Research for More and Better Wind Power

Vindforsk II synthesis report

Elforsk report 09:61

June 2009

Vindforsk Energimyndigheten ELFORSK

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Preface

Vindforsk II is a co-financed Swedish programme for basic and applied wind energy research. The programme started in 2006 and was finished on December 31, 2008. The total budget was approximately 45 million SEK.

This report includes a brief summary of the activities, and a main synthesis report with detailed accounts of the research within the programme. The report also includes trends analyses and opinions about research need in a number of activity areas.

Vindforsk has been responsible for projects in most research fields, but not all. Other research fields have been included in order to make the report more complete at the prospect of future discussions on research needs.

The parties behind the programme are the Swedish Government (through the Swedish Energy Agency), and the Swedish industry (both energy companies and manufacturing industry). Norwegian interest parties have also taken part in the programme. The Swedish Energy Agency finances the basic research programme and 40 percent of the applied programme. The industry finances the latter part of the programme with 60 percent.

A board of 10 members, representing financiers, has led the work. Elforsk AB administered Vindforsk.

This report is based on seven underlying reports that are available from Vindforsk:

Nils Andersson	Large amounts of wind power from a market and technical perspective
Åsa Elmqvist	Planning and permitting
Hans Bergström	Meteorology
Åsa Elmqvist	Environmental effects
Martin Almgren	Noise from wind power plants
Torbjörn Thiringer	Electricity systems for wind power plants
Åke Larsson and Michael Lindgren	Grid connection of wind power

Staffan Engström edited the synthesis report, and was also responsible for sections about Vindforsk, international research, effect of technical systems, cold climate, wind energy in forests, construction, and operation and maintenance. The forest section is based on a report by Staffan Engström and Jonathan Hjort.

The Board of Vindforsk II edited the summary.

Each chapter has a similar outline, describing research results, trends analyses, and future development.

Sections of trends analyses describe the state of knowledge in relation to ongoing research and wind energy development. Sections of future development describe the need of future R&D efforts and suggest measures to prioritise. I hope that the report will serve as platform for those who want to become familiar with the state of knowledge and problems in each research field, and thus be a basis for the discussions of the course of future efforts.

Vindforsk II thanks all decision makers, investigators, researchers, and all who have pushed issues forward, given their point of views, or otherwise advanced the wind power technology.

The current report is a translation of the Swedish report “Forskning för mer och bättre vindkraft”, Elforsk Rapport 08:46

Stockholm in June, 2009

Anders Björk

The programme secretariat of Vindforsk

Introduction and summary

Vindforsk II

Vindforsk's program for wind energy research and development runs for a three-year period from 2006 to 2008. It is divided into two parts, one for basic and one for applied research projects. The basic research projects are funded exclusively by the Swedish Energy Agency, while the applied research is funded jointly with stakeholders in the Swedish energy industry. The total budget for the entire period is approximately SEK 45 million.

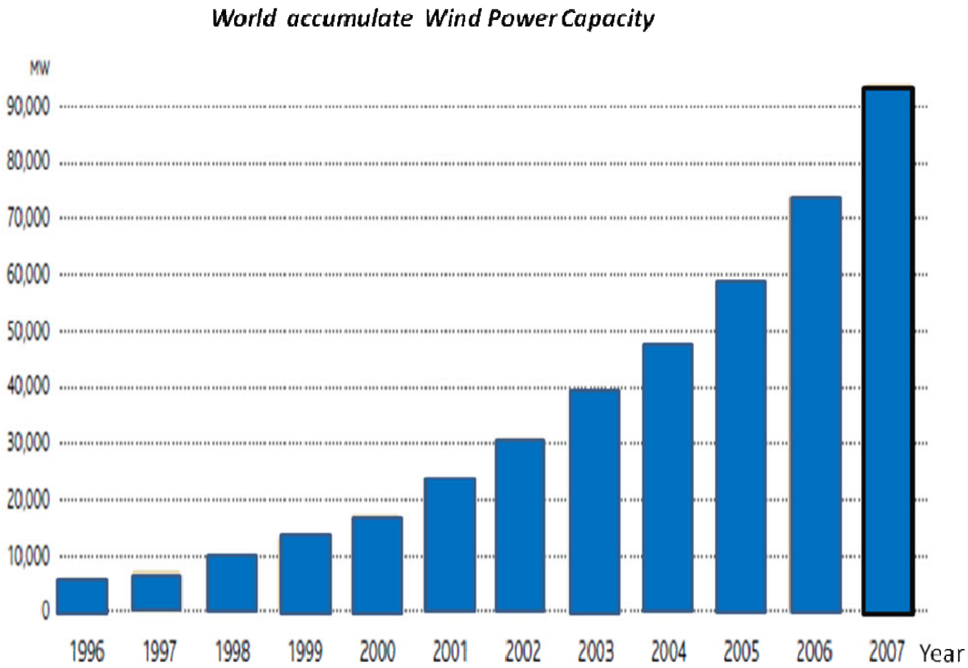
The goal of the program is to generate knowledge in order to facilitate the deployment of wind energy and its integration with the power grid. Vindforsk does not cover the entire wind energy area, but is focused on research related to technological development of wind turbines and their interplay with the technical environment in which they operate. The research is performed by universities and technical institutes, research institutes, consultants and players in the wind energy sector.

International wind energy development

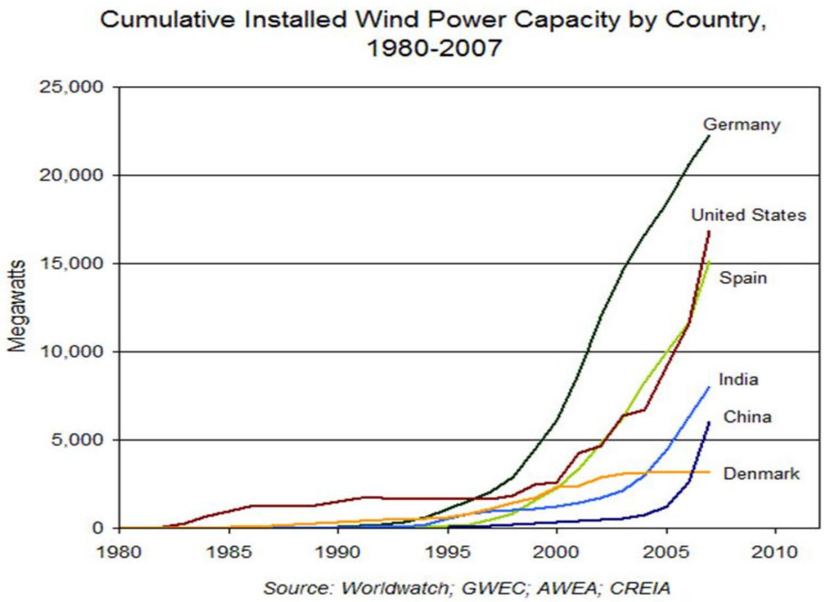
Total installed wind power capacity worldwide at the end of 2007 amounted to 94,000 MW[1]. Electrical production from these wind power plants is equal to approximately 1% of global electricity production. At the same point in time, Sweden had 832 MW of wind generating capacity that produced around 1% of Sweden's electrical output, which incidentally corresponds to nearly 1% of total global output from wind. In 2007 worldwide wind generating capacity increased by 20,000 MW and according to one forecast by BTM Consult[2] the electricity produced by wind power is expected to account for 2.7% of total electrical production by 2012.

[1] IEA Wind Energy Annual Report 2007 published July 2008 – ISBN 0-9786383-2-8, page 9

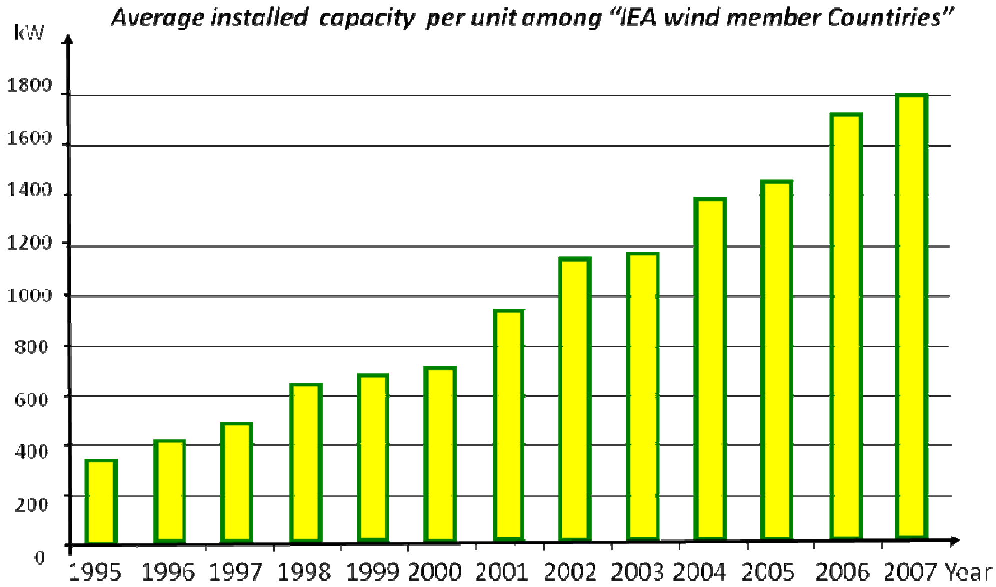
[2] BTM Consult www.btm.dk press release 27 mars 2008



At present, the rate of capacity expansion is highest in Europe (approximately 8,000 MW per year) and the USA (5,200MW per year), but China (3,500 MW per year) and India (1,750 MW per year) are fast approaching these levels. In Europe, growth in generating capacity for wind outpaced that of all other power sources during 2007. Historical growth in a few of the leading wind power-producing countries is shown in the graph below.



Seen over a longer time span, technological development has followed two main lines. The first of these is the increasing size of wind turbines which has led to cost-reducing economies of scale, and the second is the development of components that have further decreased the cost per produced kWh. The following diagram from IEA Wind Energy Annual Report 2007 shows that the average turbine size has grown at a fairly stable rate of more than 100 kW annually.

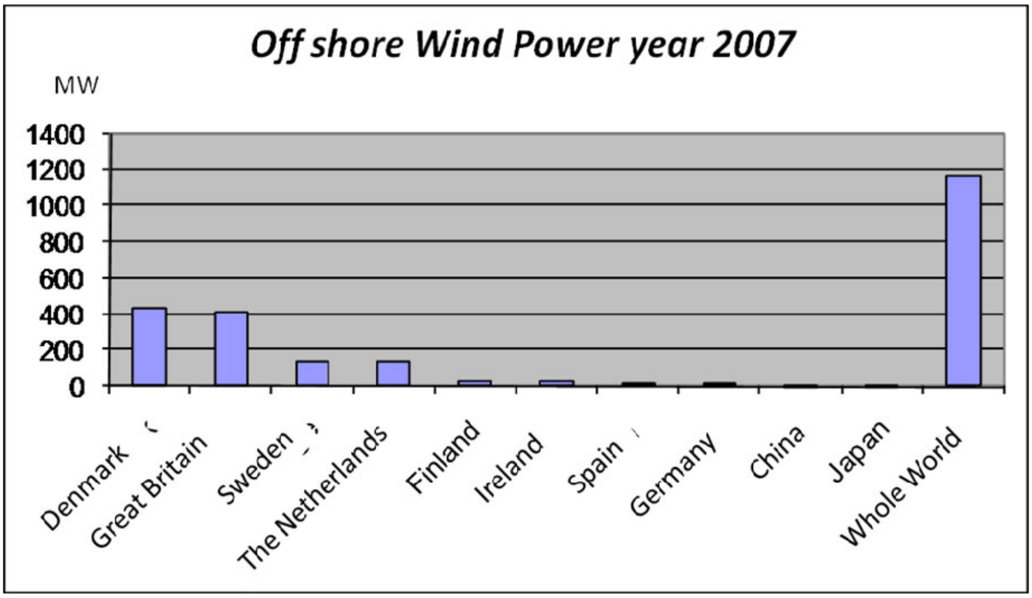


For onshore wind farms, however, there are signs of a certain restraint in further increasing the turbine size. The feasibility of transporting turbine components often sets the limit for their economically viable size.

Much of the current focus in wind power development is on increased availability and better operating performance in the sizes now in production. Examples are larger rotors for a specific output rating and higher towers to meet demand for wind turbines on sites with moderate wind resources.

Another trend in recent years is the establishment of offshore wind farms[3]. The North Sea and southern Baltic are areas where Denmark, Germany and the UK are all pursuing offshore wind development. Although Germany is just beginning its expansion, in 2009 the country will build an offshore test field[4] containing twelve 5 MW wind turbines of two different models.

[3] The graph is based in figures from IEA Wind Energy Annual Report 2007.
[4] www.aplha-ventus.de



Wind power is expected to grow substantially. According to wind power consultant BTM Consult[5] the capacity will grow to 287 GW in 2012, an increase by a factor three relative to the installed power at the end of 2007. A judgment of this cumulative market during these five years indicates an investment value of some US$ 300 billions.

The explosive growth of wind energy has been fuelled by its environmental advantages relative to other power sources, but these advantages are difficult to make visible and need to be concretised. Assistance in the form of financial support, which should be seen as a means for assigning a value to these environmental advantages, is in most cases still essential for the expansion of wind energy.

However, the costs for wind energy have fallen steadily. Analyses from the USA indicate a 50% decrease in the cost per installed kW between 1985 and 2000[6] and other countries report similar reductions. Historically, up to 60% of the cost reductions[7] have come from economies of scale, i.e. the industry has developed increasingly larger turbines, longer and more standardised series are being manufactured and/or the assembly methods have become more similar or standardised. Close to half (40%) of the cost reductions are attributed to technical improvements, product development and/or innovations in individual components or systems.

Vindforsk's task is to provide an impetus for technological advancement. The Vindforsk program is aimed at contributing to the adaptation of wind turbines to Swedish conditions, but also at creating the conditions for adaptation of the Swedish power system for wind power deployment. For example, when Vindforsk adapts the electrical systems and technical solutions in wind turbines to the Swedish grid and electricity market, this facilitates the

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[5] BTM Consult www.btm.dk press release 27 mars 2008
[6] IEA Wind Energy Annual Report 2007, page 269
[7] Cost reductions from the EU-funded TPWind initiative as cited in IEA Wind Annual Report 2007, page 23.

establishment of upscaled series in the Swedish market and therefore also results in a lower cost per kW. When Vindforsk provides support for individual design improvements, a problem is solved or the cost of a turbine is reduced. In other words, Vindforsk promotes the development of wind energy across the entire spectrum, i.e. with possibilities for upscaling and serial effects and for technological development. While the manufacturers naturally bear the main responsibility development of the components, system-related issues can be solved only in cooperation with the users.

It is estimated that a sum equal to approximately 2% of total manufacturer sales is devoted to research. At the global level, this corresponds to research investments of around SEK 3 billion annually. Added to this are government-financed research initiatives, which are estimated at just under half that amount. Although the figures are somewhat uncertain, the IEA Wind Energy Annual Report 2007 states that several countries are now intensifying their wind energy research.[8]

Sweden's R&D commitments do not stand out in an international comparison, but lie somewhere in the mid-range. On the other hand, it is difficult to make comparisons between countries due to varying methods for reporting and defining these activities.

Sweden is planning a dramatic capacity expansion over the next few years and other countries are also increasing[9] their R,D&D budgets. Against this background, there is good reason to continue supporting wind energy development and widening the scope of R,D&D initiatives. The ambition to secure a technology leadership position in any niche will most certainly require an explicit emphasis. Although the EU's joint programs have been relatively modest so far, a stronger commitment has also been indicated at this level.[10]

Report areas

General

This synthesis report has been compiled on the basis of data from the R&D program – seven underlying reports by selected authors[11]. Although Vindforsk II has not conducted research in all of these areas, by also including outside areas of interest it is possible to incorporate syntheses, evaluations and viewpoints of value in discussions about future research needs. (The

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[8] IEA Wind Energy Annual report 2007, page 23, and selected country reports later in the text.

[9] Germany doubled its R, D&D investments to EUR 35 million during 2007 and Denmark will double its level to an indicated DKK 1 billion, although this latter amount includes more than strictly wind-related initiatives – energy technologies)

[10] Proposal from the European Wind Energy Technology Platform, an industry-led forum for wind energy research and development that was created through an EU initiative.

[11] The reports and their authors are listed in the foreword.

underlying reports behind the synthesis report are available through Vindforsk[12]).

The synthesis report contains 14 chapters, of which the first two (on Vindforsk and the international outlook) are mentioned in the first section of the summary. Chapters 3-14 are more fact- and research-oriented, dealing with the technology and how wind energy influences the environment and interacts with other systems in society.

The table below shows how the program funding has been allocated according to the subject areas in the report.

Chapter in the report	Share of program funding	Chapter in the report	Share of program funding
3. Large amounts of wind power from a market and technical perspective	14%	9. Wind energy in cold climates	6%
4. Planning and permitting	-	10. Wind energy in forested areas	-
5. Meteorological conditions	7%	11. Wind turbine design	14%
6. Environmental issues	-	12. Electrical systems in wind turbine conversion systems	28%
7. Noise	9%	13. Grid connection of wind power	14%
8. Effects on aircraft, radar and signals intelligence	-	14. Operation and maintenance	9%

Large amounts of wind power from a market and technical perspective

The Vindforsk II project has studied the potential for wind energy development, its impact on power quality, the best methods for grid connection of wind turbines and farms, how the market price is affected and how wind power can be integrated with both local and nationwide hydropower production.

The Swedish Energy Agency has proposed a new planning goal for wind energy in Sweden of 30 TWh by 2020, of which 10 TWh from offshore wind

[12] www.vindenergi.org

farms. The Agency's proposal is linked to the EU's decision to increase the share of energy from renewable sources to 20% by 2020. When broken down at the national level, Sweden is expected to be assigned a target of 49% renewables, compared to the current 40%. Meeting this target will require a large amount of new renewable generation capacity and wind energy is expected to account for the bulk of this, due to its relative cost-effectiveness compared to other renewable sources.

A study within Vindforsk II clearly shows that the opportunities for wind power expansion are not limited by its physical potential. According to the study, Sweden could establish an estimated 510 TWh per year on land and 46 TWh per year at sea when the limit for exploitable potential is set at an average wind speed of 6 m/s at a height of 71 meters. The land-based potential is thus considerable. However, the ability to effectively utilise this potential – and to achieve large-scale expansion before 2020 – will depend largely on whether or not barriers are created by the permitting process, opportunities for grid connection and technical problems. The technical difficulties and uncertainties surrounding wind power in forested areas and cold climates are touched on in the respective chapters of this report.

Although the cost of new wind capacity is often higher than for other power generation technologies, its environmental advantages and renewable energy targets have motivated the introduction of support systems. Sweden's system of renewable energy certificate (REC) is now starting to accelerate the pace of wind deployment, although sea-based wind power is so expensive at present that it requires supplementary support in order to play any significant role in Sweden in a near-term perspective. The relatively young and untested technology for offshore wind turbines can be further developed, but this will require ordering of new turbines, and before that can happen there must be support systems in pace. Here, there is scope for creative R&D proposals.

The large-scale deployment of wind power will create new demands on the power system's regulation capacity. The Nordic region has access to hydropower, which is an effective means of compensating for fluctuations in wind power output. This is attractive not only for Swedish wind utility operators but also for the European wind energy industry. Studies on the need for regulation power and how to effectively exploit hydropower for power balancing and regulation in a wider perspective are therefore urgent.

A deregulated market with large amounts of wind power will also function differently than at present. Norway has launched an ambitious program where the aims are to develop wind energy, regulate this with hydropower and interact with other countries in Europe. In this context it is natural to study how future wind deployment will affect the current trading regime on the Nordic power exchange NordPool, an analysis that should be carried out in pan-Nordic collaboration.

The need for regulation power means that more hydroelectric power must be transmitted from north to south, which will affect capacity on the national grid. With the now planned additions to the total power system, including wind and nuclear power, by 2020, the supply of electricity in the Nordic market could exceed total market demand. This will require expansion of international interconnections to avoid locking Nordic CO_2-free electricity production within the Nordic system. Other technological developments could also affect the future of wind power. In order to create the conditions for an efficient electricity market based on renewable and CO_2-neutral production to the greatest possible extent, adequate advance planning is needed for grid reinforcement. Increased energy efficiency can also affect the electricity market through both higher and lower demand for electricity. The market launch of electric and hybrid electric vehicles is an example of a phenomenon that indicates rising demand for electricity, and the systems for recharging these vehicles could also have a positive impact on access to and the need for regulation power.

Numerous efforts are underway to develop smart grids in both the USA and the EU. To facilitate the expansion of wind energy, which demands adequate grid reinforcement and the right amount of regulation and backup power, it is crucial to conduct studies in a number of areas such as forecasting of electricity consumption, the structure of support systems, the need for reinforcement of transmission networks and development of smart grid technologies. It should be noted that this is not restricted to individual wind energy issues and that planning of future research needs must ensure cooperation between multiple research programs and projects, both national and international.

Planning and permitting

Society's planning determines the framework for utilisation of wind energy. But despite this, planning has not been pursued as a separate area in the Swedish wind research programs. No projects on this topic have been conducted within Vindforsk II , although three are being carried out in the Vindval[13] program.

In contrast with countries like Denmark, Sweden has no wind energy planning at the national level. An overall approach to the country's wind energy deployment is desirable for both technical and environmental reasons. Examples of closely-related regional studies are Sydhavsvind and the Offshore Bank Survey (Utsjöbanks-inventeringen).

Although both Vindforsk and Vindval are applied research programs (with a clear user perspective), some attention should also be devoted to planning in the ongoing development of these programs. There should be ample scope to create concrete tools that facilitate future wind energy projects and contribute to more efficient utilisation of resources by wind developers, public agencies and special interest organisations and, not least, more satisfied citizens. It should be noted research on acceptance is concerned not only with acceptance for the wind turbines themselves, but also for expansion of the transmission network and other infrastructure.

[13] Vindval is a research program that compiled data and knowledge about the environmental effects of wind energy, but also includes projects on acceptance and planning. The program is funded by the Swedish Energy Agency and administered by the Swedish Environmental Protection Agency, www.naturvardsverket.se/vindval

Meteorological conditions

Wind energy development requires knowledge about wind, both as an energy resource and as a dimensioning factor for the turbines. The European Wind Energy Technology Platform is urgently appealing for more research in this area. For many years Sweden has conducted high quality meteorological wind research, which has been ground-breaking in several respects but has today perhaps lost some momentum. There is reason to break this trend, particularly in country-specific areas such as wind conditions in forested areas and wind energy in cold climates.

Vindforsk II has financed three projects dealing with basic research and collection of statistical data. For future projects, it would be beneficial to increase spatial resolution in the wind mapping model to further enhance its usefulness for project development and siting purposes. In addition, the special wind conditions existing over the ocean, forest and hilly terrain call for further development of wake models, i.e how wind turbines shade each other in different terrain. Continuous measurement of wind speeds in different landscapes makes it possible to dimension wind turbines and long-term measurements also provide a basis for determining the normal wind year. There is a growing need for local wind forecasts and possible monitoring of other meteorological conditions such as icing events in order to handle wind energy in northerly climates.

Environmental effects

The environmental aspect represents both wind energy’s foremost opportunity and its greatest limitation. Although interest in wind energy stems from its low environmental impact, environmental issues are often the cause of restrictions and delays in wind energy projects.

Environmental issues have not been covered by Vindforsk II other than in relation to noise issues, which are covered under a separate heading below. The task of Vindval, a research program funded by the Swedish Energy Agency and administered by the Swedish Environmental Protection Agency, has on the other hand been to compile data, build knowledge and distribute information about the environmental effects of wind power.

Wind turbine noise

Noise accounts for a significant share of wind energy’s environmental impact and is a topic of extensive discussion in the permitting process. The currently available Swedish knowledge on this topic is based mainly on projects financed by Vindforsk and its predecessors.

In one project, sound propagation around offshore wind turbines has been investigated by measuring sound attenuation over the distance from the Utgrunden lighthouse in the Kalmar Strait to the island of Öland. The results have provided a basis for modification of the Swedish Environmental Protection Agency’s model “Sound propagation around offshore wind turbines”. A project using measurement data from the Utgrunden lighthouse to validate the calculations is investigating new types of models that include the effects of meteorological conditions such as temperature and wind gradient. Methods to calculate sound propagation are thus under continuous development – partly thanks to fast computers that now make it possible to use more physically detailed models which lead to a better ability to calculate the sound levels arising at different distances from wind turbines. The areas described as critical for future research are sound propagation in forest terrain and over the ocean surface. It is also important to increase knowledge about how consideration is taken to the masking effects of ambient noise and wind-sheltered sites with a low level of masked noise.

In other words, additional knowledge is needed and it is worth mentioning that Swedish research on turbine noise stands up well in an international comparison. However, it is also true that noise issues appear to be of greater interest in Sweden than other countries, particularly for offshore wind farms.

Questions about which noise level parameters should be used and how ambient noise sources affect the share of people who experience noise annoyance are both related to research on acceptance. During Vindforsk II, this research has taken place within Vindval and the Vindforsk projects have focused on the more technical aspects of sound propagation. In order to formulate the right noise level parameters, such as duration, in the future, is it vital to coordinate acceptance-oriented research and technical research on sound propagation.

Effects on radar, microwave link and signals intelligence

Wind turbines affect and sometimes create disturbances in existing technical systems. Aircraft must naturally be able to detect the turbines in time and the national defence does not want these to interfere with Swedish radar and signals intelligence. The military also has other interests that sometimes conflict with potential siting of wind turbines, such as the desire to maintain a system of reserve landing strips. However, this imprecise landing system requires large amounts of free space and is a case where the wind energy industry asserts that military interests must be weighed against the need for expansion of wind power. In such cases, advocates of the wind energy sector claim that in view of the overall benefits in combination with possible alternative solutions, this may not be allowed to hinder wind energy deployment. Obstacle warning lights on wind turbines are a further example of how these interests can be opposed. Obstacle warning lights are intended to prevent aircraft collisions, but can be disruptive for the surrounding environment and represent an added a cost.

This has not been a prioritised area for Vindforsk II. However, a separate research report with funding from the Swedish Energy Agency on radar interference from offshore wind farms was carried out during the period.

This chapter reviews a number of conflict areas, such as the need for ”free air space” around airports, obstacle warning lights and wind turbine interference with radar and microwave link. The chapter also presents proposals for specific areas where research can be necessary to find alternative solutions and a reasonable balance between the various interests.

Wind energy in cold climates

Some 70% of Sweden’s total surface area is at risk for heavy icing on wind turbine rotor blades and other components. However, commercially available technology is made to withstand only moderate icing. The month-long standstills that have occurred in certain turbines are not acceptable and are definitely a barrier to large-scale expansion. But in the sellers' market that exists today, icing is not a prioritised consideration for the major wind turbine suppliers since this problem is minor in a global perspective. The suppliers already have a sufficient number of customers for wind turbines not specially designed for cold climate conditions, and therefore have little interest in developing solutions.

In spite of this, new wind turbines are being built in sites affected by icing. The developers apparently do not see icing as a decisive obstacle, but at the same time express a need to address the problem. Knowledge about which areas that are at significant risk for icing and the development of techniques to prevent icing or remove ice from the rotor blades is therefore vital. Due to the small number of countries with problems of this type, it is important for Sweden to play an active role in driving development forward.

The Vindforsk II program includes one project focusing on development of methods to de-ice or prevent icing on rotor blades and two projects on ice measurement and detection. Besides contributing to increased knowledge in these areas, the research efforts can create opportunities for development of the products used in the projects. Sweden is also participating in an IEA Wind task for research on wind energy in cold climates.

For the future, it is vital not least to collect statistics and other data in order to systematise and develop knowledge about icing. Better resources are also needed, as in the case of wind mapping, for classification of local risks and the rate of icing at potential wind turbine sites.

Wind energy in forested areas

Wind energy in forested areas has not been a priority for Vindforsk II, but a keen interest in building wind turbines in forested areas has changed the need for research on this area.

This chapter describes experiences from some 60 Swedish wind turbines built in or near the forest. A few stand on open ground but are affected by the surrounding forest, while most are located in purely forested areas, often on hills and rises. A general conclusion is that energy yield predications appear more reliable for turbines in forested areas than for other turbines in the country. This is possibly due to the fact that forest projects tend to be larger, with more generous budgets for wind measurement and other validation, than the typical project in open terrain. It has been found that energy yield levels from wind turbines in forested areas are largely equal to those in other turbines of similar size.

Although the review shows that wind turbines in forested areas have good output levels and have functioned well thus far, the nature of wind conditions over the forest has not yet been studied. High turbulence intensities and wind gradients should affect output and lead to increased fatigue loadings and subsequently also shorter turbine lifetimes. Basic and applied research initiatives, like better statistics, are therefore motivated components of future programs. This applies particularly to the dynamic behaviour of winds over the forest and how they interact with a large array of wind turbines in forest terrain, as well as how wind turbine wakes[14] spread and break down.

Wind turbine design

For obvious reasons, improved technology, more advanced components and better dimensioning criteria for power plants are key drivers for the development of wind power technology and are also a central area for R&D initiatives in the international arena. Because Sweden has no suppliers of complete turbines, however, Swedish research on wind turbine design is naturally tied to the project orderer's desire to influence the suppliers and the problems Swedish sub-contractors may with to focus on. Five projects have been financed within Vindforsk II, ranging from how wind farms can be optimised with regard to wind turbine wakes to new splicing methods for steel wind turbine towers. One area of importance also for a country as project orderer is standardisation, where Sweden has been active among other things in formulating communication standard for monitoring and control of wind turbines.

The international standardisation effort is an area that deserves continued attention. There are considerable opportunities to influence activities in new fields of interest such as wind energy in forests and cold climates. Participation in the standardisation process provides valuable early-stage information about the direction of new standards.

When and if the development of Swedish-made wind turbines picks up momentum, there may be reason to support special design-oriented research with a direct bearing on the problems of this industry.

Electrical systems in wind turbines

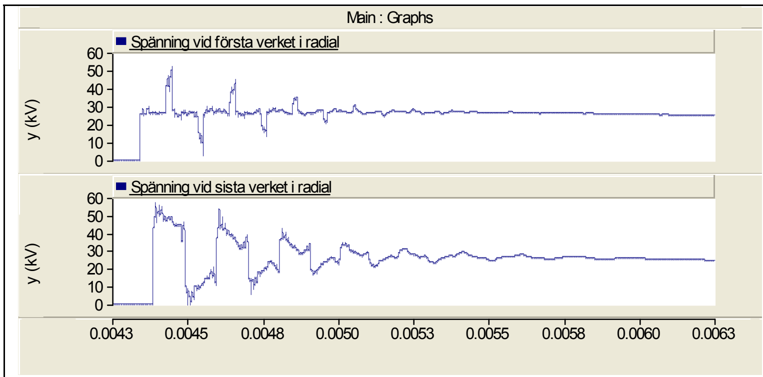
The two areas of electrical systems for wind turbines and grid connection of wind turbines are closely related, but are described in two separate chapters in this synthesis report. Both are prioritised research areas in Vindforsk II. For both historical and industrial reasons, electrical system issues are of special interest to Sweden with its world-leading industry and ongoing development. The question of how to adapt wind turbines to the local – and sometimes specifically Swedish –conditions of the electrical network system is crucial in order integrate wind generation into the Swedish power system in a technically acceptable manner.

Wind farms interact with large electrical systems, and the way in which this interaction takes place is highly important. With electronic controls, such as variable rotational speeds, it is possible to maintain high wind turbine output while also minimising mechanical loads on the turbine. At the same time, with the help of power electronics the electrical systems can make it possible for wind turbines to interact, and be effectively integrated, with the power grid. The Vindforsk projects are contributing to increased knowledge about how

[14] Wind turbines extract energy from the air by slowing the wind to a lower velocity. A wake is the name of the ”wind hole” that is created behind a turbine. Through influence from the ambient atmospheric air flow, these wakes recover at a certain distance behind the turbine.

electrical systems can be designed to achieve these goals – high output, low loads and effective interaction with the power system – at a low system cost.

However, new electrical system layouts and new equipment demand knowledge about the function of electrical systems all the way down to the detail level, where an example can be used to illustrate part of the problem. Several offshore wind farms, such as Middelgrunden and Horns Rev, have experienced transformer and generators failures. The underlying reasons are not fully known, but one possible explanation is that these failures have been caused by high frequency oscillations in the power grid. For example, switching of the now common vacuum circuit breakers can give rise to transient overvoltages (spikes). The large cable systems in an offshore wind farm can extend for tens of kilometers, and these transients travel along the network. (See diagram below).



The diagram at left shows phase voltage at the first and last turbine in a radial grid when a vacuum breaker is switched during a simulation at the Krieger's Flak wind farm.

Three Vindforsk II projects are studying the problem of high frequency transients in wind farms, and are resulting in models for electrical systems with more detailed modelling of circuit-breakers in the system. These projects are vital for successful planning and design of offshore wind farms.

Grid connection of wind turbines

The electrical newtwork owners' technical requirements for grid connection of wind turbines have become more rigorous as wind power accounts for a growing share of total system generation. The grid codes issued by newtwork owners increasingly include requirements on reactive power compensation during net-faults. Some requirements also apply to participation in the frequenct control. For instance, Hydro Quebec's code states that wind farms must be able to support frequency control by temporarily boosting reactive output current by 10%.

With regard to grid connection, the Vindforsk II projects have focused on ways during the planning and design stage to ensure that wind farms meet the code requirements of Svenska Kraftnät (the Swedish National Grid) regarding their behavior in the grid. Testing procedures are being developed to evaluate the wind turbines' ability to meet these requirements.

