



INTERNATIONAL ENERGY AGENCY

**Implementing Agreement for Co-operation in the
Research and Development of Wind Turbine Systems
ANNEX XI**

32d Meeting of Experts

Wind Energy under Cold Climate Conditions

Helsinki, Finland, March 22.-23., 1999

Organized by : VTT, Techn. Research Centre of Finland



Scientific Coordination :

B. Maribo Pedersen
Dept. of Fluid Mechanics
Technical University of Denmark



INTERNATIONAL ENERGY AGENCY

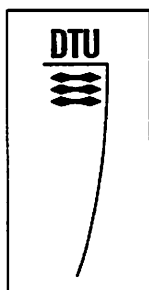
**Implementing Agreement for Co-operation in the
Research and Development of Wind Turbine Systems
ANNEX XI**

32d Meeting of Experts

Wind Energy under Cold Climate Conditions

Helsinki, Finland, March 22.-23., 1999

Organized by : VTT, Techn. Research Centre of Finland



Scientific Coordination :

**B. Maribo Pedersen
Dept. of Fluid Mechanics
Technical University of Denmark**

I

CONTENTS

	page
JONAS WOLFF Introductory Note	1
GÖRAN RONSTEN Can Delayed Stall be Caused by Ice Accretion on the Leading Edge of an Airfoil	3
JAN NORLING SUORVA - Arctic Wind Turbine in Northern Sweden	21
ANDERS SCHÖNBORG Wind Turbine in Cold Climate - RODOVÅLEN, Sweden	25
ESA PELTOLA a.o. Development and Experiences of Arctic Wind Technology in Finland	35
TOR ANDERS NYGAARD Wind Energy and Icing in Norway	45
M.DURSTEWITZ, M. HOPPE-KILPPER Evaluation of Icing Failures in the "250 MW WIND"-Program	49
PER LUNDSAGER Wind Energy in Cold Climates. Danish Experience	61
MALCOLM A. LODGE Wind Energy Experience in Arctic Regions of Canada	75
FRANS VAN HULLE Wind Energy in Kazakhstan	83
JONAS WOLFF International Co-operation in Cold Climate Wind Energy	99
LIST OF PARTICIPANTS	105
IEA R&D - ANNEX XI List of Previous Meetings of Experts	107

IEA R&D Wind**Topical Experts Meeting****WIND ENERGY PRODUCTION UNDER COLD CLIMATE CONDITIONS –****Operational experience****INTRODUCTORY NOTE**

Prepared by Mr Jonas Wolff

There is an increasing interest in wind energy production under different climatic conditions, among them cold climate and icing conditions. More and more wind turbines are being installed in cold climates and even adapted technology has been developed for that environment. Various national activities are going on in at least Finland, Canada, Italy, Sweden, etc. and international collaboration has been carried out within the European Union's Non-nuclear energy programme.

Wind turbine operation is affected by both the cold temperatures and the formation of ice on the blades and the supporting structure. Cold temperatures can be handled by material selections known in other technical fields but to prevent icing, new techniques have to be – and have been – developed. Icing affects the reliability of anemometers, which concerns both turbine control and resource estimation, and changes the aerodynamics of the blades, which eventually stops the turbine. In addition, occasional icing events can locally affect public safety.

The development of applied technology has entered some different paths and different solutions are tried out. As the applications are entering a commercial phase, there is a request to gather the experiences and monitor the reliability in a form that can be utilised by developers, manufacturers, consultants and other tenderers.

The Topical Experts Meeting will focus on site classification, operational experiences, modelling and measurements of ice induced loads and safety aspects. If there is a broad interest in the topic, the meeting can end with a recommendation for co-operation in the form of an Annex to the IEA Implementing Agreement on Wind Energy Research and Development.



1. Document			
Can delayed stall be caused by ice accretion on the leading edge of an airfoil?			
2. Date	Issue	Page	Reg no.
93-05-03	1	1(8)	FFAP-A-981
3. Issued by		Approved	
Göran Ronsten		<i>S-E Ilcor</i>	
4. Distribution			
Olof Sandberg	(NUTEK)	Hans Olsson	(NUTEK)
Bengt Göransson	(Kværner)	Anders Wikström	(Kværner)
Roland Krieg	(SMHI)	Tord Kvick	(SMHI)
Anders Ericson	(SVIAB)	Hans Ganander	(TG)
Göran Dalén	(Vattenfall)	Bruno Bergqvist	(ÅF-I)
Staffan Engström	(Ågir)	Ola Carlsson	(CTH)
		Hans Bergström	(MIUU)
		Sven Svenning	(Swedewind)
		Jan Blix	(Vattenfall)
		Tomas Lyrner	(ÅF-I)
FFA: Sektion AV (BKA, JÅD, MEB, PNM, RNG, TRS, UNE), GUS, MRS, WNS, IAL, ERK, SNI, Bibl.			

TABLE OF CONTENTS

1. Introduction.....	1
2. Why "Power peaks"?	2
2.1 Wind speed changes?	3
2.2 Turbulence intensity?	4
2.3 Yaw misalignment?	4
2.4 Wind speed gradient?	5
2.5 Ice?	5
3. Conclusions	8
4. Recommendations	8
5. References	8

1. INTRODUCTION

The Swedish wind energy program has included studies of ice detection on sensors mounted on a meteorological tower at Maglarp in southern Sweden, reference [1]. The report indicates that it poses a greater problem detecting the ice rather than the consequences it might lead to. One important conclusion in ref. [1] was that the icing problem is more severe at 75 m height than at 10 m which means that ice detectors, if they are needed and if they work, should be placed at least at hub height. Ice build ups on wind turbine blades have not caused any practical problems in the southern part of Sweden although anemometers freezing to a halt have been reported, reference [2].

On the 5th of March 1993, however, all four wind turbines (Danwind, 180 kW) at Alsvik on the island of Gotland in the Baltic sea showed an increase in output power. The Alsvik site is described in reference [3]. On three recorded occasions, the power outputs exceeded the rated 180 kW by more than 15% as a one-minute average, figure 1a,1b,1c and 1d. Shortly afterwards the grid went down as did the FFA data acquisition system. That day, the turbines stopped at several occasions because the power outputs exceeded the maximum allowed, [4].

2. WHY "POWER PEAKS"?

Figure 1a,1b,1c and 1d shows three "power peaks" numbered 1,2 and 3 for each of the four wind turbines. The mean value is based on 2 Hz data averaged during one minute and the max. and min values found within that minute.

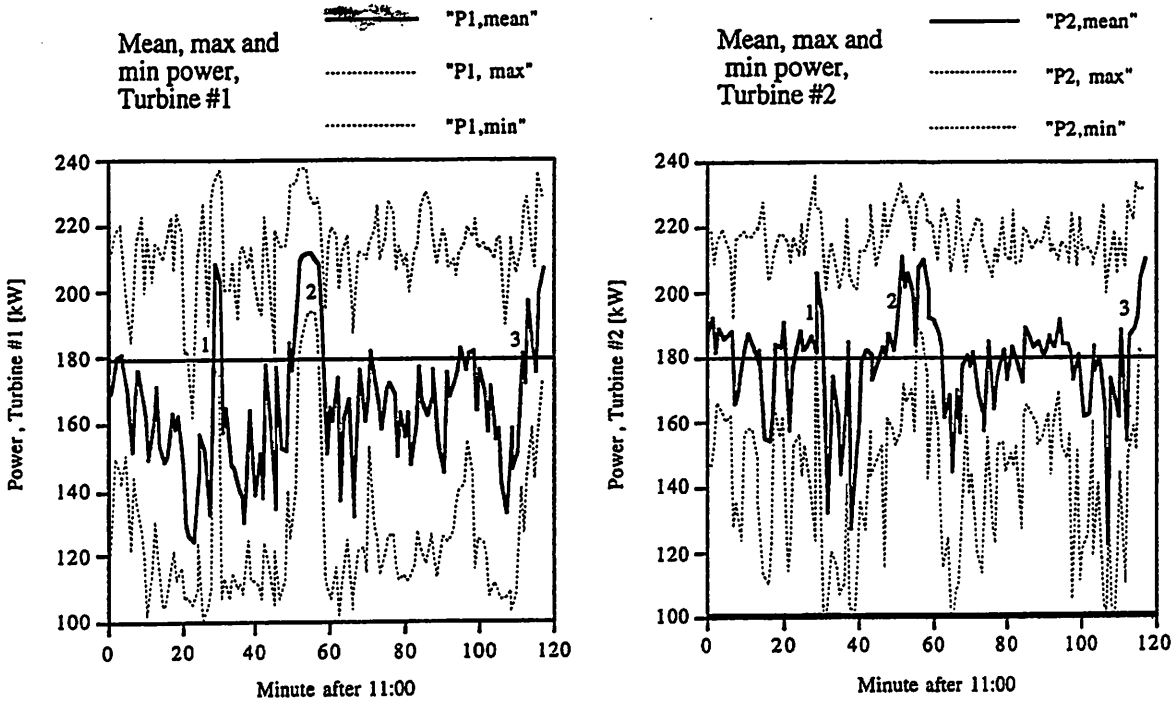
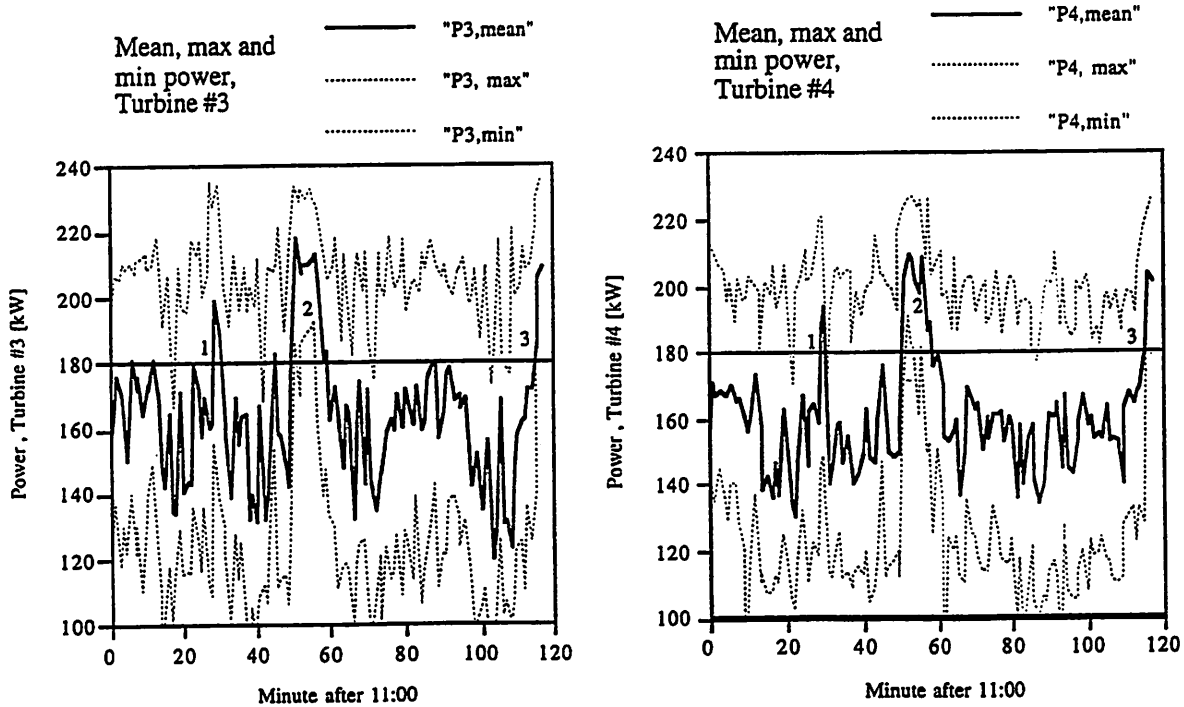


Figure 1a,1b,1c and 1d: Delayed stall was recorded at three occasions 93-03-05



The corresponding edge- and flapwise bending moment standard deviations for turbine number four are shown in figure 2a and 2b.

