricity supply and wind industries to collaborate include the need to "learn" from technical and operational solutions and failed approaches from others, to gain efficiency through the synergistic effects of collaboration such as the validation of models for wind farm dynamics and grid operation, to address common technical challenges across a wide market area, to facilitate achievement of national/regional goals and commitments for renewable energy and greenhouse gas emissions, and to provide technical expertise for regulatory and standards setting processes.

- While there is some broadly international collaboration on wind power grid integration research, a good deal of collaborative efforts tend to reflect the footprint of the impacted electricity supply market, the rate of development and penetration levels of wind power. With 75% of global installed wind capacity in OECD countries in Europe and much of it being brought on-line since the late 1990s, perhaps it is not surprising that a considerable amount of the research on grid integration is in Europe.

Table 2: Selected Collaborative Groups Involved in Grid Integration Research

Name	Founded	Primary Mission	Scope	Participants	Date: Grid Integration	Horizon: Grid Integration	Support	Access to Findings
IEA Wind Implementing Agreement	1977	Cooperative wind energy R&D	International	19 countries & EC	2002 (Annex XXI)	Near-term & Long-term	Participants financial and in-kind contributions	Participants
CIGRE	1921	Progress in engineering power systems	International	5 000 members in 80 countries	2002	Near-term & medium term	Participants in-kind contributions	Published in technical brochures
ISET	1988	Renewable energy R&D for power system engineering	Primarily Europe	Technical universities, R&D associations & industry	1995	Near-term & medium term	German state of Hesse, industry partners & EC	General results are published, details for participants
Dispower	2001	Research consortium to support grid integration of distributed generation	Europe	38 partners from 11 countries from technical universities, electric supply industry, government	2001	Near-term	~ 50% EC funding for research institutes & partner in-kind contributions	General results are published, details for participants
Risø National Lab (DK)	Lab: 1958 Wind Dept: 1977	Government research institute. Basic & applied wind energy R&D	Denmark & international	Collaboration with national & international research organisations & industry	1999	Near-term & medium term	Overall wind dept: ~85% from programme & commercial contracts; 15% DK government funding	Results are generally published
National Renewable Energy Lab (US)	1977	Government research institute. Basic & applied wind energy R&D	Primarily United States	Collaboration with national research organisations & industry		Near-term & medium term	Government funding	Public
UWIG	1989	Wind Research & utility experience sharing	Primarily US. Recent international members	Utilities, research organisations, industry, government	2001	Near-term & medium term	Participants financial and in-kind contributions	Members

(***See the appendix for profiles of the groups and their wind power grid integration activities***.)

5. General Conclusions

- As the fact that wind power developments have outpaced resolution of grid integration issues shows, it is important that policy programmes to assist in building new markets and transforming existing markets must engage stakeholders all along the commercialisation chain in an integrated and pre-emptive fashion. Policy designers must understand the interests of those involved in the market concerned and there must be clear and continuous two-way communication. In the case of wind power integration, this has fairly recently brought a widening circle of grid operators, utilities and other market players into international collaborations.

- Technology development is a continuum that spans from RD&D through market deployment. Policies that support deployment, whether for renewables or other low-carbon technologies, should be tailored to maximise the benefits of market experience or "learning". This underpins the need for collaboration in the deployment phase, as well as the RD&D phase.

- The optimal means of wind power integration depends on available local energy resources, local energy needs, regulations and the power exchange possibilities. Efficient collaborations require similar problems and options. So, as largely for wind, other clean energy technology collaborations at the market penetration phase may develop in international clusters that share common characteristics.

- Countries rarely believe themselves so dominant in a technology field that they are not willing to participate in international collaboration for fear of losing a competitive advantage. Many countries and their research and industry groups find it mutually beneficial to collaborate in order to accelerate the diffusion of information on technological and best practice innovations.

- Collaborative research groups have initiated new tasks and new consortia have been formed to address recently emerging concerns of grid integration of significant amounts of wind power in electricity supply systems. The incentive for collaboration is that through combined efforts, solutions can be more readily and efficiently identified.