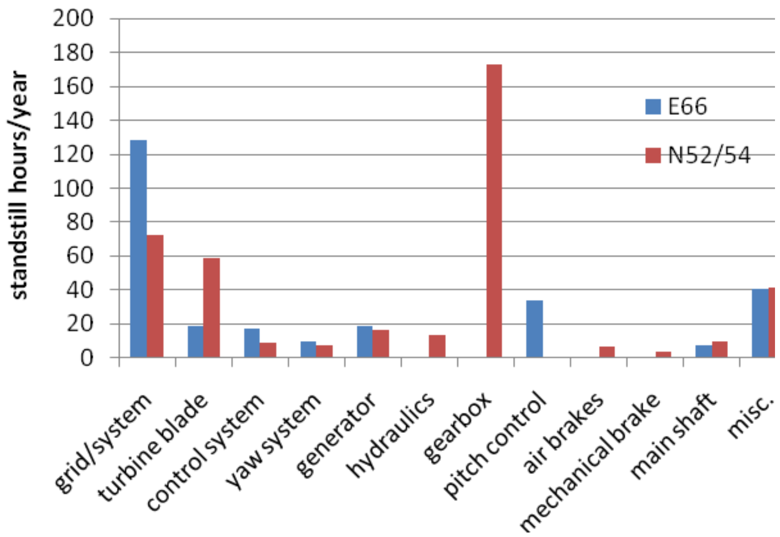
Ongoing activities are motivated not only due to the scope of this problem area, but also because Sweden has traditionally had a strong power technology industry that may be attractive for participation in wind deployment projects both in Sweden and worldwide. Areas related to usage of power electronics and direct current systems should therefore remain central in future research programs.

A closely related theme that has attracted widespread attention is the idea of a "super grid" to interlink and connect offshore wind turbines. One or more gigantic direct current grids in the North Sea and the Baltic could feed energy to different countries while at the same time interconnecting them. The Norwegian hydropower industry is interested in utilising hydropower to regulate this wind power, and Norway has launched studies in this area. Perhaps Sweden should also draw up a plan for how a super grid could affect the Swedish transmission system, the wind energy program and usage of Swedish hydropower.

Operation and maintenance

Within Vindforsk II, three projects have been carried out in the area of operation and maintenance development. One of these has applied to statistics. Wind turbines have long been considered to have an availability of 98-99%, and the statistics reported for Swedish wind turbines since the 1980s support this assumption. However, a review of the statistical data uncovers errors and misleading information in the reporting system. A more accurate availability value is more likely in the range of 90-95%, which means that production capacity has been overestimated but also that the potential for improvement is greater that previously believed.

An understanding of operation and maintenance, and the related costs, is essential for wind power development. This is even more crucial when the turbines are difficult to reach, such as in the case of offshore wind turbines, and accessibility for major maintenance will also be periodically limited in cold climates. In order to develop efficient operation and maintenance strategies, it is necessary to have knowledge not only about the service life and failure rates of individual components, but also about how the various sub-assemblies affect each other. While access to statistics, failure causes and frequencies, etc., is essential, no reliable analysis is possible until there is a sufficient volume of data, effective methods for monitoring the condition of components and developed maintenance strategies.



Causes of failures in Danish and German wind turbines according to an analysis by J.V. Tavner in the spring of 2008

The above graph from an EWEC report[15] is based on one Danish and two German databases containing data from 7,000 wind turbines over a period of 11 years. Gearbox failures are common in geared turbines, while direct drive turbines are commonly affected by malfunctions in the electrical system. Understanding the forces at work and the interplay between mechanical and electrical systems stands out as the perhaps most important factor.

Systematic data collection and good maintenance methods lead to better operating performance. One project within Vindforsk II has been aimed at improving the statistics and another at optimising maintenance in offshore wind farms. Because offshore turbines are difficult to access, they require a different maintenance strategy than used for other power generation facilities. Theese methods should also be of interest for wind energy in cold climates.

Failures lead to downtimes and cost money. After being hit by lightning and catching fire, a turbine can be destroyed if its fire extinguisher systems are not adequate. In Germany, 8 wind turbines were ravaged by fire[16] during 2002. Data from 12,000 turbines shows a failure frequency of 0.07%, which

[15] P.J. Tavner et al. Reliability of different wind turbine concepts with relevance to offshore application. EWEC 2008, Brussels 30/3 – 4/4 2008.
[16] Wind Kraft Journal 3/2005

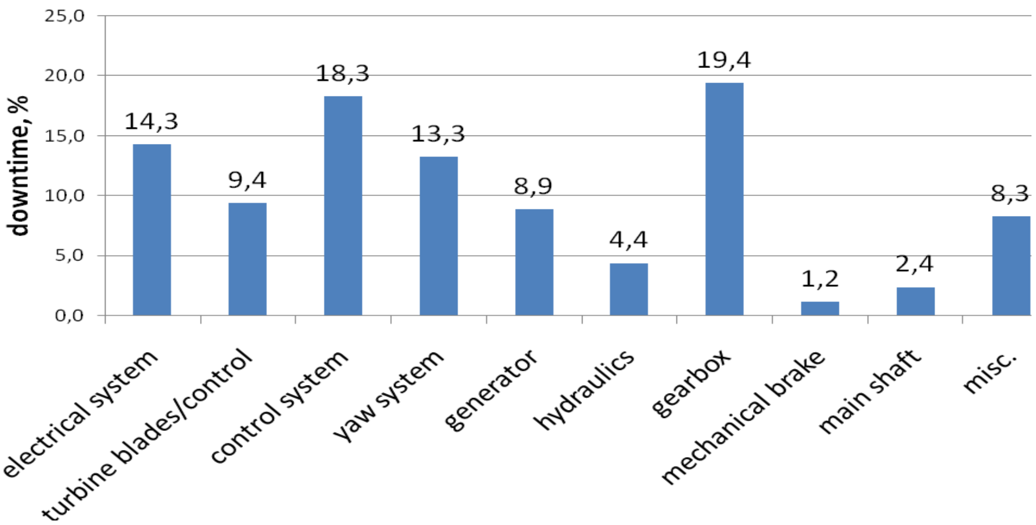
reduces reliability performance by 0.7%. Downtimes of all types affect operating economy and deserve attention.

Wind turbines have become larger, and Tavner's study indicates that this is leading to a higher failure frequency – from one failure per year for turbines with a capacity of around 250 kW to 3.5 failures per year for 1.5 MW turbines. The direct drive turbines with capacities of 0.5 MW and 1.5 MW show the same frequency of 2.5 failures per year. A rising failure rate cannot be ignored. From a technical standpoint, wind power resembles hydropower and the ambition should be to achieve the same low failure frequency and high reliability performance in wind turbines that have long been seen in hydropower plants.

Closing comments – including views on future initiatives

Priorities for Vindforsk II

Vindforsk II has been developed and continued along the same lines as Vindforsk I. The priorities have been determined by the participating companies' needs and ability to make research proposals, but also on the basis of the information or facts the researchers have had access to. Another requirement has been some type of fundamental aim for the results to be made publicly accessible – albeit at a certain delay.



Distribution of downtimes in Swedish wind turbines, based on processed data from Ribrant and Bertling (2007).

Although research on gearbox problems would top the list, as it perhaps should do considering the above graph, the opportunities for R&D in this area are limited since this type of development work must be driven largely by manufacturers. In contrast, questions related to electrical systems, control assemblies and wind energy's role in the Swedish electricity market are all ideally suited for research within the Vindforsk program.

Consequently, it is urgent to seek answers to questions that are specific to the Swedish industrial sector, Swedish society or Nordic climate. Another key aspect is to prioritise research that not only solves technical problems but also contributes to industrial development and job creation in Sweden. Examples of such areas are ideas that widen the scope for wind power to interact with electricity generation, transmission and/or consumption; innovative solutions for electrical systems in wind farms; turbine designs that enable new industrial solutions (such as towers, foundations, etc.); designs that are adapted to the Nordic climate and terrain (e.g. forest, cold, etc.) and so on.

IEA Wind Energy Annual Report 2007[17] presents a thought-provoking table in which the installed wind capacity in various countries is seen in relation to the estimated number of jobs created and economic impact.

Table 5 Wind Capacity, Jobs, and Economic Impact in 2007

Country	"Capacity (MW)"	Estimated number of jobs	"Economic impact (Million EURO)"
Germany	22,247	84,300	11,729
United States	16,904	17,000	6,165
Spain	15,145	45,000	5,000
Denmark	3,124	28,000	4,690
Italy	2,726	10,600	1,000
United Kingdom	2,390	8,000	
Portugal	2,125		
Canada	1,845	3,340*	1,490*
Netherlands	1,745		230
Japan	1,538		
Austria**	982		
Greece	874		
Australia	824	978	180
Ireland	803		90
Sweden	788		
Norway	385		
Republic of Korea	193		
Finland	110		
Mexico	85		
Switzerland	12		100

* Numbers form 2006

** Numbers from Wind Power Monthly

Although the figures in the table contain a certain degree of uncertainty, they confirm that countries which have build up their own manufacturing capacity parallel to the deployment of wind power derive double benefits from these investments. Swedish R&D should therefore continue prioritising project proposals that offer opportunities to develop Swedish industries.

[17] IEA Wind Energy Annual Report 2007 page 18

The other main objective behind Vindforsk is to promote the build-up of Swedish expertise in wind power technology at universities and technical institutes through R&D projects. All players in the Swedish wind energy sector also stand to benefit if the academic sphere is able to attract competent new young people by encouraging Ph.D. students to take on problems of both theoretical and industrial relevance.

Closing comments ahead of Vindforsk III

The program evaluation has found Vindforsk II to be of high quality and merit. This applies to both actual research results and the process behind the allocation of funds. The report points out several reasons to continue the program. These have been previously described in the applicable sections of Chapter 2, and are thereby handed over to the upcoming Vindforsk III (under development at the time this report was written). No total reevaluation of the direction and content of Vindforsk III appears necessary.

The Swedish wind energy sector is facing a daunting challenge. During the period 2009-2011 (and onward to 2015 when the planning target of around 10 TWh will perhaps be met), Sweden must expand its wind capacity by 600 to 700 MW per year in order to achieve and installed capacity of 4,000 to 4,500 MW by 2015. The necessary investments are estimated at SEK 8 billion annually[18]. If government-funded research makes up 1%[19] of this amount, i.e. SEK 80 million, the funds would in such case be allocated not only to Vindforsk but also to Vindval and other government-supported initiatives. A level of SEK 15 -30 million per year in government R&D funding for technical wind energy research through a Vindforsk III program is equivalent to what many other governments invest.[20]

Aside from the purely technical and knowledge-enhancing benefits of the Vindforsk programs, there are a few soft but no less important aspects:

- <u>The first</u> is to create greater visibility for the industry.
  - More young people are needed in the sector, since the existing wind farms must be operated at the same time that the sector orders,

[18] In a newsletter from February 2008, the EWEA (European Wind Energy Association) states that some 20,000 MW of new wind generating capacity were installed during 2007. The investments are estimated at EUR 25 billion, which is equal to around SEK 12,000/kW (exchange rate of around SEK 10/EUR). For the USA, IEA Wind Energy Annual Report 2007, page 269, shows an installed project cost of USD 1,700/kW, which at an exchange rate of SEK 7.5/USD is equal to a cost of SEK 12,750/kW. This means $650x10^3$ x 12,500 = 8,125 x 10^9 SEK.

[19] 1% of total investments is often regarded as a "reasonable" level of government R&D spending for this type of industry. Including industrial initiatives, total R&D investments often increase to 2% or more. Industrial sectors with shorter life cycles than the power industry, such as telecom, often have an R&D investment rate of 10%.

[20] In October 2008, Norway announced an 8-year co-funded wind research program through a new institute for offshore wind energy with a budget of NOK 40 million annually, or a total of NOK 320 million.

builds and perhaps even delivers new turbines.

- Greater visibility also includes achieving an even inflow of qualified employees, particularly Ph.D. students. Some type of rolling financing scheeme could possibly overcome the difficulties arising from the fact that research programs run for a fixed period that is not related to the normal Ph.D. period of three years.

- The second is to see and contribute to standardised solutions in order to cut costs and integrate players in the industry. This will require involvement in international groups.

- The third is to increase the industrial benefits of Sweden's wind energy deployment. New industrial players require support in order to take part in wind energy programs and develop new components. (At least one new wind turbine supplier was established in the summer of 2008 and there is potential to develop additional active industrial players.)

Innehåll

1 Vindforsk

1.1 Aim[61]

As for many other infrastructures, the wind power expansion involves, many considerations about implementation in existing environment and habitation. The rate of expansion is largely determined by the economical conditions. Electricity production from wind energy is a quite new technology which means that new problems are introduced concerning both technology and electricity system.

The purpose of the programme is to achieve knowledge that facilitates the expansion of wind power and the power grid integration.

1.2 Objectives

The objectives are that all activities within the programme will contribute to:

- lowering the costs for electricity production with wind power,
- facilitating the establishment of new wind power plants,
- within relevant areas, maintaining and developing the competence of research groups, and
- within relevant areas, developing and strengthening the Swedish wind energy industry.

1.3 Budget and technology areas etc

Vindforsk 06-08 started on January 1, 2006 and ran for three years. The budget was 15 million SEK in 2006 and 16.25 million SEK in 2007 and 2008, respectively, which means in total 47.5 million SEK. The Swedish Energy Agency financed the entire basic research programme and 40% of the applied programme. The industry financed the remaining part.

In addition to research financed by Vindforsk, the Swedish Energy Agency funds research projects concerning wind power through other channels, which are not included here.

The programme is divided into the following subject areas:

- Permits, environment and acceptance.
- Prospecting, operation, and maintenance of wind power plants
- External conditions, standardizing

[61] Aim, objectives, budget, and technology fields according to the programme description of Vindforsk 06-08, version according to the additional decision of 2007-02-14, www.vindenergi.org

- Technology coverage and dissemination of information.

The approved projects (through October 2008) were slightly less than the original budget. The basic research programme is funded with totally 19,6 million SEK, and the applied programme with 24.5 million SEK. The allocation of funding to Vindforsk is shown in Table 1.

Table 1. Financing of Vindforsk 2006-2008 (million SEK)

Energy companies	10.2
Svenska Kraftnät	2.4
ABB	1.5
EBL-Kompetense	0.6
Swedish Energy Agency- applied programme	9.8
Swedish Energy Agency- basic programme	19.6
Total	**44.1**

A board led the programme, approved projects within the applied programme, and gave advice to the Swedish Energy Agency regarding the basic programme. When this report was published, the members of the board were:

Stig Göthe	Chair
Jan Ahlbäck	Skellefteå Kraft
Anna Bergek	Linköping Institute of Technology
Michael Dahlgren	ABB
Lene Mostue	EBL-Kompetense
Elisabeth Norgren	Svenska Kraftnät
Martin Lindholm	E.ON
Sven Erik Thor	Vattenfall Elproduktion
Anders Björk	Elforsk (programme leader, co-opted)

2 International Wind Energy Research

2.1 Wind Energy in the World

Since the beginning of the 1990s, the wind power has expanded and at the end of 2007 the world production amounted to 94 000 MW, which means that it accounted for 1 percent of the global electricity production. At the same time, Sweden contributed with 832 MW, or 0.9 percent, of the global production. The increment during 2007 was 20 000 MW, and according to a prognosis, this will cover 2.7 percent of the electricity production in 2012[62]. So far, the main part of the expansion has taken place in Europe where the installed wind power effect during 2007 was larger than that of any other power category. During the 2000´s, only gas power plants have been installed to a larger extent.[63]

2.2 European Wind Energy Technology Platform

As a result of the EU's Council of Ministers meeting in Barcelona 2002, "Technology Platforms" for a number of areas were established. The aim was to get companies, research institutes, the financial world, and reviewing authorities to formulate an agenda for research within each of the current topics. The European Wind Energy Technology Platform was established with about 170 members distributed on a number of working groups, a secretariat, a steering group, and a board. The most visible result of the activities is the "Strategic research agenda", published in 2008.[64] The agenda considers research and research needs on wind power issues, and tangible proposals for measures. Due to the group's composition and representation, the document reflects the dominating opinions regarding wind energy community in Europe.

In each section of this report, the current suggestions from the European Wind Energy Technology Platform are summarized. The interpretation of the degree of congruence is influenced by the circumstances in each case, and may, to large degree, be the reader´s own. For example, the strong focus on meteorological research in the document may lead to the conclusion that we should commit ourselves to this topic, where we have a strong tradition and have achieved good results. The document's lack of interest for wind power in cold climate may also lead to a need for us to contribute stronger, since a large part of Sweden is exposed to icing and since we cannot count on obtaining the technology from broad.

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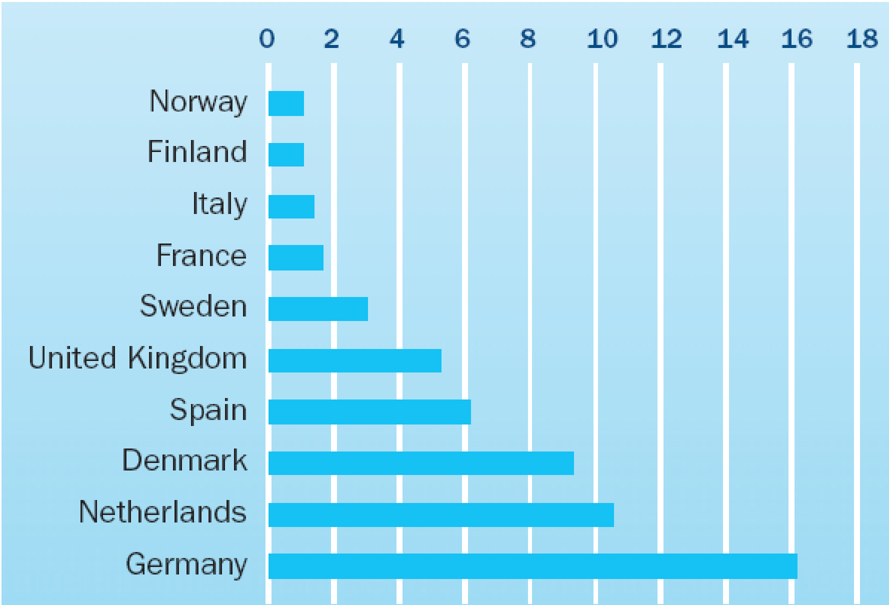
[62] BTM Consult Aps. International wind energy development. Worlds market update 2007. Forecast 2008-2012. March 27, 2008. www.btm.dk
[63] EWEA. Wind energy leads EU power installations in 2007. News release February 4, 2008. www.ewea.org
[64] Strategic Research Agenda. Market deployment strategy from 2008 to 2030. European Wind Energy Technology Platform. www.windplatform.eu



Figur 1. Government funded wind energy research in average during 1998-2005 for European countries with a budget above 1 million euro per year. Million euro in money value of 2006.[65]

2.3 Research and Development in EU and OECD

The government-funded research in the major wind power countries of Europe is shown in Figure 1, compiled by the European Wind Energy Technology Platform. Together it accounts for 520 million SEK per year. The OECD countries carry out research cooperation in IEA, International Energy Agency. The EU-research together with research in USA, Canada, and Japan give a total wind power research of the world worth 940 million SEK per year.[66] Note that the data partly refer to different periods. With this measure, the Swedish research will be 3 percent of the total, which can be compared to that Sweden has installed about one percent of the world's wind power.

The main part of the development work is done by the industry. Table 2 shows the size of research investment for some wind power manufacturers. Together, they have half the market. On average, the research cost accounts for two percent of the net sale. Assuming that other manufacturers have the same R&D proportion, the total development of the world's wind power industry should correspond to three milliard SEK, or three times the government-funded research.

[65] Strategic Research Agenda. Market deployment strategy from 2008 to 2030. European Wind Energy Technology Platform. www.windplatform.eu
[66] IEA Wind Energy Annual Report 2006.

Table 2. Costs of research and development for different manufacturers of wind power 2006. Exchange rates of September 1, 2008.

Company, country	*R&D (MSEK)*[67]	*Market proportion (%)*[68]
Acciona, Spain	216	2.8
Gamesa, Spain	317	15.6
Nordex, Germany	108	3.4
Repower Systems, Germany	134	3.2
Vestas Wind Systems, Denmark	849	28.2
Total	**1 624**	**53.2**

[67] Strategic Research Agenda. Market deployment strategy from 2008 to 2030. European Wind Energy Technology Platform. www.windplatform.eu
[68] European Wind Energy Development. Work market update. Forecast 2007-2011. BMT Consult Aps. March 2007.

3 Large amounts of wind power from a market and technology perspective

3.1 Results from the Vindforsk Programme

During the period of 2006-2008, 5.5 million SEK or 14 percent of the total funding was allocated to this activity.

Opportunities for Wind Power Expansion

V-139 Wind Power in the future[69]

Project leader: Peter Blomqvist, Vattenfall Power Consultant

The project has studied the opportunities to establish wind energy plants in Sweden by extensive surveying, combined with analyses on the effects of various economical and other conditions. According to the report, it is physically possible to establish 510 TWh/year on land and substantially less, 46 TWh/year, offshore. Considerations have been taken to wind conditions and other physical restrictions, i.e. 40 meters water depth and 4 kilometres distance to the coast for offshore establishment, as well as to conflicting interests. The subsequent analysis only discusses a tenth of reported opportunities, which also limits the criticism against the underlying study that places the plants quite densely.

On land, the limit for exploitable potential is set at an average wind speed of 6 m/s at 71 meters height, which means that the majority of the plants land in the southern part of Sweden. A large part of the land area is forested and each turbine is therefore charged in the calculation with an extra cost of 2 million SEK for heightening the tower with 20 meters. However, forests may have an advantage in that it is possible to exploit large areas having less conflicting interests.

The calculated future price for electricity is not enough to make the expansion of wind energy profitable, other than in exceptional cases. The renewable energy certificate system, however, has a decisive influence on the introduction of wind power. In the reference case, the production of wind electricity in 2020 is 10 TWh. Other renewable sources for electricity production that the certificate system enforces are met in the calculations by hydroelectric power and by bio-fuelled thermal power and industrial counter power.

Wind power deployment can be limited by *low prices on bio-fuel* (which makes thermal power more competitive), *high interest rate used for yield*

[69] Peter Blomqvist, Mats Nyborg, Danial Simonsson, Håkan Sköldber. Wind Power in the Future, Possible Development in Sweden to 2020 (In Swedish). Elforsk Report 08:17. March 2008.

calculations (that strikes against the investment-loaded wind power), *less exploitable wind power potential* (as more expensive location has to be used for a given volume of wind power establishment) and *higher investment costs* (which indirect increase the competitiveness of other renewable energy production within the certificate system).

Wind power benefits if the above-mentioned factors develop into the opposite direction, and by a larger quota of the energy certificate (as does all renewable energy production).

At the present level of energy certificate quota, the production of renewable energy will increase with 17 TWh from 2003 to 2016, and is retained at this level until 2030. Given this system, most parameter variations will give an energy production from wind energy that lies in the interval of 7-12 TWh in 2020. Note that this is only a small part of the technical potential.

If the extent of the renewable energy certificate system increases with 15 TWh, the energy production from wind energy will increase with 11 TWh (from 10 to 21 TWh). Thus, the proportion of wind energy accounts for a major part of the increase, which means that the potential for other renewable energy sources is exhausted, at this cost level.

The calculations show that wind energy production offshore has low competitiveness. It will not be profitable within the limits of the renewable energy certificate system. A particular supporting system has to be introduced in order to speed up the technical development of offshore wind power.

The project has also carried out a questionnaire regarding qualitative and non-financial conditions, in addition to pure profitability. Uncertainty concerning the financial instruments and the permission procedure were appraised to be the most important negative factors. Among positive factors, the company's goodwill and better future conditions for wind power were considered the most important. The strength of negative and positive factors were estimated to be about the same, which means that these qualitative factors do not seem to influence the result.

It was concluded that it is the politically decided subsidies that determine how much wind power there will be in Sweden. The technical potential is large enough, and does not limit the extent of wind power deployment.

Effects on electrical distribution networks

V-150 Consequences of increased proportion of distributed energy production on electricity quality [70]

Project leader: Math Bollen, STRI

Since the beginning, the electricity power industry has lived with the condition that electricity supply systems and production plants have to be dimensioned in such a way that the customers get an acceptable electricity quality. This

[70] Youngtao Yang and Math Bollen. Power quality and reliability in distribution networks with increased levels of distributet generation. Elforsk rapport V-150. March 2008.

report considers how an extensive introduction of distributed electricity production may affect the supply system, and the possible need of mains reinforcement. It is based on existing literature and reports, with focus on energy quality and the reliability in distribution networks because of an increased wind energy production.

At moderate amounts of wind power, the risk of overloading will decrease, as will the energy losses. The risk of overload can only increase if the maximal wind power production locally exceeds the sum of maximal and minimal load in the distribution line.

Energy losses can increase in some network districts if the maximal expansion of distributed energy production exceeds the double minimal load. However, a much larger expansion is demanded before the total losses will increase.

A large expansion of wind power can mean that other, conventional, types of power plants are not established. This may result in temporary voltage reductions in the national power grid, the regional power grid and the distribution network, which lack distributing energy production plants that are synchronised. However, this should not be the case for the deployment of modern wind power plants with active converters.

The effect of wind power on flicker is estimated to be small, and the wind power will probable not aggravate problems with overtones in the mains.

The reliability on the customer level will not develop negatively. On the contrary, the distributed production might increase the reliability if no other production further up in the system is taken out of drift.

The wind power’s effect on the operation reliability on the transmission level is complex. The two most important questions are how the influence of wind power will be during a major main interference, and how the supply system will respond if wind power replaces larger, conventional production-units. It is concluded that it requires very large wind power expansion in order to deteriorate the operation reliability on the level of transmission. In many cases, potential problems with security systems will be solved on this level.

V-216 Analysis of the dynamic effect of large wind parks on power system stability[71]

Project leader: Lennart Söder, Elektriska Energisystem, KTH.

When the installed effect from wind power increases, its effects on electricity main will be evident. This project develops analytical tools to analyse the stability of the grid, and investigates how the stability can improve by means of intelligent control strategies in the control equipment of the wind turbines. To be reported in 2008.

[71] Katherine Elkington. Analysis of the dynamic effect of large wind parks on power system stability. Elektriska energisystem KTH, Lägesrapport 5, May 2008.

V-104 IEA Task 25 Systems with large proportion of wind power[72]

Project leader: Lennart Söder, Ekektriska Energisystem, KTH

Within the IEA Annex 25 "Design and operation of power systems with large integration of wind power", thirteen participants from ten countries exchange knowledge in the field in separate or joint studies. The goal is to develop a method to estimate the effect of large proportion of wind energy on the power system, mainly with regard to reliability and losses.

Effects on the electricity market

V-132 Large proportion of wind power – changed market conditions?[73]

Project leader: Viktoria Neimane, Vattenfall R&D

Fluctuations in electricity production do not necessary cause major extra costs if they are known in advance. The problem for wind power is that forecast errors of up to 50 percent are rather common in the time perspective that applies to NordPool, 12-36 hours. This means that large-scaled wind power regularly results in imbalances in relation to bids made in Nordpool.

Based on a later forecast, the Balcance Responsible Party (BRP)can buy or sell electricity on Elbas before the production hour in order to reduce the forecast error. The remaining error has to be settled by the market. Will a more extensive trade in Elbas, due to wind power, lead to higher actual costs, due to increased production costs, and losses caused by transaction costs during trading?

An alternative for the Balancing Responsible Party, having a large and diverse production, is to handle one's imbalances internally. For example, if it blows too little and the wind power production is lower than expected, one could increase the hydroelectric power output. Another aspect is that geographically spread wind power plants have an advantage in that the correlation between the forecast errors of wind power plants with a distance from each other is low. This means that the forecast errors tend to compensate for each other. Thus, a Balancing Responsible Party with large production from wind power has smaller forecast errors in relation to the production, and with that scale advantages. From a market system point of view, it would be the same if one or several actors produce the energy. If the latter alternative appears to be more costly, it must depend on an incorrectly organised trade that should be adjusted.

How should a deregulated market be designed to incorporate larger quantities of wind energy into the system? Should the wind power alone pay for debited costs for energy balancing, or should the market regulations be changed? The project's goal is to describe the consequences for different BRP's when large volumes of wind energy are introduced from these points of views.

[72] Lennart Söder. System med stor andel vindkraft, IEA Annex 25. Elektriska Energisystem KTH, Lägesrapport 12, May 2008.

[73] Viktoria Neimane. Stora mängder vindkraft – förändrade marknadsförhållanden? Vatten R&D, Lägesrapport, May 2008.

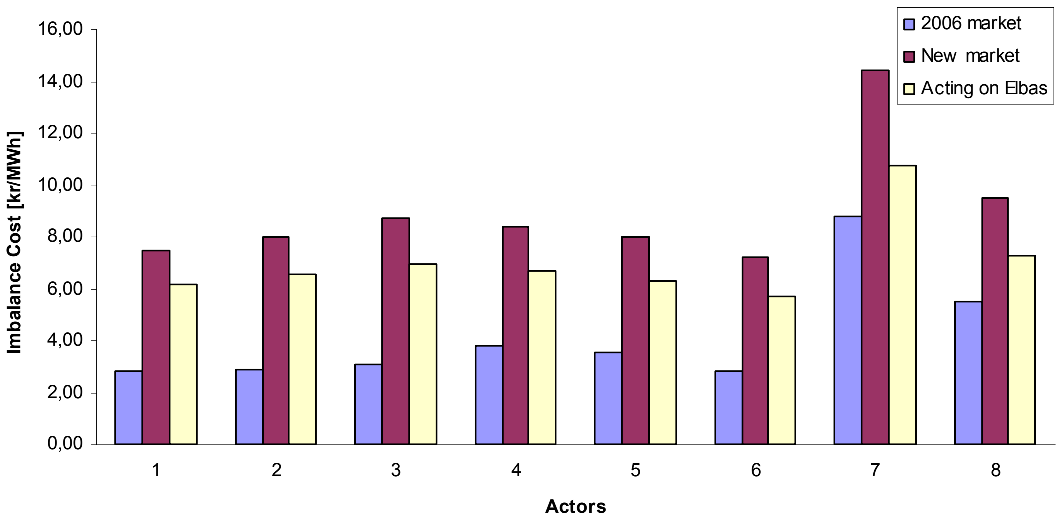
Furthermore, the project will consider possible adjustments of the institutional set of rules, and of the infrastructure that encompasses the energy market in order to adjust the system to the new circumstances.

Until now, calculations have been conducted for a case with 4 000 MW wind power that is handled by eight Balancing Responsible Partie's. Calculations on imbalances are based on statistical data, German analyses, and correlations between wind farms at different distances at a given planning time of 12-36 hours. Future prices on the regulated market and on Elbas are based on a model of the development of the energy market to 2020.

Calculations of imbalance costs for the eight actors have been done in the following cases:

- Energy production plans are handed to Nordpool 12-36 hours before actual production hour. No adjustments are made; the imbalances are deducted according to current prices on the regulated market, see fig 2, "New market".
- As above, and that actors up-date their forecasts and, if justified, buy on Elbas about three hours before every immediate production hour, fig 2 "Acting on Elbas".
- Historical data from 2006, fig 2 "2006 market".

Note that the calculations include a total range of 0,3 – 1,4 öre/kWh, and that the lowest alternative, "2006 market", probably is an underestimate of the costs of imbalance and is regarded as a lower limit, according to the authors.



Figur 2. Calculated costs of imbalance for eight actors in the project V-132. Categories and actors as above.

V-107 Coordination of wind power and hydroelectric power[74]

Project leader: Stefan Skarp, Skellefteå Kraft

A limited net capacity may lead to a wind power project not being realised, due to the high costs of mains reinforcement. To coordinate wind and hydroelectric power is a possible alternative. However, the coordination may raise other problems. The investigation focuses on a hypothetic coordination of the planned wind power park of Uljabuouda and the water power stations of Rebnis and Sädva in the upper parts of River Skellefteälven.

The study shows that coordination is possible. Since the size of the wind park of Uljabuouda is not yet decided, two different cases have been examined. One concerns 24 MW and the other 36 MW installed wind energy. The net capacity of the area is limited to 95 MW, and the results show that it might be exceeded during 18 percent of the year. The scenario has been that water power stations strictly regulate after how much energy the wind power plant produces. Each time the effect limit of 95 MW is reached in the supply net, any of the water power stations reduces the output in order to keep the load under the limit.

The results show that Sädva, the smaller station, should compensate at small regulation needs, and that Rebnis should compensate for larger fluctuations. In situations with the largest need to regulate, the Sädva station will be completely closed down. Owing to the margin of the maximal water level of the reservoirs, the water overflow can be completely avoided at the station when it stops. The water is thus "saved" when the wind blows.

The described way of operations can at most lead to twice as many turbine regulations, compared to normal operation. In order to spare the turbines from vibrations it is necessary to restrict the operations. The levels of restrictions are determined by vibration measurements.

The coordination will increase the work at the operational centre that plans and regulates the plants' energy production. In order to facilitate the production planning there is a need for wind forecasts. The levels of energy output in the area have to be monitored continuously so that the effect limit is not exceeded. This should be possible to control automatically through the operational data system, where various restrictions can be introduced. This will partly need to be handled manually. Coordination will constrain and reduce the freedom of regulation, and reduce the opportunities to optimise the production. On the other hand, net investments are avoided that might be prohibited.

V-215 Local coordination between wind power and hydroelectric power[75]

Project leader: Lennart Söder, Elektriska Energisystem, KTH.

Despite excellent wind conditions, the deployment of wind power is restricted by low capacity in the distribution networks in many areas. Earlier studies have shown that the coordination with local water power plants may allow for

[74] Stefan Skarp. Samkörning av vindkraft och vattenkraft. Skellefteå Kraft.
[75] Lennart Söder. Lokal samkörning mellan vindkraft och vattenkraft. Elektriska Energisystem KTH.

more wind power installation in areas with limited distribution capacity. In a PhD project, a method was developed for short term planning of short-term hydro-power regulation, with respect to the reliability of wind forecasts and the uncertainty of the energy prices on the spot market. The aim was to deepen the knowledge of how to coordinate wind and water power, to improve the planning method, and to analyse the effects of various factors on the coordination. The project group has worked together with the previous project (V-107) in order to benefit from a real case.

3.2 Trends Analysis

Development within EU

Wind energy accounts for 3.8 % of the consumption of electricity within EU. The installed effect in 2007 was 56 700 MW, of which over 1000 MW came from offshore production. The annual increase was 8 600 MW. The allocation varies substantially. Denmark is in top with 21.3 percent whereas Sweden only reaches 1.2 percent. The European Wind Energy Association EWEA estimates[76] that the production of wind energy within EU-27 will be 180 000 MW in 2020, of which 35 000 MW offshore.

