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MEASURES AND SUPPORT INITIATIVES

TO IMPLEMENT THE CAMPAIGN FOR TAKE OFF – BUSINESS PLAN

Study 4

„Increasing the Penetration of Wind Energy in the European Electricity Network“

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1 Problem Analysis and Objectives of the Study

Various electricity utilities in Germany, as well as in other European countries, are expecting a future wind power share of 20-30 percent, compared with total annual electricity production. Some regional utilities are already facing installed wind capacity in the range of their minimum load. The Danish government has already officially announced a wind power share of 50 per cent by the year 2030.

Because of the stochastic time series of wind power production with (single) wind turbines, utilities often treat wind power as reliable power to only a limited extent. In this context, the following consequences of increasing the penetration of wind energy are repeatedly mentioned by grid operators:

- Reduced efficiency of conventional power plants,
- Increase of necessary reserve power.

It should be noted that these reservations are only relevant for a market penetration of 20 per cent or more. In any case, a much more positive value of wind power can be attained, however, if wind power fed into electrical networks is as reliable as that of conventional power plants. Therefore, power variations should be foreseen by the grid operator with sufficient reliability. Therefore, with an increasing share of wind power penetration power prediction and monitoring systems are becoming more and more important, as well as measures for network support, complementary power plants and – where required – energy storage units.

Furthermore, the ongoing liberalisation of energy markets imply structural changes to the electricity supply system, which will provide new possibilities for independent power producers (IPP), power trading, power stock markets, etc. These new market participants will also strive for secured offers of electricity.

The study presents the current status of wind power use as well as ongoing developments and aspects of further research demand in the fields of

- wind power monitoring systems,
- wind power prediction,
- measures for network support,
- complementary power plants,
- energy storage in combination with wind turbine operation.

Furthermore, a comparative analysis of the major support schemes for wind power gives valuable insights regarding the question of supporting the further wind power development.

2 Introduction

2.1 Past, Present and Future Development of Wind Energy Use

2.1.1 Historical Overview

At the end of the 70's and during the 1980s, several European countries started with their first wind energy programmes. Most of them tried to develop – at the time - very large wind turbines in the megawatt range, with limited success, though. Utility companies preferred to test large systems in the MW class which, however, never left the prototype stage. The introduction of this converter technology at the beginning of the 80's was facing a number of problems. Tested calculation methods for system dimensioning were lacking and experience from previous models, regarding construction and operation, could not be referred to. Furthermore, it became clear that larger converters would face completely new technical challenges.

On the other hand, small converters in the 10 to 50 kW class were being developed and installed at that time, most of them in Denmark and mostly for agricultural operators.

Converters of the 50 kW class dominated the market at the beginning of the first wind energy boom in California, too. Their up-scaling into the 200 kW class occurred a few years later in the mid 1980s. By the end of the 1980's, some 16,000 converters with a total capacity of 1,500 MW, had been installed in the USA, mainly in California. The reliability figures of present converters could, however, not be met in these days.

In Europe, Denmark continued its successful policy of evolutionary growth and a clear political commitment for wind energy. It remained the leading wind country for wind power until the early 1990s. In 1991, the small Scandinavian country was responsible for two thirds (360 MW) of the total European wind capacity. Germany and the Netherlands came next with 55 MW each. Meanwhile the picture has changed quite dramatically, especially due to the massive growth of wind energy in Germany and an increase in turbine size.

In the early 90's, the 300 to 500 kW class started to be successfully introduced in Europe, marking the beginning of the wind energy boom in Germany. During its rapid development, the German WT industry successfully caught up technologically and has arrived at one of the leading places in the global wind energy market, particularly with innovative converter concepts. The mid 90's marked the development and installation of the 1 - 1.5 MW plants in Germany. This development was made possible by widely secured markets.

Two decades of plant development and operation have not only influenced turbine size, but also the technological features of modern wind turbines. The three-bladed turbine is now dominant for all power classes. Converters following the Danish concept, with stall control, gearbox and direct grid connected induction generators, are in the majority. For larger units, plants with pitch control and variable speed concepts, especially those constructed without gearboxes, are achieving growing proportions of the market. Therefore, a clear trend can be observed with the Megawatt converters, toward innovative concepts with correspondingly good prospects for their manufacturers.

2.1.2 The Market

The four largest markets for wind energy in the 1990s - Germany, USA, Denmark and Spain - accomplished approx. 80 percent of global sales in 1998 (see Fig. 1). At the beginning of 1999, the border-line of 10,000 MW of global wind capacity was exceeded.
The four largest manufacturers are supplying approx. two-thirds of the world market. Danish manufacturers are responsible for about half of the world market share. Their export share amounts to an average of well over 70 percent.

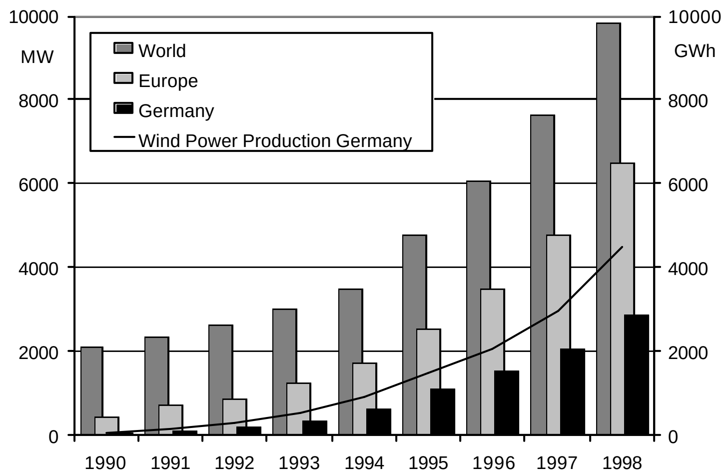


Fig. 1. World-wide growth of wind energy 1990-1998 [5]

Compared with the global image, a similar picture can be drawn for the European market, which hosts two-thirds of the total global wind power capacity. The average growth rates during the 1990s are close to those of the computer industry, or the booming telecommunications sector (see Table 1). Within only six years, between 1993 and 1998, installed capacity in Europe quadrupled and, when compared with the early 1990s, it increased tenfold.

The technology is available and continuously improving, costs have fallen substantially, and public opinion is overwhelmingly positive towards renewable energy sources. It can be seen, that the German market steadily has accounted for almost half of the total European market after 1995, while it was comparably smaller in the years before.

The three leading countries Germany, Denmark and Spain combined cover more than 80 percent of the total European wind capacity of 1998 (see Table 2). A calculable, legally established minimum price which is known in advance by all existing and potential operators, investors and banks, is common for all three countries. The level of this renewable energy feed-in tariff (REFIT) - a compensation for market distortions and non-internalisation of external social and environmental cost - is calculated in such a way to ensure economic plant operation at good locations. This is best reflected in the growth rates of wind energy in Germany which contributed half of total European wind energy capacity in 1999. Average German growth rates exceeded 50 per cent between 1993 and 1999, while in the EU they amounted to 38 per cent during the same period.

Year	EU - New MW/Year	EU – Installed Capacity (MW)	EU - Annual Market Growth	Germany - New MW/Year	Germany - Installed Capacity (MW)	Germany - Annual Market Growth
1993	332	1,245	36 %	143	337	74 %
1994	448	1,693	36 %	295	632	88 %
1995	836	2,529	49 %	487	1,119	77 %
1996	967	3,496	38 %	431	1,550	38 %
1997	1,199	4,705	34 %	507	2,035	33 %
1998	1,598	6,303	34 %	812	2,846	40 %
1999	2612	8,915	41 %	1,569	4,444	55 %
Average Market Growth in Europe 1993-99			***38 %***	***Average Market Growth in Germany 1993-99***		***58 %***

Source: Wind Directions, BTM Consult, FGW

Table 1: The Development of Wind Energy in Germany and Europe (1993-1999)

Countries with a vast wind energy potential however, e.g. Great Britain, Ireland or France, have achieved only less than a tenth of the installed wind capacity of the previously mentioned group of countries (see Table 2), even though the land area and population of both of the depicted country groups are very similar. Competitive bidding models are practised in the three latter mentioned countries. The contracted annual wind capacity or the percentage is pre-determined by the respective government. Only the most economical bids receive a power purchase contract. The resulting massive price and competition pressure leads to strong concentration effects, both in terms of locations and operators. Consequently, acceptance in the local community suffers seriously. Because of this, neither a considerable wind energy capacity has been installed so far, nor a healthy domestic industry has yet been established in these countries - despite repeated public commitments for renewable energy and excellent wind conditions.

Group	Countries	End of 1998 (MW)	Growth 1998 (MW)	Installed Capacity (W)/Inhabitant	Installed Capacity (kW)/ km^2
Countries with Price Regulation (Feed-in Tariff)	Germany	2,875	793	35.3	8.1
	Denmark	1,441	300	277.1	31.4
	Spain	707	256	18.1	1.4
	Total	**5,023**	**1,349**	**40.0**	**5.4**
Countries with Quote Regulation (Competitive Bidding)	UK	325	13	5,6	1,3
	Ireland	63	13	17,5	0,9
	France	19	9	0,3	0,03
	Total	**407**	**35**	**3,4**	**0,5**

Source: Wind Directions, FGW

Table 2: Wind Energy in Selected EU Countries (1998)

2.1.3 Extension Scenarios and Perspectives

Since the mid 80's, the plant size of series produced wind energy turbines has increased by a factor of 30, from about 50 kW rated power to 1,500 kW rated power. With the wind energy turbines of the next generation, plants with a rated power from 3,000 to 5,000 kW are already being developed, with rotor diameters exceeding 100m.

Practical experience with wind energy use in Germany and many other countries has only been made with land supported systems until now. In the future, great expectations are set on the Offshore Technology. For this purpose, individual wind energy plants are being developed with power ranges of 1.5 to 5 MW for installation in coastal waters. Off-shore wind farms are already being developed in the range of several 100 MW, the largest project in size up to 1200 MW rated power. The off-shore technology offers, among other aspects, advantages such as excellent and more steady wind flows with little turbulence at sea, and less disturbance through sound emission.

The erection of plants at sea is fully realistic, following previous experience with existing pilot and demonstration plants in Denmark (see Chapter 4.4), Sweden and the Netherlands. The organisation of repair and maintenance for the plants, however, will be more costly and difficult. The same is true for higher infrastructure costs, especially with regard to foundations and electrical infrastructure. Remote monitoring and maintenance systems must help in reducing the personnel and time costs.

Depending on the future political framework conditions, a global wind power share of 10 percent could be realistically achieved by 2020, according to the latest studies. The growth in wind power will be distributed around the world, but the fastest rate of development is expected to be in Europe, North America and China. In Europe, more than 200,000 MW could have been installed by 2020 provided that the market growth continues at a similar rate than in the 1990s. Based on these assumptions, wind power is expected to grow at an annual rate of 20% between 1998 and 2003, resulting in a total of 33,400 MW of installed capacity around the world by the end of that period. To meet the 10% target, 30% annual growth from 2004 to 2010 is required, resulting in a total of 181,000 MW installed. From 2010 onwards, annual growth rates of 20% will result in a total of 1.2 million MW being installed globally by the end of the year 2020. This will generate 2,966 Terawatt hours of electricity, equivalent to 10.85% of the expected world electricity consumption. By 2040, wind power could be supplying more than 20% of the world's electricity. Even such a high penetration rate could be integrated into the existing electricity network without any major changes.

In its White Paper of 1997, "Energy for the Future: Renewable Energy Sources", the European Commission considers a total installed wind energy capacity of 40,000 MW (80 TWh) by the end of 2010. The following forecast shows that this scenario - based on the market growth in previous years - is fully realistic, even if the present growth rate should decrease substantially by 2010.

Period	Installed Capacity (MW, cumulated)	Total Growth (MW per period)	Average Growth (MW per year)	Average Annual Growth
1993-1997 (5 years)	4.705	3.792	758	38 %
1998-2000 (3 years)	10.337	5.632	1,877	30 %
2001-2005 (5 years)	25.721	15.384	3,077	20 %
2006-2010 (5 years)	41.425	15.704	3,141	10 %

Source: FGW

Table 3: Prognosis of Future Market Developments (EU until 2010)

2.2 The Largest Wind Energy Market in Europe and World-wide - Experiences Made in Germany

At the end of 1998, over 6,000 modern wind energy plants for electric power generation operated in Germany. Their installed capacity amounted to around 2,900 MW. One year later, at the end of 1999, the number of plants amounted to almost 8,000 with an output of 4,400 MW.