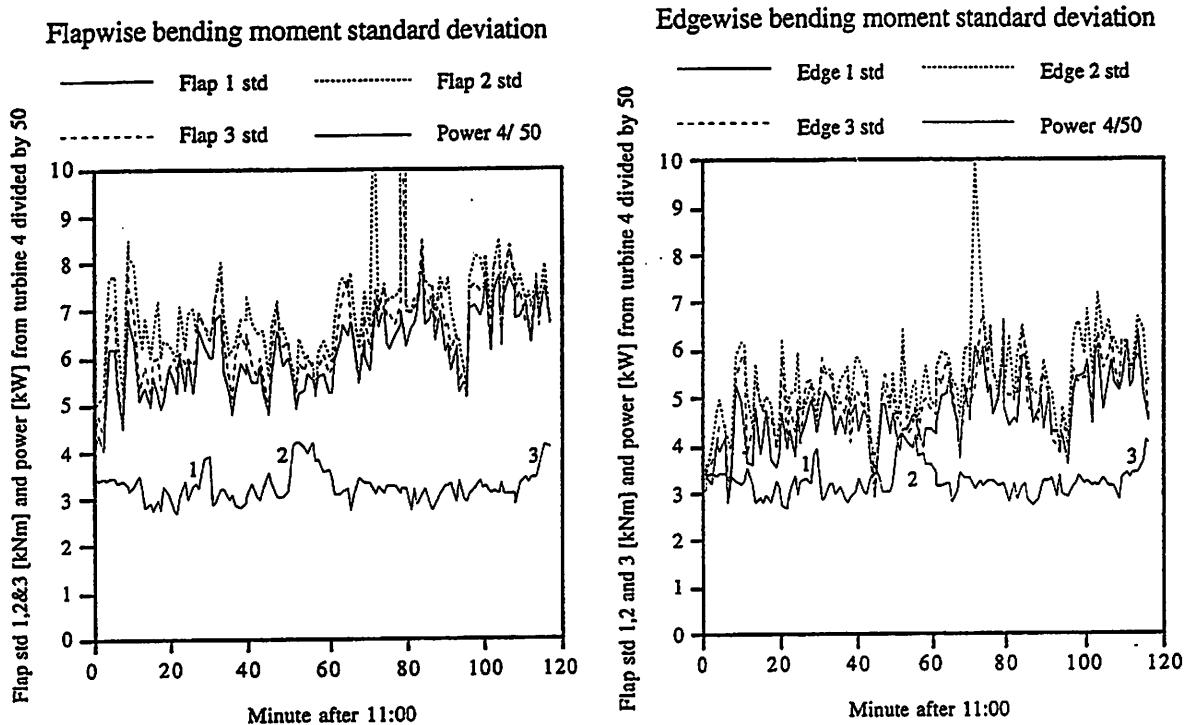


Figure 2a and 2b: Edge- and flapwise bending moment standard deviations for all three blades on turbine number four.

The load variation is actually smaller at the time of the "power peaks" than in between. What was the reason for the higher power output at these three occasions?

2.1 Wind speed changes?

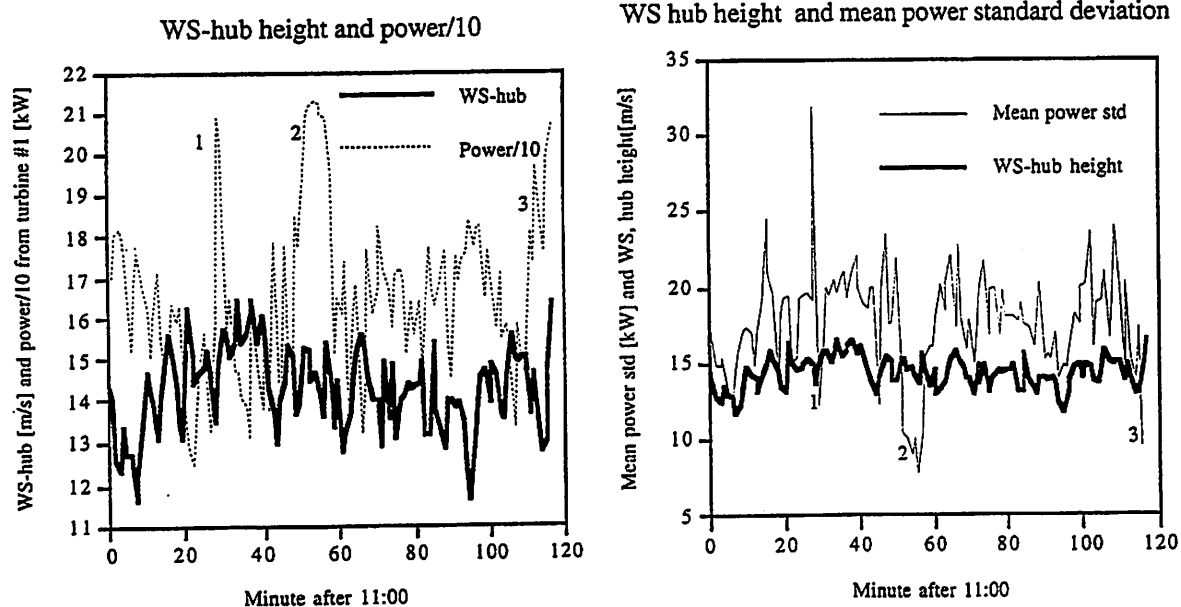


Figure 3a and 3b. Wind speed and power as well as wind speed and power standard deviation for turbine number one.

In figure 3 it can be seen that the wind turbine is operating in the stall region, i.e. the power increases with decreasing wind speed and vice versa. The power standard deviation decreases when the power exceeds 180 kW, occurrences numbered 1, 2 and 3 in the graphs. Figure 3a indicates that wind speed changes can not be the reason for these "power peaks".

2.2 Turbulence intensity?

Dahlberg & Ronsten [5] have shown that increased turbulence intensity will increase power performance. This effect is, however, small in comparison with the effect of yaw misalignment and wind gradient.

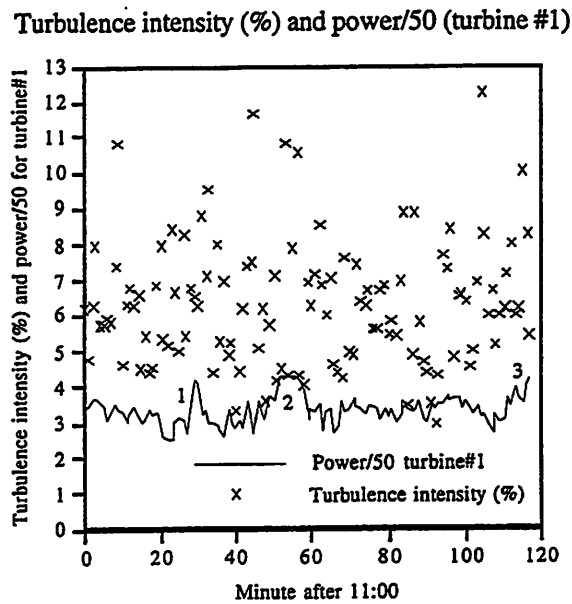


Figure 4: Turbulence intensity and power/50 for turbine #1

At none of the three occasions, 1, 2 or 3, the turbulence intensity is extremely high. In fact, during occasion number 2, it is rather low. This might be caused by ice build up on the anemometers. Figure 4 and reference [5] indicate that increased turbulence intensity can not be the reason for the "power peaks".

2.3 Yaw misalignment?

Rasmussen has shown [6] that a yaw misalignment of 30° - 40° in the stall region will increase power and loads significantly. A similar effect was shown in ref. [7] where the power coefficients for different yaw angles cross at low tip speed ratios.

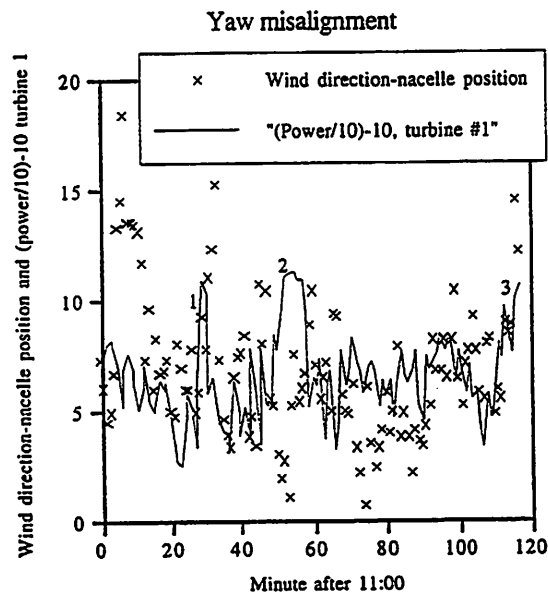


Figure 5: Yaw misalignment [$^{\circ}$] and power [kW] from turbine 1 divided by 10 and 10 subtracted in order to make it possible to show in the same diagram.