EU’s goal of increasing the proportion of renewable energy to 20 percent implies that Sweden must reach 49 percent in 2020. This is made clear in the directive proposal[77] that the European Commission presented in the beginning of the year. The increase from 39.8 to 49 percent for Sweden’s part puts large demand on the deployment of renewable energy, including wind power.

The Swedish Energy Agency

The Swedish Energy Agency has worked out a new planning goal[78] of 30 TW until 2030 for the wind power expansion in Sweden. Of this, 10 TW should come from offshore production.

In the report, the Swedish Energy Agency states the following:

“The prerequisites for a substantial expansion of wind power during the relatively short period until 2020 are that both the legal frameworks and the decision order are facilitated, while maintaining the quality of considerations of permits. Today, the permitting procedure takes too long time, for which reason a common decision order should be established. Some drafts from the committee revising the Planning and Building Act (the PBL committee), should be introduced as soon as possible. The statutory periods in matters of consideration should be adjusted in order to reduce the total handling time. Wind energy production should be excluded from the ordinance of

[76] Pure Power, Wind Eneregy Scenarios up to 2030, EWEA March 2008.
[77] Förslag till Europaparlamentets och rådets direktiv om främjande av användningen av förnybar energi av den 23 januari 2008.
[78] Nytt planeringsmål för vindkraften 2020, Statens energimyndighet, ER 2007:45.

environmentally dangerous activity, as the wind energy production is emission-free. Potential disturbance should be regulated by standard values.

A large problem for those who want to invest in wind energy is the many contacts that must be taken with authorities before the investments are carried out. On way to facilitate this, is if the main part of the contacts can be initiated and handled at one place, at a so-called one-stop shop.

The Swedish Energy Agency suggests that the Government has an inquiry made concerning prerequisites for an integrated decision order for wind energy."

European Wind Energy Technology Platform

One of the main fields of the European Wind Energy Technology Platform is wind energy integration, with the aim to reach large proportions of wind energy with low integration costs, and with retained supply reliability of the electricity network. Examples of proposed research areas are:

- Demands on the network at large proportions of wind power, and methods to verify that they are fulfilled.
- Development of methods that improve the operation, for example by the transference of operation data.
- Simulation tools to study the transient stability of the European electricity network.
- New methods to transmit electricity from offshore plants.
- Influence of a large proportion of wind energy on the operation and generation of the electricity system.
- Studies of scenarios having 100 percent of renewable electricity production.

Importance of Vindforsk's projects

The available and current knowledge in Sweden is largely based on the research projects of Vindforsk.

3.3 Future Development

The field of "Large amounts of wind power from a market and technique perspective" summarises the (energy) political ambition of bringing about an extensive electricity production using wind energy with reasonable technical solutions, and in a way that can interact with the market. This development assumes that the production goes from small to a much larger proportion. Central issues for increased wind power deployment are how effective means of control can be worked out, how the electricity market can handle the need for regulation power and back-up energy, and when and how much the grid capacity has to be expanded. Below some concrete examples are presented on areas where efforts are particularly urgent.

Means of Control

The development of the electricity prices in the Nordic countries until 2020 will probably not alone be enough to justify the intended expansion of wind power. An extensive expansion of nuclear power in Finland, natural gas fuelled electricity production in Sweden and Norway, and a much larger amount of renewable electricity production in all Nordic countries combined with the desired energy streamlining will press down the prices. Thus, economical instruments will be required to finance the expansion of renewable electricity production. It is important that these instruments are designed in a way that makes the wind power deployment cost effective, and that stimulates continuous technical development.

A renewable energy certificate system is used in Sweden to stimulate new electricity production from renewable energy sources. To increase the ambition of this system it is necessary to adjust the quotas to a new level. This will be a simple political decision, but the Swedish certificate market is, however, small. A larger market is desirable. A common Nordic market of certificates would make the price setting of the certificates more effective, and further contribute to the cost effectiveness.

It should be of great interest for the Nordic cooperation on the electricity market and for Nordic wind power players to assess the economical potential of Nordic wind power on similar grounds, and with regard to different global conditions.

A continued study could also include details about EU’s three energy political goals (climate goal, renewability goal, and efficiency goal), of which two have been specified recently.

Other issues that could be elucidated are which role the Swedish and Norwegian wind power plays, and will play, to reach these goals, and how the goals in themselves will influence wind power expansion in Europe.

Means of controlling offshore wind power

Even if the certificate market expands in the Nordic Countries, the compensation will not be enough to build wind power plants offshore. It depends so far on high costs for the turbines and their connection to the mains, bad accessibility, and that the opportunity of land-based expansion is large enough to meet the Nordic ambition of wind power deployment. If one wants to get started with the offshore expansion quickly, additional instruments will be required.

The argument to urge the technical development of offshore wind power, despite the high costs, is to meet the high demands on new capacity already in 2020. One can also count on that offshore wind power will be more important in the long term.

Sweden is one of the countries that have good physical conditions for developing offshore wind power. Already today, there are identified projects on more than 10 TWh. Many of them have already the necessary permits or will soon have them.

It is of utmost importance to investigate how supporting measures for offshore wind power can be designed, and it should be done immediately. Preferably, the design of such measures should also stimulate new manufacturers of wind power to enter the market.

Cost effective wind power technology

The technology of wind power is still a young discipline and the opportunities of improvements within its sub-disciplines are large. Research and development to achieve new cost effective wind power technology is therefore of greatest interest. Among the criteria for evaluating the research contributions, the news values of systems and technology level should be high on the list. Sustainable projects should be able to combine innovative solutions (e.g. vertical shafted turbines) with effective generator technology (e.g. synchronised permanent magnet turbines with direct drive). Trustworthy system solutions qualify to guarantee that the developed technology is applicable. Since there is a lack of manufacturing capacity in the world, and since the quality of existing constructions is too low, there are good chances for new manufacturers.

Capacity to regulate production and consumption

A large-scaled introduction of wind power will put large demands on the power system's regulation capacity. The Nordic countries have access to much water power, which is excellent for compensating for natural fluctuation in wind power output. The Svenska Kraftnät has called attention on the risk that the regulation capacity of Swedish water power might become limited when the conditions of existing court verdicts of water regulation are reconsidered.

A new investigation should be carried out that includes the existing regulation capacity of the hydro-power, as well as an analysis of how the regulation capacity of the Swedish hydro-power can be increased in a cost-efficient way.

Another question that Svenska Kraftnät has raised is how the recharging system for future electric and hybrid motor cars can be used to regulate the fluctuating wind power production. There are also other issues that could be included in such an analysis, for example electric boilers.

Reviewing procedures

An important issue for the establishment of wind power plants and connecting mains is to simplify the permitting procedures and to reinforce the reviewing authorities and environmental courts. Parts of the subject area would benefit from further research, for example matters of acceptance. Wind power related conflicts of interests are of significant importance for the opportunities of continued expansion.

Responsibility of power balancing

Ongoing projects consider how to design a deregulated market with a large proportion of wind energy. Is wind power able to carry its own balancing costs, or will it be necessary to change the rules on the market? Svenska

Kraftnät has also brought up the question about which role the system operator would have in the power balancing market.

In this context, it is natural to bring up the present forms of trading in NordPool. A review will have to be done in cooperation with all Nordic countries.

Mains connection of wind farms

The deployment of wind power is a form of distributed electricity production, which makes matters of mains connection particular important. Today, many countries experience problems with the connection of large amounts of wind power to existing electricity nets. Among the matters where continued studies should be given priority, the following may be mentioned:

- Voltage fluctuations in the supply net
- Distribution of high frequent harmonics in local and regional nets
- Overloads in local nets
- Operation reliability of the transmission net at limited conventional capacity of production

To conduct these studies, it is necessary to develop stochastic models of the production system.

It is of interest to study different forms of concession rules when planning the expansion of the supply mains, which is required for distributing electricity from the new wind farms. The Grid Connection Inquiry[79] has looked into how the concession practising should be remodelled, so that wind farms can be connected locally, and regionally, in a technically and cost-efficient way.

Another possibility is to create a new type of concession, production nets, with the purpose of transferring electricity from the wind turbines to the electricity network. The present activity of electricity distribution to customers in local supply nets would not be changed, or be exposed to competition. Introduction of production nets implies that network activity "below" the region grid level will be specialised. The area concessions are responsible for the distribution from the national electricity grid to consumers. The production net is responsible for the transmission from the electricity producers to the national grid. An important task is to investigate which cost savings can be achieved, the technical and economical dimensioning of the network, and how the set of concession rules could be designed.

Increased capacity of the national grid

The need of more regulation power means that more hydro-power effect has to be transmitted from north to south, which puts demands on the capacity of the national grid. The Nordic electricity market will expand much more than the expected increase in energy consumption. The Swedish Energy Agency has paid attention to this in a report concerning the Electricity Supply in

[79] Elnätsutredningens betänkande Bättre kontakt via nätet (SOU 2008:13)

Sweden until 2010[80]. The development in other Nordic Countries is the same, and will be enhanced further when new nuclear power is put into service in Finland. This will increase the need of electricity exportation, which will require expansion of the international interconnection as well. By that, it will be possible for the Nordic CO_2-free electricity production to contribute to the reduction of CO_2 emission on the European continent.

Hence, the transformation of the Nordic electricity market from an import region to an export region, with a greater need of regulation power, is an urgent research field.

[80] Sverige Energiförsörjning, kortsiktsprognos 2008-08-13, Energimyndigheten ER 2008:18

4 Planning and permits

4.1 Results from the Vindforsk programme

Research within this field has been outside the ambitions of Vindforsk II, and no project has been funded.

4.2 Trends Analysis

New planning goal for wind power[81] until 2020.

According to the Letter of Regulation, the Swedish Energy Agency was commissioned to prepare a proposal for a new national planning goal for wind power expansion until 2020 after consultations with the National Board of Housing, Building and Planning. As was made clear in the previous section, it is proposed to be increased to 30 TWh per year in 2020.

The Swedish Energy Agency also brings up a number of decisive factors for the implementation of the goal, for example that most ommunication with authorities should be handled by a so called one-stop shop. This is also mentioned in the previous section.

Areas of National Interest

A site that the Swedish Energy Agency considers particularly suitable for wind power production can be designated as an area of national interest for wind power. One criterion for judgement is the wind conditions in the area.

In their general planning, the municipalities consider the national interests, which are indicative for the considerations of permits regarding land and water use. The national interest for wind power is then evaluated against other existing national interests, e.g. nature conservation, cultural heritage, Swedish Armed Forces, and aerial navigation.

Areas of National Interest for wind power cover about two percent of Sweden’s land area, which corresponds to an electricity production of 20 TWh per year. In addition, there are areas of national interest for wind power on Sweden’s territorial waters and within the economical zone. The Swedish Energy Agency has a searchable map service on their internet site that shows the localisations of areas of national interest for wind power.

Inquire on environmental considerations of permits[82]

The Government appointed an inquire on environmental considerations of permits in 2007. The commission was to propose adjustments of organisations and constitutions that are required for certain cases and matters pursuant the Environmental Act and the Planning and Building Act, and for the coordination of Environmental Courts and Land Courts.

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[81] Energimyndigheten 2007 ER 2007:45

[82] Mijlöprocessutredningen (M 2007:04)

In an additional directive[83], wind power issues, among others, were included in the inquire. The aim is to identify the need for changes that will facilitate a further expansion. The proposals must imply that the handling of matters is coordinated, fastened up and becomes more effective, without overriding rules of law. The ambition is that the proposed adjustments should lead to a better coordination of matters according to the Planning and Building Act and the Environmental Act.

Experiences of wind power establishment –"anchoring", acceptance and resistance[84]

The report summarises experiences from different local processes of establishment and planning around Europe. The aim is to identify the characteristics of good and bad projects, in order to achieve establishment with fewer conflicts. The authors state that risk of local resistance is large for wind power projects. Attitudes towards a specific project varies depending on the natural environment, values of recreation, and possible tourism business, but also according to factors like organisational forms, participation, decision procedure and opportunities of economical gain. It is stressed that there are strategies to respond to a possible resistance. The strategies should be based on a genuine participation, an open dialog, and that the local population gain from the establishment. It is important, that the establishment is not enforced by external actors.

The report distinguishes between four typical cases: *"Anchoring"* –the wind farm is established and the population is positive to the project and wind power afterwards. *Resignation* – the wind farm is established while the population is negative. There is a risk of resistance in later installations. In the third case, there is a high acceptance in the local population, but no wind power is installed due to other obstacles. Opportunity for wind power establishment exists, but a changed strategy and planning process is required. In the fourth case a so called *conflict and interruption* arises, that is when protests from the local population are so strong that possibilities to establish wind power in the foreseeable future is small. These four situations are presented more closely in the report.

A potential exploiter should start with surveying the span of attitudes within the local population, and also identifying the groups that have these opinions. Local attitudes should be regarded as a process that can be influenced in a project that lasts several years. A positive attitude needs to be maintained and an initially negative attitude can be changed with time. By obtaining knowledge about the community's history, culture and present challenges, it is possible to identify means to relate them to the project.

It is also important to be clear about what the process will be about. For general planning, one should tell that this is conclusive for placement, size and design of future projects. It should be possible to participate

[83] Kommittédirektiv Dir. 2007:184 Tilläggsdirektiv till Miljöprocessutredningen (M 207:04)

[84] Mikael Klintman & Åsa Waldo. Erfarenheter av vindkraftsetablering – förankring, acceptans och motstånd. Sociologiska institutionen, Lund universitet. Under utgivning av Vindval.

economically, also under small circumstances. Finally, the authors stress that no projects should be pushed through in areas where the resistance is strong.

Establishment of wind power in Sweden – a survey of the environmental permit processes 1999-2004[85]

The report presents a survey of the environmental considerations for different wind power matters, aiming at elucidating which circumstances have influenced the Swedish wind power expansion.

Crucial issues for the study is how many of the planned projects have resulted in an installed wind power plant. It also discusses reasons for why projects have not been accomplished, and at what point in the reviewing procedure they were stopped.

A majority of the stopped projects were terminated by the exploiters themselves, in most cases after early consultation with the authorities. The reasons mentioned were opinions from civil servants at County Administrations, conflicting social interests in the surroundings, and changed financial conditions of the project.

Another result is that the majority of projects that have submitted a formal application for environmental permit were approved. According to the concerned exploiters, it is unusual that projects are terminated due to negative attitudes of the local population, but this does not imply that negative local opinions lack significance. However, it is clear that the public's attitude to planned projects did not influence the assessments of the exploiters to any greater extent.

Finally, only a minority of approved environmental permits have been appealed, and the appeals rarely lead to any adjustments.

Finding the right place[86]

The thesis stresses that the expectancy of accomplishing a wind power expansion of 9 TWh to 2015 rests on the electricity producers. However, the expansion is slowed down because the concerned authorities, energy producers, municipalities, and the public cannot agree on where to establish wind power plants.

Göteborg Energi recently planned for a 300 MW wind farm in Kattegatt, outside Varberg and Kungsbacka, with a production of 1 TWh. From a producer perspective, the proposed site met all requirements. However, the project was stopped, mainly due to a no from the concerned municipalities that feared substantial effects on the environment. The process went on for four years, being the result of a comprehensive campaign within the company to achieve acceptance for the technology and the project.

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[85] Mats Bengtsson och Hervé Corvellec. Etablering av vindkraft i Sverige – en kartläggning av miljötillståndsprocessen 1999-2004. Centrum för forskning om offentlig sektor (CEFOS) respektive Gothenburg Research Institute (GRI)

[86] Petter Rönnborg. Finding the right place. Licentiatavhandling. Handelshögskolan vid Göteborgs universitet.

The aim of the study was to elucidate the application procedure from a single electricity producer's perspective, and answer the questions: How was the decision taken? What factors influenced the choice of the establishment site and how were they evaluated? Which were the reasons to build the plant?

The results show that the decision to carry on with the project rather was a result of the circumstances than a deliberate strategic choice of the company management. The idea was born within the company, and by internal lobbying it reached the company board, which was spurred by being right in time as well as by the adversity of the municipalities. The early negative attitude of the authorities resulted in a process characterised by power struggle rather than cooperation. On of the crucial questions during the project evaluation was about its profitability from a social economical perspective, which turned out to be hard to establish.

Göteborg Energi had both direct and indirect reasons to establish the plant. Among the direct reasons it can be mentioned that the company wanted to secure the local electricity supply and strengthen the environmental profile of the company. An indirect reason was for example the connection to another large project. A provocative explanation for carrying on the wind power project was that it created space to enforce the installation of Rya thermal power plant.

This type of process occurs in the borderland between different organisational logics and norms of rationality. The localisation issue involves a number of different actors that represent many special interests that they want to protect at the consideration of permit. Society assumes that permit matters can be considered rationally, i.e. that different special interests are compared with each other in an objective way.

Despite the judgment that the localisation was the most suitable one at the west coast, priority was given to the interests that were against the establishment on the basis of municipality veto power, Natura 2000-rules and the Environmental Act.

Local Politics of Renewable Energy[87]

The thesis analyses the actions of municipalities and other local actors at the establishment of the biogas and wind power, two renewable sources of energy. It is based on six case-studies, where written documents and partly structured interviews have been the main sources of information. The first theme studies the planning and handling of local renewable energy projects. The planning of biogas projects can be particularly complex and conditions vary a lot. The planning operation must be adapted to the circumstances.

The second theme concerns conflicts in relation to the localisation of renewable energy plants, and how these can be managed by the participation of the local population. Different theoretical perspectives on localisation conflicts and citizen participation are discussed. These can have different and sometimes opposing goals for participation. The expectations must be realistic. The case-studies shows specifically that the consultation operation,

[87] Jamil Khan. Local Politics of Renewable Energy. Doktorsavhandling. Miljö och energisystem, Lunds university

the most common form of citizen participation in Sweden, has strong limitations.

The Dialogos pilot study[88]

The pilot study is aimed to elucidate how everything from single projects to strategic issues with regard to the energy system, can get a versatile treatment through citizen participation. Having access to such a method would lead to processes of permit considerations that are more effective, better opportunities to compete internationally, and increased credibility of the energy business, its companies and its authorities.

The report presents results from three case studies: Planned expansion of a new 400 kV power line at Stenkullen in Lindome, outside Gothenburg, a new waste-fuelled furnace in Uppsala, and the planned establishment of a wind farm on Lillgrund in Öresund.

The work to identify feasible ways to push the issue further continued in 2006.

Experience/perception of wind power from an environmental psychological perspective[89]

The study was carried out in Trelleborg in 2004 and was based on work within the field of man and environment. The results showed that people living within 3 kilometres from a wind power plant enjoy their living more than people living further away. One explanation could be that those who live close have accepted the wind power plant as being a part of their own environmental vicinity. According to the authors, the attitude to wind power plays a minor role compared to the location of the habitation.

Meetings among actors in wind power projects[90]

The project aimed at identifying strategies to bridge the social opposition that might come up when a wind power plant is established. A crucial condition is that the communication between parties works well and leads to constructive agreements that offer new possibilities for the local population. The project will develop a model that contributes to facilitation of the authorities' future work. The project will be reported in December 2008.

Local processes for information and acceptance of wind power[91]

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[88] Andersson, Wene, Johansson. Dialogos förstudie. Information according to Elforsk's web page, www.elforsk.se

[89] Johansson, M. och Laike, T. Acceptans av vindkraft – en psykologisk förstudie av perception och attityders inverkan. Avdelningen för miljöpsykologi. Institutionen för Arkitektur och byggd miljö. Lunds Tekniska högskola. 2004.

[90] Möten mellan aktörer i vindkraftsprojekt. Projekt inom Vindval. Projektledare Mikael Klintman, Lund universitet.

[91] Lokala förankringsprocesser, project inom Vindval. Projektledare: Lars Aronsson, Högskolan i Kalmar.

The aim of the project is to create understanding of how different ways of acting by the wind power exploiters, politicians, and civil servants will influence the public's attitude towards plans of wind power establishment in adjacent sea areas. The project started in 2006 and will finish during to autumn of 2009.

Processes of permit considerations[92]

The aim of the project is to analyse the history of permit considerations in relation to the establishment of electricity power plants in the Nordic countries, and to map the differences and the economical importance of these. The idea is also to analyse conditions for an improved Nordic harmonisation, and how former experiences can be used to increase the effectiveness. The study includes combined gas power, bio-fuelled thermal power, wind power, small-scaled hydro-power, as well as nuclear power. The project will end at the beginning of 2009.

Wind power localisation from a municipality and county administrative perspective[93]

One aim of the project is to survey and analyse factors explaining why some wind power projects are realised and others not. Another aim is to analyse differences in the acting of public authorities when handling wind power matters, why they act differently, and the importance of a public participation. The project should have been finished in 2007, but is reported as still ongoing.

Conceptual document[94]

The following compilation is mainly based on a conceptual document made before to the funding advertising of Vindval in 2007.

Strategies to increase knowledge, participation, and cooperation

The NIMBY-syndrome (Not In My Back-Yard) means that people can be positive towards wind power on an abstract level, but that the acceptance decreases when wind power is to be established locally. The syndrome occurs in many different situations, for example when a highway or tunnel will be built. Psychologists, environmental psychologists and sociologists call this concept a "social dilemma", and economists call it "game theory". Why do we emphasise the positive attitude to wind power? Does it matter if wind power is popular or not? Should we consider this at all, when establishing wind power? Wolsink[95] is critical towards the NIMBY-concept and means that it can only

[92] Tillståndsprocesser, Projekt inom Market Design. Projektledare: Patrik Söderholm, Luleå tekniska högskola.
[93] Vindkraftslokalisering ur ett kommun- och länsstyrelseperspektiv, projekt finansierat av CEFOS. Projektledare: Åsa Boholm, CEFOS.
[94] Marianne Lindström, Miljöpsykologi, Ph D Miljövetenskap.
[95] Wolsink, M. Wind Power and the NIMBY myth; institutional capacity and the limited significance of public support. Renewable Erergy 21, 49-64, 2000.

explain a small part of people's behaviour, for example to write protest letters and consult juridical help. The attitude to wind power explains, however, a much larger part of the behaviour. Most people having NIMBY-feelings are not positive to wind power, while the NIMBY-concept would imply that the individual does have a general positive attitude to wind power, but a negative attitude to wind power establishment locally. The NIMBY-syndrome may occur on individual, as well as authority level, which may cause institutional obstacles.

Khan and Åstrand[96] have analysed the decision process related to wind power in some municipalities at the Swedish west coast. The Municipalities of Falkenberg and Laholm wanted to facilitate the wind power establishment by making the planning simpler and more flexible. This has resulted in shortcomings with regard to the regulation of the plant's localisation and the opportunities for the public to take part in the planning process. In Halmstad Municipality, the regulation of the localisation and the public's opportunities to participate was given much space, but the decision process became unnecessary long. The reasons for this might be that the Municipality was sceptical about wind power, and to some extent used argument about the importance of well-laid decision processes as an alibi to limit wind power deployment. What is needed, according to the authors, is planning processes that succeed to combine the demand of participation and regulation with policy measures that contribute to an effective expansion where the local population has opportunities to take part in the ownership of the wind power plants.

According to Gardner and Stern[97], attitudes and behaviour may change by information and education, by economical incitements, and by community management, which means local groups taking part in the society process. Education and information can change attitudes toward particular matters (like wind power), but education and information cannot easily change people's deeper values. In the short term, education can help people to overcome certain internal barriers to action, particularly when it concerns matters based on misunderstandings or wrong information. If the information is in accordance with the personal values, it is easier to change one's attitude and behaviour.

Economical incitements can change people's behaviour, but not their attitudes and values. Geller[98] developed a model, the empowerment model, which put forward some individual and social factors that are necessary for the inspiration of people to active take part and care in their daily lives. These factors are self-esteem, feeling of being able to influence, optimism, belonging, and participation in a group. A community management group can be a social network that already exists, for example a stakeholder association.

[96] Khan, J och Åstrand, K. PÅ väg mot ett hållbart energisystem. I: P. Wickenbert, A. Nilsson och M. Steneroth-Sillén. Miljö och hållbar utveckling – samhällsvetenskapliga perspektiv från en lundahorisont. Studentlitteratur. Lund 2004.

[97] Gardner, G.T och Stern, P.C. Environmental Problems and Human Behaviour, second edition. Pearson Custom Publishing, Boston, 2002.

[98] Geller, E.S., Winnet, R.A. and Everett, P.B. Preserving the environment. New strategies for behaviour changes (New York Pergamon), and Geller, S. (1995). Actively caring for environment. An integration of behaviourism and humanism. Environment and behaviuor, 27, pp 184-195. 1982.

When it comes to wind power, such networks can be used for information and education, for example by establishing study circles about wind power. Increased knowledge and engagement can lead to increased responsibility for a common resource[99]

Attitudes and experienced disturbance from wind power

The most commonly experienced disturbance is noise and visual disturbance in the landscape. According to Wolsink[100], the primary local arguments against wind power are factors like noise, ruined views, conflicts with nature conservation values, and unreliability of wind power as an energy source. Wolsink means that general attitudes towards wind power are governed by "Clean" (that it is a clean energy source) and "Visual" (appearance in the landscape). However, there is no direct relation between "Annoy" (disturbance through noise, birds nature, etc) and attitude. This implies that the attitude to wind power is not influenced by thoughts about noise and danger for birds. The experienced disturbance is however directly affecting the intention to oppose a wind power project. The visual values of wind power plants have a double impact: indirectly via the general attitude, and directly via production of a resistance. The general attitude towards wind power is most critical in the planning phase. This means that the awareness is not of global nature, but relates to local conditions. Research has shown that politicians often focus on noise disturbances while media pay attention to visual aspects. In general, the resistance against wind power seems to be stronger among secondary residents, which regard the countryside and nature as a source of recreation and relaxation, than among permanent residents that are dependant on the nature for their living[101].

Kaldellis[102] investigated the acceptance for wind power in Greece, both on the mainland and on islands. The study showed that islanders were much more positive to wind power than persons living on the mainland. He thinks the reason for this is that islanders are more open for changes, and have larger need for electricity since many depend on summer tourism. Those living on the mainland often are agriculturalists and have views that are more conservative. Further, he means that no information was given to the inhabitants when the turbines were established. Information is an important aspect that must not be ignored.

An Irish study about the implementation of three wind power projects showed that the strongest objection concerned noise, then visual and electro-magnetical disturbances. The acceptance for wind power decreased during the planning process but levelled out after the installation to the same level as before the installation. The 36 percent that were uncertain seemed to be

[99] Gardner, G.T. and Stern, P.C. Environmental Problems and Human Behaviour, second edition. Pearson Custom Publishing Boston. 2002.

[100] Wolsink, M. Wind Power and the NOMBY myth; Institutional capacity and the limited significance of public support. Renewable Energy 21, 49-64. 2000.

[101] Hammarlund, K. Attityder till vindkraft. Avdelningen för Humanekologi. Göteborgs universitet. 1997.

[102] Kaldellis, J.K. Social attitudes towards wind energy application in Greece. Energy Policy, 33, 595-602. 2005.

more positive after the wind power installation. One of four was still negative to the projects[103].

Experiences of the effects of wind power on landscape

Valuations and experiences of landscapes have been studied by researchers who mean that a green environment has a relaxing effect. According to Kaplan and Kaplan[104] people resort to nature to relax from stress, find fascination and an entirety where you can get recreation, peace and quiet.

Several inquires show that people have a positive attitude to wind power in general. 72 percent in Canada, 80 percent in the Netherlands and 82 percent in Denmark answered that wind power should have high priority in society. The same is valid in Great Britain. In the Municipality of Sydthy in Denmark live 12 000 inhabitants, and more than 98 percent of total electricity consumption comes from wind energy. Thus, Sydthy has one of the highest concentrations of windmills of the world. An attitude study in the region showed that people having much knowledge about renewable energy tended to be more positive to wind power than those having less knowledge. The distance to nearest turbine had no effect on people's attitudes towards wind power in general. These persons did not think that noise and visual influence were any problem. The study showed that people living within 500 metres from a windmill were more positive than those that lived further away[105].

The typical no-teller is, according to the authors, a person who thinks that renewable energy cannot solve our energy problems; that windmills are unreliable and wind dependant; that wind energy is expensive; that wind turbines interferes with the view; and that windmills are noisy. A typical yes-teller thinks that renewable energy is a good alternative to other energy sources; that climate changes have to be taken seriously; that wind energy is unlimited as opposed to fossil fuels; and that wind energy does not pollute and is safe.

Persons without earlier experiences of windmills thought that the noise from the windmill was higher than what those who lived in the neighbourhood of the windmill thought [106]. Men experience that windmills make noise to a larger extent than women. In general, people in their middle age are more critical to wind power than other age groups.

European Wind Energy Technology Platform

European Wind Energy Technology Platform brings up the field of planning in the chapter on the improvement of administrative procedures. The document recommends that member states establish plans for the development of wind power both on land and offshore. It is also proposed that member states should arrange a one-stop-shop for the administration of permit applications.

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[103] Gipe, P. Tilting at windmills: Public opinion toward wind energy. http://www.awea.org. 1995

[104] Kaplan, R. and Kaplan, S. The Experience of Nature. A psychological Perspective. Cambridge University Press. Cambridge. 1989.

[105] Damborg, S. Public attitudes Towards Wind Power. Danish Wind Industry Association. 1999.

[106] Holding-undersögelse 1993.

It is suggested that studies related to handling of permit applications are made within the following fields:

- Development of administrative procedures concerning the exchange of wind turbines to larger ones, within a wind farm.
- Revision of the procedure concerning the establishment of environmental impact assessment evaluations.

4.3 Future Development

So far, planning has not been included in the Swedish research programmes on wind power as a specific research field. It fits in part within the area of the Vindval, but is not completely contained within the concept of Effects on the environment. Many of the obstacles for wind power establishment concern planning processes, such as opposition from the local population, politicians, and local stakeholder associations. An increasingly spread opinion is that the best way to establish wind power successfully (i.e. that as many as possible have a positive attitude to the projects after the installation), is when the implementation includes thorough and transparent planning and reviewing processes where consultations play an important role.

Since both Vindforsk and Vindval represent applied research programmes, in that they have a clear users' perspective, planning issues are relevant to include in the programmes. There are good conditions for creating tools that facilitate future wind power deployment, to contribute to a more efficient use of resources by the project companies, authorities, stake-holder organisations, and not least, to more satisfied citizens.

Studies on acceptance

Acceptance studies are often asked for when wind power projects plan their consultation and information activities. So far, they are not a natural part of wind power research. The subject in itself is an established research field, and methods are developed within other sectors. Acceptance research with focus on wind power should be performed with clearly formulated objectives. It should be clear already from the beginning of the research, how civil servants and project planners will be able to profit from the results. Potential output from such studies can be various manuals, for example about how to communicate a wind power project, and to whom, or about different ways to offer local stakeholders economical benefits from a planned project.

Planning process

Many think that the planning process should be improved by developing new methods and generating good examples, rather than by traditional research projects. For example, there is a need of methods for planning larger areas, which goes back to the fact that Sweden, in contrast to Denmark, at present lacks an overall national planning. A holistic approach on Sweden's wind power deployment is desirable from a technical as well as an environmental point of view. The surveys of Sydhavsvind and Utsjöbankarna represent work along these lines.

Value issues

The underlying values influence the opinion of what is good planning, and is therefore important to clarify. Research about value issues may contribute. Studies on nature views can show and categorise the deeper values concerning environmental and developmental issues. According to the concept of *anthropocentrism*, the nature is meant for the benefit of man; *social altruism* means that nature is meant for all (man, plants, animals), including future generations; *ecocentrism* means that nature has an intrinsic value, independent of man. By relating to these concepts, a deeper understanding of the long-term consequences of decisions made today could be reached. In extension, the physical planning could be coordinated with the energy planning in the municipalities in order to widen the overall picture that will serve as a base for the decision makers' judgement.

5 Meteorology

5.1 Results from the Vindforsk programme

During the period of 2006-2008, 2.5 million SEK, or 7 percent of total means, were granted to this field.

Regional Wind Indices in Sweden

V-114 Wind Index
Project leader: Hans Bergström, Department of Earth Sciences, Uppsala University

Wind indices are used to relate the wind energy production during a limited period to the conditions during a longer time. It is called "normal year correction". It is also important to do corresponding normal year correction to use wind measurements made during shorter periods. It has therefore been natural to base the corrections on wind indices according to historical production data of wind turbines given by the Swedish operation statistics. However, the statistics are limited to a single wind index value for Sweden, despite that there is a large geographical variation. A comparison with the corresponding Danish statistics shows large differences. There is a great need to develop wind indices for different regions in Sweden. The project's goal is to work out a new methodology to calculate wind indices for Sweden, and to settle regional indices. The project finishes in December 2008.

Larger resolution of the wind survey

V-115 Statistical analyses of results obtained by the Swedish wind survey and downscaling of results.

Project leader: Hans Bergström, Department of Earth Sciences, Uppsala University

The project "Mapping wind potential in Sweden" has generated a large database of meteorological parameters for Sweden. The horizontal resolution is 1 kilometre. The database is used by the project to extract additional statistic information of importance. The data consist of Weibull parameters, in total and sector-wise, for different wind directions, extreme winds for periods of 50-100 years with regard to different average times from one second to one hour, turbulence intensity, and the vertical wind gradient. Methods are developed to increase the resolution of the wind survey from 1 kilometre to 100 meters. These will be based on information of the wind in a 1-kilometre scale, which is applied in models that give the higher resolution. The project runs until December 2008. The new statistical information will be available on Internet.

Long term measurements

V-120 Meteorological measurements in high masts

Project leader: Hans Bergström, Department of Earth Sciences, Uppsala University

Meteorological long-term measurements in high masts are important for the knowledge about the wind energy potential and other statistical wind characteristics. To achieve underlying information about extreme conditions, it is of particular interest to measure during long periods in order to get reliable data on the low probabilities of rarely occurring extreme events. Maintaining long-term measurements is also relevant for possible changes of the climate and its effect on wind climate and wind energy potential. Studies on normal variations of the wind potential need access to continuous measurements of the wind climate during a long period. The project's measurements are made in three places in Sweden: Näsudden and Östergarnsholm on Gotland, and Suorva in the mountains of Lapland. The latest project period was finished in December 2007, but the measurements goe on for the present.