The potential benefits of international collaboration in the RD&D phase for emerging low-carbon energy technologies include: reducing national R&D costs through sharing tasks, strengthening national RD&D capabilities by learning from others, enhancing the quality of RD&D output, wider dissemination of results and hedging of technical risks. The potential benefits of international collaboration in the deployment phase include: reducing national deployment support policy costs, acceleration of market learning effects, faster development of an international market underpinned by universal standards and codes, elaboration and adoption of best deployment practices to reduce policy failures, pooling resources and strengthening efforts to support institutional and capacity building in non-Annex 1 countries.

6. Appendix

Profiles of Selected Collaborative Research Groups:

- International Energy Agency Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems
- International Council on Large Electric Systems
- Institut für Solare Energieversorgungstechnik
- Dispower Consortium
- Risø National Laboratory
- National Renewable Energy Laboratory
- Utility Wind Interest Group

International Energy Agency Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems (IEA Wind)[9]

The Wind Implementing Agreement has framed active international collaborative R&D efforts for 26 years. Its mission is to stimulate R&D co-operation and to provide high quality analysis and information on technology development and deployment and its benefits, markets and policy instruments to member governments and commercial leaders.

In the early 1970s many government research programmes included wind for power generation: building prototype turbines and performing tests, but budgets were limited and results were slow to reach other researchers. In the wake of the oil supply crisis in 1973, increased focus was directed to alternative energy development. In 1978, ten countries came together and set out frameworks for co-operative efforts. Initially there were two implementing agreements: one concerned with megawatt-scale wind turbines and the other with wind energy development in general. In 1991, the two Agreements were joined to form IEA Wind.

Over the years, the IEA wind agreements facilitated international collaboration that accelerated development of advanced wind technologies, avoided costly duplication of effort in national programmes and increased the research labour hours available to individual programmes. Of the 39 GW of global wind capacity in 2003, some 90% is installed in the member countries of the IEA Implementing Agreement.[10]

Co-operative research tasks have been a vital tool for advancing wind technology. Four R&D tasks were included in the original implementing agreement and seventeen have been added over the years. At the

[9] Lemming, J., Thor, S., *Twenty-Five Years of Successful Co-operation: IEA Implementing Agreement on Wind Energy Systems, Annual Report 2002, IEA Wind.*

[10] In 2003, Wind Implementing Agreement members included Australia, Austria, Canada, Denmark, European Commission, Finland, Germany *, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Mexico, an OECD, but not an IEA member country, also participates. * Germany withdrew in 2004.

outset, tasks were cost-shared and participants paid an operating agent to perform most of the work and all shared the results. Tasks evolved from cost-shared to task-shared: participants contributed labour and facilities to a joint programme co-ordinated by an operating agent. Up to ten labour-years of effort in each country would be applied per task. The return to each country has been those labour-years multiplied by the number of organisations working on the task. For some tasks, participants received a ten-fold increase of their labour efforts. Some research has been conducted in combined cost- and task-shared activities in which participants paid an operating agent to synthesize data generated with labour within participants' own research laboratories.

Participants have developed several mechanisms to enhance information exchange and co-operative R&D and these tools have evolved to reflect changing R&D interests. They include:

- Regular meetings of the executive committee to manage the work and to freely share research results. Since 2000, the annual report is a public document posted on the web.

- Expert meetings on narrow topics of interest to broaden perspectives and serve as a review of state-of-the-art technology and practices.

- Recommended practices such as standardised testing procedures for turbines.

- Specialised communication such as joint action symposia for specific research areas for which a periodic exchange among experts is needed, but that demands less time and money than an official task activity.

Every five years the implementing agreement members develop near-term and long-term strategic plans and identify R&D needs. The Strategic Plan for 2003 to 2008 sets grid integration of wind into national and international electricity supply systems as a priority area. It notes that development of validated models that enable network operators to reliably predict and regulate system behaviour will greatly reduce resistance to the continued expansion of both onshore and offshore wind power. Further it states that advances in system integration will have a strong influence on policy decisions over the next ten years and will be a key factor in accelerating wind power deployment.

Consequently Annex XXI – "Dynamic Models of Wind Farms for Power System Studies" was approved in 2002. This effort is expected to enhance progress through international collaboration. A diversity of views have been expressed about the levels of confidence that can be placed in models that simulate the interaction of wind farms with the grid, particularly for large wind projects. For example, progress on two large wind farms was halted in Ireland because of concerns about grid interaction. Yet participants at the first Annex meeting heard that dynamic models have been used with confidence to accept large wind farms in Texas.