There is an offset of about five degrees between the two sensors which might be caused by a shift in wind direction on the nacelle as the turbine operates, ref [8]. Yaw misalignment can not be the cause of the "power peaks" as the flap- and edgewise bending moment variations decrease in these situations (figure 2a, 2b and ref [6]).

2.4 Wind speed gradient?

The wind speed gradient in mast #1 and the power output from turbine #1 can be viewed in figure 6.

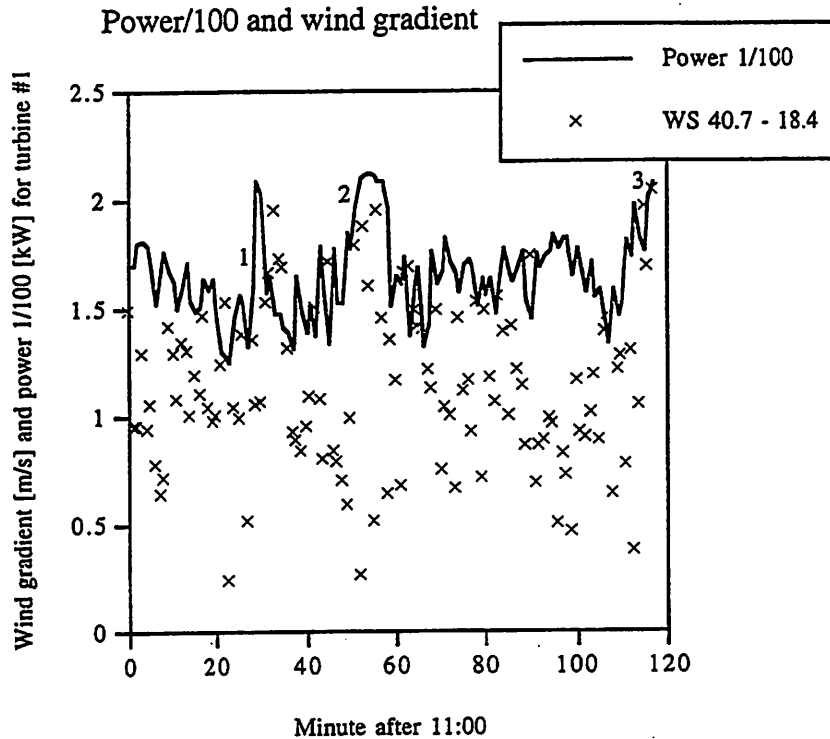


Figure 6: Wind speed gradient over the turbine and power/100 for turbine #1.

Figure 6 indicates that the wind speed gradient during the 2nd occasion is not always large and that it can not be the main reason for "power peak" number 2. If the wind speed gradient would have caused the "power peaks" the edge- and flapwise bending moments variations, figure 2a and 2b, would have increased instead of decreased.

2.5 Ice?

Meteorological data from Alsvik, including temperature distribution along a mast, are available from a data acquisition system which runs in parallel with the FFA system. There are no humidity sensors or ice detectors at the site. Hans Bergström at the meteorological institution of Uppsala university (MIUU) has extracted the temperature data in figure 7.

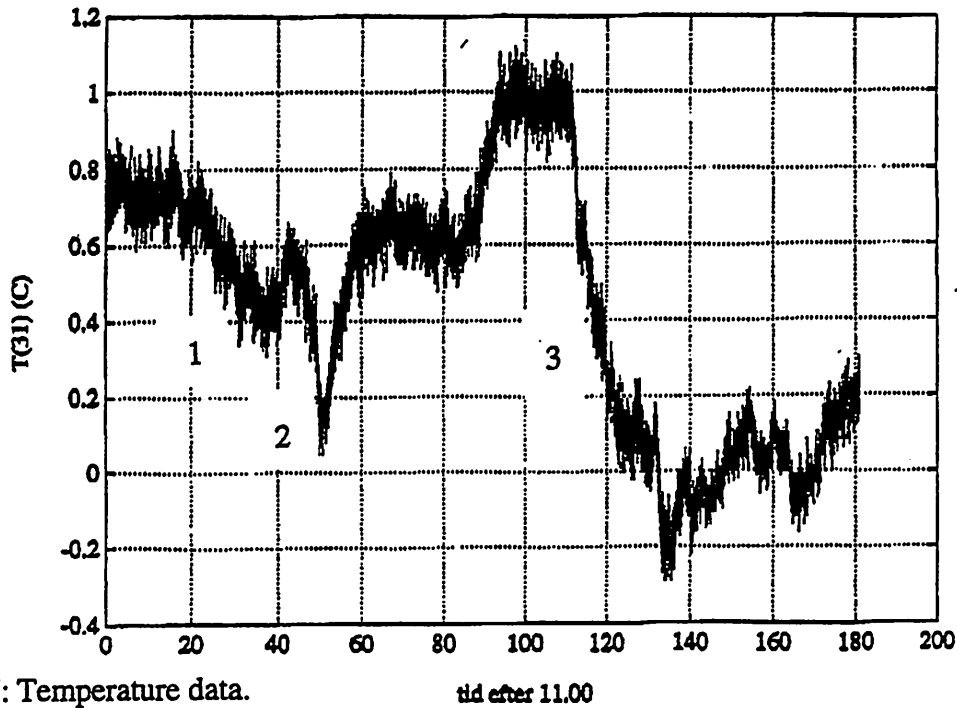


Figure 7: Temperature data.

According to Hans Bergström, it was raining of and on at Alsvik during the 5th of March.

A conclusion from the data above is that ice build up might be accounted for causing the excess power at all three occasions. What might then be the possible shape of the possible ice build up? Figure 8 was found in [9].

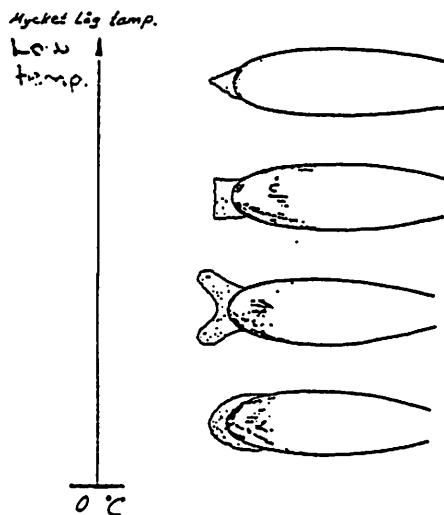


Figure 8: Simplified visualisation of ice shape as function of air temperature.

A possible ice build up in this case did not, however, occur at low angles of attack, but at angles of attack around and above stall. Referring to Mr Martin Ingelman-Sundberg, former head of the low speed wind tunnel at FFA, there exists a NASA report from the early 60's where ice shapes were formed at high angles of attack. The author have not been able to find that report in reference [10]. Curiously enough reference [11] reported about ice accretion 50 years earlier on the very same day! The content of [11] is not referenced in this report, it is only mentioned as a coincidence. Another report, reference [12], shows results from experiments but the only configuration of interest in that report, R7, was never tested.

Wind tunnel tests were carried out at FFA during the mid-seventies with the intention to map the performance of a NACA 652A215 airfoil with various ice shapes on the leading edge. As the build up of ice on an aircraft is most dangerous during the departure and the approach phase, the emphasis was put on ice accretion in combination with high lift devices such as flaps and slat. Most of the data

from these tests are therefore of little value when applied to wind turbines as only data for the clean configuration with various shapes of schematic ice configurations are of interest.

Claréus performed such a wind tunnel test and the results are available in reference [13]. An interesting comparison of airfoil performance is shown in figure 9.

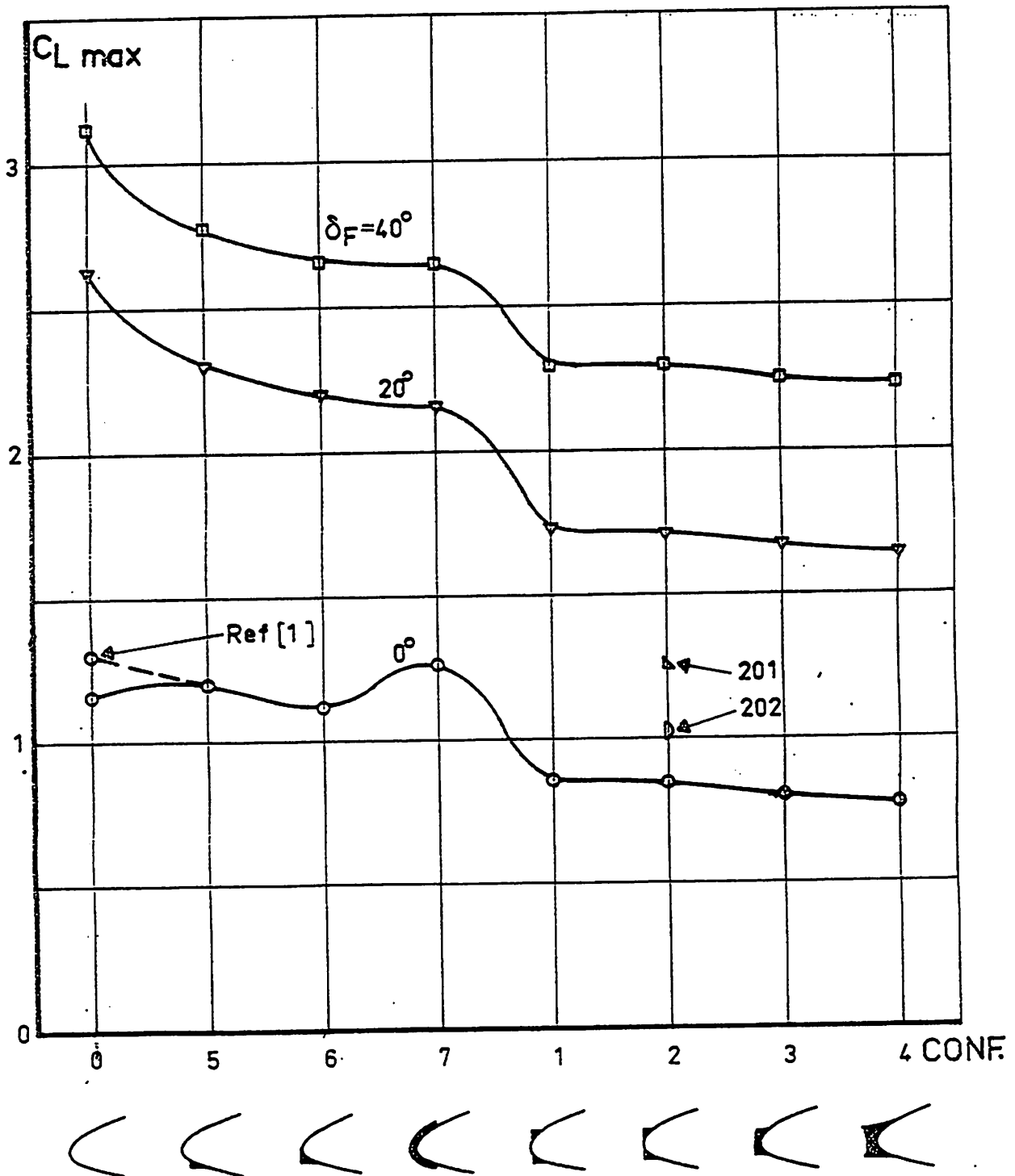


Figure 9: Maximum lift as function of schematic ice configurations and trailing edge flap deflections, reference [13].