5.2 Trends Analysis

Wind potential

After a pioneering work in Sweden in the 1970's, Risø National Laboratory in Denmark developed the PC-based data programme Wasp for surveying the winds on altitude layers that are relevant for wind energy. Since then, it has been used for wind surveys in a large number of European countries, and outside Europe. Wasp is based on simple physical relationships concerning the variation of the wind profile at different altitudes in the atmospheric boundary layers, i.e. those parts of the atmosphere that are directly influenced by the earth's surface. Regards can be taken to variation in the surface's roughness, topography, and barriers like buildings that may affect the wind in the surrounding area.

In average, a simple Wasp model will give a decent correspondence to observations, but at the risk of having uncertainty of ±20-30 percent in wind potential calculation for every singe case. It depends on that the true topography is not just hills and ridges, and that transitions between different landscape types such as forest or field are not simple. Instead, the reality is a mixed composition of topography and various land use. When the terrain is too complex, such as in mountainous areas, or when differences in temperature between land and sea affect the winds, the simple model can be completely misleading.

In order to increase the reliability in the assessments of the wind potential, there are two principal ways to proceed. The first is to measure the wind potential directly in masts on altitudes of 50-100 metres.

The problem with this method is that the country cannot be covered with measuring masts. Another way out is to use more advanced models.

During the last ten years, such advanced models have been developed by for example Uppsala University, the MIUU-model. They are time dependent numerical models (CFD, Computational Fluid Dynamics) and the core contains equations that describe air movements, based on the Navier-Stokes equation. A thermodynamic equation, describing thermal conditions, an equation describing air humidity, and several equations concerning the atmospheric turbulence are added to this. The are named meso-scale models, which means that they cover the geographical scale from micro-climate to large-scaled weather systems. They are very calculation-intensive, nowadays a minor problem. During the recently performed wind survey of Sweden, using a resolution of 1 km, a number of scenarios of the weather development were calculated that in all gave a representative picture of the wind climate. The calculation required 55 years of computer time from 24 ordinary personal computers. The result is available on Internet[107] and in a summarising report[108]. Comparisons of wind measurements at high masts in 84 places all over Sweden show, for 87 percent of the data, a correspondence between measurements and the model within $\pm$ 0.4 m/s, and a mean difference of 0,0 m/s.

After a wind survey with a resolution of 1 km to identify the most interesting wind places, often comes a need of data with higher resolution at the establishment sites. Within the Vindforsk-programme, work goes on to increase the resolution of the MIUU-model to 100 meters.

CFD (Computational Fluid Dynamics) is a general term for different types of numerical models that solve fluid dynamical problems. They have in common that they numerically solve the relations that govern atmospheric conditions, for example. Thus, the global weather models are a type of CFD-models. The term is often used for calculations of high resolution, i.e. flows around a car or an airplane. In meteorological contexts, the term CFD means detailed calculations i.e. flows around houses in a residential area.

It is important that those CFD-models used in connection with wind power include effects of the thermal stratification. Judging from presentations and reports from the last year’s wind conferences, this is often neglected. On the smaller scale of a wind farm, it is often stated that neutral condition are assumed to prevail. The arguments for this are not discussed. It could possible be due to computer time – the CFD-models used for the micro-scale are often particularly computer-demanding as the models are so called non-hydrostatic models that require short time-steps. The hydrostatic model, as the MIUU-model, differs from the non-hydrostatic model in that its equation describing vertical winds is reduced to a balance between gravity, vertical pressure gradient and density. The vertical wind is computed through the continuity condition.

An important reason for the difficulties of verifying the results of micro-scale modelling is that spatially high-resolute observations almost are lacking. There are some experiments done to study the airflow over the topography in detail, e.g. over Askervein Hill, which sometimes are used to verify

[107] http:/www.geo.uu.se/luva/default.aspx?pageid=1352&lan=0

[108] Bergström, H. Wind resource mapping of Sweden using the MIUU-model, Wind Energy Report WE 2008:1, Department of Earth Sciences, Uppsala University, 34 pp, 2008.

calculations of the model. However, the experiments are only run for a limited period, and no climatological data are obtained.

Another type of model that is used sometimes to model the winds are so called LES-models (Large Eddy Simulation). In these models, the turbulence is divided into a high-frequency and a low-frequency part. For the low frequencies, the large-scale turbulence, calculations are made by LES-models, which mean that only the small-scaled part of the turbulence needs to be parameterised. The modelling is computer demanding, however, and hardly realistic fore general use today. The models do have a potential to give interesting information about specific conditions, e.g. the turbulence around a precipice.

Turbulence

It is obvious that a rough surface generates more turbulence than a smooth one. High turbulence intensity is to be expected above the rough forest. The mechanically created turbulence is however only one source of turbulence. The turbulence intensity is also affected by the atmospheric thermal conditions. Unstable stratification increases the turbulence, whereas a stable stratification decreases it. Moreover, the stable stratification limits the altitude of the boundary layer, leading to a relatively faster decline of the turbulence intensity with altitude, as compared to a neutral or unstable stratification. Hence, in many situations the turbulence may have been reduced substantially already at 100 meters altitude, as compared to conditions prevailing closer to the treetops.

For the surface layer above low vegetation, there are experimentally produced relationships describing the turbulence variation with altitude for various roughness lengths. For this purpose, Monin-Obukhov's theory of similarity is used. As mentioned earlier, this theory is not valid above high vegetation, at least not closest to the vegetation layer, so it is uncertain how the turbulence profile will look like above a forest. According to the theory of similarity, the turbulence intensity should decline from 25 percent at 50 meters altitude to a little more than 20 percent at 100 meters altitude, but these figures are probably too high, particularly for higher altitudes.

Observations show a large variation in turbulence intensity between different meteorological conditions. At 100 meters' altitude, the flow may vary between almost laminar, having a turbulence intensity of only 2-3 percent, and strong turbulent flow, having figures of 30-40 percent. Thus, the average conditions will perhaps not give enough information. The top of the turbulence intensity distribution can be around 15 percent at 100 meters' altitude, while it is around 20-25 percent at 50 meters' altitude. As said before, the theory of similarity may also underestimate the variation with altitude.

Wind above forests

The interest to establish wind energy in forest terrain has created an increased demand on meteorological information for those areas. It is about the verification of the levels of model-calculated average winds, as well as getting information on what the winds above forests generally look like. In the first place, there is a great concern about high turbulences intensity. The possibilities of using a simpler model as Wasp for forests are also studied.

There is already a lot of knowledge about the conditions in the boundary layer above forests. As compared to the boundary layer above low vegetation, the so-called surface layer does not have the same properties. In the surface layer, which is the lowest part of the boundary layer, the turbulent flows in vertical direction only decline slowly upwards. It has been shown that the so-called Monin-Obukhov’s theory of similarity can be used to calculate the shape of the wind profile above lower vegetation. This will not apply for forests. Nor is the theory valid for lower parts of the boundary layer, the roughness sublayer. The turbulence is here influenced by coherent movements in scales of the same magnitude as the vegetation layer. The air flow can be explained by theories considering the surface separating two fluids that move with different speeds. In the forest case, the air flows with low speed in the vegetation layer, and with high speed above the treetops. The difference in flow speed between the two layers gives rise to a large wind gradient immediately above the vegetation and an inflection point in the wind profile, which creates a turbulence of the same size as the depth of the vegetation layer.

If the surface layer reaches sufficiently high up, more than 40 meter for a 20 meter high forest, Monin-Obukhov’s theory of similarity is valid for the upper parts of the surface layer. Under the circumstances of neutral thermal layering, the wind is expected to vary logarithmically with altitude in the upper part of the surface layer also above forests. This is only true if the altitude scale moves with the so-called zero-plane displacement. It is typically assumed that the zero-plane displacement is 2/3 - 3/4 of the vegetation height, ending at 13-15 meters in 20 meters high forest. Physically, the zero-plane displacement can be interpreted as the level of the vegetation where the sink of the kinetic energy has its centre of gravity, or more popularly expressed, that the flow starts at the height where the friction braking is most efficient. Another important parameter is the roughness length, which is 0.5-1 meter for forests.

Some results points to roughness length and zero-plane displacement being not only dependent on the vegetation appearance but also on the wind speed. At increasing wind speeds, the roughness length increases concurrently with a decreasing zero-plane displacement. This effect is supposed to depend on squalls easier penetrating between trees under strong winds. As a result, the friction braking increases (larger roughness) just as the centre of gravity of the kinetic energy sink lands on lower height (less zero-plane displacement). Since one phenomenon increases the wind and the other decreases it, the total effect on wind speed at a certain height will not be so large. This needs to be investigated further, which is complicated by the difficulties to quantify the effects of forest height and density.

Production in forests

We are accustomed to calculate the potential production based on the annual average wind at hub height, and have assumed that wind speed distribution can be described by a Weibull distribution. However, it is feared that this will overestimate the calculated production. Some comparisons between the real production from existing wind turbines and calculations indicate differences of 10-20 percent. Note that the used information on wind energy production actually is not good enough to make such comparisons, since the operation periods are not documented in a satisfactory way.

One reason for the feared deviation can be a large wind gradient, which results in the blades hitting air with very different wind speed during a revolution. This is particularly true for large wind turbines with large turbine diameter, where the air flow's attack angle on the blades during a major part of the revolution will deviate from the optimal. It is principally easy to calculate this using computer models that are available in Sweden, but no such calculations are available. The wind-effect relationships that are brought up in the current IEC standard assume an open terrain and thereby a modest wind gradient.

Another reason why the production deviates could be high turbulence intensity. At certain average wind, an increased turbulence will result in a higher kinetic energy of the air. There are studies showing that a wind turbine actually can produce more when the turbulence intensity increases. But it is unclear whether the results are general. For example, increased turbulence will give a more skewed flow attack, which normally lowers the production, but was found to increase the production in some cases. Observations in complex terrain indicate that the combination of turbulence intensity and wind gradient determines how much effect a wind power plant will give at various wind conditions. Individual regulation of blade angles, which is under introduction for other reasons, may be a way to optimise the operation at large wind gradients.

It is concluded that it is not enough to recognise the average wind at hub height. Descriptions of wind climatology should also include statistic information about wind gradient and turbulence.

Icing

In Svealand and further north in Sweden, periods with icing on wind turbines is normal during the winter, which affects the production, shortens the turbine's life span, and exposes the surroundings for risks.

Icing was earlier connected with simple parameters such as temperature and relative humidity, but later studies have shown that these parameters, alone, are not enough. Nowadays, the focus lies on amount and possibly the size of water drops that float freely in the air, which together with temperature and wind are crucial for the icing risk.

Large-scale weather models have long included algorithms to forecast icing for the aviation. However, these models, e.g. Hirlam of SMHI, are no boundary layer models and parameterise the atmospheric boundary layer rather roughly. There is a risk of missing essential information concerning the connection between local terrain and boundary layer when using this type of models. When mapping the icing risk in Sweden, a meso-scale model with higher-order turbulence closure should be used to calculate the turbulence. The MM5/WARF and the MIUU model are examples of this.

Wake effect

Because of energy withdrawal, there is an area behind the turbine having lower wind speed and higher turbulence. This will affect the production and load condition for turbines further away. How these wakes are filled in and dispersed is an important field for the wind power meteorology.

At wake dispersal, the turbine generated turbulence interacts with the natural atmospheric turbulence. Under conditions of low natural atmospheric turbulence, the pocket will fill in slowly and last long. High turbulence intensity results in a quicker filling of the pocket.

The simple wake models in use today (e.g. Park), use the turbine diameter as a length measure. The models give a reasonable picture of the course of the event. However, they assume that the relationships lack dimension, e.g. that the course of the event will be the same for ten-meter-turbines with a mutual distance of 50 meters (five turbine diameters), as for hundred-meters-turbines with a mutual distance of 500 meters. This is not the case.

Studies[109] show that the results improve if the division between turbines is measured in the transport time of the wind. This means, that regard is taken to the actual distances between turbines (with ten times larger division between turbines, the times become ten times longer). It means also that the wind speed influences the wake dispersal in that they last at longer distance from the turbine.

The simpler models also disregard the turbulence intensity. With high turbulence intensity the turbulent transports of kinetic amounts from the surrounding air into the wakes will be more efficient. Nor will the models regard the temperature variation with the altitude of the boundary layer, which is crucial for the stability. That relationship will allow wake effects to vary considerably with time of the day and of the year.

The turbulence above sea is normally lower than above land, which means that the wake effects should be stronger for offshore establishment. This has been confirmed at the large Danish wind farm of Horns Rev, where the wakes, according to satellite observations can last tens of kilometres behind the farm.

The second extreme is forest terrain, where turbulence normally is high. It means that smaller wake effects can be expected above forests than above open terrain and sea.

Another shortcoming of the simpler models is that they neglect the energy exchange with the surroundings. This is of less importance if the turbines and their mutual distances are small. When the wind power plant covers tens of square kilometres this will no longer be the case.

Advanced models that solve the Navier-Stokes equations are in use today. They describe the turbulent wind, reproduce whirls at the blade tips and the principal structure and distribution of the wakes[110]. It is still unclear to what extent they give enough information for making a correct statistical picture of

[109] M. Magnusson and A-S Smedman. Air Flow Behind Wind Turbines. J. of Wind Engeneering and Industrial Aerodynamics. No. 80, 169-189, 1999.

[110] See for example Ivanell et al. Numerical analysis of the tip and root vortex positi9n in the wake of a wind turbine.

the wakes' distribution and dispersal. See also the chapter on construction that refers to the work on such a wake model.

In summary, the commonly used wake models are very primitive, and the applicability of more advanced models has not yet been shown.

Sound propagation

The propagation of sound is influenced by meteorological conditions, mainly the vertical temperature and wind gradients that are important. However, models that are used to calculate sound propagation do not consider this.

The sound propagation is assumed to occur spherically. If it occurs cylindrically, we would hear high sound levels from long distances. The Swedish Environmental Protection Agency recommends a debated model of sound propagation above sea, which assumes cylindrical propagation. Measurements have been done over Kalmarsund, from Utgrundets lighthouse to Öland, 9 kilometres away. The results show that the model probably overestimates the sound levels from wind turbines on sea. However, the results are only based on measurements made at one site during the summer (July), so it is difficult to judge how universal they are. There is a need of measurements at more sites during other seasons, which is both time demanding and expensive.

The wind survey, made with the MIUU model, has resulted in a nationwide database that can be used to extract statistics about wind and temperature gradients at a horizontal resolution of 1 km. It could also be useful for a nationwide mapping of sound propagation.

Extreme winds

Extreme wind squalls of different durability and different recurring times (1 or 50 years) constitute the basic data for calculation of wind turbine loading. To create such basic information experimentally is practically impossible.

The Weibull distribution, which is exponential, appears able to describe the distribution of the average wind speed very well. An expansion of this, the so-called double-exponential distribution, gives a stable theoretical ground to calculate extreme winds. It is tested, and has been used in different forms during the last decades.

The increased importance of turbulence in connection with calculation of extreme wind speed with shorter and shorter durability can be handled by using wind spectra. Wind spectra show the distribution of different frequencies of the wind's turbulent kinetic energy (the variance), i.e. the distribution on different large elements of turbulence. An increasing part of the variance of the turbulence spectra should be included when extreme winds of shorter durability are calculated. This method appears too generate good results at comparisons with observations[111].

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[111] Bergström, H. Distribution of extreme wind speed. Wind Energy Report WE 92:2, Department of Meteorology, Uppsala University, 31, 00. 1992.

Wind forecasts

The increasing amount of wind power in the country increases the demand for good short-term forecasts of wind and production. This has already happened in Denmark and Germany, which have working forecast services being used.

The local wind forecasts are based on forecasts made by the large-scaled weather models. If these appear to be incorrect, it will be impossible to develop a good local wind forecast. This is not a problem unique for wind forecasts, but a general problem when forecasting the weather.

The local wind forecast is thus based on results from a large-scaled forecast. By comparisons with others cases, it is possible to "teach" the system to produce more detailed local forecasts. It is a statistical method without connection with atmospheric physics.

An alternative method is to produce local calculations with models that include the physics affecting the local wind conditions. As the large-scaled weather models get higher and higher resolution, the primary basic information will have more local factors. However, the weather models are not boundary layer models, and they substantially simplify the physical processes that govern local winds. A meso-scaled model, like the MIUU model, will give better results, since it can be combined with databases of formerly generated weather parameters, e.g. wind, temperature and turbulence.

A system based on this technique is already in operation by the Alarmsystemet, Svenska luftvårdsförbundet of West Sweden[112]. Now, it is tested for forecasting winds too. The first experiences indicate that the method will be applicable within production planning.

Wind measurements and wind indices

In larger wind power projects, the model calculations are normally complemented with wind measurements during 1-2 years. Since the results from such a short survey normally deviate from the long-term wind climate, it is necessary to correct them on a normal year basis, using some kind of wind index. The uncertainty of such a corrected measurement is typically of the same size as a calculated wind climatology produced with a physically good boundary layer model.

Nor is it trivial in itself to measure wind. The cup anemometer is the most common instrument type used in the wind energy context. Although they are rather robust, they still are delicate instruments requiring careful treatment. A smaller damage on the cup can lead to incorrect measurements. It is also important to assemble it correctly on the bars, which in their turn are mounted on to masts. Otherwise, there is a great risk that aerodynamic disturbances considerably deteriorate the measurement's quality. Assembling advice is found in an IEC standard. It is important to emphasize the risk of disturbances from antennae and parabolas that often occur on existing telemasts that are rented for measuring. It is important to have much air between the anemometer and the mast/antennae. A good rule of thumb is to use a long bar placing the anemometer 6-7 "mast-sides" away from the mast,

[112] http://liv.vg/alarm.htm

and to assemble the anemometer at the end of a vertical tube placing it 10-15 “bar-diameters” above the bar.

The risk of the anemometer icing and freezing arises in areas with icing conditions. The anemometer bearings can be temperature sensitive, as well. In that case, the anemometer needs heating.

It is not easy to clean observations exposed to icing. Periods with frozen cups are often simple to identify, but the measurements can also be affected by ice or frost without the cups having stopped completely. It could even result in too high values. In such cases, it is almost impossible to identify incorrect data.

A propeller or ultrasonic anemometer could be used instead of cup anemometers. The former has the advantage that transmitters for wind speed and wind direction can be included in the instrument. Despite that it is a very good instrument, it is seldom used in connection with wind energy.

The ultrasonic anemometer lacks moving parts and it is not exposed to mechanical wearing. However, without heating it is as susceptible to icing as the other types. Possibly, it is easier to identify a coat of ice or frost if it is thick enough to prevent penetration of the sound pulses.

Both types of anemometers can differ with regard to their response to skew wind attack. This applies to the propeller anemometer both vertically and horizontally if the wind vane does not manage to direct it towards the wind. For the cup anemometer, this is valid only for vertical winds. Some types respond differently on diagonal winds coming from above or from below.

Another important factor is how the anemometer works in squally wind. Some respond quickly to increasing winds, but slowly to subsiding winds. This is called over-speeding, which means that the anemometer yields too high average wind speeds. This was a big problem 20-30 years ago, when over-speeding of 10 percent was not uncommon. Modern anemometers are however better designed. The total differences of the anemometer response to skewed wind attacks today give a total error of some percent for measured average wind speed. This may seem to be a good figure, but a 2 percent error for average wind results in a 6 percent error in energy.

As the turbines become larger and thus higher, the need to measure on higher altitudes has increased. High masts are expensive, however. Remote sensing techniques, like sodar and lidar, are available today. Both types are based on a signal that is sent into the atmosphere, bounced back and detected by the instrument.

The sodar uses sound while the lidar uses laser light. The sound is reflected by turbulence structures having deviant temperature, whereas the laser light is reflected back to earth by dust and similar matter in the atmosphere. It is assumed that both structure and dust move with the wind, so the frequency of the echo will be Doppler shift displaced and it will be possible to determine the wind speed. By measuring speed in different directions, both the speed and direction of the wind can be determined.

There are today at least some types of sodar and lidar of high quality that can be used as an alternative, or complement, to mast measurements. If a relatively cheap 60 meter mast is combined with remote sensing, the altitude of measure will be extended to much more than 100 meters.

Another positive aspect on sodar and lidar is that the equipment is easy to move. One scenario can be a measuring mast on a central place and supplementary sodar recording for a couple of months on several sites around the mast in order to gather information on small-scaled variations of the wind climate.

A surface scanning lidar has been developed lately. From a single point, it can map the wind conditions within several altitude layers in an area of 10 x 10 kilometres. This, and similar techniques may be of great significance for the planning of wind power plants in the future.

European Wind Energy Technology Platform

"Wind conditions" is a key field of the European Wind Energy Platform. The ambitions are in part extremely high, and, for example, it is stated that both the energy supply and its short-term forecasts, and the dimensioning wind conditions should be established with an accuracy of 3 percent. Among the prioritised fields of research on winds above land can be noticed:

- Detailed wind conditions in complicated terrain and forests, including a large measuring project called "Askervein II". (Data from the original Askervein project in the 1980's have since then been used to verify flow models.)
- Wind conditions offshore
- Wakes within and between wind power stations
- Dimensioning wind conditions
- Wind gradients at more than 100 meters altitude
- Short-term forecasts
- CFD based models for resource determination and turbulence assessments. (See the latest Swedish wind survey, which used a CDF model).
- Development of remote sensing techniques
- Standardisation of resource determination

Importance of the Vindforsk project

The available Swedish knowledge within the research field is mainly based on results from projects funded by Vindforsk or directly by the Swedish Energy Agency. The conducted research projects have provided applicable results that seem to hold internationally. Reviewing of proposals of the European Wind Energy Technology Platform indicates that further commitments are motivated.

5.3 Future development

The knowledge about the distribution and characteristic of wind energy supplies has a continuing crucial importance for the Availability of wind power plants to produce electricity. The opportunities of further progress should be exploited within traditional and new areas, e.g. wind above forests.

Wind surveying

Methods are needed for wind mapping with high spatial resolution over limited areas, for example wind farms. Detailed wind measurements are needed for verifying (several masts, or similar).

Wind above forests

The knowledge about winds above forests needs to be deepened. There are uncertainties concerning how tree height and tree distances will affect the winds through zero-plane displacement and roughness length, particularly with regard to regional assessments in heterogeneous forested areas.

Calculations of production based only on wind speed at hub height may be insufficient. It might be better to include turbulence and wind gradient in the wind-effect relationship.

Icing

Periodically, icing can reduce the production substantially in certain areas. A survey of the icing climate is required.

Wake effects

Wake effects affect the production from wind turbines. Establishment in areas with different conditions such as sea, forest, and rough terrain, increases the importance of the wake models including the meteorological effects of atmospheric stability and turbulence. In practice, this implies that meso-scaled models should be used, which also regard the energy exchange with surrounding air layers.

Sound propagation

Temperature gradients and wind affect the propagation of sound. The propagation conditions in Sweden could be mapped based on the meteorological database that is available from the national wind survey.

Long-term measurements

Long-term measurements of wind and other meteorological parameters with high time resolution constitute an important set of information for normal-year corrections, and for studies of changes in the wind climate, of extreme wind events, and verification of theoretical distributions of extreme values.

Wind forecasts

The demand for local wind and production forecasts increases concordantly with increased proportions of wind generated electricity. The local forecasts available are mainly based on statistical analyses of earlier results. It is possible to improve the local forecasts if they are based on highly resolved results from meso-scaled models.

6 Environmental Effects

6.1 Results from the Vindforsk programme

Research within this field has not been within the ambitions of Vindforsk II, and no projects have been funded.

6.1 Trends analyses

Results from Vindval

The research programme Vindval is operated by the Swedish Environmental Protection Agency and funded by the Swedish Energy Agency. The objectives are to assemble, raise, and spread knowledge about environmental effects of wind power.

The goal is to facilitate the deployment of wind power by producing basic information for environmental impact assessments and permission processes. Research is conducted on the effects of wind power on marine environments, plants, animals, and humans, and on people's experiences of wind power. In the beginning of 2008, the state of the art was compiled in a status report. This, and other reports, are available on the Internet[113].

Human experiences
Environmental medical research shows that few people are disturbed by the noise from wind power turbines. One of the factors influencing the degree of experienced disturbance is the type of living environment. Residents in populated areas tend to be less disturbed than people living in the countryside.[114]

There are two ongoing research projects concerning people's attitudes toward and acceptance of wind power establishment. One is about how methods and strategies for planning and communication of wind power establishment affect the local population's attitude. The other describes different actors' strategies to overcome opposition and to anchor the wind power project better in the local population. The status of the planning research is described further in a separate chapter.

Sound in marine environments
Neither perch, roach nor brown trout seem to be particularly sensitive to the noise from wind power turbines. The species were chosen because they represent different ways that fishes perceive sound. Neither did Limfjord mussels seem to be affected by the noise from wind turbines.

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[113] Vindkraftens miljöpåverkan. Resultat från forskning 2005-2007 inom kunskapsprogrammet Vindval. www.naturvardsverket.se/vindval

[114] Eja Pedersen.Human response to wind turbine noise. Perception, annoyance and moderation factors. Doktorsavhandling, Göteborgs universitet. 2007

Fish
Based on earlier results about direct current, a study was carried out at alternating current cables in Kalmarsund. The study shows that south-migrating eels passed the cable with a significantly lower speed. This is not regarded to be a strong effect, but is rather bewildering than worrying. Similar studies will be conducted on cod, flatfishes, and other bottom dwelling fishes. The fish population in Kattegatt is mapped by GIS modelling.

Birds and bats
Studies carried out within Vindval confirm that the risk that migrating small birds and sea birds will collide with wind power turbines offshore is very small. The flocks make move away already at long distance.

Studies on how birds perceive wind turbine offshore with their sight show that the present colouring seem to be well suited for birds as well as for humans.

Ongoing projects investigate how birds in mountainous environments are affected by wind power. Willow grouse, golden eagle, and gyrfalcon are considered important to study.

Bats seek to wind power turbines during calm and clear weather, when insects gather around then, which exposes the bats for collision risks. This risk can be reduced if the wind turbines shut down at wind speeds less than 4 m/s, and during the time of year when the bats are most active. Since the electricity production is small then, the economic consequences should be acceptable. Further, it should be avoided to place wind turbines at known migratory passages for bats.[115]

Ecosystems
The establishment of wind power plants offshore introduces new types of habitats with hard bottoms and vertical surfaces, which may influence the balance between different organisms. There are some studies conducted in the area, for example how to choose suitable fundaments from an environmental point of view. [116]

Impact of shading on humans

Together with noise, wind turbine shading is the factor that in practice decides how close to houses a wind turbine can be placed. It has become praxis in Sweden, by virtue of a German non-published investigation[117], to allow 8 hours of true shading per year at maximum, i.e. one part per thousand of calendar time. However, a Swedish study[118] could not find any relationships between shade-time and degree of experienced disturbance. Apart from this, there are no research results about the impact of shading on humans.

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[115] Ingemar Ahlén et al. Fladdermöss och havsbaserade vindkraftverk studerade i södra Skandinavien. Rapport 5748. Naturvårdsverkets bokhandel.
[116] Rutger Rosenberg et al. Miljömässig optimering av fundament för havsbaserad vindkraft. Naturvårdsverkets bokhandel.
[117] J. Pohl, F. Faul, R. Mausfeld. Belästigung durch periodischen Schattenwurf von Windenergieanlagen. Institut für Psychologie der Christian-Albrechts-Universität zu Kiel.1999.
[118] E. Pedersen and K. Persson Waye. Audio-visual reactions to wind turbines. Euronoise Naples 2003.

Environmental effects of offshore wind power– synthesis report

Within the previous wind power programme, Elforsk published a synthesis report in 2005 concerning environmental issues related to wind power offshore[119]. A large number of Swedish and foreign reports underlie the synthesis, which also includes a survey of inquiries, projects, comments on proposals submitted for consideration to official bodies and environmental courts, which were topical at that time.

Habitat changes

The fundaments of wind power turbines offshore constitute a new substrate for attached organisms like algae and many invertebrates. These will colonise quickly, and small communities of marine organisms, including fishes, develop. The animals are attracted by the increasing availability of food, and the shelter that the artificial reefs offer. It is not possible to judge whether the fundaments lead to an increased abundance of the species populations, or just increase their density.

Birds and bats

Conducted investigations indicate that birds avoid wind farms offshore to a large extent. This is true for migrating birds as well. Collisions are unusual, and the mortality that still exists has not affected the populations significantly.

The theory of bats being attracted by the insects that gather around the turbines is considered to be valid (see also below). This effect is expected to be site-specific, depending on the area's density of insects or if it lies within a bat migratory route.

Sound and vibrations

Fishes and marine mammals are the organisms that are most exposed to sound in the water. From the few published reports, it can be concluded that fishes can "hear" sounds from wind turbines, but that they probably not will be affected to any great extent. Danish studies have shown that wind turbines offshore do not disturb harbour porpoises and seals (see below).

Sediment and sedimentation

During the building-phase, turbidity from sediments can temporarily interfere with water organisms, for example by the covering of vegetation and decreased light insolation. However, this occurs only during a limited period and will be of transient character.

Electric and magnetic fields around cables

Earlier studies were related to direct current cables (HVDC), around which a strong magnetic field is induced. Telemetric studies indicate that disturbances of the earth's magnetic field can bring eels off course some hundreds of meters. The large-scale migration is not affected at the Baltic Cable.

The control programme of SwePol included studies on magnetic impact on salmon and brown trout. It could not be proved that magnetic fields had any impact on the way fish swim.

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[119] Miljöeffekter för havsbaserad vindkraft. Elforsk ER 05:09

Since many years, there is a large number of submarine cables with alternating current, for example in the archipelagos. Since A. C. cables do not generate any static magnetic field, they have no effect with regard to this. Nor has any influence on the fish stock been proved.

Landscape view
For wind turbines on land, it has been shown that the visual disturbance are smaller if they have an attractive design. One way to reduce the visual disturbance of wind turbines on the surroundings is to place them on sufficient distance from "sensitive characteristic" of the landscape.

Status report from the Swedish Board of Fisheries

The Swedish Board of Fisheries is one of the stakeholders with regard to wind power offshore, and they compiled the results from Swedish and foreign research in the field in 2007[120]. The report points out that assumptions about the effects on fish mainly is derived from other marine activities and indirect estimates.

During the building phase, there is a risk of harming young fishes, in the first place. These effects can be minimized if establishment in particularly sensitive areas, or during particularly critical periods, are avoided. The disturbance risk during operation is considered to be low, but it was pointed out that there is a need to increase the knowledge of the area.

Wind power can also limit fishing within the specific farm. Fishing restrictions within larger farms can be positive for the development of fish populations in the long run, under the condition that the fish stay in the area and is not disturbed by the farm. For example, specific fish species may respond by gathering within the farm, or outside, which may increase harvesting opportunities.

By monitoring the ecological course of events within the farm, it is possible to decide on suitable measures if negative effects would show up. Local ecological conditions are important. In general, bottoms in shallow waters are more productive, which means that the impact risk is quantitatively higher here.

Status report from the Ornithological Society

The Swedish Ornithological Society published a compilation of the impact of wind turbines on birdlife in 2007[121]. The report states "birds are probably the organism group that have attained most attention with regard to conflicts with wind power". The potential risks are divided into disturbance, barrier effects, mortality caused be collisions, and habitat deterioration. The main part of the published studies focuses on collision risks, and they show that the risk is low, or very low, per turbine.

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[120] Revidering av kunskapsläget för vindkraftens effekter på fisket och fiskbestånden. Fiskeriverkets redovisning av regeringsuppdrag 121-3095-05.
[121] Fredrik Widemo. Vindkraftens inverkan på fågelpopulationer – kunskap, kunskapsbehov och förslag till åtgärder. Rapporten skriven på uppdrag av Sveriges ornitologiska förening (SOF). 2007

The collision risk will be a larger problem for long-lived species that mature late, and for stationary individuals that stay in the area regularly. The localisation of the wind farm is of crucial importance fro the collision risk. An unsuitable localisation of the farm, or turbine, will definitely affect the birds negatively on a population level, according to the report. The society states further, that no wind power should be established in localities having a specific area protection, in areas where threatened species occur, or in areas with exceptionally dense bird populations.

According to the report, the impact of wind farms on bird populations varies depending on technical design, area topography, placement of individual turbines, and the bird species that occur in the area.

Since previous research has been focused on collision risks, the society looks forward to research on potential effects on bird populations of the habitat deterioration and destruction that wind power establishment causes. It is important to study what can be done to reduce the negative effects, for example by changing the mutual localisation of the turbines, or their design.

Control programme

In a permit to build wind power plants, it is common that conditions to establish a control program are imposed on the exploiter. This would contain descriptions of what has to be investigated, and when, sometimes even before the plants are built. Here follow some examples of control programmes.

A control programme on archaeological and environmental values has been imposed on the Municipalities of Krokom, Berg and Härjedalen. Studies on harbour seal are included in the conditions of the deployment at Utgrunden II, and in the project at Gässlinge banks in Lake Vänern, migration birds has to be surveyed. Studies on birds and reindeer herding activities are included in the conditions for the projects of Gabrielsberget and Storliden in the County of Västerbotten.

The following example shows how a control programme can influence the final permit. The impact of wind turbines on resting geese and cranes was surveyed in a control programme[122]. The results showed that geese and cranes rested very close to the turbines on several occasions. Due to these results, the reviewing authority judged the deterrent effect of wind turbines on resting cranes and geese to be weak or moderate. They argued that future establishment of wind power can be effected since cumulative effects of wind turbines might arise, but that other factors, such as the presence of desirable crops, would influence the birds' selection of feeding areas more.

Danish experiences

Denmark has the largest accumulated experience about wind power offshore. An extensive research programme has been conducted in connection with the establishment of the large wind farms at Nysted and Horns Rev. The results

[122] Axelsson och Gezelius. Vindkraftsverks inverkan på rastande gäss och tranors fälval vid Tåkern 2002-2004. 2005

are summarized in a report of which the main outlines are reported in the following[123]. A group that consisted of the Danish Forest and Nature Agency, Vattenfall, and Dong Energy coordinated the research. The International Advisory Panel of Experts on Marine Ecology (IAPEME) reviewed the results after consultation with the World Wide Fund For Nature (WWF) and the Danish Society for Nature Conservation.