The characteristics of the cumulative wind power production depends on the regional distribution of wind turbine sites, and relates to their technical features. In 1998, the average rotor diameter of new installations has now reached almost 50 meters, the average rated power of new installations being 788 kW. In 1999, average rated power increased to 937 kW to almost one megawatt per turbine. The development of the average technical features of modern wind turbines in Germany, during past years, is depicted in Table 4.

	until 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Number of Newly Installed Wind Turbines											
	132	70	244	272	380	547	808	1017	811	810	1032
Number of Blades											
2 bladed	40%	20%	12%	16%	9%	8%	6%	2%	2%	0%	0%
3 bladed	58%	76%	87%	82%	90%	91%	93%	98%	98%	100%	100%
4 bladed	2%	0%	1%	2%	1%	1%	0%	0%	0%	0%	0%
Rotor Position											
down-wind	7%	19%	7%	6%	4%	2%	1%	0%	0%	0%	0%
up-wind	93%	81%	93%	94%	96%	98%	99%	100%	100%	100%	100%
Power Control											
stall	52%	39%	50%	57%	62%	65%	57%	55%	54%	44%	39%
pitch	48%	60%	50%	43%	38%	35%	43%	45%	46%	56%	61%
Type of Generator											
induction	64%	49%	74%	71%	71%	82%	75%	68%	68%	59%	63%
synchronous	36%	51%	26%	29%	29%	18%	25%	32%	32%	41%	37%
Speed Characteristics											
constant	56%	34%	64%	65%	66%	77%	71%	66%	67%	57%	54%
variable	44%	66%	36%	35%	34%	23%	29%	34%	33%	43%	46%

Table 4: Technical Features of Wind Turbines in Germany [3]

Currently, a share of 40 percent of all wind turbines, supervised by the German National Programme WMEP (Scientific Measurement and Evaluation Programme) is located along the North Sea and Baltic Sea coastlines and on the islands. About 35 percent of the total WT number is situated in the North German lowlands, and approximately 25 percent operates in low mountain ranges at altitudes of 200 to 1,100 metres.

Until now, a variety of manufacturers have been conquered their position on the growing

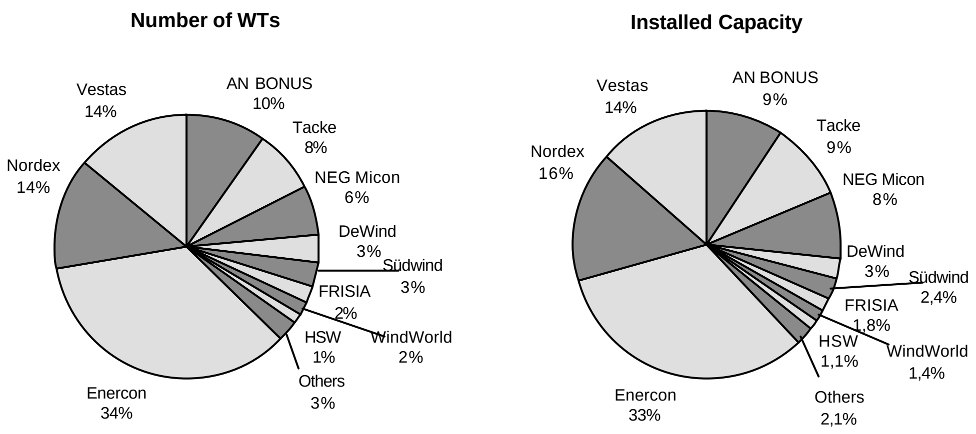


Fig. 2: Market Shares of New Installations (1998) in Germany [3]

German market, and most have continued to be active in the same segment of the market. All the plants ever installed in Germany, and most of them still operating, are from approx. 44 different manufacturers, about 17 of which were still active in 1998. Other manufacturers have either stopped working in this area completely or temporarily, or are still active under a different name after being bought or merged with another manufacturer.

Approximately 86% of WTs installed in 1998 were manufactured by six German and Danish companies. Changes in ranking from the previous year arose especially from the market losses of co-operating firms AN Maschinenbau and Bonus, which fell from 16% to 10%. Nordex was able to double its market share with a rise from 7% to 14%. The other three manufacturers held their shares in approximately the same proportions. In measuring the overall position of WTs installed in Germany, it is clear that these six manufacturers are in the top position with a market share of 80% (Fig. 2).

2.3 Liberalisation of Electricity Markets

Since the end of the eighties, it has been clear to the European Commission that a Single European Market would also require liberalising national energy markets. Due to the magnitude of this undertaking, and the different structures and mentalities of European electricity supply systems, the Single Electricity Market Directive was not adopted by the EU Energy Council before December 20, 1996, following several years of debates and intense negotiations. [6]

Member States were given time until February 19, 1999 to incorporate the Directive into national legislation, except for Greece, Ireland and Belgium who have been given respectively two years and one year more time, due to their special infra-structural / political circumstances. Being merely a framework with a few key stipulations, the Directive is in fact a system of joint basic rules allowing the individual Member States considerable scope for interpretation.

This applies particularly to the degree of market opening. Only minimum shares are foreseen in the beginning: around 25% in the first year, 28% by 2000 and 33% in 2003, i.e. one third of the European market. Further deregulation is planned for 2006. These guidelines do not preclude further-reaching deregulation at national level. Most Member States will undoubtedly go beyond the minimum levels. In a report on the status of liberalisation of national electricity markets, published at the beginning of 1998, the European Commission assumed that at least 60% of the EU electricity market will be deregulated by the end of 1999, even with conservative estimates.

2.3.1 Liberalisation in Individual European Countries

Scandinavia

In Sweden all consumers have been entitled to choose their electricity supplier since January 01, 1996, and in Finland since January 1, 1997. Without being a member of the EU, but intimately linked with power supply in Europe, Norway radically deregulated its electricity supply industry in 1991 and since January 1, 1997 all customers have been able to change their supplier at will and free of charge. Denmark will achieve deregulation of almost 90% by admitting industrial customers, with an annual consumption of 100 GWh and upwards, and all distribution companies.

Great Britain

Deregulation began in 1989, with the division of the principal generator in England and Wales - the Central Electricity Generating Board (CEGB). The generation business was split three ways and the transmission business was separated out and placed under the control of the National Grid Company. Shortly afterwards the Regional Electricity Companies were privatised and freedom of choice was gradually extended to all consumers. This process has now been completed, with consumers now able to choose from a wide range of suppliers. The market is also open to new generators, provided they satisfy appropriate technical conditions and obtain the necessary licenses.

The Netherlands

32% of the consumers have belonged to the initial "chosen few" as of 1998. By 2008, competition will be extended to all levels - down to the smallest consumer. In The Netherlands, the electricity sector has been entering its first round of privatisation. The five big distribution companies are in the initial phase of a program to sell the traditional shares of communities and provinces to private investors. Here, like elsewhere, the reasons are to strengthen the financial basis, to mass forces by the formation of (cross-border) alliances, and to utilise the market experience of new partners. The Dutch seem to have found favour with the prospect of competition relatively quickly. From the start of 1999, a spot market at an electricity exchange in Amsterdam with cross-border trading is foreseen.

Obviously, the traditionally more liberal northern countries have had a head start. In southern Europe, the concept of centralisation and existential public supply remains more entrenched. It allows only a gradual liberation of the electricity market according to the Directive.

Spain

Although Spain has also opted for a step-by-step opening of their market, it is substantially exceeding European requirements in terms of both time and volume. In future, a pool trading system, similar to that of Great Britain, will be installed. With this system, the market price for electricity on the following day is determined on the basis of hourly bids by generators and customers. The tradition of the "Service Public", once strongly dictated by central planning, has been given up to a large extent, and Spain now supports competition and free enterprise. All that remains is a supply guarantee for each inhabitant, as contained in the majority of national drafts.

France

Over the years, subsequent French governments have striven to keep the effects of the European Directive to a minimum for Electricité de France (EDF). Together with Italy and Belgium, the country is now among the latecomers with deregulation. The Government first planned to put forward a draft for implementing the Single Market Directive in fall 1999. Market opening will be oriented to the minimum stipulations of the Directive and the state will retain control. Scope for action in competition is limited: long-term state energy planning continues, the way to other business sectors such as the telecommunications market, seems to be blocked. EDF is to concentrate on its core business.

Germany

The Electricity Directive was transposed into national law with the new German Energy Law (Energiewirtschaftsgesetz) of 24 April 1998. For the first time after 1935 when the old energy law came into existence, competition was introduced and free choice for all customers (including private households). The formerly closed supply areas are now open to competition, and vertically integrated utilities had to separate their accounting for transmission, generation and distribution. Contrary to many other European countries, and contrary to the telecommunications sector which has similar structural problems, the German legislator decided to establish neither an independent electricity authority nor to introduce any regulation for access to the grid and transmission fees. These matters are now being dealt in the so-called Verbändevereinbarung, a voluntary agreement between three major associations (the electricity industry, large industrial consumers, and municipal utilities). The first Verbändevereinbarung of May 22, 1998 (VV I) had so many deficiencies that a second one, VV II, had to be adopted as early as autumn 1999. Transmission charges are to be calculated according to transparent joint criteria, whereby network use at all voltage levels is paid for once at a flat rate like a "postage stamp".

However, there is still some criticism, including reservations from the European Commission, due to a division of Germany into two zones, with high interconnection charges between them.

2.3.2 International Electricity Trade and Reciprocity

The participation of foreign companies on the Amsterdam Power Exchange is important for its liquidity, but many questions have not been resolved yet. These include dealing with the reciprocity clause of individual governments, effective until 2006. In principle, imports from abroad could be prevented when domestic providers are not offered identical terms of market access in the exporting country. Because the German market plays a central role in Europe, and will be more open than the markets of France, Belgium, The Netherlands and Austria in the foreseeable future, the reciprocity clause is a key element in guaranteeing a smooth transition in international competition. On the other hand: distributors will enjoy full market access in Germany. Some interesting variations exist, for example, in Switzerland. Access authorisation of distributors increases in percentage with the individual deregulation stages.

2.3.3 Electricity Transmission

A further stumbling block for international trade on spot markets could be the calculation of transmission charges, which are handled differently from country to country. To date, there are no standard rules for cross-border transmissions, only the pertinent national remuneration systems apply, according to the provision of the selected network access system.

In Member States where competition has prevailed for some time, i.e. Scandinavia and Great Britain, the system of "regulated network access" has been asserted: Transmission tariffs are standardised and published. Transactions are streamlined by so-called "postage stamp tariffs", which are calculated independent of transmission distance. Nonetheless, the division into "connection zones" could well result in a geographical differentiation, to stimulate a more even balance between generation and distribution. Network tariffs are also state-controlled in The Netherlands and Spain.

In view of the federal structure of Germany's electricity supply, a system of negotiated network access (Verbändevereinbarung) has been chosen as the basis model. Under this system, electricity utilities and large consumers have been negotiating the transmission tariffs and other conditions for network access directly with the corresponding network operator(s). As of the year 2000, the latter will be obliged to publish tariffs for the use of their distribution and transport networks. However, companies which opt for the single buyer model, planned in the Energy Law Amendment by the year 2005, are required to obtain official approval and publish their tariffs for the use of their supply network.

2.3.4 The Role of Renewable Energies

One of the most intensively debated subjects in Europe continues to be the future positioning of renewable energies in liberalising electricity markets. European parliamentarians fear, on the one side, that it will be difficult for renewable energies to find buyers for their relatively expensive power in an open market characterised by price reductions. On the other side, support instruments such as feed-in tariffs (REFITs), direct subsidies, e.g. investment grants, etc. are seen as special treatment which is not competitively neutral, particularly as cross-border trade increases. However, compared with past and present subsidies given to conventional energies in most member states, e.g. the coal and nuclear industries, the support for renewables is negligible. As long as this distortion in favour of fossil or nuclear fuels continues, any kind of support programmes for renewable energies can well be justified in the Internal Market.