Configuration number 7 is similar to the ice accretion at temperatures around 0° C found in figure 8. The leading edge radius is larger than the original and such an airfoil can be expected to experience a higher maximum lift. It is worth pointing out again that the shapes of the possible ice build ups at the time of the three "power peaks" are unknown.

Most likely, the build ups have followed the direction of the stagnation stream line (at a temperature around 0°) and the resulting airfoils could have had more camber as well as larger chords than the original ones. A possible reason for the decrease in both power fluctuations and load fluctuations is therefor the build up of a set of entirely new airfoils which during the above mentioned operating conditions are more insensitive to wind speed variations than the original blade geometry.

3. CONCLUSIONS

Ice accretion on the blades may have been the reason for the three "power peaks". The power outputs increased while the load variations decreased. The wind turbines at Alsvik are stall controlled, three-bladed with rigid hubs. A wind turbine with a teetered hub will be more insensitive to yaw misalignments as well as to wind speed gradients than a turbine with a rigid hub. Both hub arrangements would, however, have experienced the same power peaks if they were caused by ice build ups.

4. RECOMMENDATIONS

A wind turbine is normally stopped if loads, vibrations or power output exceed certain limits. The reasons for some stops are unknown. As ice accretion is a rare problem it will probably not be worth detecting which means there still will be a number of stops without any obvious explanations.

Wind tunnel tests with airfoils equipped with stall strips of various geometries and at different locations should be carried out in order to investigate any possible gain in airfoil performance and stall characteristics. When designing airfoils for variable speed, stall controlled wind turbines it might be worth considering optimizing the airfoil's performance within only a small range of angle of attacks and not look upon the use of stall strips as a failure but as a possible best solution to the problem as sometimes is done when developing aircrafts.

5. REFERENCES

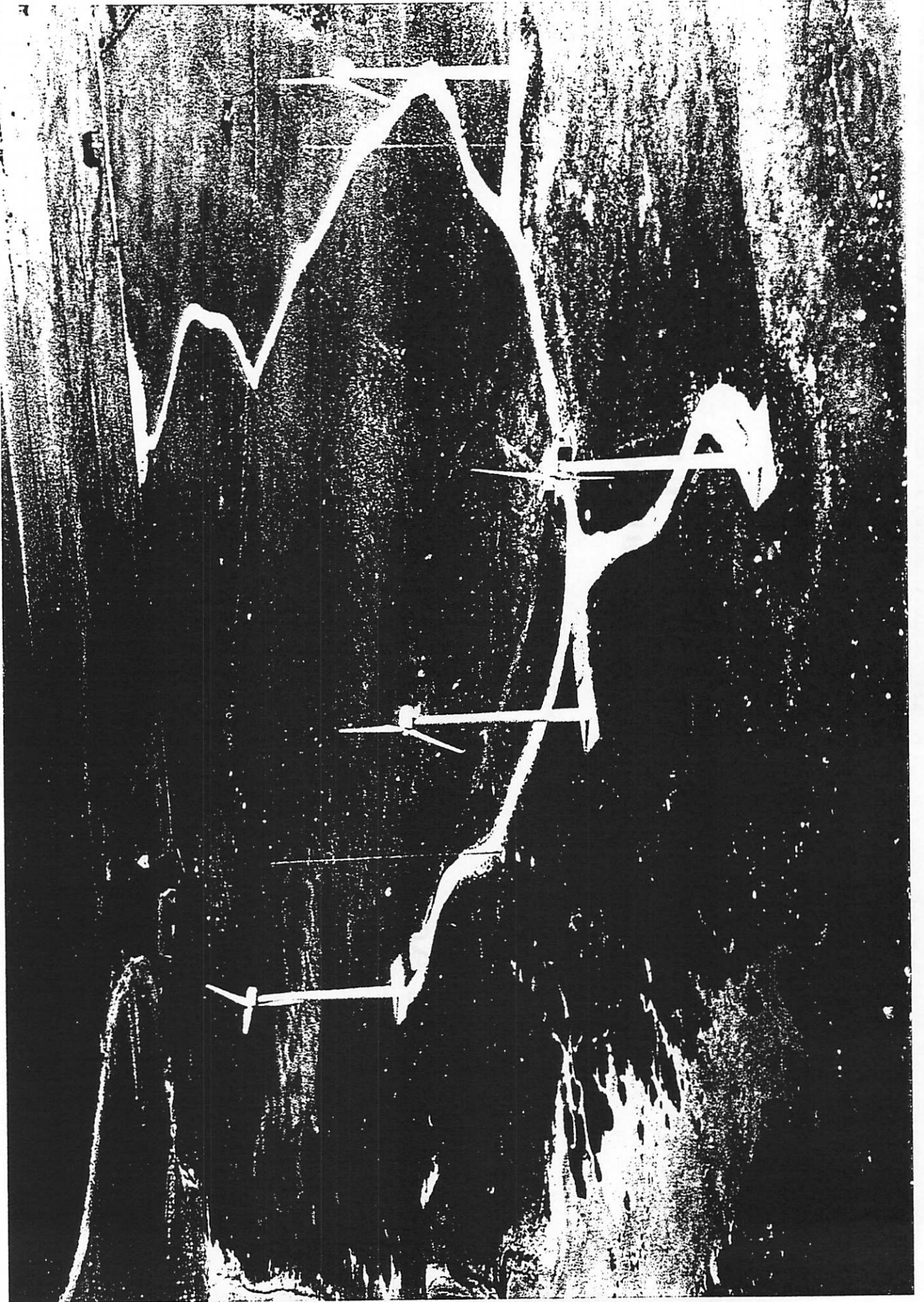
- [1] Gustafsson A., Meijer S., Kwick T., "Preparatory icing studies for Swedish prototype WECS", BHRA, 4th intl. symposium on wind energy systems, Stockholm, 1982.
- [2] Andersson A., Vattenfall, phonecall, 930419.
- [3] Poppen M., Dahlberg J-Å, Thor S-E, "Fattigue loads on wind turbine blades in a wind farm", FFA-TN 1992-21, Stockholm, 1992
- [4] Johansson B, Vattenfall, phonecall, March 1993.
- [5] Dahlberg J-Å, Ronsten G, "Some recent activities att FFA" presented in "Proceedings of the sixth IEA symposium of the aerodynamics of wind turbines", ETSU, 1993.
- [6] Rasmussen F, "Blade and rotor loads for Vestas 15", Risø-M-2402, 1983.
- [7] Dahlberg J-Å, Ronsten G, Ulén E, "Results from wind tunnel tests on a Ø 5.35 m HAWT in yaw operation", presented at ECWEC-93 in Travemünde.
- [8] Friis P., "The Tjæreborg wind turbine. Operation and results, status 1993", ECWEC 1993
- [9] "Varning för isbildning" (in Swedish), Meddelande från luftfartsinspektionen, MFL 60/1978-B, 1978.
- [10] "Icing Technology Bibliography", SAE AC-9C Aircraft, Icing Technology Subcommittee, 1987
- [11] "A report of ice accretion on March 5, 1943.", Transcontinental and Western Air, Inc., Met. Dept., Tech. Note No. 7, July 1943.
- [12] Zaguli R.J., Bragg M.B. and Gregorek G.M., "Results of an experimental program investigating the effects of simulated ice on the performance of the NACA 63A415 airfoil with flap", NASA-CR-168288, Ohio, 1984.
- [13] U. Claréus, "Ice simulation - a 2-dimensional wind tunnel investigation of a NACA 652A215 wing section with single slotted flap.", FFA TN AU-955, part 2, Stockholm, 1974.