Benthic fauna and vegetation
In total, six studies on the seabed fauna and vegetation were conducted at both wind farms. The largest effect appeared to derive from the introduction of structures with hard surfaces on a seabed that almost exclusively consisted of sandy sediments. The habitats have hereby become more heterogeneous, and the benthic fauna at the turbines has changed from a typical infaunal community (animals living under the seabed surface) to a typical hard bottom benthic community. Both species richness and biomass increased. No effects, or negligible ones, were found on the benthic fauna, on sea bed sediments, or on attached benthic communities already established.

Fish
It was not possible to show statistically that fishes are attracted to the artificial reefs that the fundaments constitute. For Horns Rev, it can be explained by the studies being made during the early stages of colonisation. The process is expected to proceed in forthcoming years. Another explanation can be that fishes are not attracted to species-poor bivalve communities.

The impact of electricity cables on fish has been studied in Denmark, as well. The observed effects were not correlated to the strength of the electro-magnetic field, and varied from avoidance to attraction depending on the species.

Lesser sandeels are common at Horns Rev. Since there is strong correlation between the occurrence of lesser landeels and the sediments' composition, both were investigated. The results show low probabilities for the wind farm influencing the sediments' composition or having a negative effect on lesser sandeel.

Marine mammals
Seals did not change their behaviour on land or at sea, neither during the building phase nor later. The only demonstrated impact was that the number of seals on land decreased when piles were driven at Nysted.

A small decrease in the number of harbour porpoises was observed at Horns Rev when piles were driven. No effects were seen during operation. However, the number of porpoises decreased at Nysted during operation as well. The effect remained during the two first years of operation, but with indications of a slow recovery. It is therefore difficult to generalise about the impacts.

Birds
Barrier effects, habitat loss, and collision risks affected the birds at Horns Rev and Nysted. Common species avoided the wind turbines, even though the

[123] Danish offshore wind – Key environmental issues. Published by Dong Energy, Vattenfall, Energistyrelsen and Skov- og naturstyrelsen. 2007

responses differed. Birds tended to avoid the immediate surroundings of the turbines, and moved along the periphery of the farm. These somewhat extended migration routes probably have no consequences.

In some cases, species have disappeared completely after wind power installation. The report points out that this possible habitat loss must be regarded in proportion to the areas available outside the farm. For most of the species in the study, the wind farm occupies a small part of the available area, and hence will have small consequences. However, the total effects of a large number of wind farms might be significant in the future.

Socio-economic effects
Both the inhabitants living close to the two wind power farms and those in the rest of the country are positive towards the plants. There are, though, differences in attitudes between the two areas as well as between the local and national populations. The results shows further that the attitudes were influenced by the visual impression of the wind farms.

General conclusions
The Danish experiences thus show that wind power turbines offshore can be built and operated without any significant negative effects on the marine environment and sensitive species. The plants at Horns Rev and Nysted have had small impacts on the environment, in total. There are positive local effects of the fundaments as they serve as artificial reefs. Contrary to previous thoughts, the effects are more complex and not so easy to generalise as believed earlier.

Experiences from countries

In Germany, which has committed itself largely to wind energy, an extensive research programme goes on concerning offshore plants, including around thirty different projects within the research platform Fino 1. The two new stations of Fino 2 and 3 are taken into use during 2007. The investigations include both technical and environmentally related issues concerning wind power deployment.

In Great Britain plans exist to establish several large wind farms offshore, for example "The London Array" having a capacity of 1 000 MW. Research on environmental impacts of offshore wind farms goes on within the Cowrie programme that studies noise and vibrations from wind turbines, effects on birds, and the influence of electro-magnetic fields on marine life.

European Wind Energy Technology Platform

The environmental issues are handled by the platform under the title "Integrating wind into the natural environment". Examples on proposed research fields are:

- The general impact of production and consumption of electricity on the environment, particularly with regard to wind power offshore and its global advantages to other forms of electricity production.

- Evaluation of the environmental impact by wind power on local to global levels.
- Establishment of a data bank for environmental impacts of wind power to reduce the need for new investigations.
- Gathering of information from control programmes, particularly with regard to bird studies.
- Impact of wind turbines on birds, bats and marine and freshwater life.
- Development of techniques to monitor the environmental impact on birds, bats and aquatic animals.
- Development of techniques to reduce the impact on radar, aviation and telecommunication, and the evaluation of these with regard to economy and financing.
- Development of methods for localisation and evaluation of wind power in the landscape.

6.3 Future Development

During several years, the common belief has been that wind power offshore will account for the main part of wind power deployment. The weak economy of offshore projects, so far, in combination with enlarged opportunities in forested areas, has focused the attention to wind energy establishment in forests and mountains. This will in turn lead to a need of studying new sets of potential problems.

Birds

As the Swedish Society of Ornithology has pointed out, among others, much of the research has so far been focused on collision risks. In the future, there will be a demand of more knowledge about disturbances and possible habitat losses. There are also suggestions about further investigations about measures that can be taken to reduce the negative effects of wind power, for example change the mutual placement of the turbines or their design. Since small birds, migratory birds and sea birds already have been studied rather closely, future attention will probable be on predatory birds. The interest to localise wind power to forests will lead to a demand for studying the effect on capercaillie, black grouse, and other grouse species. A remaining question for Vindval is if sea birds will return to their previous feeding behaviour in areas with wind turbines, and if so, how long time it will take.

Mountains

With the increased interest for wind power in the mountains, and areas close to them, arises a need to know how the animal life, for example predators such as bears and wolverines will be affected. The mountainous environment brings on new conditions for the assessment of exploitation on the ground surface that is needed in connection with wind power establishments. How should roads be planned, and fundaments be designed, to give a minimal effect on the mountain ecosystem?

The mountainous environment also puts demand on knowledge about the co-existence of wind power and reindeer herding, and how new forms of co-operation can be found. The research need about the effects on various industries is described in the chapter on wind power planning.

Forests

The interest of establishing wind power in forests has actualised studies of its effects on forest animals. Game species such as moose and roe deer are mentioned in this context. The behaviour of those animals is relatively well known, and limited studies are considered to suffice to draw conclusions about their response to wind power.

Roads and infrastructure

Related activities such as road alignments and cable pulling may affect the environment, which motivate investigations. Another effect is the increased human activity that plant surveillance and increased road accessibility will result in.

Noise, light and shade

The issue about human experience of wind power will continue to be important to handle. It might be more interesting to elaborate upon the true experience (e.g. of obstruction light) than more thorough attitude inquires.

The effect of the total sound picture when a large number of turbines are built should be clarified. There are uncertainties about the extent to which existing calculation programmes are able to describe this situation correctly. The uncertainty occurs in both directions.

The present praxis concerning allowed shading time at residence etc. is based on an almost non-existing scientific base. Research in the area is strongly justified.

Positive environmental effects

To give a fair description of wind power opportunities it may be necessary to make comparisons with alternative ways of electricity production. It could also be questioned whether environmental effects automatically should be regarded as negative. In some contexts, wind power establishment will produce local benefit, when it gives shelter or new habitats for endangered plants or animals. Such effects should be elucidated as well in an objective document supporting a decision.

Interdisciplinary studies

It is a great challenge to decide how the knowledge coming from traditional studies of environmental effects should be applied in a useful way.

For example, a study that results in information about what proportion of a population will be at the risk of being affected in a certain way might result in more questions than it answers. Questions that handling officers and decision makers need answers to can be: What does this mean? Is it a large or small proportion in this context? Is exactly this effect crucial for the population's survival? Which are the alternatives? What happens if the planned plant will not be built? This kind of questions is not commonly answered by traditional research reports.

There is knowledge within other scientific fields that could by applied on the environmental effects of wind power. Examples are risk evaluations, environmental ethics, system optimization, and systems ecology.

Research completed?

In discussions between representatives from authorities and the trade, it is often stated that more research has been conducted on environmental effects of wind power than is justified, and that a majority of all studies shows that it involves minor problems and limited effects. By that, many think it is appropriate to "put down the foot" and declare a number of research fields completed for the time being. In a possible extension of Vindval, it is planned to handle this by collecting existing knowledge and letting it be evaluated and synthesised by expert panels. Conclusion will be drawn based on today's state of the art.

An obvious example is the noise from offshore wind farms. No one complains, and no cases exist when somebody have been able to hear them at the actual distances. Still, many millions of SEK have to be allocated to the investigation of sound propagation, which in addition has appeared to be theoretically and practically difficult. The reason for this in the current case was that a governmental authority specified a sound propagation model to be used, which – if it had been correct – would give significant noise levels and reasons for complaint.

Another experience is that when a question is solved, new ones arise. When an area ends up in media, individual interests gain a disproportional weight. The issues might possibly be easier to handle if an overall picture concerning which questions are important, and which are of minor importance, would be developed.

Finally, some argue that the permission procedure pursuant the Environmental Act includes an imbalance between the advantages and disadvantages of an establishment. As an example may be mentioned that the design of consultations and environmental impact assessments results in a highlighting of negative effects, while it is difficult to give the positive effects a fair treatment. In this light, the focus should be to find forms to describe the possibilities of wind power to reduce the emission of carbon dioxide rather than initiating further research within more or less peripheral fields.

7 Sound

7.1 Results from the Vindforsk programme

In 2006/2008, the Vindforsk programme granted 3.6 million SEK, or 9 percent of total funding, to projects within this field.

Noise propagation over sea

V-121 Sound propagation from offshore wind farms

Project leader: Mats Åbom, Marcus Wallenberglaboratoriet, KTH

The aim of the project was to work out basic information for revision of the Swedish Environmental Protection Agency's calculation model for sound from offshore wind turbines. It assumes a cylindrical sound propagation, which means that the damping is lower than with the spherical propagation model that otherwise is supposed to be the proper one.

The developed measuring method means that sound with well-defined frequencies is sent from a highly placed sound source and is recorded by a number of microphones placed along a straight line directed towards the sound source. In this way, a direction-sensitive microphone is created. The recording equipment was placed at Hammarby on Öland. A Kockum Sonics Supertyphoon was used as sound source, having fundamental harmonics of 200 Hz and high harmonics at 400 Hz, together with a loud speaker, with a quarter-wave tube that was pitched to 80 Hz. The sound pressure level of the typhoon was 141dB re 1 pW at 200 Hz, no value being given for 400 Hz. The sound pressure level for the 80 Hz source was 124 dB. They were placed at 30 meters height above sea level at the former lighthouse of Utgrunden. To analyse the signal at the receiver, a technique was used that included time averaging, a Kalman filtering, and FFT (Fast Fourier Transform) in several steps. The distance between sound source and microphones was 9.75 kilometres above land.

The recorded data were corrected in several ways in order to get damping values due to the geometrical distribution. Reflection amplification at water surface was set to 3 dB. Calculations of damping by air absorption was made for different frequencies according to ISO 9613-1, and based on air temperature, relative air humidity and air pressure at the source, and the ground damping (of sound transmission above land) set to 14dB at 200 Hz. The values of 80 Hz and 400 Hz were not supposed to be influenced by ground damping. Then they were weighted together.

The ground damping is an interference phenomenon, and its largest effects use to be around 200-400 Hz for soft ground. The damping above hard surfaces is less, and displaced towards higher frequencies. Ground damping can be calculated with Nord2000[124]. An alternative would have been to calculate the ground damping and then make corrections.

These corrections give a cumulative distribution of the damping, according to Fig. 2[125]. The figure shows that the damping exceeds 64 Db, which corresponds to the propagation model of the Swedish Environmental Protection Agency, during slightly more than 90 percent of the measuring time, and exceeds 80 dB, corresponding to spherical propagation, during slightly less than 40 percent of the time. Damping of the equivalent sound pressure level corresponds to 68 dB. The authors conclude that the model of the Swedish Environmental Protection Agency overestimates the sound level with about 5 dB in the present case, and that the switching point to cylindrical propagation should be set at about 700 meters.[126]

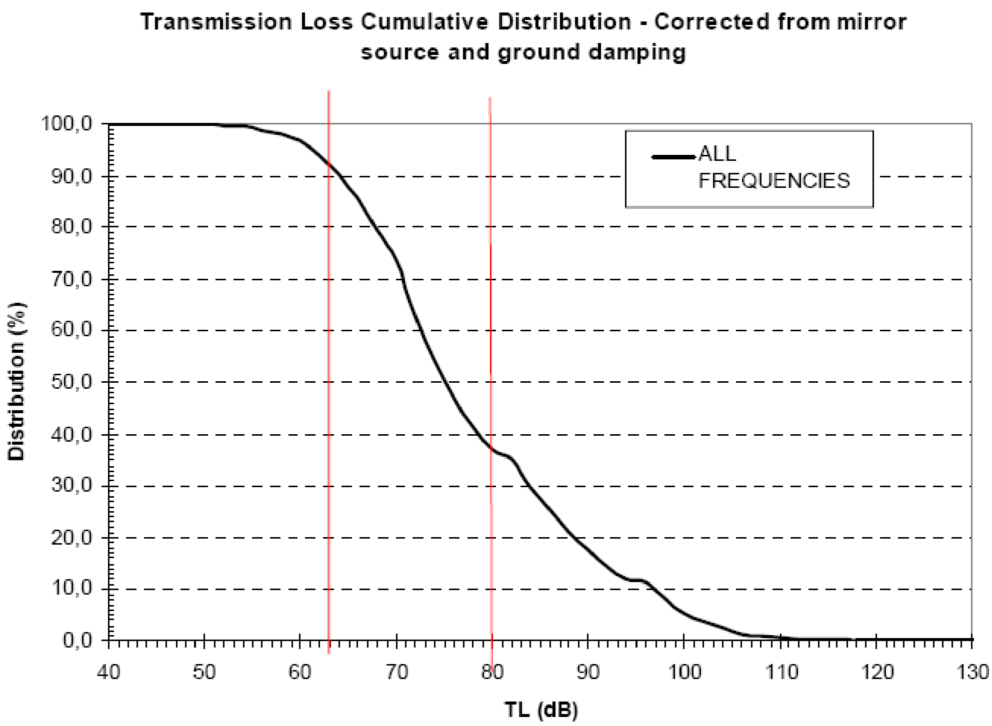

Figure 2. The cumulative distribution of the geometrical damping of sound propagation measured at Kalmarsund after corrections and co-weighting. The vertical line at 80 dB corresponds to true spherical propagation. The vertical line at 64 dB corresponds to spherical propagation for 200 meters and then cylindrical propagation (model of the Swedish Environmental Protection Agency).

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124 Nordic environmental noice prediction methods, Nord2000. Summary report. General Nordic Sound propagation model and applications in source-related predictions methods. Delta report AV 1719/01, Lyngby Denmark 2002.
125 Boué, M. Long-range propagation over the sea with application to wind turbine noise. Technical report TRITA-AVA 2007:22. ISSN 1651-7660, MWL/KTH, 2007
126 Boué, M. & Åbom, M. Ljud från vindkraftsverk. V-201 sammanfattning, www.vindenergi.org nedladdad juni 2008.

The measurements were conducted during ten days in June 2005, and one week in June 2006. The author communicates personally that the results are only valid for the given season and locality[127].

One reason why the experiments were carried out with so low frequencies is that the high frequencies are damped by air absorption at such long distances that was the case here.

V-233 Predictions of wind turbine noise based on detailed meteorological and geographical information

Project leader: Ilkka Karasalo, section of Human and Techniques, FOI

The project analyses existing data on sound propagation above Kalmarsund (project V-201) by comparisons of calculations done with propagation models that use detailed meteorological data during a week. The project is presented in a status report[128].

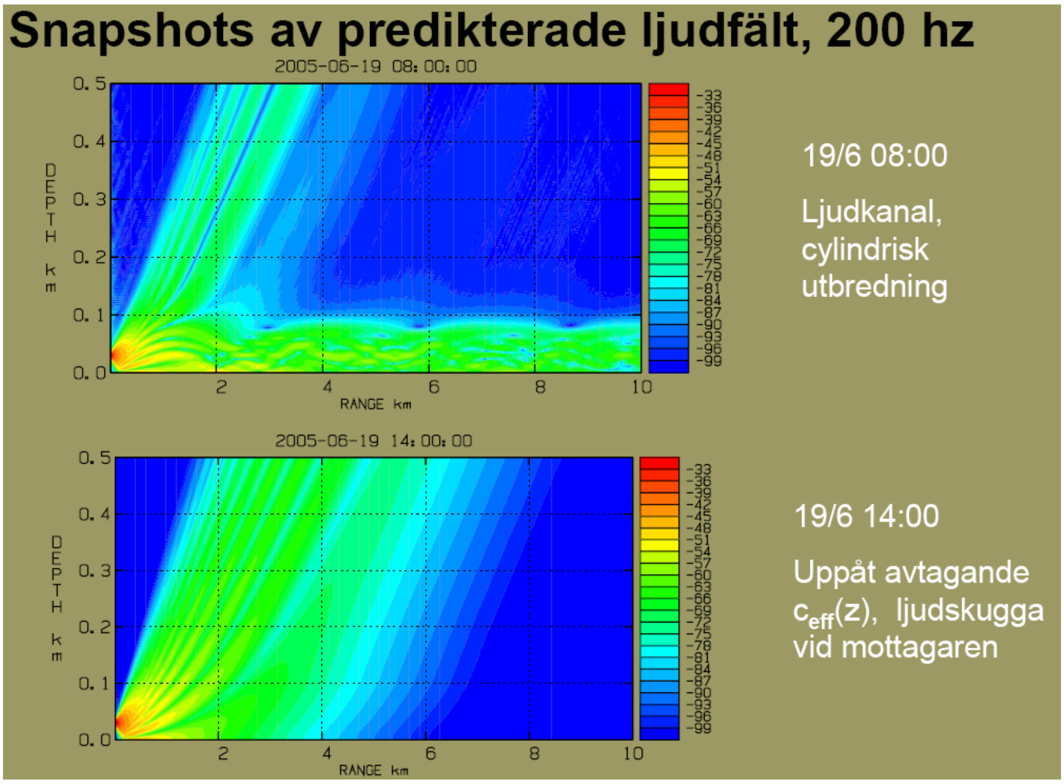

Figure 3. Calculated damping of sound propagation in experiments at Kalmarsund in a vertical plane through the source and the receiver, and by analysis with the programme XRAY at FOI.

[127] Åbom, M. Personlig kommentar till Martin Almgren, 2008-06-23.
[128] Karasalo, I, Cederholm, A. & Andersson, B.L. Prediktering av vindkraftbuller. Lägesrapport. PM uppdragsnummer B21002, FOI 2008-05-05.

Recorded data include temperature, wind speed and wind direction at a 90 meters high mast on the former lighthouse of Utgrunden, wind speed and wind direction up to an altitude of 4,5 kilometres through tracking of free balloons, and pressure, temperature and air humidity up to an altitude of 13 kilometres by means of radiosonds. The balloons and radiosonds were released from Hammarby on Öland where the sound was recorded. The data were used to calculate wind speed, absorption and density for different distances and altitude between the sound source and the measurement site. By mean of this data, damping could be calculated in its turn. Some snapshots are seen in Figure 3. The upper picture shows a case with cylindrical propagation, and thereby small damping. The lower one shows a case with large damping.

The analysis presented so far shows a bad correlation between sound propagation calculated with the XRAY programme and the measured sound propagation. Later calculations made with the so called "normal-mode model" and the Parabolic equation have given better results[129][130].

V-228 Sound masking by wind induced background noise

Project leader: Mats Åbom, Marcus Wallenberglaboratoriet, KTH

The project's aim was to investigate how roaring from sea waves masks the noise from wind turbines, and how it will influence the experienced disturbance. It is a continuation of a previous project that studied the background sound from the vegetation[131] [132] [133] [134] [135].

The experiments with background sound from vegetation showed that persons still could distinguish the turbine noise when this was 8-18 dB weaker than the ambient sound.

The project goes on. The goal is to develop a calculation model that makes it possible to estimate if tree sighing and wave roaring can be used to mask wind turbine noise.

[129] Karasalo, I., Cederholm, A. & Andersson, B.L. Prediktering av vindkraftsbuller (V-233). Presentation vid referensgruppsmöte och vid Vindforsks programkonferens på KTH 14-15 maj, 2008.
[130] Åbom, M. Personlig kommunikation till Martin Almgren. 2008-06-23
[131] Bolin, K. Masking of wind turbine sound by ambient noise. TRITA-AVE 2006:86 ISSN 1651-7660, Licentiate thesis MWL/KTH 2006
[132] Bolin, K. MASK2 – Lägesrapport för för perioden mars 2007 – december 2007, MASK II P-nr. 20134-3, MWL/KTH 2008
[133] Bolin, K. Investigating the audibility of wind turbines in the presence of vegetation noise. Second International Conference on Wind Turbine Noise, Lyon 20-21 September 2007
[134] Appelqvist, P., Bolin, K., Almgren, M. & Åbom, M. Masking of wind turbine noise by sea waves. Second International Conference on Wind Turbine Noise, Lyon 20-21 September 2007
[135] Appelqvist, P. Maskering av vindkraftljud via naturligt bakgrundsljud – särskilt havsbrus. Examensarbete vid ÅF-Ingemansson och KTH, TRITA-AVE 2006:100, MWL/KTH 2006

7.2 Trends analyses

The former, relatively restricted, attitudes towards wind power in Sweden has for example been manifested in regulations for noise from wind turbines that generally are more strict than in other countries, and much more strict than for other activities (aviation, road traffic, and to some extent industries). This may explain why the environmental medicine research in Sweden shows that few people are disturbed by wind turbine noise, according to the previous chapter.

Elforsk report of 2006

The report[136] included a compilation of literature on the state of the art in 2005. Among other things, it was stated that if the calculation model of the Swedish Environmental Protection Agency for sound propagation were generally valid, there should exist complaints about noise disturbances from offshore wind turbines. We have not been able to find any, neither from Sweden (Bockstige), Denmark (Middelgrunden and Nysted wind farm and Horns Rev), nor from the Netherlands. When the model of the Swedish Environmental Protections Agency for noise calculations for wind power offshore is applied on Middelgrunden and Nysted, the noise level lands at about 48 dBA for land areas at a distance from the wind farms of 4.5 and 7 kilometres, respectively. According to disturbance studies from Environmental Medicine at the University of Gothenburg, many people experience these levels being disturbing.

To set standard values for noise from wind turbines, two methods are used internationally. The first specify a standard value for equivalent noise levels. The second relates the noise level to the ambient sound. The Swedish Environmental Protection Agency plans to specify a standard value for equivalent noise, and a stricter standard value for localities with topographically unfavourable conditions. The reason is that it might exist localities with such topography that they have a low ambient background sound while the wind power plant is audible. In such situation, a higher turbine noise should be allowed if sea roaring masks the noise, for example. An alternative that is considered to give fewer problems with complaints afterwards is a standard value based upon measured ambient sound in combination with an upper limit.

Masking of wind turbine noise by natural background sound

Wind power deployment in Sweden has been debated because of potential noise disturbances. In several countries, not including Sweden, the noise from wind turbines is related to the background level. Masking by natural ambient sound, such as wind induced sound from vegetation and waves, is possible when it resembles the dominating broad-banded wind power noise. When the ambient sound is lower than normally, e.g. when the topography shelters the buildings against wind, the disturbance can be larger than normal. Wave sound can reduce the disturbance in coastal settlements. An undergraduate

[136] Almgren, M. Ljud från vindkraft. Utredning inför Naturvårdsverkets allmänna råd. Elforsk rapport 06:02, mars 2006

thesis develops a model for shore sounds and elucidates its potential to mask wind power noise[137 138].

There are well-elaborated models for predicting vegetation sounds. A field study was performed to establish how sea roaring could mask wind turbine noise. Measurements were carried out on fifteen localities along the Swedish coast. The analyses showed that masking effect at the shoreline was good for the current Swedish standard value of 40 dB(A). If the turbine noise is on the same level as the sea roaring, which is slightly more than 60 dB(A) for waves of half a meter, the masking effect will be more uncertain. The conclusion is that measurements together with calculations should be done for places with deviating levels of background sound.

Low frequency sound and infrasound

Sound within the frequency range of 20-200 Hz is called low frequent, and below that it is named infrasound. High levels can be harmful, which has led the Swedish National Board of Health and Welfare and the Swedish Work Environment Authority to issue directions about maximal acceptable levels. These are exceeded in many cases, for example in office premises and truck cabins. Aircraft technicians that have been exposed to low frequent sound above 90 dB have suffered from a disease called vibro-acoustic disease (VAD), with symptoms such as thickening of tissues in the heart and the vascular system.

One reference[139] claims that even sound in the lower infrasound range and low frequent sound from wind turbines could result in vibro-acoustic disease. In connection with the application for the planned wind farm Andmyran in Norway, a report was prepared[140], which stated that other researchers do not accept the hypotheses of that reference. It is not reasonable with injuries from sounds that are below the sensitivity threshold for low frequent sound or infrasound. At 500 meters distance from the planned wind farm the noise falls 5-10 dB below the standard value of the Swedish National Board of Health and Welfare.

Apprehensions have been expressed in Denmark that the new generation of much larger wind turbines will cause high levels of low frequent sound. The issue was studied by measurements at Risø experimental station in Høvsøre, where the presently largest wind turbines of Denmark are established. It was concluded that the new generation of wind turbines does not cause more low

[137] Appelqvist, P., Bolin, K., Almgren, M. & Åbom, M. Masking of wind turbine noise by sea waves. Second International Conference on Wind Turbine Noise, Lyon 20-21 September 2007

[138] Appelqvist, P. Maskering av vindkraftljud via naturligt bakgrundsljud – särskilt havsbrus. Examensarbete vid ÅF-Ingemansson och KTH, TRITA-AVE 2006:100, MWL/KTH 2006

[139] In-home wind turbine noise is conducive to vibroacoustic disease. Mariana Alves-Pereira, ERISA-Lusofona University, Lisbon, Portugal

[140] Almgren, M. & Solberg, S. Andmyran vindpark, Norge. Riktvärde för lågfrekvent ljud. ÅF-Ingemansson AB och Kilde AS rapport 12-02917-07101600 på uppdrag av Andmyran vindpark AS

frequent sound at neighbours than the smaller ones. In summary, the infrasound is negligible[141].

Areas with lower background sound than normally

The aim of the referred project [142] is to develop a method to measure the background level at sites planned for wind power establishment. One application is to find out if the background level at the nearest settlement is lower than normally, in spite of hard winds at hub height. One result is that measurements should be made during a couple of weeks every season. In addition, it is studied how the background sound will influence the audibility of wind turbine noise, and how this can be applied in Swedish guidelines for wind power noise.

European Wind Energy Technology Platform

European Wind Energy Technology Platform raises the noise issues to a limited extent in the chapter on the integration of wind power plants in the natural environment. Activities are proposed in the following fields:

- Methods to calculate, limit and monitor sound propagation from wind turbines.
- Environmental impact assessments should be evaluated afterwards in order to establish the true noise impact in relation to the previously calculated.

The importance of Vindforsk projects

Available and current Swedish knowledge in the field is largely based on results from projects that were funded by Vindforsk and its precursor. The conducted research projects have given applicable results and seem to hold internationally. The interest for noise issues is greater in Sweden than in other countries. This is particularly true for noise from offshore wind turbines.

7.3 Future development

Noise has traditionally limited opportunities of wind power establishment in Sweden, a country that has widely dispersed settlements, and much stronger regulations about wind turbine noise than many others have. Even though the relative importance of noise issues tends to have diminished lately, there is a need to clarify the particular conditions for the "new" application wind power in forests. Sound propagation over sea is still not adequately clarified, regardless whether it is a real problem or not. Masking effects and their opposite need further investigations.

[141] Low frequency noise from large wind turbines. Summary and conclusions on measurements and methods. EFP-06, Report AV 140/08. Client Danish Energy Authority, 2008

[142] Appel, D. Kvantifiering av områden med lägre bakgrundsljud än normalt vid vindkraftsprojektering. Examensarbete vid ÅF-Ingemansson och KTH. Rapport under utarbetande 2008

Noise emission from wind turbines in forest terrain

Is the wind more turbulent in forests terrain and how will it influence the noise generation? What effect will skew wind attacks on the rotor have on the noise generation?

Sound propagation in forest terrain

The Swedish Environmental Protection Agency's calculation model for the propagation of wind turbine noise over land assumes a flat ground in open terrain. Thus, it does not consider forested land with porous surface, trees that spread the noise, waters and rock surfaces, nor horizontal variations in gradients of wind speed and temperature. Compare with corresponding calculation models for roads, railroads, and industries that consider the porosity and topography of the ground surface. Nord 2000 is such calculation model, but it is not validated for forest terrain and long distances. Nord 2000 therefore needs to be validated for sound propagation over forests.

Sound propagation over sea

The Marcus Wallenberg laboratory has proposed that the Swedish Environmental Protection Agency's calculation model for the propagation of wind turbine noise over sea is modified so that the distance for the switch to cylindrical propagation is changed from 200 to 700 meters. There still exist uncertainties, see the reservations previously mentioned. The modelling by FOI should give some answers. In order to verify it, calculations should be done for some offshore wind power plants, e.g. Bockstigen, Lillgrund and some Danish plant. In cases when the noise levels will be 40 dBA or more, supplementary measurements should be made. Comparative calculations should be done with Nord 2000[143] that was developed by the Nordic Countries together. It is a path acoustic model where the ground damping effect is modelled according to geometrical path acoustic theory, and the shadow damping effect according to geometrical diffraction theory.

Another uncertainty is the effect of source height and extension. At measurements in Kalmarsund, the source height was 30 meters, while a large offshore wind farm has its source distributed from 50 to 150 meters' height.

In analyses of the data from Kalmarsund, it was assumed that the signal of 200 Hz was reduced with 14 dB due to ground damping, while the damping effect at 80 and 400 Hz was set to zero. The frequency range around 200 Hz has large impact on the dBA level, which motivates further investigations.

Masking of wind turbine noise and audibility

If the noise from a wind turbine is not audible from a house due to masking sound, the noise in itself cannot be disturbing. The question is at what level the noise will be disturbing. There are several studies on this issue and they should be compiled.

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[143] Nordic environmental noise prediction methods, Nord2000. Summary report. General Nordic sound propagation model and applications in source-related predictions methods. Delta report AV 1719/01, Lyngby Denmark 2002

Background sound in wind-sheltered sites

More experiences and measurements are needed from existing wind power plants where houses in wind-sheltered sites are suspected to have higher risks of experienced disturbance at 40 dBA than sites with normal wind.

8 Effects on aviation, radar, radio relay links and signal intelligence

8.1 Results from the Vindforsk programme

Research within this field has not been within the ambitions of Vindforsk II, and no projects have been funded.

8.2 Trends analyses

Airports

With the modern equipment for approach procedures of the civil and military aviation, the restrictions for wind power establishing outside the airport's immediate neighbourhood are rather small. These restrictions are motivated by the requirement of absence of obstruction that exists for the aviation, and are therefore not commonly negotiable. There are some exemptions from this, which are treated further below.

MSA areas

There are so-called MSA areas (Minimum Sector Altitude) around the airports, which are used during instrument approach procedures. In a number of cases, this altitude has been set so low that no wind turbines can be built. Increasing the MSA will not cause any problems for the air traffic in most cases, but it requires an administrative procedure. The wind power industry has initiated an action to increase the MSA in Sweden.

In-flight with direction finding

A remaining problem is that the military authorities still keep direction finding navigation as a reserve. It is an old system with bad precision that demands large obstruction-free areas in order to be used fully, about 650 square kilometres at each of the 39 airports in Sweden. In one case of wind power establishment, landing in the actual runway direction would be possible during 80 percent of the year's hours as compared to 88 percent without wind power. With a modern navigation system, it is possible to land during 99.7 percent of the year's hours[144]. The wind power industry claims that the military interest of using this old system cannot motivate that so large areas are inaccessible for wind power deployment[145]. A topical matter may come to be decided by the government.

[144] S. Engström. Molnbas och landningsbar tid med olika inflygningshjälpmedel vid Karlsborgs flygplats. Ägir Konsult AB. PM 2007-04-02.
[145] Konflikt mellan vindkraft och militär pejlinflygning. Skrivelse från Svensk Vindkraft till Miljö- och samhällsbyggnadsdepartementet 2006-12-15.

Obstruction lighting

Wind turbines may, like cell phone masts etc., constitute obstacles for the aviation, which leads to requirements that they should be marked with paint and light. The lights might disturb the surroundings and cause extra costs. The present regulations[146] imply that wind power turbines of 45-150 meters height (to highest blade tip) must be painted white, and during dawn, dusk and darkness have a red blinking light of 2 000 candela on the nacelle. The light can be reduced to 200 candela in darkness. Any requirement about lighting during daytime does not exist any more for wind power. They are visible anyway. At altitudes of more than 150 meters, the light must be of 100 000 candela, white, and blinking night and day. During darkness it might be reduced to 2 000 candela. According to some information, the present light colours of the plants will be accepted as "white". The proposal allows for alleviation for groups of four turbines, and more, in that the high intensive lights only must be present on the most peripheral turbines.

The present rules are based on recommendations from the International Civil Aviation Organisation (IACO), which are not binding. An international working group is preparing a proposal on common European imperative rules about obstruction lights[147].

Most wind power in the world today is found in Germany that has prepared their own regulations for the marking of wind power turbines. These are ambitious., For plants higher than 150 m, they are however less rigorous than those present in Sweden.

In Germany, wind power turbines are marked according to rules from 2007[148] [149], regardless of height (also more than 150 meters), in daytime with painting or white blinking light of 20 000 candela, and during the night with permanent red light of 10 candela or red blinking light of 2 000 candela. In order not to disturb the surrounding housing, it is allowed to screen-off below the horizontal plane. In exceptional cases, wind turbines under 100 meters are marked.

The German regulations admit also that the lights of 20 000 and 2 000 candela are reduced to 30 percent when the visibility is 5 kilometres and to 10 percent when the visibility is more than 10 kilometres. Compact visibility measurement equipments are use for the purpose. They consist of a single unit. Adjacent blinking light must be synchronised, which can be done by GPS-technique without internal cable connections.