Whereas some Member States abide by the simple form of preference declaration, other countries have introduced a purchase obligation like that in Germany, e.g. Denmark and Spain. In Great Britain, Ireland and France this is linked to a tendering system and financed by a fee payable by the customer. In The Netherlands, it is arranged via so-called "Green Certificates" on a voluntary basis. These certificate system is still in a kind of testing phase, with limited success so far in terms of effective market penetration. Furthermore, there are a number of widely different benefit regulations. Scandinavians work predominantly with investment subsidies and tax concessions.

In June 1998, the European Parliament resolved to urge the Commission to introduce European directive for renewable energies, according to the White Paper proposals. In a paper published at the end of March 1998, the Commission itself pointed out the need for a community-wide, competition-conform system for promotion of renewable energies. On several occasions in 1998 and 1999, the Council stressed the subsidiarity principle and the freedom for member states to choose the support system they find most adequate for supporting renewable energies.

3 Wind Power Supply – Case Study Germany

3.1 National, Regional and Local Aspects

Some coastal regions and communities in northern Germany already cover more than 10% of their total electricity demand by wind energy. In some areas, wind turbine operators even achieve a degree of self-sufficiency of 60% or more. Even in regions with lower wind speeds a significant contribution can be achieved.

In absolute figures, Lower Saxony has the largest share of wind energy capacity in Germany with a total of 1,200 MW at the end of 1999. In relative terms, Schleswig-Holstein leads the 16 German states (Länder) with a total installed capacity approaching 1,000 MW (978 MW as of 31st December 1999), generating approximately 2.000 Mio. kWh of wind generated electricity annually. This translates into a share of more than 15 per cent of the state's total electricity consumption in 1999. Based on the past development, the state's own voluntary target for 2010, set in 1990 - a wind power share of 25 per cent – can be reached as early as 2002 or 2003. According to the government of Schleswig-Holstein, a quarter of total electricity consumption supplied by wind power would not create any major additional investment in grid infrastructure.

In 1998, the total German wind energy production of around 4,500 Mio. kWh (2,874 MW), supplied more than 1 percent of the country's electricity consumption (net power consumption from general supply grids: without internal power station consumption, net loss or generation in private plants). As of 31 December 1999, total capacity jumped to 4,444 MW. This is almost a doubling of the 1998 growth (54 % of total 1998 capacity). An additional 1,569 MW had been erected between January and December 1999!! Assuming an average wind year, wind power is already producing two per cent (8.5 billion kWh annually) of Germany's total electricity requirements. By 1999, average turbine size has grown to almost 1 MW (937 kW). In 1998 it was 785 kW, while five years ago, in 1995 it was just half of today's size, i.e. 457 kW.

Future short and medium-term projections for the next 5-7 years estimate that a share of five per cent wind power in Germany (see table 5) is an absolutely realistic figure. Most of the past and present contribution of renewable energy - 5 per cent of Germany's electricity - came mainly from hydro power. This figure can be significantly increased in the medium run. According to estimates released during a public hearing on the new law for renewable energies in the German Parliament, wind power could easily supply 15 per cent of total German electricity requirements by 2020, ten per cent coming from on-shore and five per cent from off-shore installations.

Both an examination of the four states with the highest wind power shares, as well as the whole of Germany, shows the enormous growth in recent years (figure 3). In consideration of the available potential for energy savings, it will become clear which share wind energy can provide, at least regionally.

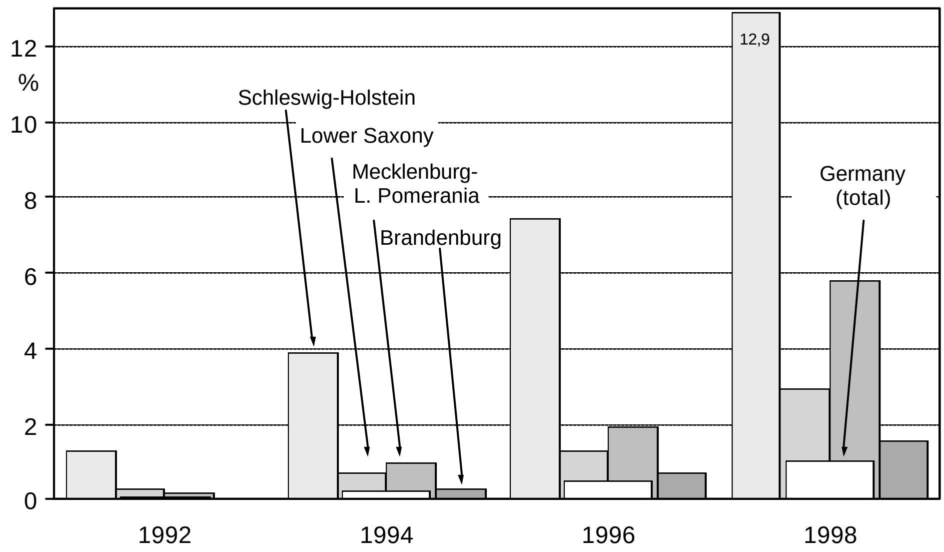


Fig. 3: Wind Energy Feed-in Related to the Public Grid in Germany [3]

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
New Wind Turbines erected	820	1000	950	925	900	875	850	825	800	775	750
Average Rated Power [kW] per new turbine	630	850	900	950	1000	1100	1200	1300	1400	1500	1600
New Capacity Installed [MW]	517	850	855	879	900	963	1020	1072.5	1120	1162.5	1200
Total Number of WTs	5100	6100	7050	7975	8875	9750	10600	11425	12225	13000	13750
Total Installed Capacity [MW]	2040	2890	3745	4624	5524	6486	7506	8579	9699	10861	12061
Total Annual Electricity Production [TWh] from Wind Energy	3.0	4.9	6.6	8.3	10.0	11.8	13.7	15.7	17.8	19.9	22.2
Wind Power Share of Annual Electricity Consumption	0.7%	1.1%	1.5%	1.9%	2.3%	2.7%	3.1%	3.6%	4.1%	4.5%	5.1%

Table 5: Scenario for the Development of Wind Power in Germany by 2007

3.1.1 Equivalent Full Load Periods

In order to evaluate and compare efficiency, the annual energy production of a WT is often related to its rated power. The quantity of the so-called equivalent full load period is dependent on the amount of energy from wind, the site conditions and the hub height of the WT. It is also influenced by the degree of efficiency achieved from given conditions and the proportion of rated power to rotor area. The reliability and availability of WTs, which is generally very high in Germany (based on WMEP data), can also drastically influence the number of full load hours in unfavourable individual cases.

Figure 4 shows the average equivalent full load periods (bars), for the individual federal states, and their respective standard deviations as an indication of fluctuation (almost 70% of all values are inside the "H-lines"). High equivalent full load periods were noted in coastal states, where individual plants measured over 3,000 hrs, in some exceptional cases in recent years. In Lower-Saxony, the results show wider variations. This corresponds with the geographical features of the state, reaching from the North Sea coast to low mountain ranges several hundred kilometers far into the mainland. In average, coastal locations in Germany can expect full load periods around approx. 2400 hours, while inland locations show values in the region of 1200-1500 hours.

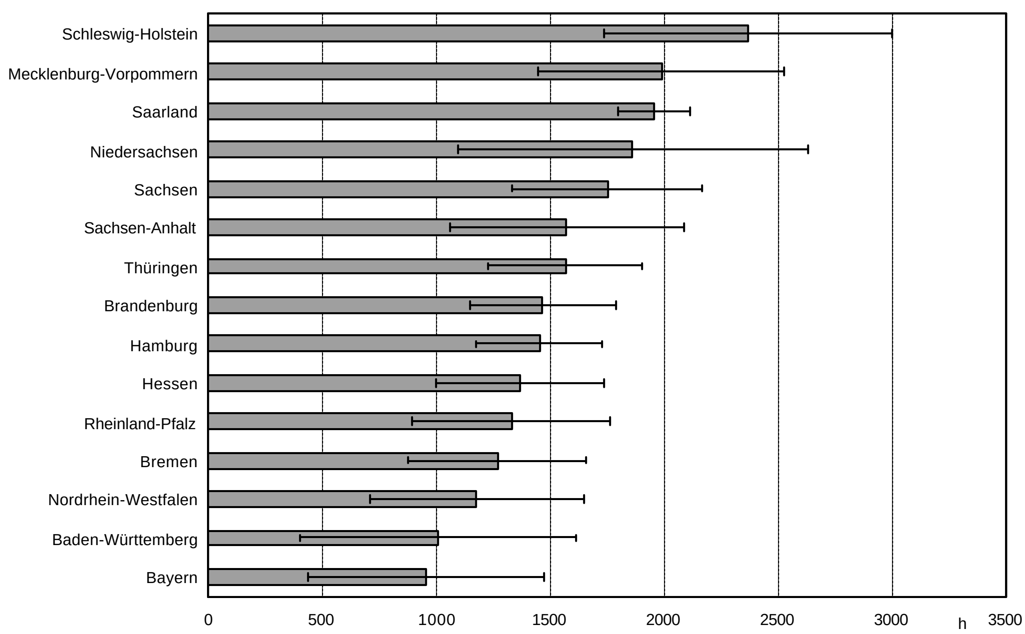


Fig. 4: Equivalent Full Load Periods [3]

3.1.1 Degree of Self-Sufficiency

The degree of self-sufficiency reflects the proportion of the individual operator's electricity demand that is met by the WT. It depends on the quantity of wind energy produced and energy demanded, but is even more dependent on the chronological correspondence of production and demand. The degree of self-sufficiency is scattered because households usually adjust their energy consumption, in varying degrees, to the actual wind energy supply.

Up to 60% of a household's annual consumption can be covered by the WT, only when the WT's annual electricity production is more than five times the household's consumption (Fig. 5). In this case, about 80% of the WT's electricity production had to be fed into other grids, or used elsewhere. But the situation will become more advantageous, if more households or other users with different chronologies of demand are supplied.

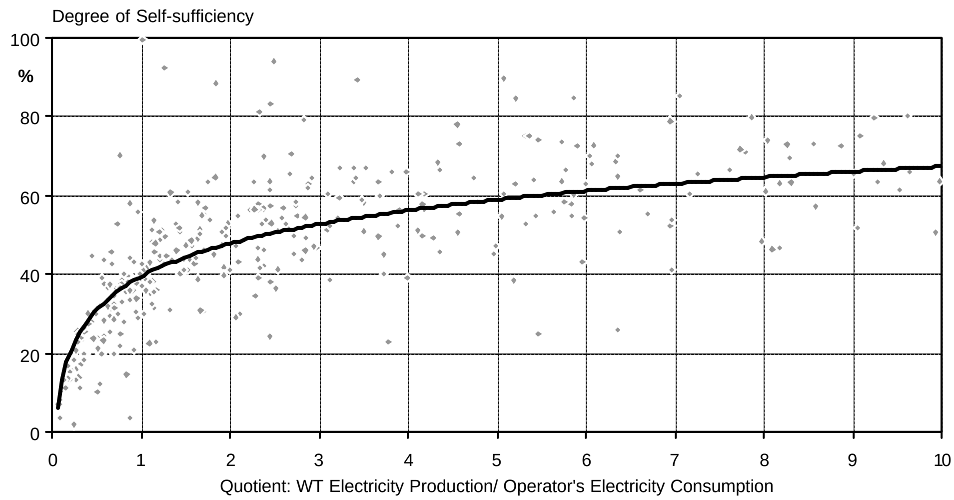


Fig. 5: Degree of Self-Sufficiency [3]

3.2 Statistical Features of Wind Power Supply

As a common statistical representation for conventional power stations, power duration curves offer information about the annual period of availability for each power level. In the case of the cumulative power of widely-dispersed WTs, regional and annual differences regarding power availability can clearly be identified.