**Can delayed stall be caused by ice accretion on the
leading edge of an airfoil?**

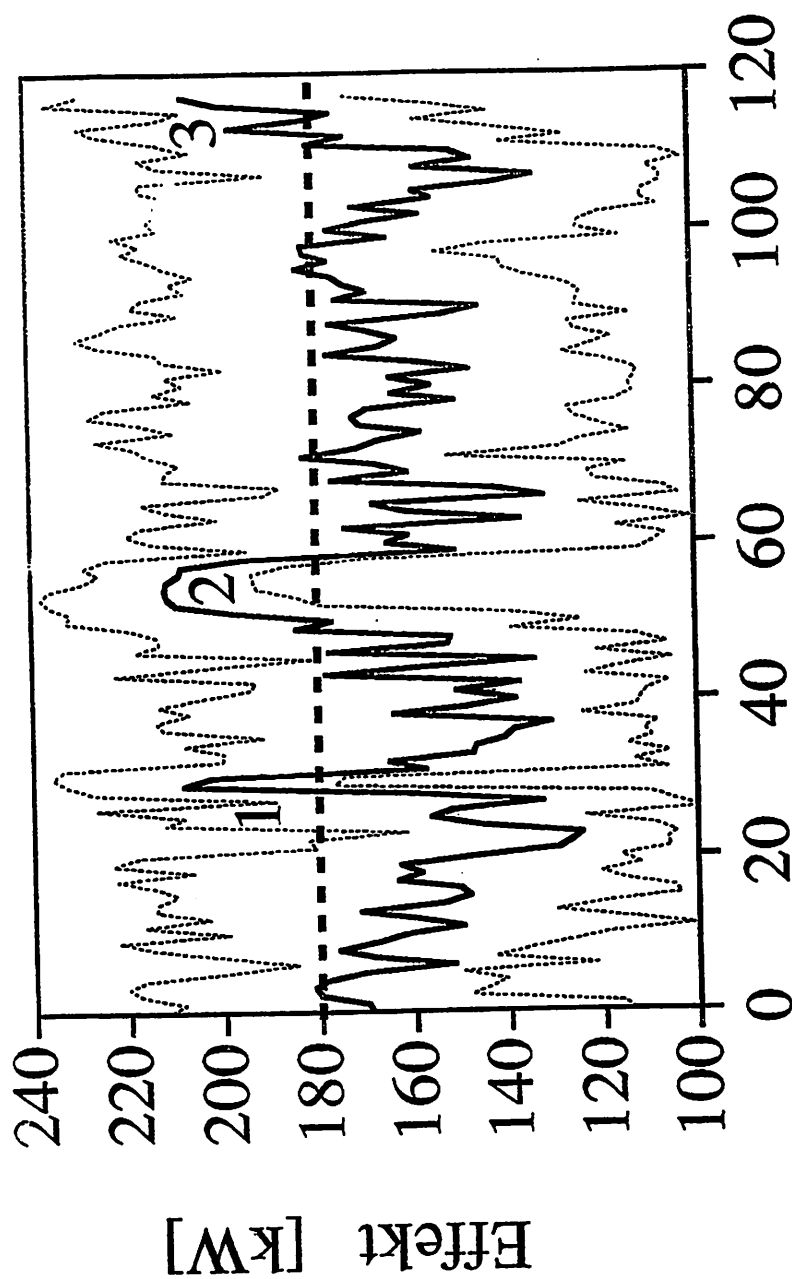
Göran Ronsten

FFA -

The Aeronautical Research Institute of Sweden



1-min medelvärden, min and max effekt
under 2 timmar, Turbin #1



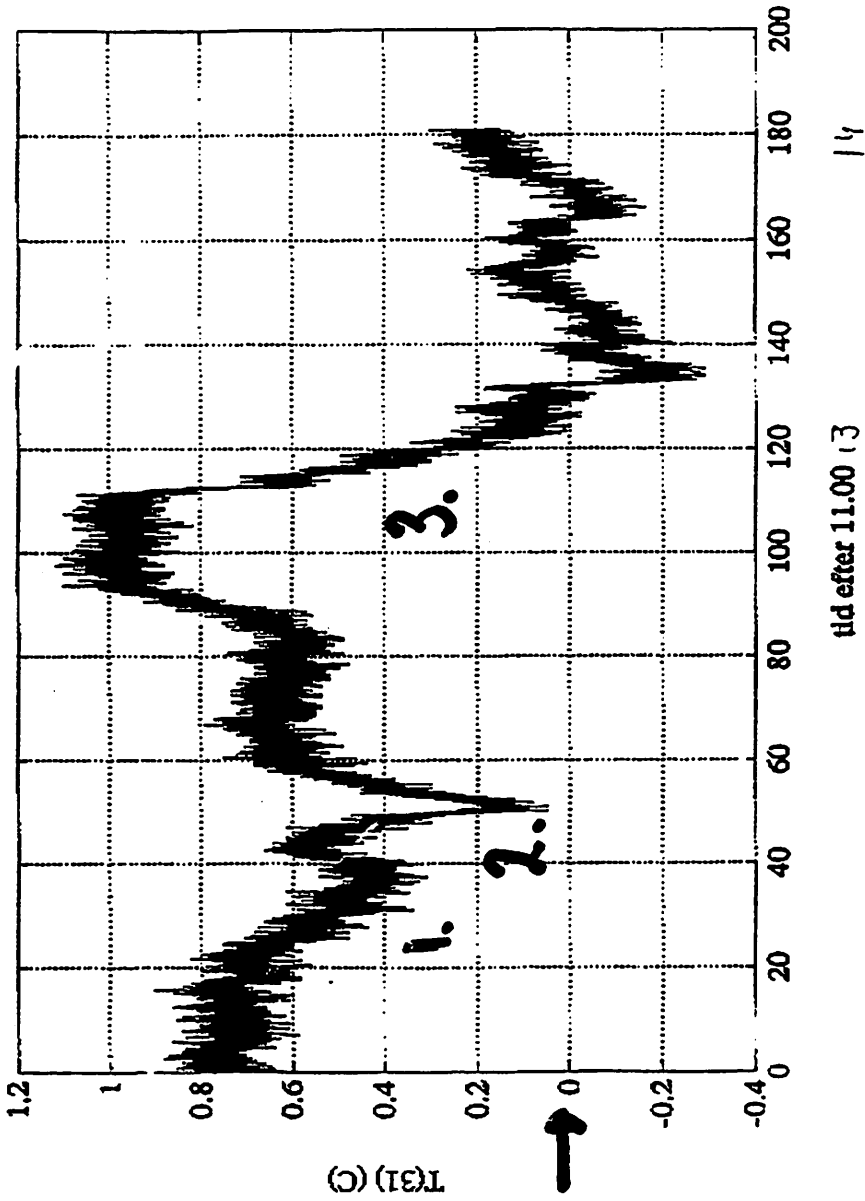
Delayed stall caused by ice accretion on the leading edge?

Factors checked:

- Wind speed
- Turbulence intensity
- Yaw misalignment
- Wind speed gradient
- Temperature

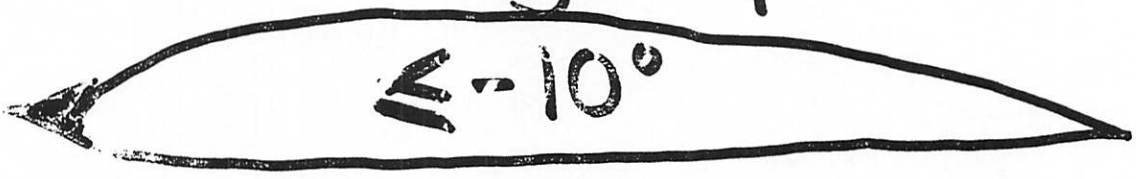
Temperatur

Alsvik 930305

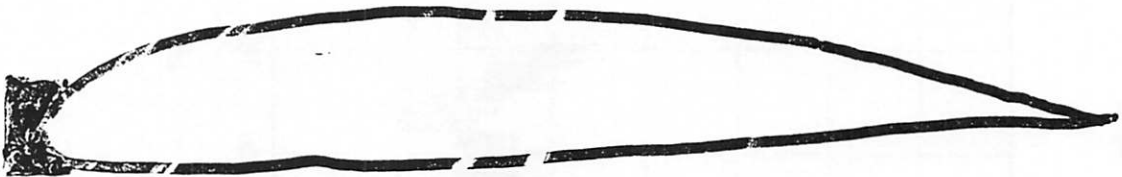


Låg temp¹⁶

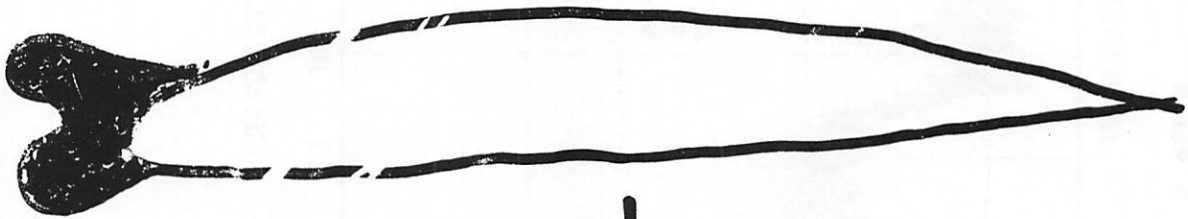
$\leq -10^{\circ}$



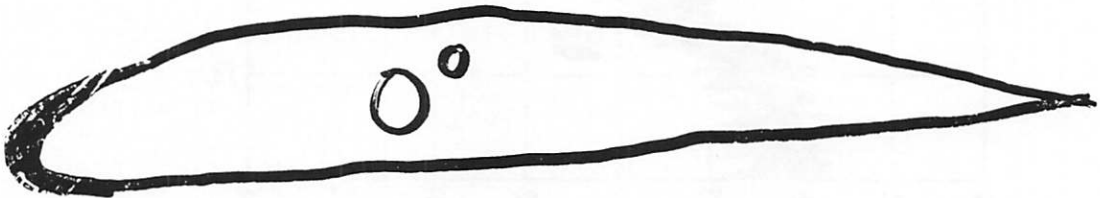
↓ hög. temp.



↓ hög. temp.



↓ hög. temp.



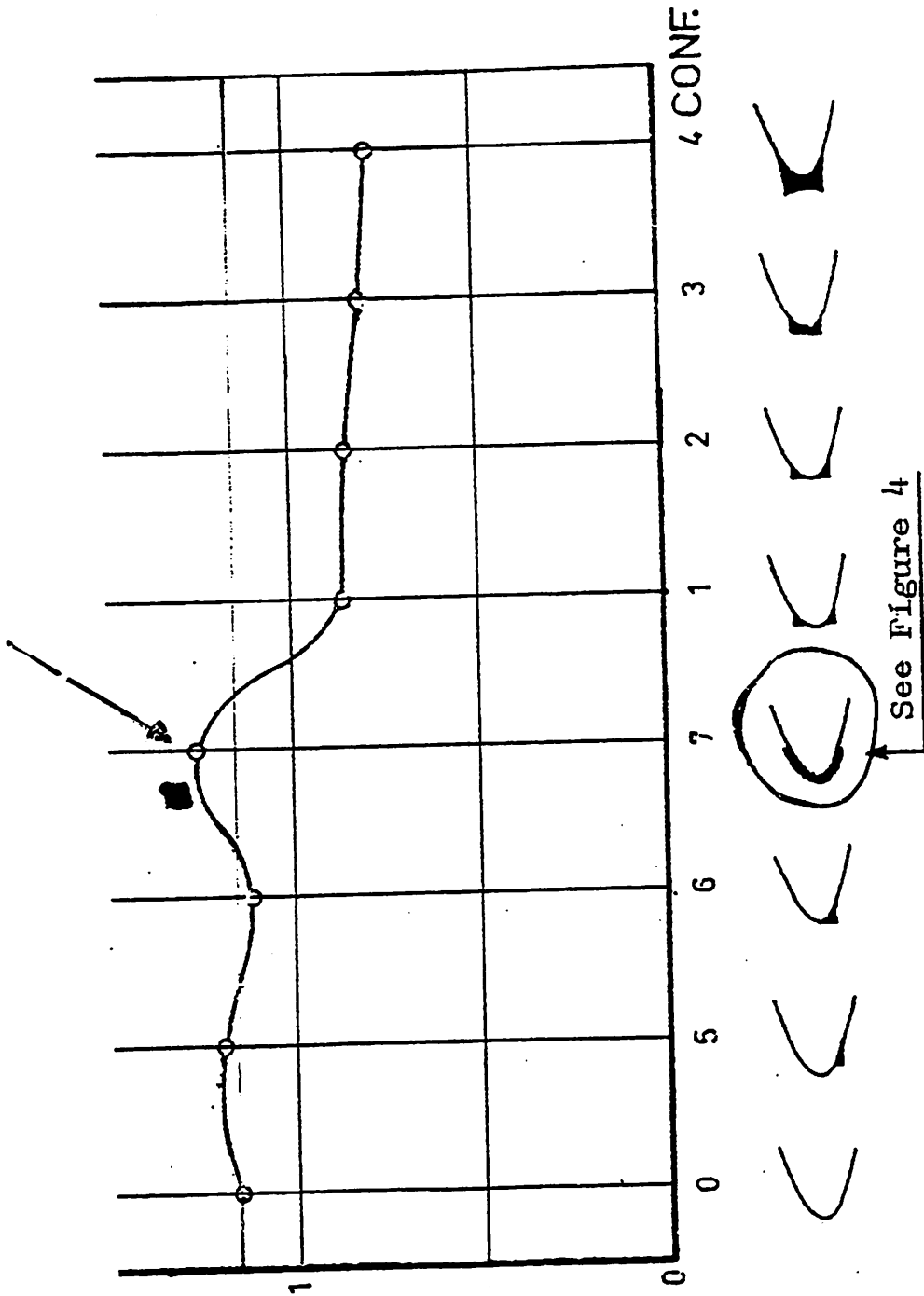


Figure 10. Effect on maximum lift of ice shapes consider of importance for transport (= large) aircraft.