Obstruction light is certainly motivated with regard to aviation, but also involves a conflict with military helicopter traffic where the crew use light

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[146] Luftfartsstyrelsens föreskrifter och allmänna råd om markering av byggnader, master och andra föremål 2008:47. Tillgänglig på www.lfs.luftfartsstyrelsen.se.
[147] Luftfartsstyrelsens föreskrifter och allmänna råd om markering av byggnader, master och andra föremål 2008:47. Tillgänglig på www.lfs.luftfartsstyrelsen.se.
[148] Nachrichtliches Behanntmachung der Allgemainen Verwaltungsforschrift zur Kennzeichnung von Luftfahrthindernissen. Nachrichten fur Luftfahrer. NfL I 143/07.
[149] LED obstruction lighting for wind turbines. Honeywell Airport Systems GmbH, broschyr 2007. www-honeywell.de/airportsystems

amplifiers, so-called night vision goggles. The military defence consider those to be disturbed by the wind turbine's obstruction lights[150].

The wind power industry has objected to the recently introduced regulations being so far-reaching, particularly for plants with a total height of more than 150 meter - a height that makes wind power more profitable in forest terrain. For the present wind power establishment it will involve millions of SEK for investments in obstruction light. In the first place, the industry suggests that Sweden adopts the German rules. Bearing in mind the German domination in wind power, the future joint European regulations will likely be influenced by them. In the long term, it can be discussed if mast lighting will be required at all for establishments outside the airports' surroundings. Obstruction lighting beyond airports has no consequences for most aircrafts since they fly at much higher altitudes. Aircrafts and helicopters flying low can use the GPS facility of the instrument panel, which indicate closeness to different types of obstructions. Such equipment is used already today.

Radar

Radar is based on radio waves that are transmitted from an antenna, reflected back by any object, and received by the antenna. In this way, it is possible to determine the position, speed, and maybe altitude of objects in the air, on water, and on ground (from aircrafts). If a high building, a bridge, or a wind turbine stands in-between the object and the antenna, the object might end up in radio shadow and become "invisible" for the radar. For wind power plants, the tower is of major importance for normal radar, while the turbine blade and nacelle are of less importance since they have smaller geographical extension. A disturbing object may also cause additional reflections of the signal and by that, false echoes. If an aircraft is above a wind power turbine, it might be difficult to distinguish the echo from the aircraft from that of the turbine.

The problem of inadequate or false indications on the radar is as old as the technique itself. However, the introduction of a large amount of high objects on land and sea is a new situation. The military and civil authorities in Sweden and Great Britain, for example, have initially responded by wanting to forbid those activities they don not control, or have resources to study. A number of studies in the field have gradually been conducted in Sweden[151] [152] [153]. A great deal of international work goes on as well[154]. The military defence has

[150] Försvarsmakten, Högkvarteret. Yttrande avseende planerad vindkraftspark på Lunnekullen belägen i Tibro och Karlsborgs kommuner. 2007-09-21. HKV beteckning 13920:73440.

[151] Rapport 2 angående projektet "Vindkraften och försvaret" beträffande förstudie radar och förstudie radiolänk. Försvarsmakten Högkvarteret 1997-09-17, 13920:71892.

[152] Rapport från Huvudstudie radar, vindkraftprojektet. Försvarsmakten Högkvarteret 2000-03-17, 13920:62916.

[153] Utredning av vindkraftens effekter på militära övervaknings- och kommunikationssystem mm – slutrapport. Försvarsmakten Högkvarteret 2004-02-11, 21863:61798.

[154] Radar, radio and wind turbines. 53rd IEA Topical Expert Meeting. Organised by Department of Trade and Industry. Oxford, UK, March 2007. Scientific co-ordination Sven-Erik Thor, Vattenfall AB.

recently carried out a project concerning the effects of offshore wind turbines on the radio coverage, after they discovered that their earlier analytic tools have been too "blunt". The project investigated to what extent the wind farm at Yttre Stengrund in Kalmarsund affected the possibilities to detect an aircraft-towed ball with a diameter of 60 centimetres with radar. In addition, a comprehensive theoretical analysis was made. The fundamental conclusion is now that "most wind power establishments offshore can be solved with regard to radar conflicts"[155]. Any corresponding study of the transmission conditions for radar over land does not exist.

The report also presents a more realistic attitude about the capability of radar, and the interference from obstructions such as wind turbines. Concerning problems with shading behind wind turbines, it is established that there is a surplus of signal intensity within the coverage area, which means that the damping behind wind turbines of 6-10 dB does not matter when it comes to larger objects. Therefore, the opportunities to detect normal ships and aircrafts are not effected, see the left column in Table 4. On the other hand, it is known that smaller boats cannot be accurately detected even without wind turbines because they disappear among the wave reflections, and are hidden by the radar horizon at longer distances. For the same reason, neither aircrafts nor robots are seen at very low altitudes before they come close. It is an old tactic trick to fly extremely low to avoid discovery. The same condition applies to ships and aircrafts constructed by stealth technology. Such aircraft can have a radar target area the size of a bird instead of tens of square metres, which is the normal. The only objects that are at risk to be hidden by a wind turbine are robots that are not flying low.These will probably fly low anyway as well, in order to avoid discovery.

Table 4. Effect of wind power turbines on radar coverage over sea. Wind turbines placed between radar and objects to be detected

Visible in spite of wind turbine	*Not visible even without wind turbines*	*Not visible behind wind turbines*
Ships Aircrafts on normal altitude	Small boats Aircrafts and robots on very low altitudes Aircrafts and ships constructed by stealth technology	Robots on normal altitudes

The easiest way to avoid problems, if any, is to make sure that more than one radar station covers a specific area. In some Swedish cases, the exploiters have compensated the risk for radar disturbance by financing a smaller radar that is mounted on one of the turbine towers at sea.

[155] HKV 2008-06-04 10 757:71038 Rapport från flygprov radar

A protection area of 100 kilometres is established over sea next to the main searching direction of the coast-based radar stations. This implies that a potential installation of wind power must be investigated. This demonstrates that that disturbance is largest from objects relatively close to the radar. The protection areas reach only 2 kilometres from the station for other directions and for radar searching over land.

The military defence upholds prohibition against establishing wind power closer than 5 kilometres from weather stations[156]. It is based on a European recommendation, which nonetheless can be questioned since the function of the weather radar cannot be as critical as, for example, the radar that monitors the air traffic.

In Great Britain, the leading company of defence systems, BAE Systems, has developed a soft ware to suppress echoes from wind turbines, which makes it possible to continuously track aircrafts that pass above wind turbines, with risks for hiding[157].

It has been put forward in many contexts that the stealth technique could be applied on wind turbine design. In practice, it means that blade and tower should be made with sharp edges or be covered with radar absorbing material. With such solution, it would be possible to reduce the above-mentioned problem. However, better radar software is probably a cheaper alternative. The shading effect of wind turbines is principally not possible to get hold of in this way.

The shipping can be expected to have objections concerning wind turbines that are invisible on the radar.

Radar in aircrafts

The phenomenon with aircraft radar that can lock on wind turbines has been known ever since the 1980th (Jakt-Viggen), but the military defence has previously not prioritised a solution on this issues. The problem arose in connection with a project in Västergötland[158], but is topical for all airports with military aircraft traffic.

The present problem arises when several aircrafts start after one another and those behind use the radar in start mode in order to control those ahead. The radar is of Doppler type, i.e. it distinguishes mobile objects from stationary. A wind turbine rotor is perceived as a mobile object, and it has happened that the radar, just after taking off, will be locked on a wind turbine instead of on the aircraft ahead. If this happens, the pilot must initiate a new search at which the radar locks on the right object. Several cases of wrong locking have occurred with JAS 39 Gripen. The locking was caused by two small wind

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156 Information till länsstyrelserna samt kommunernas plan- och bygglovavldelningar (motsv.) avseeende delar av riksintresse för totalförsvaret. Försvarsmakten, Högkvarteret. 2007-03-19

157 Advanced digital tracker. Informationsblad från BAE Systems Integrated Technologies Ltd. BAE Systems 2007.

158 Försvarsmakten, Högkvarteret. Yttrande avseende planerad vindkraftspark på Lunnekullen belägen i Tibro och Karlsborgs kommuner. 2007-09-21. HKV beteckning 13920:73440.

power turbines outside the Såtenäs air force wing, F7, where all Swedish training on JAS takes place. None of the cases was reported to be an incident, i.e. a potential dangerous event. There is a project proposal[159] concerning analyses and test flights to study the issue closer, and suggest solutions. In the simplest case, it might be sufficient to use the speed limit of 200 km/hours that already exists in the radar programming in ordernot to be locked on cars. To be sure that wind turbines are excluded, the speed should be changed to 360 km/hours (i.e. 100 m/, i.e. the highest blade tip speed plus marginal). Other changes of parameters and software may be considered. No changes in the physical technical equipment in the aircrafts, or on ground will be necessary. It has also happened that the radar has locked on wind turbines during "normal" target searching, but this problem will not be solved with the suggested measures.

Radio link

Radio links are used to transmit information with high frequent radio waves that are sent out and received by directional parabolic antennae. Transmitting and receiving antennae are normally placed in masts to attain the free visibility that is required. Radio links are in civil and military use. Examples of civil users are Teracom that transmit radio and television programs, and Telia and other cell phone operators. The military system is also used by "blue-light-authorities". Modern links utilise digital technique. The transmission is influenced by the weather conditions. The capacity is lower than that of optic fibre, for example.

Since free visibility is required between the transmitter and the receiver, it is obvious that obstacles such as wind turbines can interfere with the connection. Teracom argues, for example, that wind power turbines must be placed 350 meters beside a link stretch[160].

A seemingly authoritative account is found in the so-called Bacon report[161] from the British governmental Office of Communications (Ofcom). The limit for acceptable signal/disturbance relations is set to 70 and 50 dB, respectively, for the two cases described below. The report states that a 60 kilometres long intercommunication with a frequency of 1.5 GHz needs a free zone of maximally 300 meters from the visual line in the near surroundings, which reaches to a distance of 6 kilometres from both antennas. However, a 20 kilometres long intercommunication with a frequency of 7 GHz needs only 20 meters of free space between the visual line and objects like wind turbines. In general, higher frequencies reduce the requirement of free space, at the same time as the sensitivity increases in those cases when obstacles are within the "forbidden" area.

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[159] Ansökan om forskningsstöd, Försvarets Materielverk, Kjell-Åke Eriksson, utkast juni 2007.

[160] Jan-Peter Bengtsson, nätansvarig frekvenser, Teracom AB. Presentation vid VIND 2007.

[161] D. F. Bacon. A proposed method for establishing an exclusion zone around a terrestrial fixed radio link outside of which a wind turbine will cause negligible degradation of the radio link performance. Tillgänglig på http://www.ofcom.org.uk/radiocomms/ifi/licensing/classes/fixed/Windfarms/windfarmdavidbacon.pdf

The SG-Wind (cooperation group of wind) is a joint research project of the National Defence and the Swedish Energy Agency to investigate the impact of wind power on different technical systems of the defence. Already before this project, research has been conducted on the effects of wind power on radio links. The first report is from 1979, and the first measurements were reported in 1988. A report from Ericsson[162] presents results from 1997-2000 of measurements on digital links with a frequency of 2, 7 and 18 GHz. Each link stretch passes a group of wind turbines, and the shorter reference links were free from wind turbines. The "wind turbine link" was in every case 48 kilometres long, and wind turbines were present within a 5 kilometres long area that started 17 kilometres from one of the ends. The number, type, and placement of the wind turbine in relation to the link stretch are not specified. The interruption time during the worst 30 days in 2000 was 2 hours and 12 minutes in the "wind turbine link" for the 2 GHz band, and the interruption time was 39 hours and 8 minutes in other links. Thus, the availability was 99.7% and 99.9%, respectively, which sounds rather good for a worst period. For the 7GHz band, the corresponding figures for the worst period were 5 hours and 46 minutes interruption time in the wind-turbine-link case (99.2% availability), and 30 minutes interruption time in the reference case. No differences were found for the 18 GHz band. These experiments clearly show that the radio link function is significantly affected by several external factors, not least the weather. The report authors themselves present an evidently weak conclusion, "it cannot be excluded that a wind turbine within a link stretch can influence the function of the digital radio link system with frequencies of 2 and 5 GHz", which by the way was the assumption when the study started.

The final main report[163] from SG-Wind presents the conducted research, which is said to have improved the calculation models of interference. In conclusion, the report states that the signal/interference relationship will determine whether interference from a certain wind power installation along a link stretch is acceptable or not. What signal/interference relationship that was chosen and how this will interfere with the link's function was not presented. Neither was the interference with different link types or frequencies or connections with performed experiments and calculations.

A report from Elforsk[164] analyses how cell phone equipment can make use of wind turbines. Microwave links for signal transmissions to the base station are placed on the turbine tower, below the turbine plane. The cell phone antennas are placed on the tower within the turbine plane. The placement directly on a wind power plant is apparently not considered an obstacle for the radio link function.

The Electric Wiring Act applies only to physical wires, and the building permission gives no right in relation to the terrain in between. According to

[162] Joakim Riedel. Results for the 2, 7 and 18 GHz measurement extensions. Appendix B to Doc: ERA/SV-01:1049.
[163] Rapport avseende huvudstudie radiolänk i vindkraftsprojektet. Försvarets Materielverk PRO LED 13920:3436/04. 2004-04-17.
[164] Staffan Sandorf. 3G-utrustning i anslutning till vindkraftverk. Elforsk rapport 03:32. pdf

the Environmental Act, the preferential right of defence interest protects military installations.

Signal tracking

The defence authority still tracks radio signals from the ground to monitor foreign powers. Only two stationary signal tracking stations on land remain today, on southern Gotland and in southern Skåne. There are also possibilities to set out mobile stations. Sweden tracks signals also from aircrafts and vessels. The military defence claims it is too expensive to rely only on such methods, the way great powers do.

Since the idea of the technique is to distinguish signals close to the noise limit, the defence claims that also the marginally added interference sources are critical. In the first place, it is the position determination of the tracked object that becomes more difficult, while the opportunity of take part of the information is unaffected. The signal tracking is primarily restricting the installation of wind power offshore. In a project,[165] it was concluded that the present prohibition zone for each of the mobile signal tracking stations can be reduced from 200 kilometres coast-line and 100 kilometres out from the coast to one tenth of these figures by investing 1 million SEK in modifications of the software. For the two stationary stations, the prohibition against wind power establishment within 100 kilometres is still maintained.

8.3 Future development

The possible conflicts of wind turbines with aviation, radar, radio links and signal tracking are found within a number of disparate fields for which continued research might be necessary in order to achieve discussions that lead to a more reasonable balancing of the interests.

Obstruction lighting

Practical examples are needed to determine a level for obstruction lighting that satisfies the aviation's requirement of safety without unnecessary disturbing the surroundings, including other air traffic, and without casing unreasonable costs. In the long term, the obstruction lighting might be replaced by GPS technique.

Radar

An investigation of the distributional conditions for radar over land, corresponding to that made for offshore wind power, could clarify the effects of wind turbine on radar under these circumstances. Other possible study objects could be the turbine blades' effect on Doppler radar, and the origin of semblance objects through reflecting.

[165] Utredning av vindkraftens effekter på militära övervaknings- och kommunikationssystem mm – slutrapport. Försvarsmakten Högkvarteret 2004-02-11, 21863:61798.

Radar in aircrafts

The proved interference with JAS radar during start can most likely be solved by modifying the parameter settings or the software.

Radio link

The basic phenomena are clarified, but the practical consequences are not, in spite of the issue having been studied since the 1970's.

Signal tracking

The conducted projects have shown that the restrictions in at least one case could have been reduced drastically. The field is generally hard to access due to secrecy. It mostly concerns the evaluation of civil demands against military ones.

9 Wind power in cold climate

9.1 Results from the Vindforsk programme

In 2006/2008, the Vindforsk programme granted 2.2 million SEK, or 6 percent of total funding, to projects within this field.

Measurements of icing in masts and wind turbines

V-151 Synoptical measurements

Project leader: Patrik Jonsson, Saab Security

In a mast in Sveg, icing is measured on four levels up to 240 meter. The results are compared with observations on the nacelle of an adjacent wind turbine and with calculated results. The project is part of the EU-project COST 727. The measuring device was taken into use in February 2008, and the project will be reported in December 2008. Icing has been registered on several occasions.

Test with icing indicators on wind turbines

V-153 Ice distribution on wind turbines after detection

Project leader: Rolf Westerlund, Holooptics

A wind turbine of 600 kW in Härnösand was equipped with an optic ice indicator, which was developed by the company Holooptics in Stockholm. Different designs of the indicator are tested. The stationary indicators are of two types, which measure both icing and ice occurrence without de-icing. The turbine blades have also indicators of ice occurrence on them. The observations can be correlated with the wind turbine's effect and meteorological data from a measurement mast. The equipment was taken into use in the beginning of 2008, and on at least one occasion, the course of an icing episode has been documented with all ice indicators. The project will run until December 2008.

Participation in IEA Task 19 Cold Climate and pre-study for icing mapping

V-158 IEA Task Cold Climate and pre-study of icing mapping

Project leader: Göran Ronsten, Windren AB

Since 2008, Sweden takes part in the cooperation of IEA Task 19 Cold Climate, which, among other things, aims at reviewing the international standards concerning wind power in cold climate, and recommending methods to establish the affects of icing on production and loadings. Other participants are USA, Canada, Norway, Finland, Germany, and Switzerland. The project also includes a pre-study on the mapping and icing and an evaluation of a wind turbine's wind-effect in Aapua, Norrbotten.

Technique preventing icing by a combination of blade characteristics and microwave de-icing

V-238 New technology for de-icing turbine blades

Project leader: Lars Bååth, Section for economy and technique, Halmstad University

Halmstad University conducts a pre-study on how to prevent icing by choosing the right blade structure and other characteristics and by using microwaves. A problem in this context is that pure water and ice absorb microwaves poorly. Possible solutions are to increase the frequency to millimetre-waves, or to absorb the microwaves in the surface layer of the blade.

Calculations of sea-ice loads on structures at sea

V-225 Ice loads on near-coastal fundaments

Project leader: Lennart Fransson, Building constructions, Luleå University of Technology

A doctoral work studies the load of sea ice on structures at sea, for example wind turbine towers offshore. Data from the lighthouse of Norströmsgrund in the Gulf of Bothnia have been analysed in relation to the contact width, thickness and temperature of the ice. The ice pressure's dependence on geometry and friction has been studied by means of numerical simulations, and the compression strength of the ice has been tested at different temperatures. The final report that will be released during 2008 includes recommendations of fundament dimensions from different zones in the Baltic Sea.

In addition to the above-mentioned projects, which are Vindforsk activities, the Swedish Energy Agency supports the development of de-icing techniques at the company MW Innovation in Boden, and the Swedish participation in the EU project of Cost 727 Atmospheric icing of structures. The authority has also granted money to Skellefteå Kraft's wind farm establishment on the mountain of Uljabuouda, and to the development and demonstration of a de-icing system to be installed on two turbines each in Aapua and Bleikevare and on all wind turbines at Glötesvålen.

9.2 Trends analyses

General situation

Around 1990, wind power in cold climate with icing risks on the blade was identified to be a relatively large application in Finland, Sweden and Canada, as well as the upland interior parts of Europe. Initially, the turbine manufacturers showed a considerable interest, but later on it diminished. It is relatively simple to construct turbines that manage to operate in low temperatures, mainly by choosing suitable steel qualities and introducing heating of strategic components. Most manufacturers can offer this now. Feasible de-icing solutions using electrically heated surface layers on the blades were presented early, but have still not been developed into commercially available solutions. This is probably due to the large pressure for "normal" localisations on the market, rather than the extent of technical problems. One manufacturer, Enercon, already today offers de-icing with circulating warm air in the blades. There is another alternative with electrically heated front edges. De-icing can only take place during standstill and at gentle icing. Apart from these turbines, there are no de-icing facilities on the turbines that are installed in areas with icing conditions.

In spite of some cases with standstills for several months due to icing, the deployment of wind power is accelerating in areas exposed to ice. The exploiters are apparently not regarding icing to be a significant obstacle. However, they express a need to control the problem, mainly by being able to measure loads and production.

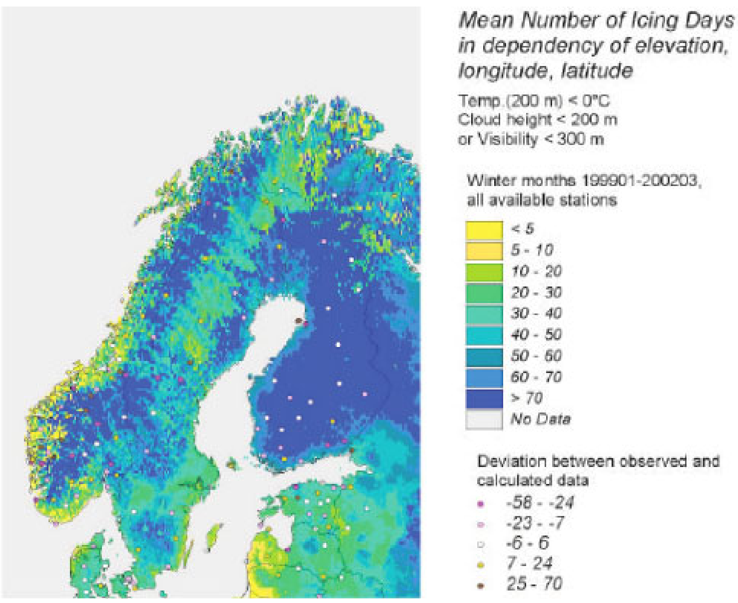

Figure 4. Map of icing risks according to the criteria of temperature below the freezing point, and cloud altitude below 200 meters, or visibility less than 300 meters[166].

Icing risks and production losses in Sweden

According to prevalent opinions, there is an obvious risk of icing on masts, and therefore also on wind turbines in Sweden in places north of a line Karlstad-Gävle. This represents 70 percent of the land area. The trend of building larger and higher wind plants further increases the icing risk. The latest available mapping of icing risks, a result from the EU project New Icetools, further confirms the referred opinion, see Figure 4. The selection criteria are temperature below the freezing point, and cloud altitude below 200 meters or visibility less than 300 meters. It is perhaps surprising that icing risks occur on the South Swedish Highland where evidence is lacking,

[166] Dobesch et al, A new map of icing potentials in Europe – problems and results. Boreas VI, Pyhätunturi, 2003.

but not for the interior of Norrland. The figure shows that deviation between calculated and observed data is relatively large. According to later experience, icing mainly correlates with the presence of water in liquid phase at temperatures below 0 °C[167]. Clouds or reduced visibility are often due to free-floating water drops, but could also be caused by ice crystals, which thus do not give rise to any icing risk. Icing could also be caused by sublimation, which is when ice crystals precipitate from water vapour, hoar frost. Thus, there is room for more research and new compilations.

In Sweden, no systematic mapping of the production losses due to icing has been conducted for the approximately hundred wind turbines installed in areas with icing risks, not even within the special project about operation monitoring. In connection with a survey concerning the experiences of wind turbines in forests, new experiences of icing were received from about 30 plants in northern Sweden, se Chapter 10. For single installations, e.g. Hunnflen at Äppelbo in Dalarna and Aapua in the County of Norrbotten, there is information on months of standstill due to icing. For the turbines included in the investigation, the production losses were estimated to be between 4 and 10 percent of the annual production. It was pointed out that these figures were rough estimates, not based on measurements.

Technique for de-icing

Since 60-70 years, various techniques of de-icing are used on aircrafts. Heating with electricity or warm air is common. As mentioned earlier, these heating techniques are used on wind turbines as well. On aircrafts, rubber bladders are used to break the ice mechanically, by alternately filling and emptying them with air. Rather extensive trials with this technique have been performed on wind turbines, but is has not come into practical use. The maintenance requirement is probably too high. The use of material with surface characteristics that prevent the ice to get attached should be attractive on both aircrafts and wind turbines, but might be constrained by the need to regularly exchange the surfaces.

The use of microwaves for de-icing is limited by the pure water's poor absorption of microwaves.

The technique of using electrical resistor elements in the blades is generally regarded to be the most promising. When de-icing has been offered as a modification of already manufactured blades, the cost has been too high, about the same as the blade cost. The Swedish Energy Agency funds a project where the company MW Innovation in Boden develops a de-icing technique with graphite based resistor elements. They count on being able to offer the application as inserts when the blade is manufactured and as mats on the surface when the blades are modified. At present, an erosion trial is conducted on a wind turbine at Näsudden, without running de-icing.

A distinction is made between "anti-icing" systems and "de-icing" systems. In the former case, ice is prevented from forming. In the latter case, the ice present is removed. Due to the effective heat emission of an operating turbine

[167] Dobesch H, Nikolov D, Makkonen L, Physical processes, modelling and measuring of icing effects in Europe, Oesterr. Beitr. zu Meteorologie und Geophysik, No 34, 2005.

blade, the effect requirement in the former case is much larger than in the latter. In both cases, dimensioning and effect requirements are affected by the demands that are put on the system. Should 90 or 99 percent of the cases succeed? How many standstills must be avoided? The possibility to consider this is limited by our small knowledge about what already installed wind turbines are exposed to.

Those wind turbines that are installed today, are without exceptions blade pitch regulated. This is an advantage during de-icing as the blade flexibility facilitates to break and remove the ice. When de-icing occurs by mean of electrical heating, the electricity consumption in most cases is said to be a few percent of the turbine's total production, at maximum[168]. The referred cases concerned turbines with stall regulation., The stiff blades of these are more difficult to de-ice than the more flexible blades of the pitch-regulated ones.

Indication of icing risks

If one has a turbine that is equipped with de-icing, there is still a problem to know when to switch it on. Those ice indicators that are used on aircrafts since long time have seldom worked out well on wind turbines. Newer types are being developed with financial support from Vindforsk, among others. It is, however, found that even very simple methods work well in practice. One such method is to set the turbine's effect in relation to the wind speed. If this relationship deviates from the normal, and the temperature is within the risk for icing, one could try to carry out a de-icing cycle. Another method is based on the fact that the ice in practice never arises equally on the three blades, and therefore will be recognized by variations in electricity effect or forces on the construction with a frequency of 1P, i.e. one turbine revolution. The simplest indication will be to observe the variations of the electricity effect.

Aid from Canada?

The power company Hydro-Quebec presently performs an extensive purchasing of 2 000 MW wind turbines for cold climate in Canada. One could expect the company to take advantage of the opportunity to raise demand on de-icing systems, for example. This is however not the case. One contributing factor is that icing is not a problem at the low temperatures (-30^{o}C) dimensioning the electricity system load in the area[169].

European Wind Energy Technology Platform

The European Wind Energy Technology Platform mentions "cold climate" as being an example of a more challenging resource that will come into question when the deployment increases. No activities are proposed.

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[168] Göran Ronsten. Svenska erfarenheter av vindkraft i kallt klimat – nedisning, iskast och avisning. Elforsk rapport 04:13.

[169] E-post från Sören Krohn, konsult till Hydro-Quebec, till Göran Ronsten, 2008-05-08.

The importance of Vindforsk projects

No projects within the field have been reported yet, so no results can be evaluated. The economic resources are small also in relation to other projects within Vindforsk. As a consequence of de-icing still being considered a small niche on the market, and the actors in other countries not raising any demands, the ongoing and future effort of Vindforsk can be of a strategic importance.

The only project concerning offshore wind power can probably be important for the creation of criteria for the dimensioning of towers exposed to sea ice.

9.3 Future development

A large part of Sweden is exposed to icing risks wintertime. This fact in combination with the leading wind turbine manufacturers obviously being uninterested to supply turbines with functioning de-icing motivates further resource allocation to the field.

Operation experiences

Collection of experiences from the about hundred wind turbines within areas exposed to icing. The goal is to clarify how much of the production that is lost due to icing of varying severity, and thereby establish standards for de-icing, including ice indication. The project can be designed to have intensive surveillance on a smaller number of plants, and a more general surveillance on the others. The former can require installations of equipment for indication and monitoring. The project should be coordinated with the continuous operation monitoring, see section Operations and maintenance.

De-icing technique

Continued development of de-icing technique.

Purchasing of technique for wind turbines with de-icing

Technique purchasing of complete wind power plants with de-icing according to requirements specification. Any subsidy should concern the extra costs.

Indications of icing

Techniques for icing indications in masts in a way that is relevant for icing on wind turbines. The purpose is that the technique is applicable on wind measurements in masts.

Mechanism of icing and loads

Mechanisms of the origin of ice on wind turbine blades and how the ice will affect the loads on constructions, preferably as international collaboration.

Mapping

A general mapping of ice occurrence on wind turbines at elevations of current interest.

10 Wind power in forests

10.1 Results from the Vindforsk programme

Research within this field has not been within the ambitions of Vindforsk II, and no projects have been funded.

10.2 Trends analyses

The Swedish Energy Agency’s survey of experiences

The interest of establishing wind power in forests has increased substantially in Sweden and adjacent countries. One reason is that Sweden’s latest wind mapping showed good wind opportunities also in forested areas, under the conditions that towers and turbines reach high enough. In that way, it is possible to achieve large connected wind power establishments that concurrently are less controversial with regard to the permission process. However, the projects are in part controversial with regard to production and loads since there are no verified experiences. Therefore, in 2008, the Swedish Energy Agency conducted a survey of known experiences of wind power in forests in Sweden[170]. The following documentation is from this survey that focuses on know experiences from about sixty wind power plants in Sweden and some additional foreign examples. Some of the “forest plants” are placed on open grounds but are affected by the surrounding forest. Most of them are placed in pure forest areas, often on hills and other elevated stretches.

Examples of establishments

In the Swedish examples, the *numbe*r and *site* correspond to that in the operation monitoring of Elforsk. *Real/calculated* refers to the relationship between the production during the latest twelve months (through March 2008) divided by previously calculated production, and with corrections for wind index (1. 15) and availability, both for the latest twelve months. *kWh/kW* is corrected in the same way.

[170] Kring vindar och vindkraft i skog. Kunskapsinventering. Energimyndigheten ER 2008:21

Munseröd, Tanum, County of Västra Götaland

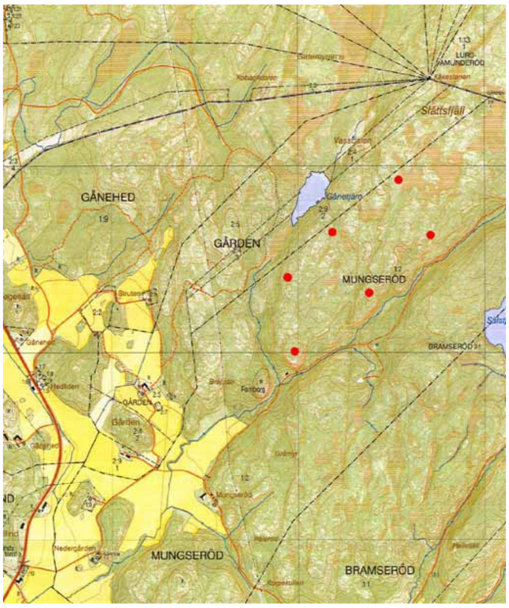

Photo Eolus Vind

On a tree-covered mountain plateau in Tanum Municipality about 75 meter above the surrounding terrain. Owner/Representative: Bengt Sernestrand. Project planner: Eolus.

No	**Site**	**Type**	**Effect kW**	**Rotor diameter m**	**Hub height, m**
830-835	A9f	NEG Micon	1500	72	67

In operation	**Calculated, MWh**	**12 months, MWh**	**Availability 12 months, percent**	**Real/Calculated, percent**	**kWh/kW**
Jan-06	2 800	3 237	100	101	1 877
Jan-06	2 800	3 114	100	97	1 805
Jan-06	2 800	3 145	100	98	1 823
Jan-06	2 800	2 767	100	86	1 604
Jan-06	2 800	3 278	100	102	1 900
Jan-06	2 800	3 092	100	96	1 792
Average				**96**	**1 800**

Hunnflen, Äppelbo, County of Dalarna

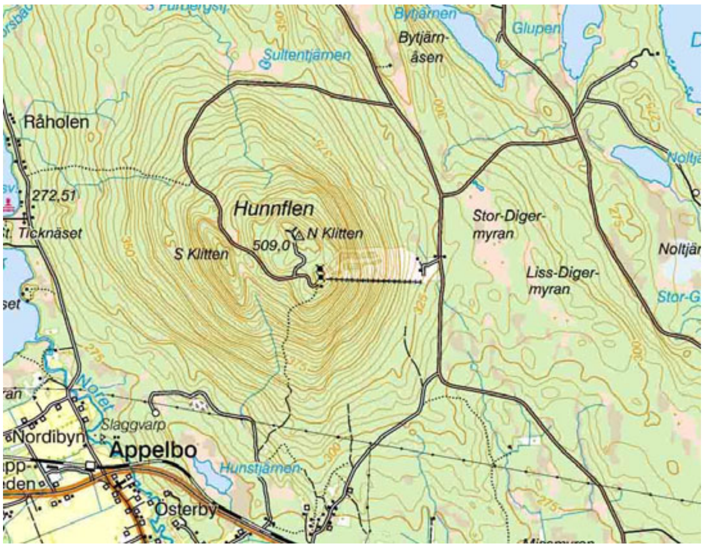

Foto Vindkompaniet

On marked forested hill at 509 m. a. s. l. and 200-250 meter above the surrounding terrain. The first wind evaluation was based on measurements from a 20 meters high mast, placed unsuitable close to a forest edge, which gave a calculated production of 1600 MWh. The two newer turbines were considered to produce 1850 MWh annually based on previous production, wind data from Borlänge airport, and atmospheric pressure data from NCAR.

The turbines have been considerably exposed to icing at several occasions, of which the worst stopped the operation for two months. The production losses are hard to quantify, but are estimated to at least 5 percent. Owner/Representative: Äppelbovind ek. för., among others. Project planner: Vindkompaniet.