Figure 6 shows the 1998 power duration curves of regional WT groups. On the island of Fehmarn, at least 20% of the total installed WT capacity was available during approx. 5,000 hrs

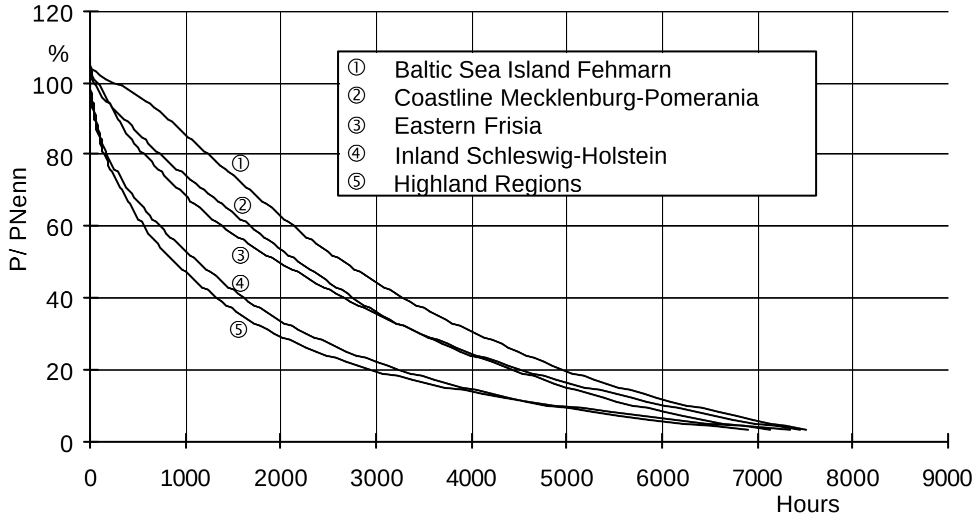


Fig. 6: 1998 Power Duration Curves of Regional WT Groups [3]

of the year. WT groups at widely-spread sites in low mountain regions and the Schleswig-Holstein inland region, exceeded the 20% level of their total capacity for 3,000 hrs in 1998.

Power duration curves can offer probability information for system operators concerning the power levels to be expected, without reference to the exact time sequence. For power management questions in a time range of hours, detailed information is provided in the following sections.

3.3 Fluctuations of Wind Power Time Series

In the time range of minutes, the power of single wind turbines is especially dependent on local meteorological conditions and the individual WT's operational behaviour. Various wind turbine models reach short-term values of up to 1.5 times their rated power (compare Figs. 7 and 8).

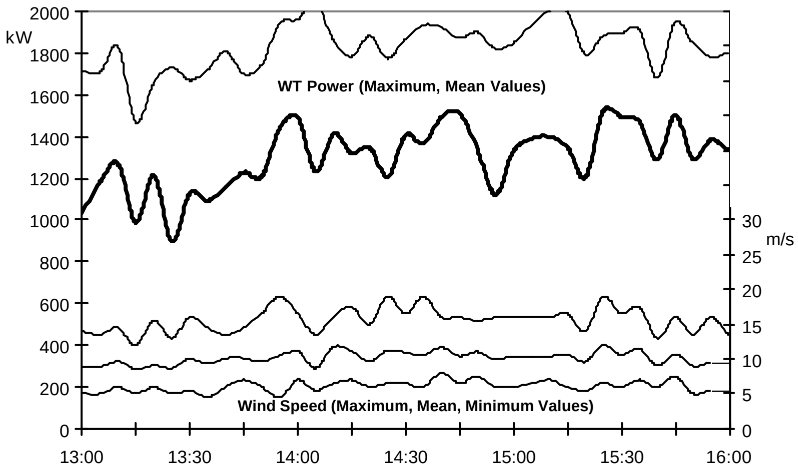


Fig 7: Short-term Maximum Power from WT (1.5 MW Rated Power), Constant Speed Operation [3]

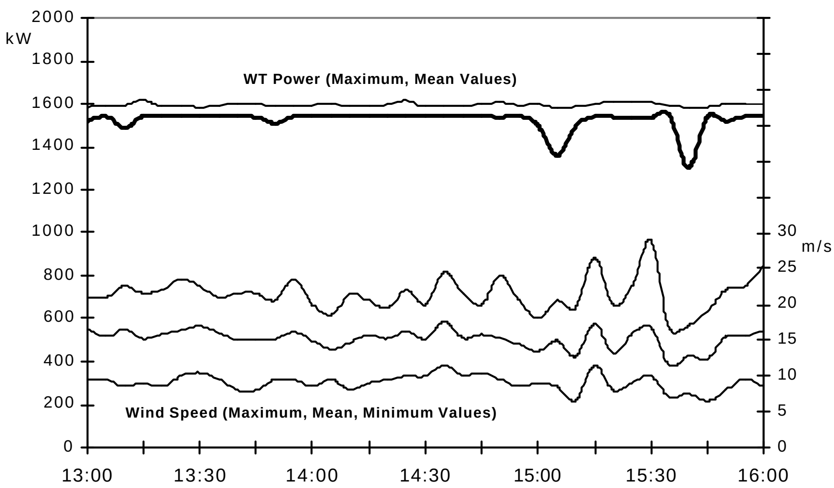


Fig. 8: Short-term Maximum Power from WT (1.5 MW Rated Power), Variable Speed Operation [3]

Furthermore, very high power gradients are produced by shutdown events during full-load operation. Such transient states are not only registered at normal cut-out wind speed, but also at lower mean wind speed, e.g. by gusts causing rotor overspeed.

In a wide regional distribution of wind turbines, short-term and local wind fluctuations are largely balanced out. The cumulative power course is affected through weather conditions, especially in the summer months where warming of the atmosphere occurs, which leads to effects on the day's course (Fig. 9). Fluctuations of the cumulative power course have, nevertheless, comparatively lower gradients and can be satisfactorily predicted through special prognosis procedures (see Chapter 5.1).

The power data for 1998 was analysed, for both the selected individual plant and the regional groups of WTs in the WMEP, in regard to the fluctuations in 1-hour mean gradients and also in relation to long-term fluctuation.

The extent of the documented power changes within several hours is as large as was expected, in the case of the 600 kW plants. With 4-hour mean gradients, variations over the total power range were reported. The frequency values depicted in Fig. 10 are of special interest, particularly in comparison to the pertaining values of plants in widely-spread regional groups, where power variations in 4-hour mean gradients of merely 60% of the installed total power are shown (see Fig. 11).

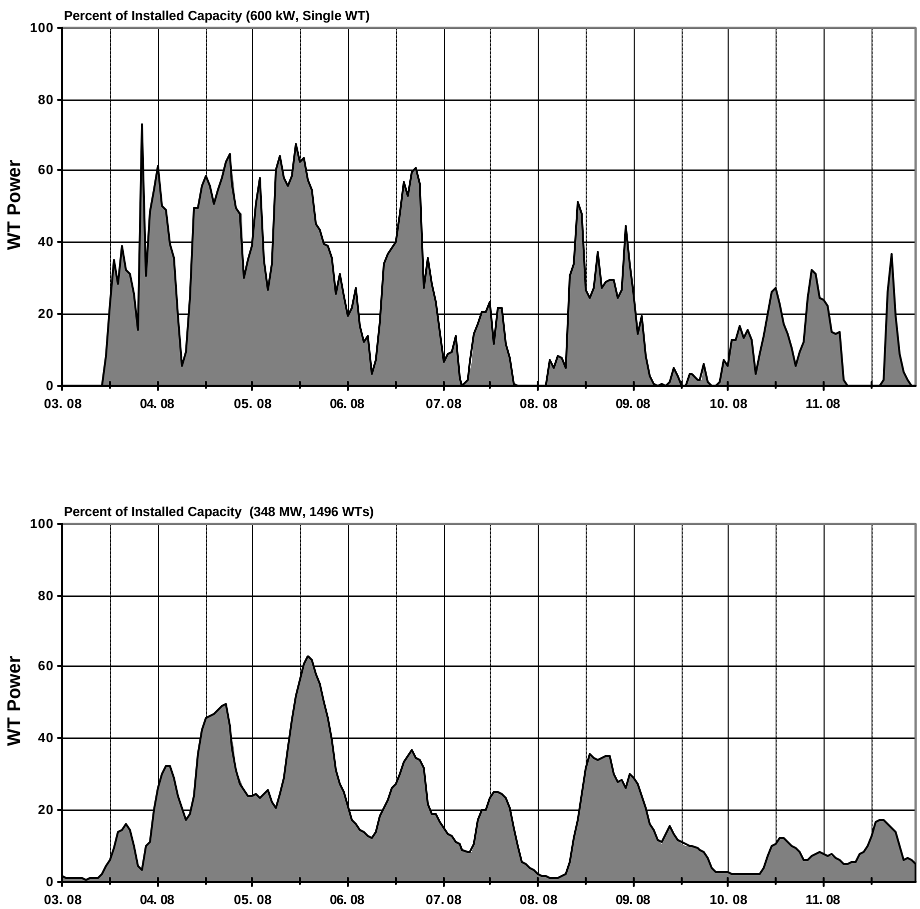


Fig. 9: Comparison of WT Individual and Cumulative Power [3]

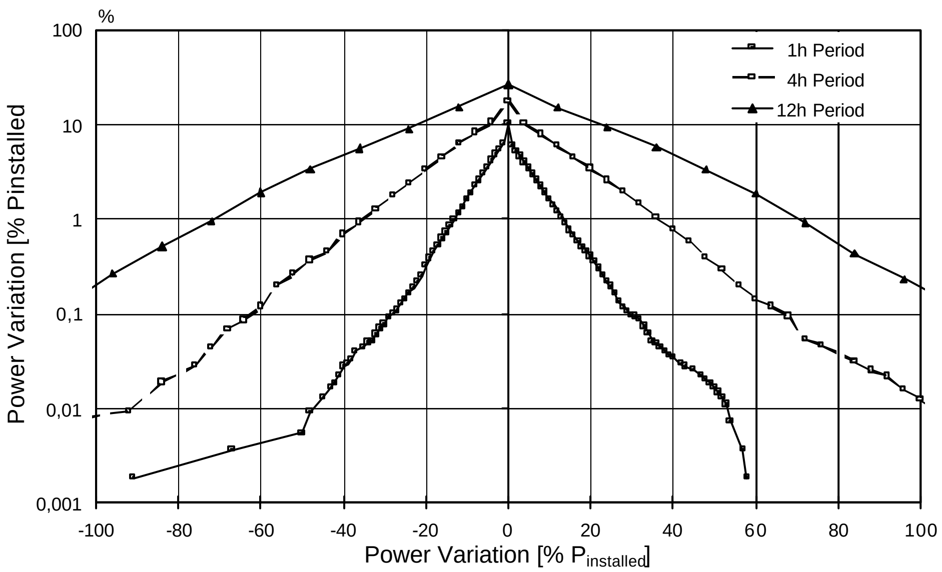


Fig. 10: Probability of Power Changes (Individual WT) [3]

Despite the extent of fluctuation, Fig. 11 also shows that the power level remains (calm periods included), from one hour to the next, with a probability of 10%. The frequency distribution of power changes is not symmetrical in the case of individual plants: The increased number of 1-hour values in the area of negative power change can be traced to cut-off procedures in plant operation near rated power.

The statistical analysis of the power time series for the 1496 plants in the WMEP, in one, four and twelve hour mean gradients resulted in frequency distribution power changes as given in Fig. 11. The hourly mean gradient of only ±1% of installed capacity occurs with a probability of approx. 25%. This persistency is also found for extended periods, if the widening of the gradient intervals is taken into account (4 hours: ±4%; 12 hours: ±12%).