By facilitating a co-ordinated effort to develop wind farm models suitable for evaluating power system dynamic and transient stability, the results of the work will assist in the planning and design of wind farms. The task has participants from nine countries (Denmark, Finland, Ireland, Netherlands, Norway, Portugal, Sweden, United Kingdom, United States) with research institutes and universities carrying out the work to develop and test wind farm models, as well as doing grid studies in co-operation with wind turbine manufacturers and utilities.

As wind generation has become a mainstream technology, issues of power variability and scheduling have produced a keen interest in the potential for combining wind generation and hydropower systems. In 2003 a Topical Experts meeting was held. Participants concluded that formal collaboration on wind/hydro integration would be beneficial and the first meeting was held in February 2005. Annex XXIV –

"Integration of Wind and Hydropower Systems" has participants from seven countries (Australia, Canada, Finland, Norway, Sweden, Switzerland and the United States) which will contribute to case studies that specifically look at grid integration of wind power. The work will focus on wind and hydropower integration issues, hydrologic impacts, market, economics and modelling.

Since the wind implementing agreements began their co-operation more than a quarter of a century ago, wind turbine technology has advanced from a few prototype machines at government test sites to a significant commercial industry. Some essential features of these successful collaborations have included:

- Interested and active participants: participants send information to the operating agent and/or perform tests and measurements.

- Involvement of users: representatives from industry, utilities, research institutes, universities and government organisations participate in planning and execution of tasks.

- Well-defined scope: the number and type of subtask topics are limited and the work of participants is defined clearly.

- Multidisciplinary approach: participants take work from other fields and apply to wind.

- Multi-national approach: participants take a model or tool developed in one country and apply it in other countries.

- Dissemination of results: results are published or presented at international conferences, Topical Expert meetings, in annual reports and on web sites for members and the public.

Web reference: www.ieawind.org

International Council on Large Electric Systems (CIGRE)

CIGRE is a non-profit organisation with about 5 000 members in 80 countries. Founded in 1921, its aim is to facilitate and promote progress in engineering related to electric power systems and the international exchange of technical knowledge. Traditionally it has focussed on generation and high voltage transmission. Market restructuring, increased attention to environmental and social factors and new actors conducting business in the electricity supply sector, led CIGRE to expand its field of activity in 2002 to include all aspects of electric systems, adding distribution systems and demand.

CIGRE noted the concerns that the changes in the electricity sector posed for distribution utilities and transmission system operators as a growing number of small- and medium-size generators integrate at various grid levels. In 2002, a CIGRE Study Committee established a strategic plan for 2002-2006 for work under the rubric "Distribution Systems and Dispersed Generation". Its aim is to synthesise state-of-the-art practices, exchange information on research projects, support the development of internationally accepted standards and benchmarks, and provide recommendations for grid access rules. The first report deals with uncertainty from the rapid increase in wind farms and recommends standards for grid code requirements. The working group noted that the changes in wind power development are so rapid that the review will need to be updated in one year to 18 months time.[11]

As the integration of distributed generation is viewed as a radical change in the development and operation of distribution networks and ambitious plans for wind power development that will affect whole electric systems, the collaborative actions undertaken have a short-term perspective. Several activities have been completed and six working groups will complete additional tasks in two to three years. In addition, four areas for action with a medium-term perspective have been set. About 100 experts are involved from utilities, grid operators, research institutes in some 30 countries, of which about a quarter are non-OECD member countries.

Working groups, such as “Connection and Protection Practices for Dispersed Generation”, bring together experts from fifteen countries, are open to CIGRE members who generally cost and task share. Another working group, “Development of Dispersed Generation and Consequences for Power Systems”, includes members from Australia, Greece, Italy, Japan, Netherlands, Norway, United Kingdom and United States, with co-operation from Canada, Denmark, Germany, Israel, Korea and South Africa. When actions are completed and approved by a Study Committee, the results are published in the CIGRE journal ELECTRA and as a CIGRE technical brochure, which are available to the public.

CIGRE provides a forum to unite key partners and disseminate technical information to a very targeted audience. In its view, international technical collaboration is particularly beneficial since the energy and environmental problems that stimulate dispersed generation are global issues. The main benefits of the CIGRE collaboration on integration issues come from exchange of best practices and lessons learned in various countries, and increased awareness.