Delayed stall caused by ice accretion on the leading edge

Conclusions:

- **Ice accretion on the leading edges is the most probable reason for the power peaks**

Next task

- Image analysis of ice accretion on a Bonus 600 kW (Vattenfall utveckling AB, STEM and FFA)
- Correlation between ice and loads
- Cooperation with Bonus (and VTT?)
- Starts 2nd quarter 1999

SUORVA – ARCTIC WIND TURBINE IN NORTHERN SWEDEN

Jan Norling
 Vattenfall Utveckling AB
 814 26 Älvkarleby
 SWEDEN
 Tel: +46 26 83 521
 Fax: +46 26 83 670
 jan.norling@utveckling.vattenfall.se

ABSTRACT: The strive of developers and local initiatives to find sites with good wind conditions for wind turbine installations has made the areas in northern Finland and Sweden attractive. However, it is not a common and well-established knowledge how to build and operate wind turbines in the prevailing arctic conditions in this area. The Swedish utility Vattenfall has built its first arctic wind turbine with the purpose to gain and deepen knowledge and experience. The work presented here describes the project, the site and initial experiences.

Keywords: Suorva - Wind Turbine – Icing/Frost– Low Temperatures

1. INTRODUCTION

Building of arctic wind power plants in northern Scandinavia started in Finland and has increased with several projects in Finland, Norway and Sweden. As in all projects there are some specific types of problems and is so as well in arctic projects.

The question raised by the wind turbine developers and turbine owners / operators is whether wind power in arctic climate with its associated problems has a role in the future market or not. This leads to more questions about public acceptance, environmental impact, acoustics, power performance, icing, availability, operation and maintenance, costs etc.

The answers are not clear and obvious and that is why Vattenfall started the Suorva project.

2. THE SUORVA PROJECT

In October 1998 the Swedish utility company Vattenfall built a wind turbine equipped for arctic conditions at a site called Suorva. Suorva is located 100 km north of the Polar Circle near the springs of the Stora Lule River. The Suorva project goes back to 1992 when a local initiative group studied the possibilities to build a wind power plant due to the supposed good wind conditions. In 1995 a 36-meter meteorological measurement mast was built on Vattenfall land on a ridge between two hydropower dams. The positive measurement results initiated a discussion with Vattenfall to build a wind turbine and in late June 1998 the necessary permissions and support from the authorities was obtained. The wind turbine in Suorva was built.

The project has a building and an evaluation phase and is financed by Vattenfall and the Swedish State Energy authority, Energimyndigheten. Vattenfall has the overall management function with experts participating from Vattenfall and external organisations.

Building and commissioning

In early August 1998 Vattenfall signed a contract with Bonus Energy A/S to deliver one arctic equipped 600 kW Mk IV wind turbine to Suorva. At the same time we had contractors for road and foundation work to investigate the site. This resulted in two contracts and the work started in August 18th. Due to the weather conditions in Suorva the time schedule was critical. The risk of being stopped several weeks because of high wind speeds and snow was big. The time schedule stated October 8th for erection.

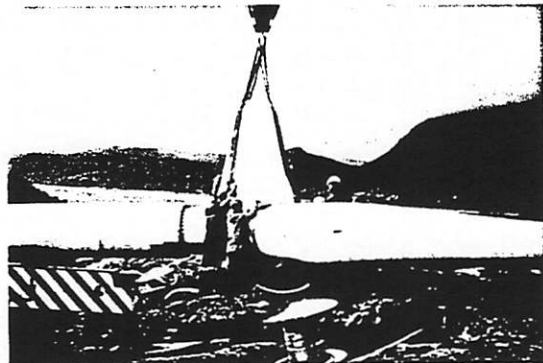


Figure 1: Suorva lift of rotor.

There were minor delays in the building of the rock foundation that caused extra costs but the time schedule was kept and the tower was erected and the nacelle was lifted up during October 8th. The rotor had to be lifted up the next day due to wind speeds over 12 m/s which was the limit for the crane.

In October 13th 1998 the wind turbine delivered electricity to the grid for the first time.

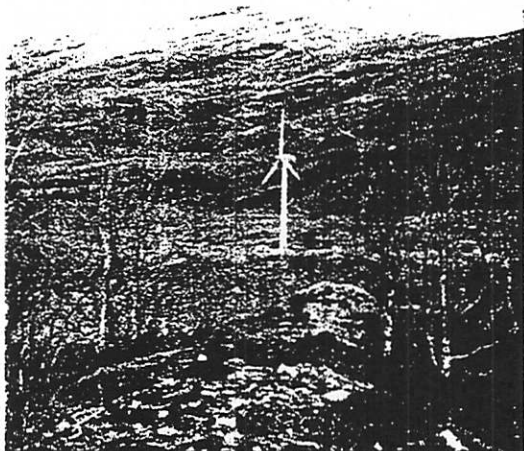


Figure 2: Suorva wind power plant.

Evaluation

An evaluation programme is planned and will be in progress during 1999 to 2001. After the erection of the wind turbine, the evaluation programme has been finalised with the following contents:

- operation and maintenance
- public acceptance
- environmental impact
- power performance
- ice - loads/stresses
- acoustics

3. THE SUORVA SITE

Suorva is located at latitude north 67.30° and longitude east 18.15° in the north of Sweden. The site is characterised by the surrounding mountains with peak heights of 1400 - 1500 meters above sea level. The peaks are within 5-6 km from the site in the south-west and north-east directions. The foundation is situated 470 meter a.s.l. on a small ridge in the valley.

North-east of the site is Sweden's second largest water reservoir for hydropower purposes. The reservoir has a regulation span for the water level of 30 meter from top level +453 meter a.s.l. to the bottom level. This can be of importance for the acoustic evaluation.

The measurements of wind conditions have been coordinated by the local initiative group Suorvavind HB, Mikael Segerström and analysed by Hans Bergström from the Department of Meteorology, Uppsala University. The results from the first year is:

- annual mean wind speed at the height of 35 m was estimated to be 7.5 m/s with the highest observed wind speed 32 m/s
- channelling effects in the wind direction distribution in the direction of the valley, see fig 2
- icing conditions, defined as occasions with a relative humidity above 95% and a temperature below 0°C , were experienced during 2-4 % of the time.

On the mountain Juobbmotjåkko, 7-8 km south-east direction from the turbine, the windspeed is measured on a 50-meters mast. The mast is located 900 meter a.s.l. As an example of the very high wind speeds, measurements made in December 1997 shows 1-minute average windspeeds over 50 m/s during a 5-hour period before the anemometer broke down.

The people that lives and visits the area is reindeer herders, service personnel for two hydropower plants and tourist boarding houses. Another large group is fishing-tourists and walkers. Their opinion about wind power in this particular area is going to be gathered by interviews.

The service personell of the nearest hydropower station are living 3-4 km from Suorva and they are regularly visiting the turbine. The daily supervision with statistics and fault alarms is managed by the Vattenfall wind turbine remote monitoring centre at Gotland in the south of Sweden.

Suorva is 110 km from the nearest village Porjus. The existing local 10 kV-grid and road was as near as 300 meter from the turbine site. The local electrical consumption in the area is transmitted on a 40 kV line 110 km from Porjus so the Suorva turbine reduces the grid losses.

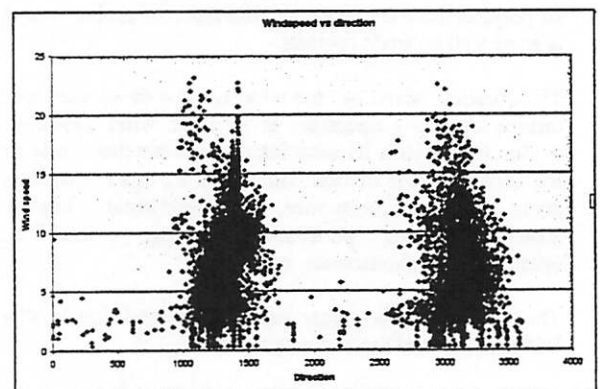


Figure 3: Suorva windspeed vs direction Nov-Feb 1999.

4. POWER PLANT DATA

The turbine is a three-bladed Bonus Mk IV with arctic equipments and the rotor is an upwind model with 44 meter diameter, 1520 m^2 swept area. Rotor speed is 27 or 18 rpm depending on which generator used. Output power is 600 kW from an asynchronous generator at 690 V. The output power is transmitted by 20 meter cable to an 800 kVA transformer, 690 V to 12 kV.

The transformer is located in a small house which has a grey colour to melt in to the surroundings. The house is anchored in the rocks in each corner with steel-wires due to the risk of being moved by strong winds.

The three 19-meter blades have a VTT / Kemijoki developed blade heating system, JE-system. The system uses a carbonfibre surface mainly on the outer part on the blades and on the leading edge. Heating is regulated by signals from a Labko ice-detector and thermistors between the carbonfibre and the original glass-fibre surface to a separate control system. If the ice-detector shows ice and the wind speed is below 11 m/s, the

heating is 9 kW on each blade. If the windspeeds exceed 11 m/s the heating is 15 kW / blade.