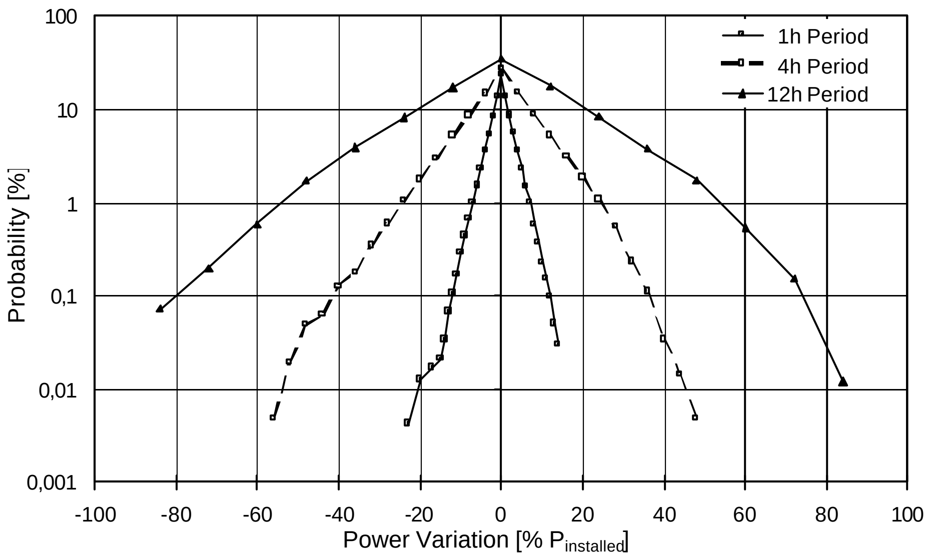


Fig. 11: Probability of Mean Power Changes (1496 WTs) [3]

Fig. 11 also gives the highest mean gradient to be expected: With a maximal 1-hour gradient in the annual course of the WMEP plants distributed Germany-wide, an increase of 14 percent of the total installed power (04.04.98, 10-11 a.m.) was determined, as was a power decrease of 23 percent (05.03.98, 6-7 p.m.). In 4-hour mean gradients the maximal positive and negative power changes are evident at approx. 60%, and approx. 80% of the total installed power within the 12-hour interval.

3.4 Duration of Calm Wind Periods

In general, statements regarding the frequency and duration of calms depend on the power level chosen for the definition of those periods. When choosing a level of 2% of the installed power – being the precision of the measurement equipment – the power duration curve of the WTs dispersed over Germany shows approx. 1000 hours of wind calm.

In the case of isolated or regional systems, a higher power level may be appropriate, especially for dimensioning storage systems. The following evaluations refer to studies regarding the North Sea Island of Pellworm, where the mean annual consumer load has been used as reference for defining calm wind periods [7].

The calm wind period evaluations are based on wind measurements taken from a pre-existing plant on the North Sea island of Pellworm, from 1993 -1996. In this period, two years of good wind conditions (1993, 1994), one year below average (1996) and also an average year (1995) occurred. Because of these results, it is ensured that no extreme year was included in evaluations.

The most important characteristics of a calm period evaluation are the annual calm period duration and the frequency distribution in different classes. These are particularly of interest for later storage dimensioning. A storage system should be dimensioned in such a way, that the service security for the electrical energy requirements are given, also when wind energy plants produce insufficient electrical energy.

From the wind speed and power measurement data, data is selected in which the given power of the wind energy plant is not more than the annual load average of 630 kW. The periods, when this is the case, are defined as calm periods. Through this, the failure periods of the wind energy plants are calculated. Periods when the wind speed is greater than 5 m/s, but the plant does not supply power to the grid, are defined as failure periods. All calm wind period evaluations are based on measurement data from the WMEP. The important values for these two evaluations are combined in Table 6.

Extension Level	5.9 MW Wind Capacity	10.7 MW Wind Capacity
Annual Average Load	0.630 MW	0.630 MW
"Wind Calm" – Definition	10.7% of installed capacity	5.9% of installed capacity
Data Availability	98 %	98 %
Average Total Calm Wind Period Duration (referring to "Wind Calm" Power Level)	2778 h/a	2004 h/a
Average Number of Calm Periods	869	694
Average Calm Duration	3,2 h	2,9 h
Longest Calm Period	74 h	62 h

Table 6: Summary of Calm Wind Period Evaluations, Pellworm 1993-1996 [14]

The total calm wind period duration in average, amounted to approx. 2780 h for the first extension level (5.9 MW), whereby the values for individual years are between 2380h and 3060 h. With the second extension level (10.7 MW), the total calm wind period duration was reduced to approx. 2000 h. This limit value was mainly dependent on the shut-down wind speed of wind energy plants. It is also interesting to note that the short calm wind periods (less than 12 hours) made up about 50% of the total calm wind period duration.

It should be stressed here again that the case of Pellworm can provide useful information. However, it should be noted that when analysing larger areas than the island of Pellworm, the duration of calm wind periods is even lower. The same is true for areas with higher average wind speeds, e.g. many regions in the UK, Ireland, the south west of France, and many parts of Greece and Spain.

3.5 Conclusions

The production figures of wind turbines operating in Germany reach an average of approx. 2,200 to 2,400 full load hours at coastal sites, approx. 1,300 to 1,500 full load hours at inland sites, respectively. A positive legal framework in Germany allows for a profitable operation with these average production figures which are significantly lower compared with many other European regions. Based on the development of the 1990s, wind power in Germany will therefore contribute a value of roughly 5 percent to total electricity consumption by 2007 at the very latest.

The question of the resulting effects on grids, power plants and electricity trading has been treated in this part of the study particularly according to the statistical analysis of cumulative wind power curves.

The rated wind power to be installed for reaching a requested kWh-coverage depends on the wind potential, the full load hours at a given site or region, respectively. For achieving the above mentioned figure of 5% of the German electricity demand, equivalent to 22.2 TWh, presumably 12,000 MW installed wind power will be necessary (see Table 5), based on an average of 1,700 full load hours. Many other areas in Europe can produce up to twice as much electricity with a comparable total installed capacity.

The security of electricity supply in the European Union is accomplished within the interconnection of grids and power plants by redundant power plants leading to a sufficiently dimensioned reserve power. As a matter of fact, the predictability of load curves is diminished by the fluctuating wind power, which results in new requirements for power plant scheduling. Yet, so far no additional reserve power had to be installed in Germany however, as the already existing controllable sets are used for the balance of fluctuating wind power.

The dimensions of controllable sets within the interconnection of power plant and the necessary characteristics of their control behaviour are particularly influenced by the dynamical behaviour of wind power being presented in this study. Power measurement curves representing the overall “wind power plant” installed in Germany document the spatial balancing effects. As a decisive result of those evaluations, the maximum fluctuation of wind power sum curves is limited to a value below 25% per hour. This maximum power variation (e.g. 500 MW per hour in the case of 2,000 MW installed wind power) is compensated by other power plants in the interconnection of grids (see chapter 5).

4 Wind Power Supply - The Case of Denmark

4.1 Energy 21 - Danish Plan of Action

The Danish government's commitment to wind has been enshrined in a succession of energy plans. In 1981, the first plan *'Energy 2000'* envisaged 1,000 megawatts of wind energy by the year 2000. This total has already been exceeded in 1997.

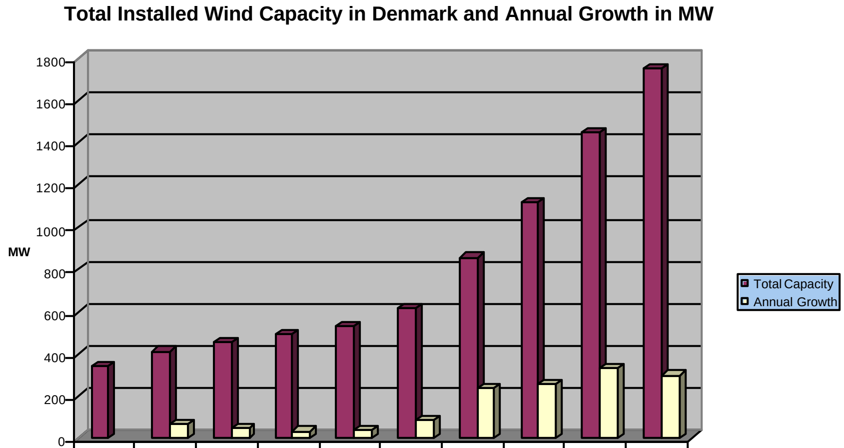
In April 1996, the Danish Government released its new plan of action in the field of energy. '*Energy 21'* includes a number of new initiatives to secure the fulfilment of the goal of reducing the national CO_2 emissions by 20 % during the period up to 2005, compared to 1988 levels, and halving the 1988 figure by 2030. Energy 21 has maintained the goal of erecting 1,500 MW of land based turbines before the year 2005[8]. This objective had been already realised six years ahead, in 1999.

"One of the keys to Denmark's success in wind energy has been a consistent national policy resulting in a strong domestic market" observes Paul Gipe, US wind energy analyst.

By 2030, wind power is expected to supply 50 % of Denmark's electricity and a quarter of its total energy requirements. This is the most ambitious wind energy target in the world. To reach this level, a capacity of 5,500 megawatts will have to be installed by then. This will save 14 million tonnes of CO_2 each year. 4,000 megawatts of the total are planned to be erected in offshore wind farms.

In early 1999, the total installed wind power capacity of 1,500 megawatts supplies already 10 per cent of the country's electricity. This figure was actually set in Energy 21 as the target for 2005. The impressive growth of total installed wind energy capacity can be seen in Fig. 12. Wind energy is now the *"cheapest option to cut greenhouse gas emissions"*, according to Egon Soegaard, President of the Danish electric utility Elsam.

To show its commitment to CO_2 reduction, the Danish government decided in 1997 to phase out coal completely as a fuel in power stations. As a first step towards this long-term objective, a halt has been called to proposed coal-fired plant. This follows a decision as long ago as 1985 to build no nuclear reactors in Denmark.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	Dez 99
Total Capacity	343	413	458	491	532	619	857	1116	1450	1750
Annual Growth		70	45	33	41	87	238	259	334	300

Year

Figure 12: Total Installed Wind Capacity in Denmark and Annual Growth in MW

4.2 Wind and Hydro Solution

New management systems will have to be devised to ensure that such large quantities of wind power are integrated smoothly into the national electricity grid. In the Nordic system with large hydro capacities, Denmark is very well situated to integrate its growing wind power capacities into the Scandinavian electricity system. It has been proposed by various studies, commissioned by government agencies to exploit the excess quantities of hydro power produced in neighbouring Norway. When the wind blows strongest, the hydro reservoirs would be turned down, when the wind dies down, they would be opened up again. Such adjustments are possible in a matter of seconds.

Denmark's energy and environment minister Svend Auken is convinced that Denmark *"will be making the most effective renewable system in the world, using a massive Danish wind energy system and massive Norwegian hydro power, and all to our mutual benefit."* [9]

4.3 Wind Power in the Danish Electricity Grid

The vast majority of wind turbines installed in Denmark is grid connected. When analysing a typical weather pattern in Denmark, it becomes clear that wind energy generally fits well into the consumption pattern. Usually, the winds are low at night, and higher during the day, i.e. wind electricity tends to be more valuable to the electrical grid systems than if it were being produced at a random level.[10]

4.4 Offshore Wind Power

There are great wind resources at sea and large-scale potential in Danish waters for installing wind turbines in the many areas where the sea-depth is relatively shallow. Based on the experience from the two existing demonstration plants at Tuno Knøb and Vindeby, which are relatively close to the coast, new plans for installing large offshore wind farms in the 21st century have been developed.

A recent survey by the Maritime Wind Turbine Committee of the Ministry of Environment and Energy (Vindmøller i danske farvande, 1995) indicated four larger areas where future off-shore construction should preferably take place. These areas have a potential of up to 8,000 MW, corresponding to an estimated energy production of 15-18 TWh, or 54-65 PJ a year. This is five times the total wind turbine capacity installed in 1999.

In June 1997, the electric utilities and the Danish Energy Agency published a report entitled "Action Plan for Offshore Windfarms in Danish Waters". It concludes that it is both technologically and economically possible to construct offshore wind farms, that can produce electricity at the same average price as land-based turbines.

Five potentially suitable areas for developing offshore wind farms have been identified in the report: Horns Rev off Esbjerg, areas in the Kattegat south of Læsø island, the area at Omø Staalgrunde in the Smaaland waters, and two areas south of Lolland and Falster. These commerical offshore wind farms (120-150 MW each) will be located some 15-40 km from shore, at water depths from 5 to 10 meters, possibly 15 meters.

These projects will help the industry and utilities to further adapt wind power to their needs and to improve foundation and electrical connection. Optimising these technologies for remote offshore sites will be important, however, to ensure reasonable economics.

The project that will be realised at first – beginning construction in 2000 - is a smaller offshore wind farm close to the Copenhagen harbour at Millegrund. It is a co-operative initiative of private citizens with the support of the municipal utility of Copenhagen.