Web reference: www.cigre.org

Institut für Solare Energieversorgungstechnik

The Institut für Solare Energieversorgungstechnik e.V. (ISET) is engaged in applications-oriented research and development in the areas of renewable energy and decentralised power supply engineering. Activities include theoretical investigations, experimental studies, field tests and the development of components and systems. ISET works closely with industry to produce practical applications for electrical and systems engineering.

ISET is a non-profit technical institute founded in 1988 with basic support from the German state of Hesse and is affiliated with the University of Kassel. Support also comes from industry partners and the European Commission. ISET is a member of many scientific associations and networks. It co-operates with many companies and R&D institutions all over the world. Its most important international collaborators are with technical universities, industrial partners and R&D associations, primarily in Europe. An example of successful co-operation on a European level is the *European Academy of Wind Energy*, which was founded in 2003 on an ISET initiative and sets up a “network of excellence” among the leading European R&D institutes in wind energy. The network provides joint training of PhD students, international training and joint research projects.

[11] CIGRE Working Group C1.3, *Electric Power System Planning with the Uncertainty of Wind Generation*, 1 March 2005.

ISET activities in wind energy focus on cutting costs, both of the technology itself as well as the costs of grid integration. For the later, the R&D activities include information systems, power management and grid optimisation. In association with industrial partners and other national and international research institutions, a sample of R&D themes is wind power predication tools for optimal power plant deployment planning, information systems for grid operation and integration of large-scale offshore wind power developments.

The R&D priorities are defined by ISET and are related to the R&D programmes of the German Government and the European Commission. The proportion of short-term versus long-term R&D for grid integration work is about fifty-fifty.

The project partners generally own the equipment and other products emerging from the R&D, but they often find wider applications. For example, ISET prediction and system management tools initially were developed in a research and evaluation project with the grid operator, E.ON Netz. These tools are now in use by all German transmission system operators to manage large-scale wind power feed-in. The details of ownership of software and tools developed with industry partners are managed by contract. General results are accessible to the public.

ISET is the lead organisation in Dispower: a research project concerned with grid reliability with a high penetration of renewable generation resources in the European grids. (see profile)

Web reference: www.iset.uni-Kassel.de

Dispower Consortium

Distributed Generation with High Penetration of Renewable Energy Sources

This research consortium supports the integration of renewable energy sources and distributed generation in the power supply of European interconnected and island grids. Its mandate states that in “planning such fundamental structural changes, a global approach that takes into account grid control methodologies, stability aspects, power quality and safety is indispensable”.

The Dispower Consortium is composed of 38 partners from the electric power industry, distribution and transmission system operators, service companies, the United Kingdom Met Office, numerous research centres and universities from eleven European countries. It is supported by the EU 5th Framework Programme to contribute to the implementation of Key Action 5 “cleaner energy systems”. The consortium was formed in 2001 and the research programme is expected to be completed in 2005. It is co-ordinated by ISET. (see profile)

Overall objectives of Dispower are to elaborate strategies for grid stability and system control in distributed generation networks, prepare safety and quality standards, develop planning and design tools to ensure reliable and cost effective integration in regional and local grids, adapt test centres and provide training. Activities to achieve these aims are carried out through eleven work packages. The consortium sets priorities on a broad basis to make use of different national resources. In each research area, experts are selected by the co-ordinator and they are the lead to design and organise the related work package by integrating additional specialists who take responsibility for specific subtasks.

For example, one of the work packages focuses on grid stability and control with an aim to develop equipment and systems to ensure that electricity networks with a high penetration of distributed renewable energy sources are operated effectively and economically. Twenty partners are collaborating on this work and they represent technical universities, electrical equipment designers and manufacturers, and international-scale and local utilities. Its eight tasks are supported with about 50% funding from the European Commission and 50% from in-kind contributions of technical expertise and facilities from the partners. Results from the projects are used in products and services produced and made available to the project partners as well as being offered to external parties. One example is the implementation of grid control algorithms for invertor-coupled generators.

Adaptation of existing professional tools for planning, design and operation of distributed generation grids is the focus of another work package that involves eight collaborators representing software development, industrial R&D, electrical equipment development and technical universities. One subtask successfully adapted a wind power prediction tool for market-based trading in an electricity pool in 2003. By correlating the relationships between variations in the meteorological data and the wind power output, the accuracy of forecasts have been improved for bidding into the pool and for network system control. This tool is available to wind farm operators, grid system operators and energy traders on a licences basis. Another tool has been developed to model the general dynamic behaviour of the major types of wind generators available today in order to perform grid connection studies for wind farms.