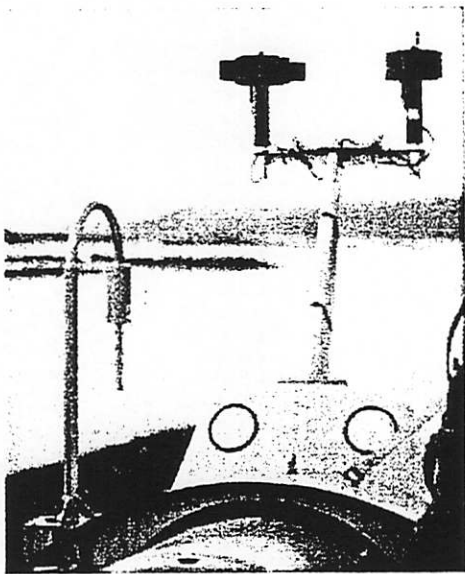


Figure 4: Suorva, heated sensors and ice detector.

The arctic equipment also includes heated vindvane and anemometer from Hydrotech, heated gearbox and control system. The lubricants is of low-temperature type with low viscosity.

The tower consists of two sections, 10 and 30 meter respectively. The bottom is bolted to the foundation with 112 bolts in a circle diameter of 3 meter. The foundation is a rock version 6-meter square with a minimum thickness of 0.9 meter. The foundation is connected to the rock by 40 pieces of 32 mm diameter iron in grout filled 8-meter deep holes.

To control the site we have two telephone wire channels. One for the meteorological mast system and one that is divided by the PLM-system, the control system, the energy measurement system and the separate Vattenfalls fault alarm system.

More to read about Bonus Energy A/S experience from building and operating WT in arctic environment is to find in [1].

5. MEASUREMENT SYSTEMS

The evaluation programme depends upon two measurement systems and the control system. The wind turbine manufacturer Bonus Energy has placed a system (PLM-system) in tower bottom to measure various parameters. It is separated from the regularly control system. This system samples with 25 Hz and examples of parameters measured are wind speed, wind direction, temperature, output power, flap- and edgewise bending on vings, torque on main shaft, parameters from the anti-ice system etc. Data can also be obtained from the control system.

The meteorological conditions are measured by anemometers at four heights on a 39-meter mast near the turbine a searate measurement system. The anemometer on 12 and 39 meters level are heated Vaisala. Wind

direction and temperature is also measured. The system stores 1-minute averaged data.

For an extended meteorological evaluation there are one 50-meter mast, mentioned in the text earlier, and one 10-meter mast placed in the valley. Both have anemometers and windvanes and are within 10-km distance from the turbine.

6. EXPERIENCE GAINED

The Suorva turbine has produced nearly 0.6 GWh since the commissioning date October 8th. The availability was 96 % during the first four months, excluding periods with low temperature stops. The average ambient temperature in Jan./Feb. was -12.5°C with a minimum of -37°C . During the same period the average wind speed was 7.4 m/s with a maximum of 23.1 m/s.

Energy consumption of the blade heating system, the JE-system, has so far been less then 2 % of the produced energy. After minor problems initially the system is now working properly.

In the transformer house there is space for measurements of energy and for telephone equipment. During a snowstorm in January the space was filled with snow and the tele equipment broke down. The door is now tightened with rubber strip.

During the first five months newspapers and television have given attention to Suorva and is with few exceptions mainly positive.

REFERENCES

- [1] H.Stiesdal, H.Kruse Bonus Energy A/S
10 year with arctic modifications – a
manufacturers experience

Anders Schönborg, AGRIVIND AB

WINDTURBINE IN COLD CLIMATE - RODOVÅLEN, SWEDEN

Picture 1. Is there a golden treasure to be found among the Swedish fjelds, or - maybe even better - an everlasting source of clean and renewable energy?

Eager to get an answer to that question our company, AGRIVIND, started this windturbine project called "The first Swedish turbines in cold climate" in the middle of last year, 1998.

Picture 2. AGRIVIND is a small company owned by the chairman of the Swedish wind turbine society - Lennart Blomgren - and me - Anders Schönborg.

During 10 years AGRIVIND has been involved in approximately 10 % of Sweden's more than 400 wind turbines, in the beginning only responsible for foundation and concrete work but later on more and more initialising and selling of whole projects, mostly to farmers and local people in some sort of economic association.

During this period we have encountered increasing difficulties in getting all the permissions you need to build wind turbines in Sweden.

There are two things that complicate the establishing of wind turbines in Sweden.

Firstly, the very low price you get as a producer of electrical energy. This forces you to build the turbines in coastal areas where you very easily come into conflicts with other interests like summer cottages, bathing, other sorts of outdoor life etc.

Secondly, the very tough regulations of noise levels along with the fact that Sweden some 150 years ago carried through a nation-wide partition of land and moved the houses belonging to the farmers out from the villages and into the fields, that makes it a lot more difficult to find areas where there is space enough between the wind turbines and the farm buildings and other kinds of housing.

These are the main reasons why it would be so advantageous in Sweden to solve the problems of wind power in cold climate. The fjeld area represents a big part of the total area of Sweden and it is also sparsely populated. An example of this is the province Härjedalen in which we are now with this development project. There is only one inhabitant per square kilometre.

- Picture 3. The name of the place for this project is Rodovålen, a small mountain top located at 62° north, in the middle of Sweden, with a sub arctic climate.
- Picture 4. Local people and the local authorities have been very positive to the project from the beginning. At the end of June last year we started the project by building roads and digging for the foundation.
- Picture 5. Three different turbines from three different companies are taking part in this project.
- Picture 6. Number one. The first Nordex turbine ever built in Sweden, a 600 kW machine on a 46 metre high tower built in the northern part of Sweden and with a 43 metre rotor. This turbine was meant to be equipped with a brand new de-icing solution
- Picture 7. from LM Glasfiber in Denmark. They had made some very promising tests with microwaves and wanted to make a full-scale test under tough conditions. The more they tried, however, to implement the solution the more difficulties arose. At first the turbine had to be delivered without de-icing system but in all other respects adapted for the cold climate
- Picture 8. Number two. A Bonus turbine, 600 kW, Mk IV 44 metre rotor and a 40 metre
- Picture 9. tower with the transformer in the bottom. This machine has a newly modified

- Picture 10.** Kemijoki solution for heating the blades. At the moment there are five 600 kW
- Picture 11.** Bonus turbines with similar solutions - two in Sweden and three in Finland.
- Picture 12.** Number three. An NEG Micon turbine 750 kW. 44-metre rotor and a 50 metre high tower. This machine is bought without a de-icing system but it is prepared for such a one on the blades.
- The experiences from the building period show that it is far more expensive to build roads and concrete foundations. For example:
- the concrete costs more than 50 % more here than in the southern part of Sweden. Everything you need is far away. The crane had to drive for 12 hours to come to Rodovålen. The period when it is possible to build roads and foundations is very short. The first snow may come in the middle of September.
- Picture 13.** The place, the climate and the conditions are tougher than expected. The humidity is worse here than in the northern part of Sweden and Finland and because of that the whole turbine is very easily rimed. Sometimes a heavy load of snow appears on the blades.
- Picture 14.** As you can see there is absolutely a need of an efficient de-icing system in this kind of climate. Wind turbines with a de-icing system have - during the first two months - produced almost three times more energy than those two turbines without de-icing equipment.
- Picture 15.** A month ago LM Glasfiber changed the rotor on the Nordex turbine to a de-icing version and at the same time Bonus repaired damaged cables and hydraulic.
- Picture 16.** hoses through the main shaft

- Picture 17. On the first Nordex rotor there was a number of these yellow spots on
- Picture 18. the blades and through this round window there is a camera recording the growth and the thickness of ice and rime on the spots. On the replaced rotor there are less yellow spots because of the results from the first one.
- Picture 19. You can see the rather heavy rime and snow on this 20 kv grid and the radio link mast.
- Picture 20. It is surprising how much snow the blades are able to catch.
- Picture 21. At the moment we have problems with the bladebrakes on the Nordex turbine. Because of ice they got stuck when the turbine is standing and can't turn themselves into the right position again.
- Picture 22. This little twist causes a reduction of energy production for as much as 50 %.
- Picture 23. On this picture you can notice a difference between the length of the heating systems on the Bonus and the Nordex turbines. The Nordex version has a longer unheated rootend than Bonus has. The Nordex turbine has a thin layer of metal stripes
- Picture 24. under the bladesurface and each blade heating has an effect of 10 kw. The Bonus turbine has some kind of carbonfibre under it's surface and are working with 15 kw on each blade.
- Picture 25. From this picture you can see how the heating is working on the Bonus turbine for 24 hours, between 3 and 6 degrees below zero.
- Picture 26. During the last week in november 1998 the production has been 32.000 kwh and the consumption for heating 1.500 kwh aprpr. 5 % of the production.
- Picture 27. This is showing the windspeed, heating and temperature for the same period.
- Picture 28. And this one - power and windspeed also for the same week.