Number	**Site**	**Type**	**Effect kW**	**Rotor diameter m**	**Hub height, m**
482	E13a	NEG Micon	900	52	49
800, 801	E13a	Vestas	850	52	65

In operation	**Calculated, MWh**	**12 months, MWh**	**Availability 12 months, percent**	**Real/Calculated, percent**	**kWh/kW**
Dec-00	1 600	2 365	99	130	2 308
Apr-05	1 800	2 443	98	120	2 550
May-05	1 800	2 071	94	106	2 254
Average			**97**	**119**	**2 371**

Råshön, Offerdal, County of Jämtland

Photo Vindkompaniet.

On a forested hill ridge, 3.5 kilometres northeast of Änge community in Krokom Municipality. The turbines are established at approximately 700 m a. s. l. and reach 300 to 400 meters above the surrounding terrain. The availability report is obviously incorrect for number 782, and it is therefore not included in the calculation of the average value. The turbines have been considerably exposed to icing, the losses are estimated to 5-10 percent. Owner/Representative: Offerdals ek. för., Skara Vindkraft, among others. Project planner: Vindkompaniet.

Number	Site	Type	Effect, kW	Rotor diam., m	Hub height, m
777- 783	E12b	Vestas	2000	90	80

In operation	Calculated, MWh	12 months, MWh	Availability 12 months, percent	Real/Calculated, percent	kWh /kW
dec-04	4 031	4 178	100	90	2 422
dec-04	4 319	4 725	100	95	2 739
dec-04	3 613	4 180	100	101	2 423
dec-04	4 023	4 114	100	89	2 385
dec-04	4 032	4 115	100	89	2 386
dec-04	4 054	1 170	100	25	678
dec-04	3 955	4 356	100	96	2 525
Average	**(not782)**		**100**	**93**	**2 480**

AApua, Norrbotten County

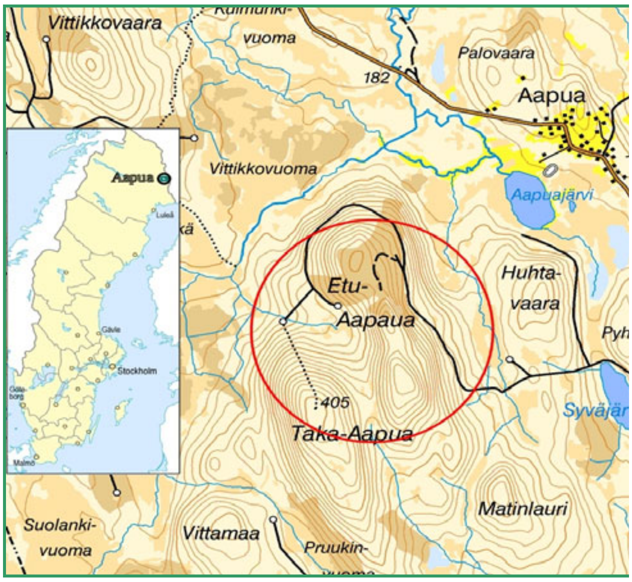

Photo Göran Ronsten

Etu-Aapua is a ridge to the west of Aapua village in Övertorneå Municipality. The wind power plant is located at 350-400 m. a. s. l. and reaches 300 meters above the surrounding terrain. Measurements started in 2000 with a 10 meters high mast that was replaced by a 30 meters high one in 2001. Wind calculations were made by EMD, Denmark. Considerably exposed to icing, losses are estimated to 10 percent. Owner/Representative: Sveriges Vindkraftkooperativ among others. Project planner: Vindkompaniet.

Number	**Site**	**Type**	**Effect, kW**	**Rotor diam., m**	**Hub height m**
809-815	M27i	Vestas	1500	82	78

In operation	**Calculated, MWh**	**12 months MWh**	**Availability.12 months, percent**	**Real/ Calculated, percent**	**kWh/ kW**
okt-05	4 465	5 061	96	103	3 056
sep-05	4 232	4 558	93	101	2 841
sep-05	4 140	4 339	95	96	2 648
sep-05	4 344	4 669	94	99	2 879
sep-05	4 397	4 490	86	103	3 027
sep-05	4 500	4 678	95	95	2 855
sep-05	4 613	4 990	97	97	2 982
Average			**94**	**98**	**2 898**

Nordschwarzwald, Germany

Photo: wat/MFG

Just more than 40 kilometres WSW of Stuttgart in northern Schwarzwald, between Pforzheim in north east and Freudenstadt in the south. The turbines are located at 805 to 855 m. a. s. l. and reach 470 kilometres from the coastland.

Locality	Nordschwarzwald
Tools	10 st Vestas V90 (2000 kW) and 4 st Vestas V80 (2000 kW)
Rotor / tower height	90 m / 125 m 80 m / 100 m
Installed effect	28 MW
Calculated production	61 GWh/year
Calculated kWh/kW	2 179 kWh/kW
Start of operation	July/August 2007

There is no information about the actual production for these and the other 70 German wind turbines in forests that are included in the report. Neither was it possible to receive production data from 25 British wind turbines. However, data exists from three Finnish turbines but the pre-calculated production is lacking. In no case was it possible to figure out to what extent the investors' expectations were fulfilled.

Production of Swedish wind turbines in forests

In the report, the results were systematised in that the relationship between real and calculated electricity production and Availability time were compared to parameters such as wind turbine size, year of operation start, and hub height. The sixteen turbines in forests were also compared to corresponding data from all turbines in Sweden at that time, approximately 800.

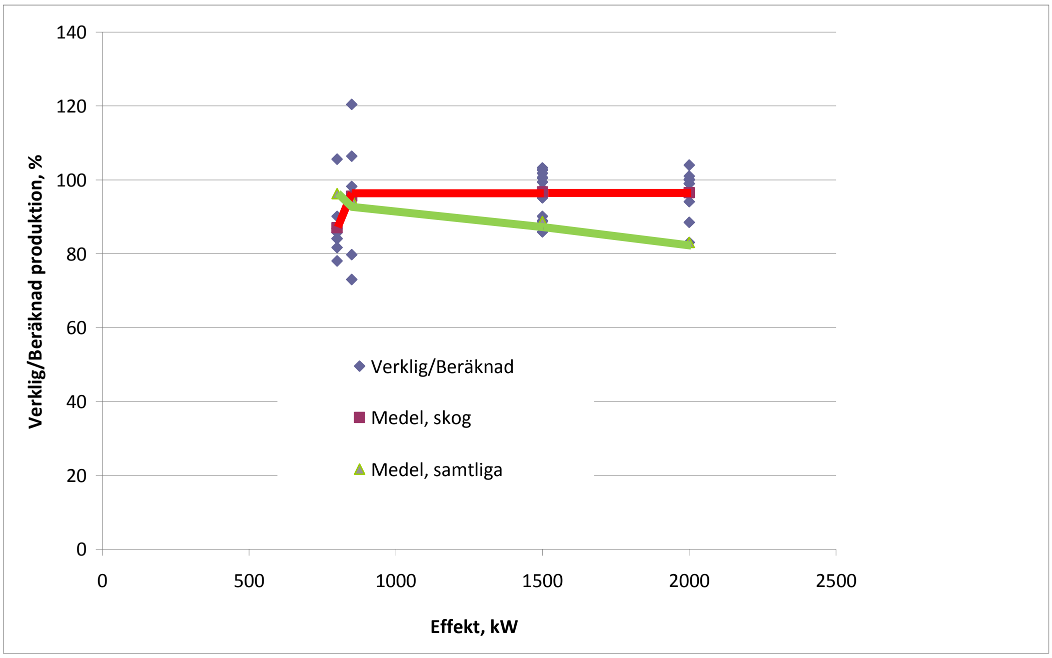

Figure 5. The relationship between real and calculated production in percent as a function of turbine size (effect) in kW. The diagrams show values for individual turbines in forest (blue), and their average (brown), and for all wind turbines in Sweden at a given size as a comparison. For the forest turbines, the period is April 2007-March 2008 with corrections for Availability and wind index (1.15). For all turbines, the period is the calendar year of 2007 with corrections for wind index (1.10). Only turbines sizes existing in at least five specimens are included. Basic data comes from the Operation monitoring of Elforsk.

Figure 5 shows the relationship between real and calculated electricity production as a function of turbines size, measured in generator effect, for turbines placed in forests and for all turbines in the country. Note that the values for individual turbines in forest show a rather wide distribution, between 75 and 12 percent. The mean values for each size class show a more aggregated result, between 80 and 100 percent. It is obvious that the result is very even, except for the smallest size class, and almost 100 percent for the forest turbines, in contrast to the all-turbines category. One explanation could be that wind power projects in forests have gone through an ambitious planning with regard to wind measurements, for example. The result will also constitute an effective argument against the statement that it is not possible to calculate the result in this type of terrain.

Reservations can be made about the results not being representative for various reasons. However, there is no reason to believe that the possible error sources would have a selective influence on turbines localised in forests, compared to turbines placed in open terrain. Therefore, these results ought to be justifiable.

In summary, it is concluded that there is a tendency in the data that production predictions for turbines in forest are more reliable than that for all turbines in the country, and that they produce as much as the others. In single cases, it is a matter of how ambitious the project planners have been. When it comes to the forest projects, they have been able to allocate more resources on the task because of the projects' size.

Load situations, IEC standards

The existing international standard for wind power, IEC 614 00, is written for localisations in open terrain. The wind gradient, and often the turbulence intensity, normally deviates from what is specified in the standard. It is easy to establish that the standard, including calculations on lifetime and wind-effect-graphs etc, does not apply on turbines located in forest. On the other hand are the present experiences concerning both production and lifetime generally good. There are examples of wind turbines in forest that have been operated for five years, or more. From an endurance point of view, the difference in dimensioning for a lifetime of 5 or 20 years is marginal - the turbine that lasts for five year is about the same that can last for 20 years. The state of the art apparently needs to be improved in order to be able to explain why things work well, so that it later will be possible to predict when they will not. Such a work can in the long term result in a standard covering the forest application.

European Wind Energy Technology Platform

The European Wind Energy Technology Platform focuses on wind power in the section on wind conditions, where research is recommended in connection to a large measurement trial, "Askervein II".

10. 3 Future development

Wind turbines on forested grounds is an application that has become possible during recent years because of the latest wind mapping, and because large turbines have been available on the market. Even if the operation experiences have been good until now, the high levels of turbulence and wind gradients justify the performance of particular programmes for measurements and evaluations. A possible result would be the formulation of new standards for wind power in forest.

Wind and wake effects are also treated in the meteorological section.

Measurements and evaluations at a large wind turbine

The basic needs for improving our knowledge about the interactions between wind power plants and winds in forests can be covered by measurements and evaluations in connection to a wind power plant of representative size and construction. The turbine should have a size of 2-3 MW and be blade pitch regulated. Close to it, there should be at least one mast, and supplementary equipment for remote sensing (sodar, lidar). The plant itself, is to be equipped with a measuring transducer (strain gauge, accelerometers etc). To receive meaningful load measurements, it is necessary to have access to construction data for the plant in order to imitate and verify operation situations and results by simulations. This requires that the aggregate supplier agrees to such cooperation that will benefit all parties, while it does not reveal any big secrets. The general construction of wind turbines is a public property nowadays.

Vattenfall presently plans a project in Skåne that would be suitable for the proposed activity. There are also other possible cooperation projects.

11 Construction of wind power plants

11.1 Results from the Vindforsk programme

In 2006/2008, the Vindforsk programme granted 5.3 million SEK, or 15 percent of total funding, to projects within this field.

Optimisation and controlling of a wind power station

V-123 Design tool optimization of wind farm topology and operation – Topfarm.

Project leader: Ingemar Carlén, Teknikgruppen AB

This EU project is partly funded by Elforsk and is run by nine European research institutes and companies. During two years, they will develop methods and calculations tools to increase the production from groups of wind turbines, and concurrently reduce the endurance loads of vital components. The Swedish part will result in a new generation of software that simulates the turbulence within wind energy stations, and controlling routines for generators, yaw regulation and blade pitch regulation.

Methods for joining steel shell towers

V-223 High strength towers

Project leader: Milan Veljkovic, Building construction, the Luleå University of Technology

The conventional method to join sections of windmill towers is by screw joint reinforcement between flanges, which are welded to both ends of the sections. This method is expensive because of high manufacturing costs of the flanges, and because area changes and welds involve additional endurance instructions, leading to thicker tower plate than would otherwise be necessary. A more optimal solution will be to join the tower sections by overlapping screw joint reinforcements, but it has had limited applications because of difficulties to reach the tower from outside during assemblage. The proposed method means cutting up tongues on the lower/inner tower section and putting the upper/outer tower section into place in spite of pre-mounted screws, see Figure 6. Within the EU project, which ends during 2008, such joints are tested for endurance.

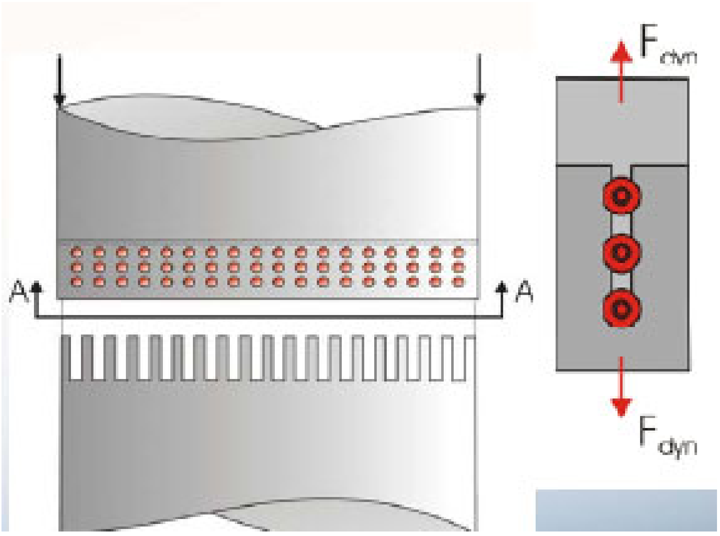

Figure 6. The principle design of tower joining according to Veljkovic[171]

The Germanischer Lloyd that participates in the project will clarify the possibilities of taking the joints into practical use.

Calculating wakes with a CFD model

V-219 Numerical calculations of wakes

Project leader: Dan Henningson, KTH

The project is included in a doctoral work and aims at describing the wake and its successive filling by means of numerical calculations with a CFD model (computational fluid dynamics). The model will be able to treat up to nine wind turbines concurrently. The work has until now resulted in a number of reports [172] [173] and will be finished during the year. See also the meteorology section where the research situation concerning wakes is described.

Participation in international standardisation work

V-103 Standardisation

Project leader: Jan Blix, Vattenfall AB

The technical committee TK88 works with standards for the wind energy field in cooperation with IEC and Cenelec, the corresponding international bodies. IEC has published a number of standard in the Series 614 00. A working group focuses on safety issues mainly with regard to dimensioning. During a turbine's lifetime, the structures are exposed to a number of load changes. A

[171] Milan Veljkovic. Höghållfasta torn. Presentation vid Vindforsk-konferens, Stockholm, 2008-05-15.

[172] Stefan Ivanell et al. Stability analysis of the tip vortices of a wind turbine. American Institute of Aeronautics and Astronautics.

[173] Stefan Ivanell et al. Three dimensional actuator disc modelling of wind farm wake interaction.

good description of the the wind and the loads is required in order to receive a reliable operation. A supplement to the basic document and a well worked-out version of a document on offshore wind power is expected to be published in the end of 2008, or the beginning of 2009.

The opportunity of establishing wind power close to settlements is constrained by requirements of low noise levels. The acoustic standard regulates how to measure and interpret the results from noise observation of wind turbines. The working group of IEC plans to publish a new version of the document at the end of 2008.

Several groups are working with standards for measuring performance (power output as a function of wind) of individual and groups of wind turbines. They will describe useful methods and treatment of the data.

The standard regarding electricity quality becomes more and more important when the amount of wind energy increases in the electricity net work. Wind turbines are often connected far out in the grid, where the wires are weakly dimensioned, which necessitates particular demands. The standard has been revised during the year. An important issue of the standard has been to specify the requirements on both individual turbines and groups to handle short net disturbances without being disconnected (fault ride-through).

The main part of the communication standard for monitoring and controlling of wind power plants was finished in 2008.This international cooperation was led by Anders Johnsson, Vattenfall Research & Development AB. The standard will facilitate the communication with turbines of different makes and types. This is mainly important for larger wind plant owners. The remaining section on condition monitoring will be published in 2009.

A new working group is considering the definition of the "availability" concept. The work will be finished in 2010.

11.2 Trends analyses

The extent of wind power research and development in the world is very large today. An increasing part of the activities takes place at manufacturing companies, with no public publication of the results. This is also the case for a large part of the EU projects. Sweden has earlier had a comprehensive research in the field, but it has disappeared as the attempts of establishing wind mill manufacturing has ceased. The technique is still far from ready, which means there are plentiful opportunities for research and development that can influence the design of future wind power plants.

European Wind Energy Technology Platform

European Wind Energy Technology Platform (2008) devotes a lot of space for the construction field. Research is proposed within the following areas:

- Basic understanding of the wind turbine as a turbo machine.
- Methods for load calculations.
- New materials

- Optimised design.
- Verification.
- Reliability of components such as drive systems (gear wheels), blades and towers.
- Improvements of electricity high voltage components for increased efficiency.
- Further development of electrical converters for higher efficiency.
- Development of new, light direct driven generators with low maintenance demand.
- Regulation systems that increase the power output and production and reduce the loads.
- Control algorithms that ensure the aero-elastic stability of the wind power plants.
- Sensors, for example lidar, to be able to measure the wind before it attacks the turbine.
- System for the regulation and maintenance based on condition control.
- Innovative wind turbines and components.
- Integrated construction methods.
- Further development of standards for wind power plants that make use of the opportunities for technical improvement, and at the same time keeping the confidence for reliability and production.

The importance of Vindforsk projects

The Swedish activities in the field are very limited from an international point of view, which is explainable with regard to the present lack of national wind power manufacturing.

11.3 Future development

With an exception for the area of standardisation, the Swedish activities are mainly connected with the extent to which a more extensive manufacturing of wind power plants and components will occur in the country.

Standardisation

An obvious task for continued Swedish contribution is the international standardisation work. The reason for this is the opportunities to influence the work and the choice of the areas of interest (for example forest and cold climate that have been missing earlier), which can be achieved by receiving early information through participation.

Miscellaneous

The continued activity within the field of construction can hardly be exhaustive, for resource reasons. Therefore, it is reasonable to have an ad-hoc approach in those activities where Sweden have an interest and can contribute with competence, in particular in EU-funded projects where match-financing is needed. If the wind power development will gain speed in Sweden, there are reasons to fund research as a strategic support.

12 Electricity systems for wind power stations

12.1 Results from the Vindforsk programme

In 2006/2008, the Vindforsk programme granted 10.9 million SEK, or 28 percent of total funding, to projects within this field.

High frequent transients in wind farms

V-220 Analysis of high frequent electrical oscillation in wind farms

Project leader: Torbjörn Thiringer, Department of Energy and Environments, Chalmers

V-110 Analyses of transients in cables

Project leader: Ambra Sannino, ABB Corporate Research

V-108 Design of electricity systems for offshore wind farms[174]

Project leader: Micael Lindgren, Vattenfall Power Consultant

The wind power stations of today are connected to traditional A.C. system with a permanent frequency of 50 or 60 Hz, except for the 7 MW plant Tjäreborg in Denmark. Thus, the frequency is the same within and outside the farm. Many of the offshore farms, e.g. Middelgrunden and Horns Rev, have been affected by breakdowns in transformers and generators. The reasons are not fully known, at least not officially. However, a common explanation is that high frequent oscillations have caused the breakdowns. The vacuum circuit breakers that are now so common cause a lot of high frequent transients when switching in and out. The extensive cable network in an offshore wind farm may include tens of kilometres and creates opportunities for transient propagation. When they hit the turbines, the windings of transformers and generators will be damaged. The vacuum breakers are used because they are an environmentally friendly alternative that can manage without too much maintenance. This is the focus of the three cooperative Vindforsk projects.

The work included component modelling and simulations. Verifying measurements were done at ABB Corporate Research where a partial wind farm radial had been built up. A radial is a cable that connects wind power turbines to the transformer platform. In this case, the cable set up consisted of a 600 m sea cable, a wind power transformer, vacuum breakers and a high performing system for data collection.

[174] Michael Lindgren, David Söderberg, Anton Dahlgren. Design av elsystem för havsbaserade vindkraftparker. Elforsk rapport 08:14, februari 2008.

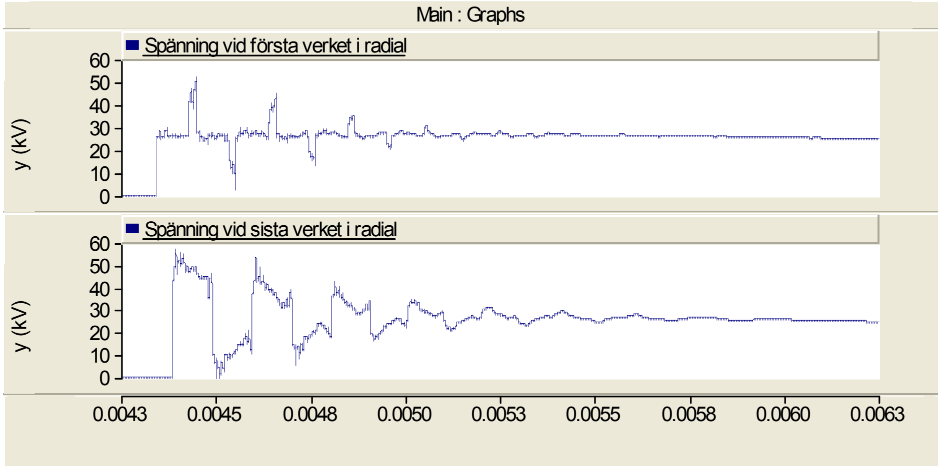

Figure 7. Phase voltage at the first (upper graph) and last (lower graph) turbine in a radial grid when a vacuum breaker is switched during simulation at Kriegers Flak.

One of the projects (V-108) studied different alternatives of electrical system design for a big offshore wind power station, 640 MW, at Kriegers Flak south of Trelleborg. Here, half a percent of the effect is lost in the local collection network and more than one percent in the export cable to the mainland. The transient simulations show that when a breaker is switched on, the instantaneous voltage will alter between zero and twice the nominal value before it stabilises at 30 kV, see figure 7. This means that the components are subjected to strong loads.

Reliability of the collection network

V-118 Reliability analysis of the electricity system within an offshore wind farm with A.C. subtransmission

Project leader: Bengt Frankén, STRI

The project has worked out a method of reliability calculations. It can be used for decisions on sea cable systems for offshore wind farms. The method regards the topical cable configuration and uses data for the included components such as failure frequency, repair time, and switchover time.

The method consists of three parts:

The first part calculates energy losses due to errors in a basal configuration. It is feasible to start from a configuration that lacks redundancy.

Part two introduces the redundancy into the system. The choice of redundancy is based on each component's contribution to the losses. The differences between the non-supplied energy in the basal configuration and in the new will be the additional energy that can be delivered.

The third part is an economic evaluation where the additional energy that can be supplied is recalculated into increased receipts.

The experiences from the case studies can be summed up as follows:

The largest loss depends on the long repair time of components placed offshore. Two types of redundancy can be distinguished depending on the switchgear type that is used. Remote controlled load disconnectors with remote indication of erring cable segments result in repair times with a duration from some minutes up to an hour. Further improvements could be brought about by using full effect switches, which together with a suitable relay protection equipment reduces the number of breaks. The additional gain is however limited due to the high cost, including switchgear that stands the higher current leaking.

Verification of ride-through function for mains interference

V-144 Modelling of measures on DFIG with a Ride-Through equipment

Project leader: Torbjörn Thiringer, Department of Energy and Environment, Chalmers

Because wind power now starts to be an important source of electricity production, it requires that the wind turbines, like other power plants, must endure different types of mains interference without being de-energised. Doubly fed non-synchronous generators (DFIG, doubly fed induction generators) are the most commonly used for wind power plants because the cost is low, the efficiency is high, and above all, they have appropriate dynamics. One disadvantage is that they, in their basal design, do not manage error incidents with under-tension voltage, since it leads to larger rotor currents than what the converter is dimensioned for. However, it is possible to complement the electricity equipment so that it will resist such error incidents. A wind power plant with ride-through function and a particular measurement equipment has been installed in Tvååker in Halland. The complementation consists of electrical resistors (braking resistor) connected to the generator converter's D.C. path via transistors. The installation of these components will prevent over-loading of the converter.

Two error incidents were recoded when a flash of lightning hit a power line, which made the voltage of the turbine fall to half respectively a fraction of the normal value for tenth of a second. The failures were automatically disconnected and the voltage returned to its original level. It resulted in strong over-currents in the generator's stator and rotor. The ride-through function worked as planned and the wind mill was not disconnected from the grid. The project continues until 2008/2009 when the results will be available in a final report.

International cooperation about electricity systems for offshore wind farms

V-106 Annex 23 Offshore wind energy technology and design

Project leader: Ola Carlsson, Department of Energy and Environment, Chalmers

Sweden participates in the Annex 23 of IEA, Offshore wind energy technology deployment, where electricity systems for offshore wind farms are studied. Both classical A.C. systems, as well as transmissions with high voltage D.C.

are studied. An overall ambition will be to create an international forum for the exchange of knowledge and experience, and to establish joint connection rules and standards for offshore wind power. Concrete cooperation projects are within the following areas:

- Large-scale integration of wind power in the Nordic grid. Financers: Nordic Energy Research, Vattenfall and Svenska Kraftnät.
- Issues about stability in the transmission net with regard to wind power.
- Models of wind power for studies of electricity systems, Sydkraft's research foundation
- D.C/D.C. converters in wind farms, Vindforsk
- D.C. wind farm with series-connected wind turbines, Sydkraft and Swedish Energy Agency (finished).
- Controlling methods for wind energy generators and wind power plants, Vindforsk (finished).

The EU Interreg IV programme of the North Sea region has granted money to the project "Power Cluster", which has participants from Norway, Sweden, Denmark, Germany, the Netherlands, and Great Britain. The project's goal is further development of business options, education and information about wind power. Chalmers is responsible for the education that will be conducted in cooperation with the Region of Västra Götaland[175].

The use of D.C. transmission to control voltage and reduce flicker

V-157 Optimal solutions for D.C. connections in HVDC wind farm

Project leader: Fainan Hassan, STRI

The project studies how a D.C. transmission can be used to control the voltage at the point of connection, and to reduce the flicker level on the connecting mains. This is possible with a converter that uses power electronics like IGBT (Insulated Gate Bipolar Transistor) with a PWM (Pulse Width Modelling), and thereby controls the active as well as the reactive effect fluxes from the wind turbine to the electricity net. It became known that there are limitations for the use of the method. The availability of reactive effect is one limitation, the reactance of the net is another, and the band width of the regulation system a third.

The two first limitations mean that considerable voltage dips cannot be regulated. As a result, the wind farm is at the risk of being disconnected if the voltage falls below a certain value. The third limitation means that quick voltage fluctuations, expressed as flicker, cannot be counteracted. Flicker means visible and annoying variations of the bulb's luminosity.

If a current-chopper unit is used on the D.C. link (the same idea as mentioned earlier in connection to the ride-through system for DFIG), it will be possible to alter the active effect flux. An algorithm for current limitation has been

[175] www.power-cluster.net samt http://www.chalmers.se/ee/SV/forskning/forskargrupper/elteknik/forskningsprojekt

introduced, which reduces the active effect in cases when the reactive effect is not sufficient to regulate the voltage. It results in a better regulation capacity. Furthermore, the time constant of the chopper unit is considerably shorter than that of the reactive regulation, which means that also quick voltage fluctuations can be counteracted. The flicker situation is measured in the P_{ST} value (short-term flicker severity). The simulations revealed that the reactive effect regulation, alone, could lower the flicker value with 15 percent, whereas a combination of reactive and active effect regulation lowered the value by 23 percent.

Within the project, it remains to make simulations to figure out what combinations of reactive and active effect regulations will give the best electricity quality to the lowest costs. Different ways of energy storage will also be tested.

Internal A.C. voltage net and A.C. /D.C. converters

V-208 New topology for more effective A.C. /D.C. converter to future offshore wind farms

Project leader: Hans-Peter Nee, EKC, KTH

If a wind power station is connected to the public electricity network via direct current, there is no reason to regenerate an electricity network within it with frequencies close to 50 Hz. A strong motive for this is that the units for voltage conversion can be made smaller if the frequency is increased, as the sizes of the key component, the transformer, is inversely proportional to the frequency. It should be pointed out that high frequency transformers are used in D.C. /D.C. converters.

The project has studied a technique for transmitting electric effect from a large wind farm to a suitable connection point in the network. The technique is based on D.C. transmission, which is characterised by being completely controllable, also at error incidents, leading to increased supply reliability. Since the technique builds on so-called soft-switching, and that the wind power plants are armed with thyristors, the losses will be smaller than with the D.C. technique of today. Further, the initial cost will be much lower as fewer semi-conductors are needed, and because the transformer size decreases substantially when a network with intermediate frequency is used within the wind farm.

It has been shown that the commutation of the new A.C. /D.C. converter can be realised within the entire field of operation with thyristors that cannot be turned off actively[176]. Measurements and results from a new modulation strategy have shown its applicability in the new A.C. /D.C. converter[177].

[176] Norrga, S. Nee, H.-P. Modulation Strategies for a Mutually Commutated Converter System in Wind Farms". European Power Electronic conferance 2007, 2-5 Sept. 2007, Ålborg, Danmark, P. 1-10.
[177] Meier, Stephan, Kuschke, Maren, Norrga, Staffan. Space Vector Modulation for Mutually Commutated Isolated Three-Phase Converter Systems. Power Electronics Specialists Conference, 2008,Rhodes, Greece, 15-19 June 2008, P. 4465 – 4471.

Laboratory trials with a 20 kVA prototype, constructed by the project, have shown that the new technique with converters that are armed with thyristors works well experimentally[178].

A preliminary compilation points at the possibility of the new technique to improve the economics of wind farms at large distances from a starting point in the network. A final report on the economic results is expected at the end of 2008.

An ongoing study treats the intermediate frequency network within wind farms. The goal is to prove the possibility of constructing such network without having too large occurrence of electrical oscillations within the frequency range of 1 kHz up to some MHz. The study includes numerical simulations in PSCAD, analytical calculations of intermediate frequency transformers, and practical measurements on cables at ABB Corporate Research in Västerås. The study will be finished at the end of 2008.

Internal D.C. voltage network work D.C. /D.C. converters.

V-204 D.C. /D.C. converters

Project leader: Ola Carlson, Department of Energy and Environment, Chalmers

The most far-reaching solution is to design a wind power farm where the generators produce alternating current, but where both the internal net and the net distributing the electricity to the mainland is based on direct current, at different voltage levels. This implies a demand for D.C. /D.C. converters at the individual turbines as well as at the transformer station, which can alter the voltage level. The project has studied a number of converters and voltage levels. The most attractive choice showed to be a so-called fullbridge-converter with phase angle control, where the voltage fluctuations are taken care of in the first step. The project is now studying different transient courses of events and error incidents. The project will be finished in late 2009.

12.2 Trends analysis

Technical trends of electricity techniques for wind power

At the moment, the industry standard for large wind turbines reaches 3-4 MW, and the ambition seems to be a badly needed improvement of the reliability, in the first place. The research front, represented by the extensive EU project Upwind, works further towards 10 MW turbines.

Gear boxes still break, and the interest for direct driven solutions is large. In addition to Enercon, the German Vensys has reach a volume production of direct driven wind turbines through licence to the Chinese Goldwind.

[178] Stephan Meier, Staffan Norrga and Hans-Peter Nee. Control Strategies for Mutually Commutated Converter Systems without Cycloconverter Turn-off Capability. Power Electronics Specialists Conference, 2008, Rhodes, Greece, 15-19 June 2008, P. 1344 - 1350

The net owners' demands on wind power plants has increased in pace with the increasing proportion of wind generated electricity production. The demand for reactive effect feeding at error incidents has turned up in many of the net owner's directions. Hydro Quebec requests that the wind power should contribute to the frequency regulation by occasional increments of the effect by 10 percent.

Research abroad in wind power electricity technique

Risø energy research centre, which has merged with the DTU (Danish technical university), has significantly expanded its activities in the wind energy field lately. Much research concerns the interaction between wind power plants and the electricity network. An interesting theme is to make use of the batteries of hybrid/electric vehicles to level out the effects of wind power plants. A superconductive wind generator could become much smaller than a conventional one. The integration of smaller wind power deployments to the net is also considered. The wind power manufacturer Vestas having an office within the Risø area illustrates the industrial link.

Another important seat of education is Aalborg that for long has been sponsored by Vestas. One reason for this is the manufacturer's difficulties to recruit enough competent personnel. The research at Aalborg has traditionally been focused on power electronics and driving systems, still reflected in their ongoing research. A project concerning the dynamic interaction between the electricity net and wind power plants has started as well.

It should be pointed out that Denmark has a different structure for research funding than Sweden, with better access to internal funds. There are, for example, 10 senior researchers on wind power in Aalborg, which is more than the total amount in Sweden.

There is a manufacturing in Finland of slip-ring non-synchronous generators (DFIG) as well as direct driven permanent magneto generators, both intermediate and fast rotating, and electricity systems for them. This has resulted in close cooperation between ABB and the technical universities in particularly Helsinki and Lappeenranta. Further, wind power plants with intermediate rotating generators are also produced in Finland, for example with a delivery of 30 MW to Skellefteå Kraft. Finland is strong when it comes to mechanical construction and controlling techniques. An important factor is that ABB located their driving system activities to Helsinki at the end of the 1980's. It has also resulted in a number of hiving-offs with production of generators and converters.

The Norwegian University of Science and Technology (NTNU) in Trondheim has been committed to experimental approaches and has built an expensive research laboratory. One track is direct driven PM generators that recently started to be tested experimentally in sizes of 50 kW. It can be mentioned that the Swedish owned wind power manufacturer Scanwind uses this technology and has taken advantage of the knowledge at the university. Research on the operation of DFIG wind turbines is also conducted. The energy research institute Sintef, next to NTNU, studies the interaction between electricity nets and wind power plants.