4.5 Wind Energy and Electrical Tariffs

Electrical Energy Tariffs

Electricity companies are generally more interested in buying electricity during the periods of peak load (maximum consumption) on the electrical grid, because this way they may save using the electricity from the less efficient generating units. According to a study on the social costs and benefits of wind energy by the Danish AKF institute, wind electricity may be some 30 to 40 per cent more valuable to the grid, than if it were produced completely randomly. In some areas, power companies apply variable electricity tariffs depending on the time of day, when they buy electrical energy from private wind turbine owners. [10]
Normally, wind turbine owners receive less than the normal consumer price of electricity, since that price usually includes payment for the power company's operation and maintenance of the electrical grid, plus its profits.

Environmental Credit

The Danish government and the power companies started as early as in the 1980s to promote the use of renewable energy sources, especially wind power. Therefore, they offer a certain environmental premium to wind energy, e.g. in the form of a refund of electricity taxes and an additional price premium etc. on top of normal rates paid for electricity delivered to the grid.

Various other governments and power companies around the world followed the Danish model during the 1990s, most importantly the German and Spanish with their Feed-in Laws that support wind power by paying REFITs to make investments economically attractive. The higher prices paid under these statutorily granted schemes are regarded as compensating for non-internalising the external social and environmental cost of conventional electricity generation. Various studies have been undertaken during the past ten years which have tried to monetarise the external cost of fossil fuel generation (coal, oil, gas) or nuclear power. Depending on the effects taken into account for these studies, e.g. including the consequences and damage of global warming or of a major nuclear accident, the additional cost of electricity can be as high as 10-15 Eurocents per kilowatt hour.

Capacity Credit

To understand the concept of capacity credit, we have to look at its opposite, power tariffs: Large electricity customers are usually charged both for the amount of energy (kWh) they use, and for the maximum amount of power (kW) they draw from the grid, i.e. customers who want to draw a lot of energy very quickly have to pay more. The reason they have to pay more is, that it obliges the power company to have a higher total generating capacity (more power plant) available. Power companies have to consider adding generating capacity whenever they give new consumers access to the grid. But with a modest number of wind turbines in the grid, wind turbines are almost like "negative consumers": They postpone the need to install other new generating capacity. Some power companies therefore pay a certain amount per year to the wind turbine owner as a capacity credit.

The exact level of the capacity credit varies, however. In some countries it is paid on the basis of a number of measurements of power output during the year. In other areas, some other formula is used. Finally, in a number of areas no capacity credit is given at all, as it is assumed to be part of the energy tariff, including an environmental credit. In any case, the capacity credit is usually a fairly modest amount per year.

Future System and Market Development

It remains to be seen, if wind energy in Denmark will continue to develop in a similar stormy way as it did in the past. In spring 1999, the government decided to replace the old system with a new one. Until then, private wind turbine operators received a statutorily granted REFIT of 85 per cent of average household tariffs (appr. € 0,07/kWh). After a decision of the Danish parliament in May 1999 on the future electricity system, a radical change in the support system for renewable energies was adopted. It is foreseen to introduce a system of tradable certificates for renewable energies instead of the previous REFIT system. The new system was supposed to be operational by 1st January 2000. However, due to structural and operational difficulties the introduction has been postponed for another two years. The current transitional phase increases the insecurity in the market, since the future consequences of the new system are not clear at all yet. In any case, electricity distributers respectively consumers have been obliged to have 20 per cent renewables in their portfolio by 2003.

4.6 Conclusions

Denmark has been the forerunner in terms of wind energy development during the 1980s and 1990s. With a wind power penetration of more than 10 per cent nation wide, the Scandinavian country has demonstrated that the integration of a substantial share of wind energy is not a problem for system operators. With their off-shore plans, the Danes are once again taking the lead, both technologically as well as in terms of system integration. The approach to use the Nordic hydro power system to integrate the growing Danish wind power capacities into the

Scandinavian electricity system proves that large amounts of wind power can in fact constitute a major share of the European electricity system of the future.

In terms of giving wind power its real value per kWh, it is important that the electricity tariff does not only take into account the capacity credit of wind energy, but its environmental credit, too. Both have an effect on the renewable energy feed-in tariff (REFIT), and should be reflected accordingly. Starting in Denmark, the most effective approach to support wind energy in Europe during the 1990s, clearly was the definition of standard power purchase agreements (REFITs) When REFITs reflect the real generation costs of wind, combined with a committed government policy and local people who are given the right incentives to invest, the Danish success story of wind energy development can be repeated not only in Germany and Spain, but in many other European markets, too.

The future of wind energy in Denmark is not quite clear yet, however. The change in the support system for renewable energy, replacing the old and effective REFIT scheme by a new and yet untested model of tradable green certificates, makes the future Danish wind energy market, including off-shore, increasingly more insecure and unstable.

5 Options for Power Maintenance and Increased Network Capacity

5.1 Online Monitoring and Wind Power Prediction

Power producing utilities have to continuously adapt their power generation schedules according to the requirements of the system operator, e.g. to the expected load, the availability of the power stations, the balance of electricity exchange with other utility companies, and also the consideration of necessary power reserves. For utilities with high shares of wind power, the term “availability of power plants” implies online acquisition of the power of all WTs operating within their grids As the measurement equipment of every single WT is not realistic, the task has to be fulfilled via the extrapolation of online data from selected wind farms. The following description is based on current work within a project of a German utility with already more than 2000 MW total installed wind capacity [4].

The actual feed-in of wind power to supply areas is determined by equation systems and parameters, which also take into consideration the spatial distribution of WTs. The measurement data of the chosen wind farms is, thereby, transmitted by leased lines to the control centre (see Fig. 13).

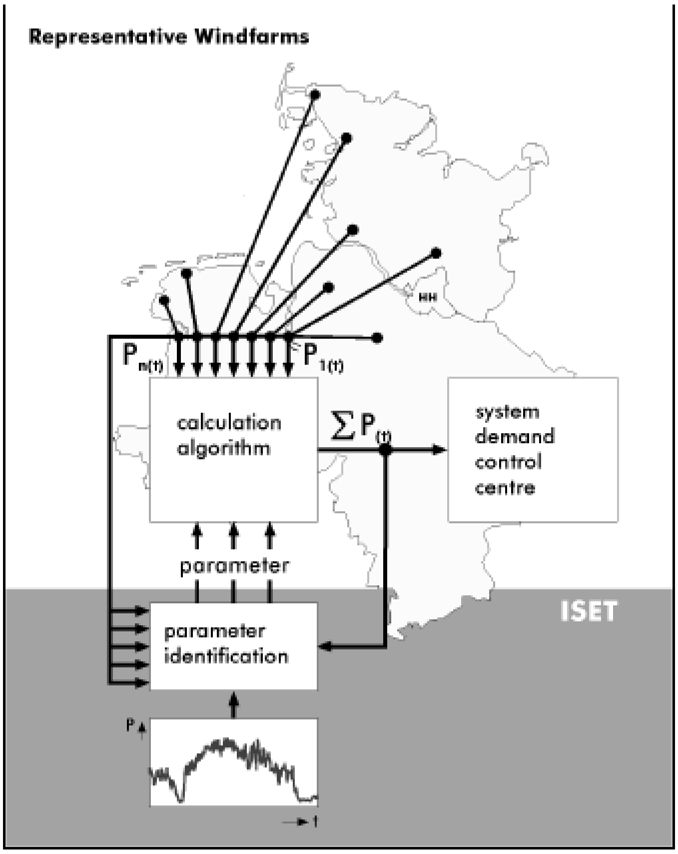


Fig. 13: Online Acquisition and Projection [4]

The online evaluated time series for the load dispatcher are compared with extrapolation of wind and power data retrospectively and, by means of parameter optimising, continually conformed and improved. Through this regular testing and conforming of parameters, a high level of precision for the described procedure can be obtained.

Besides precise knowledge of the statistical behaviour of fed-in wind power, the prediction of short-term to medium-term power, expected for the generation schedule and load management of utility companies, is of increasing importance. Different estimations and procedures already exist for the prediction of wind power. These models for wind power forecast are based on the ability of neural networks to approximate associations which are not linear, and to intercede in the case of vague, incomplete or inconsistent data. Furthermore, no knowledge of physical or meteorological associations with the problem is necessary in modelling.

Based on online monitoring of the wind power supply, the short-term forecast for the period from 1 to 4 hours, e.g. by means of artificial neural networks, is another important step towards improved integration of wind energy into the load control and generation schedule of utility companies with high proportions of wind energy.

Figure 14 depicts an example of a wind power prediction, carried out by means of artificial neural networks, for one hour average values, the prediction period also being one hour. The prediction of the total wind power output for longer time periods will be possible in the future by using meteorological information as additional input data.

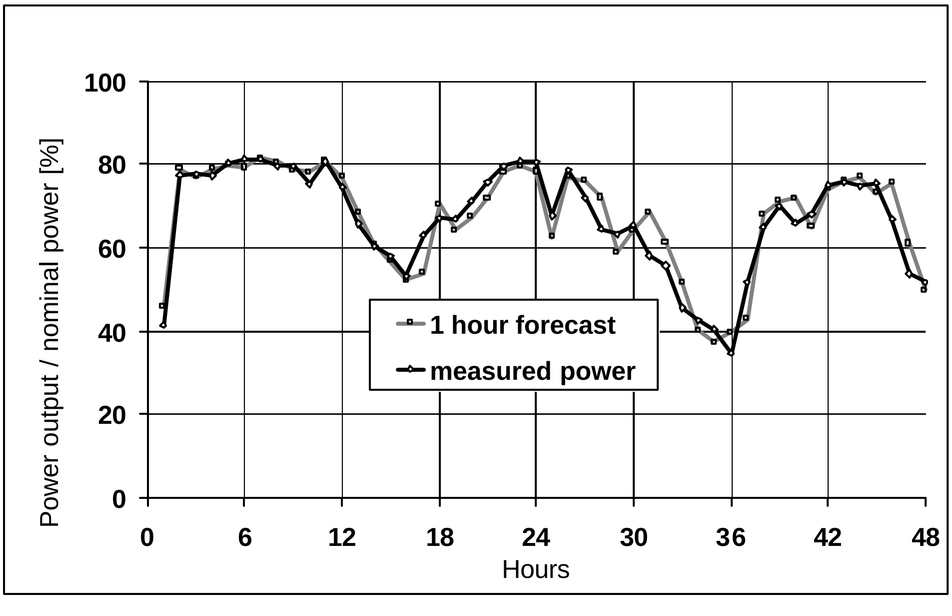


Figure 14: Measured and Predicted Sum Curve [4]

As the presented model for the online monitoring of large wind capacity can be adapted to various supply systems, it is of special importance for various European electricity utilities, in order to improve the grid integration of their wind capacities. Further improvements can be attained by using the WT control facilities within the system demand control centres.

5.2 Load Management

Improving the congruence of electricity demand and production is the major task of measures for shifting or limiting the demand. Those measures play an important role within the load dispatch procedure of utilities like the North German utility SCHLESWAG [11], but investments have to be justified in deregulated electricity markets. Both aspects are presented in the following chapters.

5.2.1 Experiences in Germany (Utility SCHLESWAG)

Because electricity must be generated at the moment of its consumption, customers determine how much plant capacity is necessary at any one time. Because of this, the load of the electricity grid, and the operation of power plants changes in the course of days and years. In comparison to the previous decade, the daily load curve in Winter, when the peak load occurs, is now substantially more balanced. This means that power plants are able to operate more regularly, and therefore, more economically for the customer.

Utility companies decide, based on technological, economic and scientific considerations, which power plants can cover the load most economically at any one time. Therefore, standard power plants are employed for the around the clock basic load requirements. They are characterised by low generation costs.

Power plants which are designed for changing performance requirements, and whose generation follows the fluctuations of consumption, are used for medium load requirements. In western Germany, these are predominantly mineral coal power plants. They cause higher fuel costs, but lower fixed costs than standard power plants. Their operating periods vary between 4,100 and 4,900 hours, in 1993.

In peak periods, power plants are utilised where the output is available at short notice and which allow repeated daily start-ups and shut-downs, as well as quick changes in the power demands. Their working capacity is, like pump-storage plants, generally limited to a few hours - or they cause, with relatively low investment costs, comparatively high fuel costs, as with gas turbines.