The primary incentive for participation in the consortium is to gain technological leadership in a rapidly progressing field. By establishing an interdisciplinary research community network, the project partners benefit from the combined know-how in the consortium and can avoid duplication of efforts.

Web reference: www.dispower.org

Risø National Laboratory

The Risø National Laboratory was founded in 1958 as a government institute and became the Danish Energy Research Laboratory. In 1977, wind energy resource assessment and testing activities were initiated. Since the establishment of the Danish Test Station for Wind Turbines at Risø in 1978, it has served as a vehicle for research and technological development. It is a key facility for the development of the international certification system and standards for wind turbines. Risø experts participate in various international committees to develop norms and standards that can be included in international certification schemes, which create a basis for a higher level of harmonising the wind turbine type approval systems in various countries.

The primary objectives of Risø’s Wind Department are to advance technological development and application of wind energy through R&D, educational activities and knowledge-based commercial services. RD&D activities range from boundary layer meteorology, fluid dynamics and structural mechanics to power and control engineering and wind turbine loading and safety. Risø takes part in international wind RD&D, turbine projects and in the solution of problems encountered in the application of wind power such as grid integration. Funding for the Wind Department is about 85% from programme and commercial contracts and 15% from the Danish Government.

Risø is the lead organisation for the collaborative research project, “Wind Power Integration in Liberalised Electricity Markets” (WILMAR). The key task of the project, in which three industrial partners collaborate with scientific institutions in five countries, is to analyse the integration of wind power in a large liberalised electricity system covering Denmark, Finland, Germany, Norway and Sweden. Launched in November 2002, the project is to investigate the technical and economic problems related to the fast introduction of large amounts of wind power. WILMAR is expected to develop a planning tool suitable for the analysis of the integration of renewable power technologies to be applied by system operators, power producers and energy authorities; to quantify the costs of integration of high shares of wind power in an electricity market; and to make recommendations about the usefulness and performance of different types of integration measures. Results are expected in October 2005.

Risø wind energy projects and services have been carried out in more than 50 countries across all continents, typically in the form of feasibility studies, project design, wind measurements, technical specifications and performance verification for wind farms. Institution building and capacity building in national technology centres and with authorities, particularly in India and Egypt, have been major activities since the late 1990s.

Risø has been involved in the acceleration of wind power in India for more than a decade. Technical assistance has been provided for the establishment and operation of the government institution Centre for Wind Energy Technology (C-WET) – a national test station with facilities for testing and certification of wind turbines and the capacity for monitoring their technical performance. Since late 2003, C-WET has been functioning as a full professional organisation with a provisional turbine type approval system. A final type approval system based on international standards will be implemented soon.

Growth in wind developments in some regions of India outpaced the capacity of the grid to evacuate the power. This caused outages and reduced the return from the wind farms. In 1998, C-WET and Risø collaborated on a research project to study wind power integration in weak grids in India. It developed recommendations related to wind turbine practice and grid connection. The findings and recommendations have been disseminated to industry and electricity boards, and are published.

Web reference: www.risoe.dk

National Renewable Energy Laboratory (NREL)

Since 1980, research and testing sponsored by the US Department of Energy Wind Program has helped to reduce the cost of wind energy in the United States and one of the programme goals is to further reduce the cost of utility-scale wind energy production. In addition, the programme works to address market barriers and facilitate the increase of wind energy capacity. To accomplish these goals, two research laboratories, the National Renewable Energy Laboratory (NREL) and Sandia National Laboratory, work with private industry partners and researchers from universities to develop advanced wind energy technologies. The objectives of the research programme have a domestic focus and technical and scientific results are disseminated in forums relevant for worldwide distribution. International collaboration is largely through the IEA implementing agreement. The wind energy research conducted at both laboratories is divided into two main categories: *Technology Viability* and *Technology Application*.

As part of NREL, the National Renewable Energy Laboratory Wind Technology Center (NWTC) conducts research and provides industry partners with support in design and review analysis; component development; systems and controls analysis; structural, dynamometer, and field testing; certification; utility integration; resource assessment; subcontract management; and technical assistance.