The Aachen Technical University in Germany deserves to be mentioned because E.On has located their new research centre here. There are already about 25 doctoral students within power electronics and driving systems.

Since many years, the Energy Research Centre of the Netherlands, ECN, carries on broad research about wind power, and concerning electricity systems together with Delft University of Technology.

European Wind Energy Technology Platform

The need for research on electricity technology in not so pronounced within the European Energy Technology Platform, maybe because the field is still relatively new in the wind power context. Examples of proposed research fields:

- Improvements of high voltage electronics aimed at increasing the efficiency and decreasing the costs.
- Further development of converters aimed at increasing the efficiency, and improving controlling capability and electricity quality.
- Development of new, light, direct driven generators with small maintenance needs, including the use of high temperature superconductors.
- Further development of standards for wind turbines with regard to net-owner demands.

The importance of Vindforsk projects

For historical as well as industrial reasons, Sweden maintains an extensive activity within applications of electricity power technology on wind power techniques, where Vindforsk projects have been a natural continuation. Concurrently with the stations, transmission distances, and coverage becoming larger, there is an increasing demand on accomplishments of the electricity technique. The potential for further improvements is large, so the projects will be of great importance.

12.3 Future development

As touched upon previously, the development of power electronics for the wind turbine’s electricity systems can give advantage like cheaper installations, lower maintenance costs, and increased capability of controlling effects and voltage. In order to realise this, both basic and applied research need more resources. Below examples are given of areas that need further development.

Internal wind power nets for direct currents and intermediate frequency

The design of internal networks in wind farms and their components is of economic significance, and has become an important research field. Research funding is motivated to further develop different solutions for D.C. /D.C. and D.C /M.F. converters.

High frequency modelling of networks offshore and on land

Previous studies on causes for breakdowns of generators and transformers have resulted in a large interest for how transients originate and spread in the internal networks of offshore wind power stations. Similar problems have occurred in the supply net system, where wind power plants and other power electric equipments have interfered with electric net communication facilities. The focus is mainly on aerial lines, transformers, and loads connected to the electricity network.

Frequency regulated wind power plants

The increasing wind power deployment has also resulted in a need to use it for frequency regulation. There are two variants. In the first, the turbine is run at highest possible effect. When necessary, the turbine can be slowed down for about ten seconds, which gives it the additional energy needed for frequency regulation. DTU, Vestas and Östkraft test the technique in close collaboration. In the second variant, the turbines are kept at a lower effect than the available, which means that the effect can be changed upwards or downwards when necessary. To keep this preparedness will result in energy losses, and is thus less attractive.

Modelling of electricity systems for studies of gear boxes

As the gearboxes still break down, there seems to be a need to improve the accessible driveline types. Note that high frequent transients seem to be a plausible explanation of the breakdowns of generators and transformers – they probably interfere with the gear cogs.

Using electric and hybrid vehicles for temporary storage of wind power electricity

Hybrid vehicles are under introduction, and pure electricity cars are expected to follow. The cars are charged from the electricity net, but can also be used for energy storage to level out the production from wind power turbines. How this will function is still an unexplored field. Vattenfall, Göteborgs Energi and car manufacturers are already active in the plug-in-hybrid field.

Integration of wind energy in existing supply systems

As far as can be judged, around some thousands megawatt of the Swedish wind power will be installed in smaller groups, which are connected to the existing supply net. Therefore, net owners, wind power planners etc have a considerable interest in investigating how this can be made in economically and environmentally satisfying ways.

Super grid in the North Sea and the Baltic Sea

A theme that has attracted a lot of interest is to establish a “super grid” for linking offshore wind farms and connecting them to the electricity net. It would be enormous D.C. networks in the North Sea and the Baltic Sea that feed energy to different countries, which also will be integrated in a stronger way than today. This expansion will probably occur gradually. It is important for society that a plan exists for the situation in 30-40 years.

13 Connection of wind power plants

13.1 Results from the Vindforsk programme

In 2006/2008, the Vindforsk programme granted 5.2 million SEK, or 14 percent of total funding, to projects within this field.

Evaluation of wind farms with different electricity systems

V-218 Wind power design for HVDC connected wind farm

Project leader: Torbjörn Thiringer, Department of Energy and Environment, Chalmers

The project's goal is to study whether a wind farm including plants with simple electricity equipment (DFIG with a particular small rotor converter, maybe with only rotor resistance control, optislip), combined with high voltage D.C. transmission (HVDC), can be as efficient as a corresponding farm having full-effect converters, and to evaluate the total costs. The study assumes that the plants lack fault ride-through systems, which means they do not by themselves fulfil the net requirements.

The studied set-up was an offshore wind farm connected to the electricity network on the mainland through a HVDC transmission. HVDC is normally justified when the distance to a suitable point of connection to the net is longer than about 50 kilometres, or when connecting to a weak net. The converters are assumed voltage-stiff, which gives a good controllability. In spite of the intention to use simple wind turbines, the system will still fulfil the requirements of Svenska Kraftnät and other net operators.

The reference system is a wind power plant with a full-effect converter. Vattenfall uses this technique together with A.C. transmission in the Lillgrund wind farm outside Malmö. However, the present study assumes that HVDC is used for the transmission to the mainland, which means that the entire effect will pass four converters (from A.C. to D.C. and vice versa) before it reaches the point of connection. The main part of the effect will pass only two converters in the rotor converter systems that have been studied in this project, which reduces investment costs and losses. The project continues until the summer 2009.

V-138 Dynamic performance of a wind farm connected by HVDC

Project leader: Andreas Pettersson, Gothia Power

The project's aim is to study the opportunities to use an HVDC installation with transistor technique (VSC-HVDC) to regulate connected wind turbines within a farm. Instead of regulating each turbine individually, the HVDC installation will control the number of revolutions in the turbines by regulating the frequency in the wind farm's electricity net. Such a solution does not require converters for each turbine unit in order to achieve a slow variable number of revolutions. Thus in principle, it will be possible to use directly net-connected generators. For wind power plants in the MW class and more, it can still be advantageous to use DFIG wind turbines that have smaller converters for the reduction of mechanical loads in the wind power plant, and thereby reducing the driveline cost. The project will be reported during the autumn 2008.

Demands for grid connection

V-129 and V-143 Development of a method to test the capability of wind power plants to fulfil Swedish demands for grid connection

Project leader: Evert Agneholm, Gothia Power

The Swedish net demands for wind power plants are documented in AMP[179], ASP[180], and in the directions for production plants of Svenska Kraftnät[181]. At present, guidelines are lacking to verify the fulfilment of the requirements. This is grave, as there is a risk that net owners and wind power owners cannot evaluate the manufacturers' test results. The V-129 project worked out a verifying method, and the V-143 project develops it further in trials on scale models. The latter project ends in autumn 2008.

The project develops scale models of wind power plants connected to a frequency converter whose software can be programmed to model stationary deviations in voltage and frequency, net interferences, and to vary the short circuit effect and impedance of the net. Results from the net simulations will be possible to use for controlling the converter. The scale models will be exposed to the trials that will be developed. The process will answer questions on how the methods work in practice, and give feedback to AMP, ASP and the directions of Svenska Kraftnät. The project will also summarise the demands that apply in Denmark, Germany, Spain, and Ireland, and the methods they use to verify the fulfilment.

The advantage of tests on scale models is that the interaction between the wind farm and the grid can be tested at extreme interferences in the electricity net, something that normally does not occur. Thus, it is possible to identify potential stability problems, or undesired disconnections of the wind farm. In general, the supplier must be responsible for fulfilling the demands made for net connections. Only wind turbines that are certified according to current tests should be allowed to be connected to the electricity net.

Large commercial wind farms should be equipped with facilities that permit logging of the behaviour of the wind farm during real net interferences. Such a facility is installed in the wind farm on Lillgrund.

Project V-101 ASP Connection of large production plants[182]

Project leader: Åke Larsson, Vattenfall Power Consultant

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[179] AMP, Anslutning av mindre produktionsanläggningar till elnätet, Svensk Energi, 2002.
[180] ASP, Anslutning av större produktionsanläggningar till elnätet, Elforsk rapport 06:79, 2006.
[181] Affärsverket Svenska Kraftnäts föreskrifter och allmänna råd om driftsäkerhetsteknisk utformning av produktionsanläggningar, SvKFS 2005:2, 2005.
[182] ASP, Anslutning av större produktionsanläggningar till elnätet, Elforsk rapport 06:79, 2006.

When larger wind power plants are to be connected to the electricity grid, questions arise about the grid's transmission capacity, voltage fluctuations, losses, leakage currents, relay protection, dynamic stability etc. Since few larger wind power plants have been installed in Sweden, the experiences are limited. It is difficult to conclude what should be investigated. It is important for net owners and electricity producers that there are explicit demands and recommendations on how the net connection should be made, what studies should be conducted, and what demands a wind power plant must fulfil.

The aim of the V-101 project is to elucidate how connection to the grid of large wind power farms should be made, and what requirement they must fulfil. The report treats generally how production plants larger than 25 MW should be connected to the regional network. It describes the demands that Svenska Kraftnät makes on the production plant, and what demands a net owner should make. It describes electricity quality, what investigations are needed to conduct during the net planning, relevant protection against wrong disconnections, a checklists for net owners, and what information should be exchanged between net owners and producers. There are examples on some large wind farms that are either installed or planned on land and offshore. Today, a revised ASP report is needed that focuses on the connection of wind farms to the regional network. A revised version of the ASP report could also include administrative routines that facilitate the contacts between net companies and electricity producers.

13.2 Trends analyses

Regional network and national grid

The wind power plants must be localised to places with good wind conditions. These places on land and offshore seldom coincide with available regional and national grids that have sufficient capacity.

The economic responsibility for electricity networks varies among countries and is of course a political issue. In Germany, the national grid owner (TSO Transmission System Operator) is obliged to build and operate electricity grids offshore since December 2006. In Sweden, the Grid Connection Inquire[183] discusses the economic matters.

Network structure and technical choice

The question about network structure can result in needs for the deployment of new transmission lines to collect and transmit the wind power production to the national grid and to increase the transmission capacity between different countries. In this way, it is possible to level out variations in wind energy production, and thereby reduce the regulation need.

The question about technical choice concerns conventional A.C. technique versus high voltage D.C. (HVDC). D.C. has many advantages compared to A.C., and a range of different applications of the HVDC technique are studied

[183] Bättre kontakt via nätet – om anslutning av förnybar elproduktion, SOU 2008:13.

all over the world, see the projects V-128 and V-138. Research within the A.C. technique is mainly about cables where forced water-cooling gives about 50 percent increased effect transmission as compared to a conventional cable[184]. Another variant is gas-insulated lines (GIL), which have larger capacity and lower capacitance than conventional cables[185]. One more variant is cables with four conductors for a four-phase system, which gives lower magnetic field and temperature increase compared to an ordinary three-phase cable[186].

Requirements of the electricity network on production plants

Because of the fast and large-scaled deployment of wind power, more and more countries have prepared requirements, so-called grid codes, applying on wind farms that are to be connected to the grid. Former connection requirements mainly concern the impact of wind power plants on the local transmission net. For Sweden's part, they are found in AMP[187].

The owners of transmission and national grids (TSO), and Svenska Kraftnät in Sweden make the demands[188]. Examples are interference durability, reactive effect regulation, communication, and controllability. Interference durability refers to a wind farm that maintains the production in spite of deviations in voltage and frequency, and remains connected to the grid even if the voltage of the connected grid transiently falls to zero, a so-called fault ride-through. Spain has moved even further ahead and demands that wind farms should contribute to the voltage regulation.

These grid codes differ so far among countries. The wind power manufacturers have difficulties to fulfil some of the demands, which means that they affect the choice of technology[189]. The manufactures try to adjust the constructions for an international market. If the demands differ between countries, there is a risk that the product is adapted to the worst case, which will result in a more expensive product, or that certain markets are just given

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[184] H. Brakelmann, D. Zhang, "HVAC cable systems with forced water cooling for wind energy transmission", 7th International Workshop on Large Scale Integration of Wind Power and on Transmission Networks for Offshore Wind Farms, 26-27 May, 2008, Madrid, Spain.
[185] C. Rathke, M. Siebert, L. Hofmann, "Grid integration of offshore wind farms using gas-insulated transmission lines", 7th International Workshop on Large Scale Integration of Wind Power and on Transmission Networks for Offshore Wind Farms, 26-27 May, 2008, Madrid, Spain.
[186] H. Brakelmann, J. Brüggmann, J. Stammen, "Connection of Wind Energy to the Grid by an Optimized HVAC Cable Concept", 7th International Workshop on Large Scale Integration of Wind Power and on Transmission Networks for Offshore Wind Farms, 26-27 May, 2008, Madrid, Spain.
[187] AMP, Anslutning av mindre produktionsanläggningar till elnätet, Svensk Energi, 2002.
[188] Affärsverket svenska Kraftnäts föreskrifter och allmänna råd om driftsäkerhetsteknisk utformning av produktionsanläggningar, SvKFS 2005:2.
[189] S. Bolik, "The impact of Grid Codes on the development of wind turbine technologies", 7th International Workshop on Large Scale Integration of Wind Power and on Transmission Networks for Offshore Wind Farms, 26-27 May, 2008, Madrid, Spain.

up. The need for harmonising has been identified within the EU, and several programmes addressing this issue have started.

European Wind Energy Technology Platform

European Wind Energy Technology Platform considers the subject field mainly under "wind energy integration", earlier described in section 2, Large amounts of wind power from a market and technology perspective.

The importance of Vindforsk projects

See the corresponding in section 10 Connection of wind power plant.

13.3 Future development

Further work is justified to update the demands on grid connection of wind power farms, in general and concerning insulation levels of equipments, for example.

Updating demands for grid connections

An update of the present demands for grid connection of larger production plants, ASP, is necessary. It should include recommendations for the design of connections with the regional network, and examples of how the directions of Svenska Kraftnät shall apply.

Interaction between wind farms and electricity networks

Net owners are not quite sure about how wind farms interact with the electricity net. Therefore, it would be worthwhile to make measurements in some wind power plants during interferences in the connected network, and present the results together with simulations. Large commercial wind farms should be equipped with facilities that permit logging of their behaviour during real interferences. Such a facility is installed in the wind farm on Lillgrund.

Alternative solutions to fulfil insulation margins

A standard for the choice of insulation levels and for over-voltage protection equipment is lacking today. There is a need to evaluate alternative solutions in order to guarantee that the insulation margins of the electricity system will be fulfilled. The result should include recommendations for insulation levels, and how margins of switching impulse withstand levels (SIWL) and lightning impulse withstand levels (LIWL) should be evaluated by means of calculations and simulations. An Elforsk project[190] has earlier touched upon this, but the issue needs further treatment. Such work should include how the structure and dimensioning of an electricity system will affect the size of over-currents and over-voltage in different parts of the system.

[190] Design av elsystem för havsbaserade vindkraftparker, Elforsk projekt 08:14, 2008

14 Operation and maintenance

14.1 Results from the Vindforsk programme

In 2006/2008, the Vindforsk programme granted 3.4 million SEK, or 9 percent of total funding, to projects within this field.

Operation monitoring

V-102 Wind power statistics – operation monitoring

Project leader: Nils-Eric Carlstedt, Vattenfall Power Consultant AB

The project collects and analyses operation data from wind power plants in Sweden. During the period when investment subsidies were paid out, reporting was obligatory. The transition to subsidies through electricity certificates removed this obligatory. The issue is now reconsidered. The reporting occurs by monthly and annual reports available on the Internet[191]. There is also an automatic reporting, now including about half the wind power plants. These results are available on the Internet, too. The statistics is commented in the following.

Optimal maintenance control of offshore wind turbines

V-120 Optimal maintenance control

Project leader: Lina Bertling, Electro technical theory and construction, KTH

This doctoral work aims at developing methods to optimise the maintenance of a wind power turbine, with a particular focus on offshore wind power where transport and weather dependence increases the costs. In the first phase of the project, the most important areas of concern were identified for maintenance of wind power turbines where the gear and the driveline in general are the main sources of problems. Equipment for vibration monitoring is nowadays installed in order to discover failures at an early stage. The cost for e.g. transports could be reduced if decisions that are more confident could be taken concerning how long a component can be used before it is exchanged.

Much of the production losses are also caused by smaller components with high failure frequencies, such as hydraulic pistons, and electrical motors. The availability could be increased by exchanging such components for preventive purposes. Since no one has kept track on which components have been exchanged, and when, this will hamper the introduction of such maintenance philosophy.

Routine maintenance of wind turbines typically includes inspections, oil sampling, lubrication, and tightening screw joint reinforcements. It takes place according to a timetable once or twice a year. The inspection could

[191] www.vindenergi.org/driftuppf.htm

instead occur at "opportunistic" occasions when the turbine stands still because of calm weather, or when it is visited to correct errors. This would decrease the costs and increase the production. The project develops an optimisation model for opportunistic maintenance of wind turbines. It can be expanded to include preventive exchange of components. A case study is conducted at the offshore wind park Lillgrund in cooperation with Vattenfall.

Operation reliability of wind turbines

V-121 Optimal maintenance control of wind power plants by means of condition controlling systems concerning reliability and costs

Project leader: Arnt Eggen, Sintef Energiforskning AS

This Norwegian project, partly funded by Vindforsk, has its starting point in those methods that are used for the maintenance of hydropower, which can be appropriate, as they are systematic and well known within the organisations concerned. The project's goal is to develop a manual for condition control of wind turbines, a model for the breakdown of components in wind turbines that includes calculations of remaining lifetime, a method to register the operation history of wind turbines, and instructions on how maintenance-related aspects should be handled in delivery contracts[192]. The project ends in 2008.

14.2 Trends analyses

Availability factor of wind power plants

Wind power plants have since long time been considered to have a high and even availability, defined as the time the plant is ready to generate (whether the wind is blowing or not) divided by the total lifetime. Assuming that the failures are distributed randomly over time, the availability is the possible production of a plant expressed as a proportion of the production of a plant having 100 percent availability. During the period of 2002-2007, it is reported that Swedish wind power plants had a highest annual value of 99.8 percent, and a lowest value of 98.1 percent[193]. The availability value of 2007 was 98.7 for the 810 participating plants. The figures are based on the reports the plant owners compile manually and send in monthly.

However, also an automatically reporting system calls up the wind power plants every night and automatically collects information of the production etc during the last 24 hours. According to this method, the availability factor was 94.4 in 2007 for those 444 wind power plants that had opportunities of reporting operation conditions. These figures are not quite certain either, as the control systems of different products differs, and because automatically reported information that a plant is available does not necessarily means this is the case.

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[192] Arnt O. Eggen: Driftsikkerhet for vindturbiner. Forskning om vindkraft i fokus. KTH, 2008-05-15.
[193] Elforsk Driftuppföljning för vindkraftverk, 2007.

For example, some products report loss of off-site power as failure, while others do not[194]. According to the existing definition, they count as failures.

A detailed study of Vattenfall AB's wind power plants in the cited annual report gives a more balanced picture. The 46 wind power plants on land had a mean availability factor of 91.8 percent in 2007, and the 12 plants offshore had 76.4 percent availability. The offshore wind farm on Lillgrund that was put into service at the end of 2007 was not included. One of the plants on land, Näsudden II, was out of operation. It is now scraped. The offshore plants at Yttre Stengrund were likewise out of order, waiting for a new gear. It could be reasonable to omit Näsudden II from the statistics, in which case the land-value for Vattenfall increases to 93.8 percent. Yttre Stengrund should however burden the statistics, as the intension is to put it into service again.

In summary, it is found that the current picture of the availability of wind power plants is not correct. A further review of the statistics shows that 57 plants were reported to not having produced at all during the year, but evidently, they were excluded from the compilation. Even if all other plants would have been failure-free – which they were not – the availability had decreased to 93 percent. The availability was 100 percent for 630 manually reported plants, which is not in accordance with information from the automatic reporting. It is more likely that the availability is 90-95 percent. This rather poor value signals that there is a potential for considerable improvements.

Availability is a combined effect of how often errors occur and how long time it takes to attend them. Periods of standstill are affected by the time it takes to get spare parts, the access to maintenance personnel, and transportation opportunities, particularly offshore. It is natural that offshore plants, even at the same failure frequency, have a lower availability, as bad weather can prevent the access, and that it takes longer time to get lifting devices etc in place.

Effects of total breakdowns

Attention has lately been paid to several cases with total breakdowns of wind power plants. This can be problematic for the picture of wind power as being a safe and environmentally friendly source of energy. In addition, it is natural to make rough estimates on whether the breakdowns will have any serious consequences for the wind power economy.

Fire is one prominent cause of breakdowns, often due to lightning or electric malfunctions. If a fire starts in a wind power plant in such a way that the automatic fire extinguisher system is insufficient to put out the fire, there are practically no chances to reach the fire from outside. The plant must be left to burn itself out, which is a spectacular experience. Fire destroyed eight wind power plants in Germany in 2002, the worst year so far[195]. At that time, Germany had 12 000 wind turbines so the fire frequency was 0.07 percent.

[194] Anders Andersson, Styr- och mätteknik Sverige AB, personligt meddelande 2008-04-18.
[195] Wind Kraft Journal 3/2005

With a normal lifetime of a plant of 20 years, the corresponding decrease in availability will be 0.7 percent in average, a not insignificant value. Until now, 1-2 wind power plants have been destroyed by fire in Sweden (out of totally 850 in 2008), which gives a similar frequency. One way to reduce the effects of a fire is to use metal nacelles instead of glass fibre reinforced plastics. A tendency to such a change has been noticed lately. This also means improvements in lightning protection and cooling.

The wind power industry does not follow up breakdowns of wind power plants in the world on their own. According to an Internet site that belongs to an anti-wind power organisation[196], there were totally 301 breakdowns of wind power plants between 1975 and 2006. Today, there are about 100 000 larger wind power plants in the world. As most of them have been installed in recent years, it is plausible to distribute the breakdowns over, let say, five years. It will give a breakdown frequency of 0.06 percent, which is about the same as the worst-years values for fires, mentioned earlier.

In can be concluded that breakdowns due to fires and other reasons have significant effects on the wind power economy. The circumstance that insurances cover the damage risks does not reduce the problem– it will just reallocate the costs.

Failure-frequencies and failure periods of different components

A wind power plant consists of a number of components and systems. Since the availability is determined by their combined failure-frequencies, it is natural to study the plants component by component.

A recently published report[197] is based on two German and one Danish database, which include operation reporting from totally 7 000 wind power plants during eleven years. The failure-frequencies for different components are, arranged in decreasing frequency: electricity net and other electricity systems, turbine blades, control systems, yaw systems, generators, hydraulics, gearboxes, pitch regulations, air brakes, mechanical brakes, main shafts, and finally other non-specified failures. The frequency varies between 0.32 and 0.02 failures per component and year.

When studying the output from the databases, it is noticed that components of the oldest Danish plants have the lowest failure frequencies. It can be explained by their less complicated constructions, and that it was economically possible to dimensioning them generously. It is further noticed that generators, hydraulics and brakes have higher failure frequencies when installed in wind turbines as compared to other industries. A reasonable explanation could be the severe environment of wind power plants. However, the gears in wind turbines showed a lower failure-frequency than for other industry.

[196] www.windaction.org
[197] P J Tavner et al. Reliability of different wind turbine concepts with relevance to offshore application. EWEC 2008, Bryssel 30/3 – 4/4 2008.

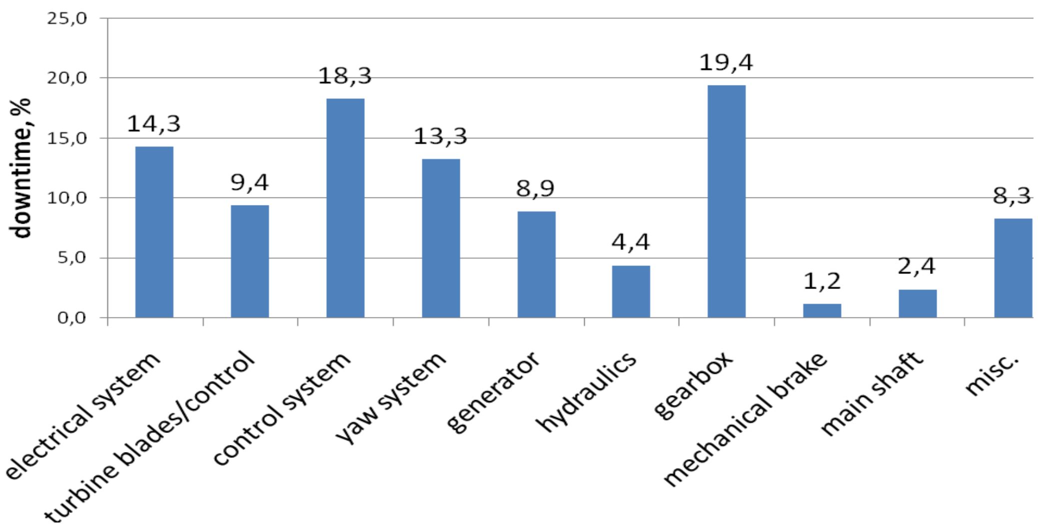

Figure 8. Percentage distribution of standstill periods for Swedish wind turbines, based on processed data from Ribrant and Bertling (2007).

In another study[198], the KTH researchers Johan Ribrant and Lina Bertling studied failure frequencies and standstill periods for Swedish wind turbines, which increased from 527 to 723 during the studied period of 2000-2004. The results are summarised in Figure 8. The tendencies are similar in both studies for most systems. The gears seem to be the dominating failure source, counting for 19 percent of the standstill periods. When evaluating the importance of gears, it must be considered that some of the turbines have direct driven turbines without gears (30 percent of the German[199] , 11 percent of the Swedish[200]), which means that a corresponding stock lacking those would have a failure percentage of 27 and 21, respectively. The low growth of the market has affected the Swedish results, in that the more reliable small and old turbines account for a larger share of the stock. It can be compared with results from the Danish database. In the German study, the electricity net seems to be a large failure source, but this tendency is not found in the Swedish study, or in the previously referred Danish study. This failure source i, by the way, mainly outside the influence of wind power technology.

198 Johan Ribrant and Lina Margareta Bertling. Survey of failures in wind power systems with focus on Swedish wind power plants during 1997 – 2005. IEEE Transactions on energy conversion. Vol. 22, No 1, March 2007.

199 C. Ender. Windenergienutzung in der Bundesrepublik Deutschland – Stand 31.12 2002. DEWI Magazin. Nr. 22, Februar 2003.

200 Elforsk. Driftuppföljning för vindkraftverk, 2002.

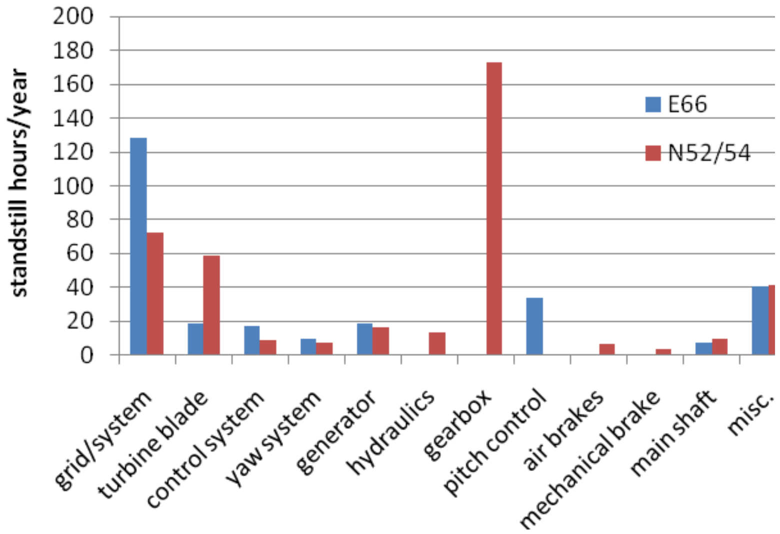

Figure 9. Annual periods of standstills in hours due to failures in different components of direct driven E66 (blue) and geared N52/54 (red) turbines, based on results according to Tavner (2008).

Comparisons of geared and direct driven turbines

A detailed investigation studied data from one German database regarding a direct driven 1.5 MW wind turbine and a geared 1 MW turbine. The failure frequency for the gear has now increased to more than 1.5, which means it will break after less than two years. In the previously presented study material, the failure frequency was 0.13, and time until failure was thus close to 8 months. It is worth noticing that the product in this case has not appeared in the debate about gear failures. Figure 9 shows the combined data on failure frequencies and data on standstill periods per failure. It shows that the gear dominates the standstill periods almost totally.

Table 5. Gear failures in Swedish wind turbines 1997-2004, according to Ribrant and Bertling (2007)

Year	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*1997-2004*
No. failures	21	41	52	26	30	42	13	7	232
Total failure time, h	4031	2518	5061	6172	5228	12589	3987	2309	41895
Average time per failure, h	192	61	97	237	174	300	307	330	181
Proportion of standstill time, percent	9.4	5.3	7.3	15.5	13.6	33.5	14.8	17.4	14.6

Ribrant and Bertling have deepened the analyses of gears in wind turbines. Table 5 shows that 232 failures were recognised in Swedish wind turbines during the period 1997-2004, i.e. half of the turbines on average. The number of failures and failure times tend to decrease at the end of the period, but the average time per failure has rather increased. This can be the result of increasing sizes and difficulties to get new gears.

The importance of size

Wind turbines have become larger and larger over the years. According to Tavner (2208), this has led to consistentlyincreasing failure frequencies, from one failure per year for turbines of 225-250 kW to 3.5 failures for 1.5 MW turbines. The direct driven turbines of 0.5 and 1.5 MW have the same failure frequencies, 2.5 failures per year. On the other hand, they escape the long failure periods of the gears.

The size increment has occurred in parallel with heavy efforts in research and development. The increasing failure frequencies must be regarded as a failure.

Comparisons with hydropower technology

The failure frequency in the German data for the electrical generators in wind turbines, both high-speeded with gears and the slow direct driven ones, is more than 0.1 failure per year, according to Tavner 2008. In industrial applications, the high-speed generators have a failure frequency of 0.05 per year. This may be compared with statistics on hydropower generators. According to a compilation[201], 69 out of 1 199 generators, of total 48 629 MW (mean size of 40 MW), failed during a period of ten years. The failure frequency was 0.006 failures per year and generator, and a tenth of failure frequencies for generators in the industry. Wind power has apparently a long way before its installations come near the reliability that is taken for granted within hydropower.

Wind power is similar to hydropower in that the processes take place at normal temperatures and low speeds, even though a large number of load variations that cause exhaustions distinguish wind power. In long-term, the development of wind power technology should be able to reach the low failure frequencies and high reliability that characterise hydropower.

Condition based maintenance

Maintenance can be preventive or repairing. A planned preventive maintenance of wind turbines typically occurs twice a year. An alternative or complement that is presented now is the opportunity to base the maintenance on the actual condition of the unit. It is possible to monitor a gear by keeping track of vibration levels, and the oil's condition and contents of particles. The advantage is that damages can be discovered and repaired before it has gone too far, and that unnecessary maintenance efforts can be avoided. An Elforsk

[201] J L Garcia Araco (Spain). Cigré Working group A1.02. Survey of hydrogenerator failures. Study committee SC 11, EG11.02 Hydrogenerator failures. 14/08/03.

project[202] has made a pre-study regarding the prerequisites for a reliability-based maintenance of wind turbines. Condition monitoring systems (CMS) are in practical operation for wind turbines, particularly in Germany, but not yet in Sweden. Companies separated from the wind turbine suppliers have developed most of the systems. The project concludes that it is profitable to introduce a system for condition monitoring if the availability will rise with 0.4 percent.

European Wind Energy Technology Platform

European Wind Energy Technology Platform stresses that operation and maintenance become more and more crucial with increasing turbines sizes and offshore placements. A goal for the field is to optimise maintenance strategies to increase availability and reliability. Examples of proposed research areas are:

- Identification of failures by indication on the physical effect caused by failures in wind turbines components
- Integration of condition monitoring and error predictions by the turbine's control system
- Development of maintenance strategies that include preventive, failure frequency based inspections, with the practising of condition monitoring

Importance of Vindforsk projects

The output of operation and maintenance is of significant economic importance for the owners of wind power plants, directly through their costs and indirectly through potentially increased production due to improved availability.

In spite of shortcomings, Elforsk's project for operation monitoring constitutes an important source of information on how wind turbines function in practice. The participation is still high, although decreasing because the obligatory reporting no longer exists for new turbines. Many other countries have no open reporting, to disadvantage for all.

The conducted research projects have given applicable results and seem to hold internationally.

14.3 Future development

Regardless of the extent to which the monitoring of operation results of the existing wind turbines is considered to have a scientific character, it is a necessary basis for our possibilities to develop wind power technology towards increased availability and decreased maintenance costs. Additional

[202] Lina Bertling, Thomas Ackermann, Julia Nilsson och Johan Ribrant. Förstudie om tillförlitlighetsbaserat underhåll för vindkraftsystem. Fokus på metoder för tillståndskontroll. Elforsk rapport 06:39. Maj 2006.

work within the field can lead to improved methods of maintenance, and specifically the development of methods for dimensioning gears.

Operation monitoring

The evident basis for carrying out measures to improve the operations results and restrict the maintenance costs is simply to be familiar with reality. It is crucial to monitor production, availability and failure causes of existing wind turbines. The experience shows that reporting and result processing have not worked satisfactory. They must be improved. It is likely that all wind turbine owners will be conditioned by the certificate system to report production, most appropriately through the automatically report system. In addition, a more limited group of particularly motivated owners can communicate their detailed experiences of operation.

Maintenance methods

The previous outline shows there are good opportunities to design maintenance methods systematically that will improve the operation results and limit the costs. This work must continue.

Gear dimensioning

Gears account for a large and increasing proportion of the failure periods of wind turbines. Even if the suppliers of gears and wind turbines have the primary responsibility, it is justified to improve the situation in different ways. We should investigate the previously overlooked causes of heavy loads, and thus untimely wearing. One example is the voltage fluctuations caused by vacuum breakers, which are mentioned earlier to be the reason why generators and transformers break down.