Rotating power plant capacity must be reserved somewhere for every power demand. Therefore, this power availability is included as a component of the total power price. In Germany it is called capacity price. The other component is largely dependent on the fuel costs: It is called the processing price.

Schleswag pays its supplier PreussenElektra [PE] a capacity and processing price, like any other special contract industrial customer. The PE load dispatcher employs the power plants available to it, according to performance requirements, and following scientific criteria.

Because Schleswag cannot employ in-plant systems, it attempts to keep the power from PE to a minimum, in agreement with its customers. This is a type of demand side management which has been practised for decades. Two options are available for this:

- Displacement of a part of the consumption in periods of weak load, through lower prices - the low tariff periods.
- Reduction of the daily power peaks.

When a daily load curve is analysed, recurring time periods which effect the power can be observed on work days: Night-time quiet, breakfast at home, beginning of production, breakfast break, midday peak, afternoon drop and evening peak. In order to reduce these peak periods, a variable power measurement can be arranged with the special contract customers (industrial customers). In this context, the special contract customers are obliged, in the settlement months of January, February, November and December, to reduce their power cover on demand from Schleswag by at least 20% of its available power, or rather, to the agreed ordered power.

In the 1950's, system demand control at fixed times took place with timers. At the beginning of the 1970's, a flexible instrument was being developed with audio-frequency centralised control technology: besides fixed periods, time-variable tariff control demands could be sent, which where suitable to the output. These would carry out the tariff commutation, or power measurement, on location. The great progress was in that the power measurements were only activated by actual need, i.e. peak periods. A customer would now only be required to reduce load approx. 10 times in the month, on average (duration of approx. 60 min each). As Schleswag saves through buying power from PE, the special contract customers save with Schleswag. Approx. 600 special contract customers use this contractual possibility. Control through the telephone is agreed upon for the 15 largest special contract customers. Altogether, Schleswag has an available power of 40 to 50 MW, which it can influence itself.

Another option is to give incentives for a more balanced demand of private customers. Such a system was tested in the Schleswig-Holstein municipality of Eckernförde until 1996, involving 1,000 households. With the support of the state government and the European Union, the local utility introduced and tested a special tariff system for the tested households, the so-called Eckernförder Tarif. [12] Each customer got a signal light in his home, which enabled him to observe and to influence his own consumption patterns by reducing demand during red or orange light periods (peak load or medium) because the tariff was higher during these times (up to € 0.36 per kWh), compared with a low tariff during green light periods (weak load) when the tariff was only € 0.06 per kWh. Average household tariffs in Schleswig-Holstein are between € 0.12-0.15 per kWh. Therefore, consumer acceptance for the new system was very high and led to a shift of consumption from peak load periods into medium and low load periods. In the long run, it could be well envisaged to use such a price signal for regions with high wind power penetration.

5.2.2 Reactive Power Charges

Most wind turbines are equipped with induction generators. These generators require current from the electrical grid to create a magnetic field inside the generator in order to work. As a result of this, the alternating current in the electrical grid near the turbine will be affected (phase-shifted). This may at certain times decrease (though in some cases increase) the efficiency of electricity transmission in the nearby grid, due to reactive power consumption.

In most places around the world, the power companies require that wind turbines be equipped with switchable electric capacitor banks which partly compensate for this phenomenon. (For technical reasons they do not want full compensation). If the turbine does not live up to the power company specifications, the owner may have to pay extra charges.

Normally, this is not a problem which concerns wind turbine owners, since the major wind turbine manufacturers routinely will deliver according to local power company specifications.

5.3 Complementary Power Plants

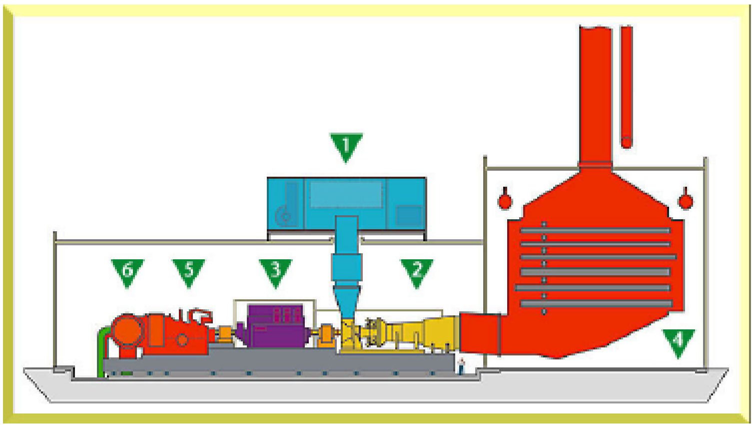
Within the electricity generation system of

- Base load sets,
- Controllable sets and
- Peak load sets,

an increasing part of controllable sets is affected by growing wind power penetration levels. Yet, the maximum power changes to be expected remain in the range of approx. 20 to 30 percent of the installed capacity per hour (see evaluation of German data in Chapter 3.3).

In the case of a power generating utility with e.g. 2000 MW installed wind capacity, this is equal to 400-600 MW per hour to be compensated by rapidly-controllable power plants. Combined-cycle power plants, which have gained raising importance during the last years, have good opportunities to fulfil the tasks of such complementary power plants.

In combined-cycle plants, gas turbines and steam turbines are linked together by unfired heat-recovery steam generators (Fig. 15). This component utilises the exhaust gas from the gas turbine to produce superheated steam. The steam-turbine cycle thus utilises no extra fuel, which means a substantially better overall efficiency can be achieved compared to other kinds of power plant. Those plants have a typical capacity range from 100 to 700 MW, comparatively short construction time and are capable of efficiency levels of over 58%.



1: Intake Installations with Air Filter
2: Gas Turbine
3: El. Generator
4: Heat-recovery Steam Generator
5: Steam Turbine
6: Condenser

Fig. 15: Main Components of Combined-cycle Power Plants

5.4 Active Network Support and Network Control through Wind Turbines

This subject is currently being addressed by the EU Project "Grid Control with Renewable Energy Sources" [13]. This project is aimed at developing, testing and implementing a Grid Control Unit (GCU).

The objective of the GCU is to provide a system for the control of grids, with a high percentage of electricity produced by Renewable Energy Systems. The newly developed GCU will align the operational behaviour of renewable power plants, especially PV-plant and wind turbines (single or as hybrid systems), with that of conventional power plants. The GCU will enable renewable power plants to participate actively in supporting the grid (voltage, power factor) and improving the power feed into the grid.

The advantages of the GCU arise from the improvement of power quality, especially in weak grids, with a large supply of renewable energy sources and an increase in the calculable/predictable amount of wind energy. Improved economics could also be expected, as well as a higher level of acceptance of wind energy in the changing structure of electrical power supply. The following benefits are expected:

- The state of operation and the feed-in power of renewable power plants can be monitored exactly. Some grid characteristics, like voltage amplitude, power factor and reactive (and active) power feed-in at renewable energy source locations, could be automatically influenced by the Grid Control Unit (GCU), or directly by the power system control centre.
- Improvement of the calculable energy fed into grid of renewable energy sources.
- Supply of peak capacity and reserve power by renewable energy sources.
- Taking over of regulation tasks in the power plant network (primary regulation, secondary regulation, tertiary regulation).
- Improvement of the power quality, by automatic compensation of grid influences, with the GCU.
- The possibility of integrating more wind energy plants into weak grids, without an additional extension of the grid.
- The costs for the Grid Control Unit (Hardware, Software, Installation) with approx. 5 kEUR/connected power station are considerably less than the extension of the grid.

The main hard and software components of the GCU system can be used in multiple applications, not only for the control of electrical grids and renewable power plants, but e.g. for the monitoring of electrical systems, chemical processes and process automation.

5.5 Energy Storage Systems

An additional positive valuation of wind power can be attained if the wind power input to electrical grids is dependable enough to be seen as a source of constant power. To achieve this, wind power fluctuations would need to be predicted with adequate reliability. This could only be accomplished by combining WTs with storage systems.

The overall objective of future projects in this context will be to improve the possibility of integrating wind generators into the grid by using modular battery energy storage (MBES) in combination with a wind power prognosis system (WPPS).

The expected achievements would be:

- reliable wind power,
- higher cost effectiveness for wind power, in particular for a higher penetration rate in weak grids,
- higher peak power by WTs and
- better cost effectiveness for system technology and the modular battery energy storage.

WTs combined with energy storage have, until now, only been applied in isolated systems. In these cases, energy storage devices have been necessary for the complete balance of all fluctuations of energy demand and production. As they must be designed to cater for the longest expected wind lapses, storage devices are very large and expensive. Storage equipment for long-term load balance has also been tested for grid-connected WTs, but has failed due to lacking cost-effectiveness.

The energy storage device is not designed to overcome long-term wind lapses, but used only as a short-term buffer for the stochastic component of wind power generation. This can be accomplished by separating the determining elements of wind power (e.g. daily variations) and the remaining stochastic overlay. The determining elements can be predicted in a time range of hours by suitable prognosis methods. Only the remaining stochastic component of wind power, which is induced by local and short-term effects, must be balanced by energy storage devices. Wind power can thereby contribute to a steady load and an increased security of energy supply. By taking the resulting capacity credits into account, wind power can become considerably more cost-effective in future energy supply networks. Such storage devices would even be able to supply peak power or primary reserve, and could yield decisive advantages for future energy supply systems with high shares of renewable energy.

The energy storage requirements in the time range of minutes and hours can now, and in the future, be facilitated by electric-chemical storage devices and especially lead-acid batteries.

It is evident, that the energy density of up-to-date electrical-chemical storage devices is at least nine times higher than that of other systems, like flywheels, super-conducting magnetic energy storage systems (SMES) or Supercaps. Therefore, the only applicable storage device available at present is the lead-acid battery.

The MBES should include a lead-acid battery optimised for this application, supplemented by a sophisticated battery management system, a well tuned power converter, and a battery temperature control system. To achieve high flexibility, all components should be integrated into one easily transportable container.

The compact and modular design aids in significantly reducing the expected costs for producing large quantities of MBES. Should other storage systems prove to be more successful in the future, the experience gained would still be of great value.

5.6 Conclusions

Wind power production curves show natural variations, which however are considerably diminished by spatial balancing effects, as has been depicted in Chapter 3. In the interconnection with rapidly controllable power plants, which are the larger part of currently installed conventional power plants, the wind power output variations do not produce serious *technical* problems. Yet, for *economical* reasons, further reaching measures for a better integration of large amounts of wind power into the electricity supply are highly reasonable.

In this context, the knowledge of the wind power currently being fed into the grid has to be considered as a main focus. The statistical parameters presented in Chapter 3 already give important indications on the approximate wind power to be expected – information, which can be sufficient for grid operators with low shares of wind power. Yet, in the case of larger shares with a noticeable influence on the power plant scheduling, the knowledge of the wind power curve to be expected short-tern to medium term is essential.

Currently, the development of reliable *prediction methods* is of great interest in research, where most satisfying results are to be expected in connection with *online-monitoring* of the total wind power in utility areas. Furthermore, in certain cases the “value” of wind power – with respect to both energy economics and finances – can be considerably increased by suitable *energy storage facilities*. To a certain extent, a guaranteed wind power production can thus be enabled.

6 Isolated Systems and Weak Grids – Greece

Often the highest technical potential for wind energy can be found in isolated areas or in regions with a weak grid infrastructure. Especially on the Greek islands, the grid infrastructure is weak or insufficiently equipped to deal with large amounts of wind power. However, various studies, e.g. on storage options, power control concepts, etc. have been undertaken to allow for a higher penetration of wind power in weak grids.

A higher wind penetration in isolated regions or islands usually helps to substitute liquid fossil fuels which in many cases have to imported. In the case of Greece, for example, the entire power production with fossil fuels depends on oil imports.