Technology Application at NREL includes systems integration which aims to help remove market and institutional barriers to wind turbine deployment. NREL also assists in the testing and analysis of solutions to current operational challenges. For example, NREL is involved in research related to grid integration and documentation of advances in the related technology. The programme co-operates with industry partners and major industry organisations such as the American Wind Energy Association, the Utility

Wind Interest Group, the National Wind Co-ordinating Committee and in the IEA Wind collaboration. Systems Integration research includes grid integration, modelling and market assessment.

Utility Grid Integration

The integration of wind energy into the electric generation supply mix is an issue that industry grapples with. Research conducted at the NWTC aims to increase the understanding of integration and valuation issues, especially performance and operation of modern wind farms. Researchers work with wind developers and electricity suppliers, using a range of methods, tools, and analyses to further the understanding of the economic and operational effects of wind generation on the electric supply system.

Wind Farm Model Development

Different wind farms are connected to various kinds of utility grids. The NWTC studies the behaviour of power systems under different conditions to identify grid stability and power quality factors that factor into the development of wind farms.

Planning Models and Operations

Researchers are studying how multiple wind power plants or multiple wind generators smooth each other's output in a variably windy environment. Output variations are also being studied in the context of wind farm integration into utility grids.

Market Assessment

Technical improvements in wind turbines have brought the cost of wind power very close to a competitive level with traditional forms of energy generation. This decrease in cost coupled with increased consumer demand for green power means the market for wind power is growing. The goal of this activity is to assess and monitor the domestic and international markets for wind technology in a changing business and policy environment. The impact of future market developments is also being assessed to inform the US wind industry of technological requirements for successful wind power development.

Web reference: www. nrel.gov.wind

Utility Wind Interest Group

The Utility Wind Interest Group (UWIG) was established in 1989, as a non-profit corporation, largely for utility self-education and sharing experiences related to wind power. This role has evolved to addressing research topics and providing knowledge. UWIG provides a forum for the critical analysis of wind technology for utility applications and to serve as a source of credible information on the status of wind technology and deployment. The group holds technical wind forums, organises research projects related to wind power integration and engages in other technical programme activities through the co-ordinated efforts of its members. It operates in collaboration with the US Department of Energy and its National Renewable Energy Laboratory, which provide co-funding for the group.

The UWIG currently has 68 members, including investor-owned and public utilities, as well as associate members from industry, grid operators, government, and academic organisations. Until recently, UWIG membership has been almost entirely US-based utilities and organisations. However, in the last two years, Électricité de France and ESB National Grid (Ireland), and the Independent Electric System Operator (Ontario, Canada) joined the UWIG. This reflects the growing interest internationally in collaboration to better understand and address the issues associated with incorporating increasing amounts of wind capacity into utility systems.

Grid integration issues are a major focus of the UWIG, which participates in funded studies and provides a forum for discussion at both domestic and international levels. There is a growing effort to identify issues important to the industry and take actions to understand and resolve them before they become barriers, addressing near-term issues first by necessity.

UWIG's "Operating Impact and Integration Study" user group has sponsored work since 2001 on the cost of ancillary services (regulation and reserves) for wind plants, which stimulated a number of related studies. The studies examined utility systems with different mixes of generating resources and have employed different analytical approaches. The user group has compared and analysed the results of different studies done in the United States and abroad. Comparison of study results has led to several insights:

- The incremental costs of ancillary services attributable to wind power are low at low penetration levels and rise with increasing levels of penetration

- Costs are driven by uncertainty in wind plant output in the unit commitment time frame. There is significant value to a good wind forecast to reduce the associated cost of uncertainty

- Even at moderate wind penetrations, the need for additional generation to compensate for wind variation in the hourly time frame is substantially less than one-for-one and is often closer to zero, given the normal operating reserves already being carried by the utility

Results of the work conducted by the user groups are provided to the UWIG members. In addition, the user groups identify gaps in the work that need to be filled, and help UWIG members to understand the application of results to their own situations. UWIG members set research priorities. Projects are carried out with a combination of consultants and volunteer labour, with funding solicited from member organisations and industry associations. Results are first made available to UWIG members, and later to the general public. The primary incentive to belong to UWIG is to help identify, understand, and resolve important issues associated with the interconnection and integration of wind plants on utility systems.

Web reference: www.UWIG.org

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