6.1 The Example of Crete

Despite its vast potential of renewable energy sources (RES), mainly solar, wind and biomass, Crete is almost totally dependant on imported energy – in 1990 dependency on diesel and fuel oil was 100 %. The steady increase in electricity demand exceeds the corresponding rates of the Greek mainland system

Connecting the island's grid with the mainland electrical grid is not an alternative. It would be a very difficult task and extremely cost-intensive due to the strong undersea streams between Crete and South Peloponese, the high risk of earthquakes, the environmental problems associated, and the problems of security of supply under extreme conditions. Additionally, the construction of new thermal plants in Crete to fully cover future demand raises significant objections due to public opinion reactions and environmental impacts. On the other hand, RES - especially wind - have a very significant potential in Crete and the public is rather positive to the establishment of RES plants on the islands. Crete could become one of the showcases in Europe for exploiting the wind in isolated systems.

At present, two power stations (Linoperatmata and Chania) with twenty thermal power units compose the existing conventional electrical generation system of the island. Both of them are relatively close to the major city of Heraklion. Therefore, the supply system appears to be rather centralised. This leads to several structural disadvantages of the system, e.g. high losses due to high lengths of medium voltage lines, and difficulties in providing back-up capacity during maximum loads with conventional units.

The main characteristics of the daily load profile is the high difference between the minimum and maximum load (1,815 GWh, with 400 MW installed by 2000). Safety margins are set at 20 per cent. Strong seasonal variations occur in electricity demand due to the development of tourism. Major peaks can be observed in August (due to tourism), and at New Year's Eve. Several failures of Crete's electrical system to meet the demand have recently occurred, caused by power shortages during peak hours, both in summer and winter.

"An Implementation Plan for the Large Scale Deployment of Renewable Energy Sources in Crete", developed under the Altener programme in 1998, shows that the contribution of RES can reach 39.4 % of the total annual electricity demand by 2005, and up to 45,4 % by 2010 [14]. The share of intermittent sources (wind farms and PV stations) in Crete's electricity production is expected at 12 per cent in 2000, rising to 20 % in 2005, and to 23 % by 2010. This would lead to significant fuel substitution and avoided CO2 emissions (976,000 tons per year in 2005 and 1,238,000 tons in 2010). In addition, the mean cost of RES electricity production in Crete is less than the mean cost of conventional units' electricity production.

With average wind speeds exceeding 7 m/s in many locations, the natural conditions for harnessing wind power on the island are very good. Applications for installations in specific sites in the order of 200 MW have been registered recently, most of them in the east of Crete. At the end of 1999, approx. 50 MW wind capacity have been installed. By 2000, installed capacity from wind farms will reach almost 100 MW, and 200 MW by 2005, provided a pumped storage system is installed. The share of wind power could become even larger provided additional storage units are installed. These would be used to store excess wind power, and be used for electricity supply during peak demand hours.

6.2 The Case of Kythnos island

On the Greek island of Kythnos, valuable experience was made since 1983 with one of the first projects for developing methods for active – and reactive power control of weak hybrid power supply systems. The main criterion for the operational control has been maximum fuel saving, and in this way full utilisation of renewable energy. The island consists of 3 small villages with a minimum load of 60 kW.

The diesel power system consists of eight independent units with a total nominal power of 2.26 MVA which feeds the 15 kV island supply grid by means of three transformers. The wind farm originally consisted of five Aeroman 11/20 kW units which were replaced in 1989 by five 33 kW turbines. The solar generator (100 kW_p) feeds a battery unit.

It has been shown that during low consumer demand periods, e.g. during winter with average consumption between 80 and 150 kW, the wind farm can supply all electricity needs for the island without the diesel station being started. Variations of the wind energy supply, or short-time excessive load increases on the consumer side have been covered by suitable power storages (e.g. battery-converter units). To a certain degree, consumer demand can be brought in line with the wind energy supply, e.g. water reconditioning systems, cooling or heating aggregates.[15]

The possibilities for the control of an electrical power supply system can be easily transferred to similar conditions at other locations but apply to larger systems as well. The considerations are aimed at maximum fuel savings by a control of power flows of the various supply units, without neglecting the usual demands on electrical power supply systems, like grid stability, voltage and frequency constancy, etc. It was shown that based on effective power management systems, renewable energy supply systems with wind power can be given highest priority in supplying consumers. The storage of excess renewable capacity in larger systems can be done with pumped hydro instead of battery systems in a small system.

6.3 Conclusions

The analysis of two isolated grids in Greece has shown that wind energy can be perfectly used for reducing energy dependency, harmful atmospheric emissions from conventional fossil fuel power stations, and stabilising the grid by using a more decentralised structure of power plants. In isolated grids, storage capacities are of more importance than in the highly interconnected Central European electricity network. Combined with new forecast and prognosis methods for wind power, including online monitoring, storage systems for wind power such as pumped hydro, biomass and battery systems can be introduced fast and effectively. When taking external costs of conventional power generation into account, these isolated systems based on renewables can be implemented in a highly economic way, thereby leading to an improved balance of payments.

7 Measures for Integration of Wind Power in Liberalised Energy Markets

The question of how wind power can achieve high penetration levels as fast as possible is still a highly political one. It has been most recently challenged at European level after the adoption of the European Directive 96/92/EC for an Internal Electricity Market. This Directive not only introduces competition in a gradual way, it also allows to give priority to RES, both at distribution and transmission level, as stated in articles 8 (3) and 11 (3). Article 8 (4) allows to give preference to domestic sources of energy, e.g. renewable energy sources, up to a share of 15 per cent. Furthermore, Article 3 (2) of the Directive contains a more general provision which allows Member States to impose Public Service Obligations (PSO) on their electric utilities or the consumers, e.g. for environmental or health reasons. This provision is transposing the environmental provisions of Article 6 and 174 of the Amsterdam Treaty into the electricity sector. In this respect, the precautionary approach and the polluter-pays-principle of Art. 175 (1) are of special importance.

In addition to the Electricity Market Directive, the Commission's White Paper 'Energy for the Future: Renewable Sources of Energy' (COM (97) 599 fin.) published in November 1997, explicitly calls for an environmental bonus to be granted for RES electricity, due to their avoided external cost. In order to achieve the target of 40,000 MW wind energy by 2010, the White Paper stated that

> *" ... a significant contribution from wind energy from 2010 can only be achieved if conditions of access to the European grids are fair for the wind generators."*

Fair prices and fair access to the grid are regarded as a prerequisite for further, massive market penetration of wind and other RES. This is not only clearly shown by the success of wind power in certain EU Member States but it has also been acknowledged by the European Commission in its White Paper.

Fair conditions imply fair pricing with a compensation for the external costs associated with conventional electricity generation. Following this concept, the most effective way to achieve a high penetration rate of wind power during a relatively short period of time has been proven to be a system of statutorily granted minimum renewable energy feed-in tariffs (REFITs). During the 1990s, these REFIT systems have been applied most successfully in Denmark, Germany, and Spain, and some other member states as well, e.g. Italy, Greece, Portugal, Austria etc., Denmark has achieved a wind power share of 12 per cent, with such a framework. Now the Scandinavian country is heading for 20 % and more, with a new system yet to be tested.

Germany has become the undisputed world market leader in terms of total installed wind capacity. At the end of 1999, Germany accounts for more than 4,400 MW. In the most northern German state, Schleswig-Holstein, the share of wind power is approaching 20 per cent in 2000. The state's original target for 2010 was for a 25 % wind power share.

In contrast to the highly effective REFIT schemes, another concept of competitive bidding has been followed in the UK, Ireland and France. When comparing these other instruments applied in Europe with the REFIT type system, the success of the latter becomes apparent immediately. The comparative analysis shows that REFITs are more successful than competitive systems by a factor of more than 10. Furthermore, empirical analysis proves that a rapidly and ever increasing market penetration leads to further cost reduction and innovation caused by economies of scale, competition and learning curves.

Any future support scheme for wind power and other RES should be based on undeniable empirical facts. The EU White Paper clearly identified the reason for the success of wind power in Germany, Denmark and Spain by observing:

> *„A major factor in the recent market success of wind energy in the Member States such as Denmark, Spain, and in particular Germany, which now has the world's largest electricity generating capacity from wind, has been the price to be paid by the utilities to wind generators for sale onto the grid."*

And the Commission concludes with a reference to the precautionary principle:

> *„Any major changes that might be made in this regulatory structure should encourage and not jeopardise the appropriate development of wind energy."*

To conclude, RES deserve fair prices to successfully compete with conventional energies on the electricity market. These REFITs are a simple and effective means to compensate for the massive market distortions in the existing electricity market as well as for non-internalisation of all social and environmental costs associated with conventional electricity generation. In the very long run, most of this might be achieved by an energy taxation which is high enough to make renewable energies competitive with conventional sources of energy, whereas RES need to be exempted.

8 Summary and Outlook

In various European countries, the use of wind power has seen impressive progress during the past years, both in technological terms as well as in terms of the degree of market penetration. Within only six years, between 1993 and 1998, installed capacity in Europe quadrupled and, when compared with the early 1990s, it increased tenfold. The average annual growth rate during this period was 38 per cent, in Germany it was even as high as 58 per cent. This increase of installed wind capacity has been concentrated on the countries with statutorily granted minimum renewable energy feed-in tariffs (REFITs), which have been applied most successfully in Denmark, Germany, and Spain.

In Germany, the total wind energy production of around 4,500 Mio. kWh in 1998, supplied approx. 1 percent of the German energy consumption. This figure is supposed to increase to a nation-wide value of approx. 5 percent by 2007 at the very latest. Several German regions are already covering more than 10% of their total electricity demand with the use of wind energy. Schleswig-Holstein leads the German states with a 13% share of the total electricity production in 1998, and a share of 20% is to come by 2000. The official state government's objective of 25 per cent will be realised many years ahead of 2010.

To show its commitment to CO2 reduction, in 1997 the Danish government decided to phase out coal completely as a fuel in power stations. By 2030, wind power is expected to be supplying 50 % of Denmark's electricity and a quarter of the country's total energy requirements. This is the most ambitious wind energy target in the world. To reach this level, a capacity of 5,500 megawatts will have to be installed, of which 4,000 megawatts are planned as offshore wind farms which are to be integrated with the Nordic electricity system, mainly based on hydro reserves.

In Greece, as in many other parts of Europe, the highest technical potential for wind energy can be found in isolated areas or in regions with a weak grid infrastructure. "An Implementation Plan for the Large Scale Deployment of Renewable Energy Sources in Crete" shows that the contribution of RES can reach 39.4 % of the total annual electricity demand by 2005, and up to 45,4 % by 2010. The share of intermittent sources (wind farms and PV stations) to electricity production will be 12 % in 2000, 20 % in 2005, and 23 % in 2010.

By the end of 2010, the European Commission considers a total installed wind energy capacity of 40,000 MW, as declared in its White Paper of 1997, "Energy for the Future: Renewable Energy Sources". In the context of the liberalisation of the electricity markets, the Commission pointed out the need for a community-wide, competition-conform system for promotion of renewable energies taking into account environmental and other external benefits of RES accordingly. This will be especially necessary in those cases, where short-term market effects might endanger environmentally reasonable politics.

The increasing penetration of networks with intermittent power sources will be accompanied by a variety of technical measures. Currently, utility-wide wind power monitoring systems are being developed. As the measurement equipment of every single WT is not realistic, the task has to be fulfilled via the extrapolation of online data from selected wind farms across a given supply area.

The wind power prediction of short-term to medium-term power that is to be expected for adapting the generation schedule of conventional power plants and for the load management of system operators, is of increasing importance. Different estimations and procedures already exist for the prediction of wind power. For short-term prediction up to several hours, these models for wind power forecast are based on neural networks, while the prediction for longer time periods needs meteorological information as additional input data.

An increasing part of controllable sets is affected by growing wind power penetration levels. Therefore, a rising number of rapid-controllable power plants could be needed for compensation. Combined-cycle power plants, which have gained rising importance during the past years, have good opportunities to fulfil the tasks of such complementary power plants.

In distinct cases, energy storage in combination with wind turbine operation can improve the possibility of integrating wind generators into the grid by using modular battery energy storage (MBES) in combination with a wind power prognosis system (WPPS). Further measures for network support will enable renewable power plants to participate actively in supporting the grid (voltage, power factor) and improving the power fed into the grid.

In addition to those measures being limited to local and utility-wide application, trans-national and even trans-continental installations are to be studied in the near future. The interconnection of Danish wind power and Norwegian hydro power might become a most promising example.

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