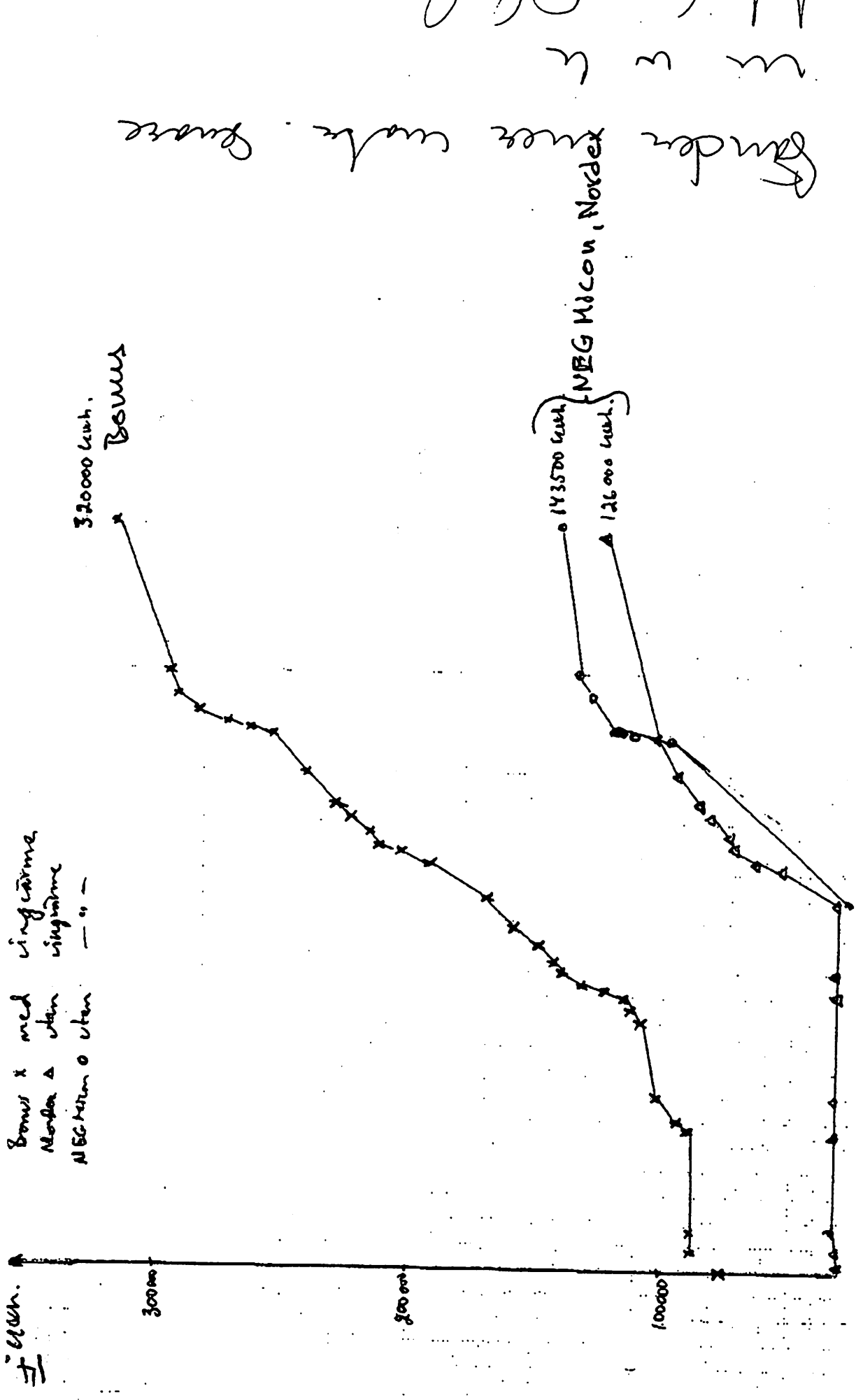
From AGRIVINDS point of view we think that it's too early to draw any conclusions so far because of too many initial problems but we think that in the long run we and the participants in this project will be able to succeed.

Finally I have to tell you about a rather odd task in this project. We have to watch if the wind turbines are disturbing the reindeer's habits

Picture 29. As you can see on this picture they are not afraid at all, they stayed here for a period of three weeks in January and February.

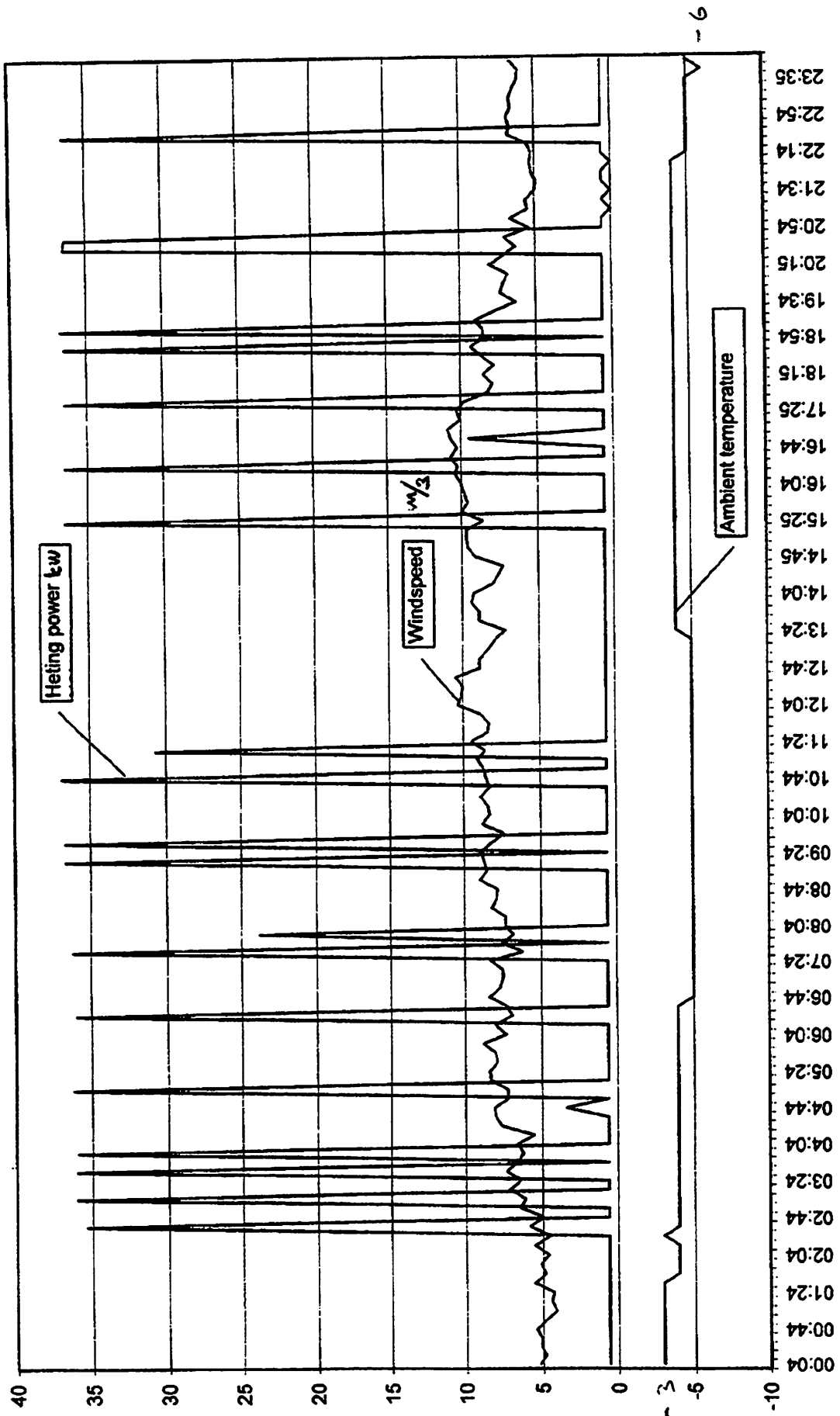
Picture 30. On the contrary they are causing harmless damages on the plastic hubs at the bottom of the towers.

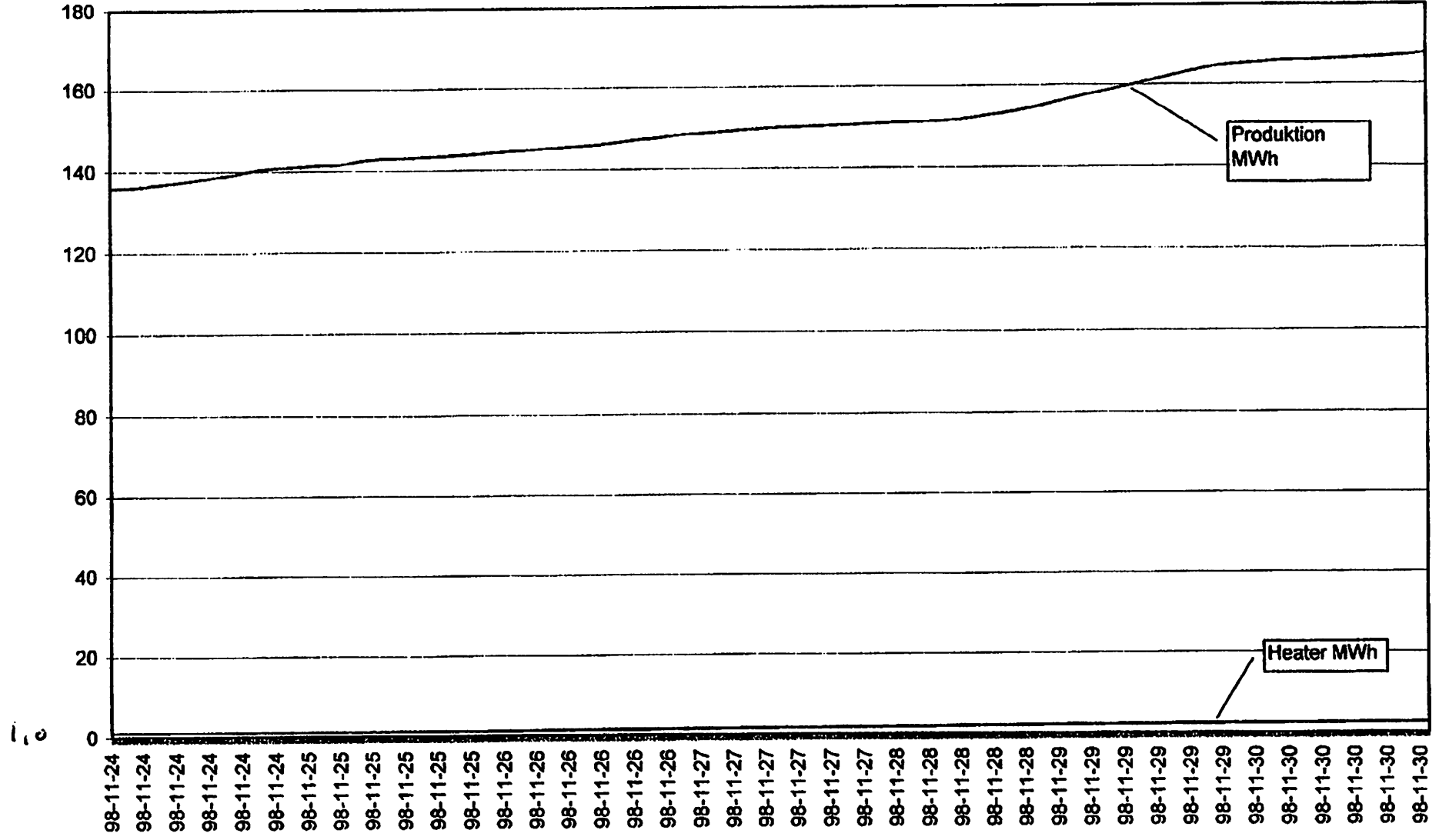
Bonus x med ringlörme
 Marka Δ utan ringlörme
 NEG-kon o utan — " —



Year	1981	1982	1983	1984	1985	1986	1987	1988
Value	1039.7	3210.5	1081.0	6.5	110.9	7.9	7.3	73.6

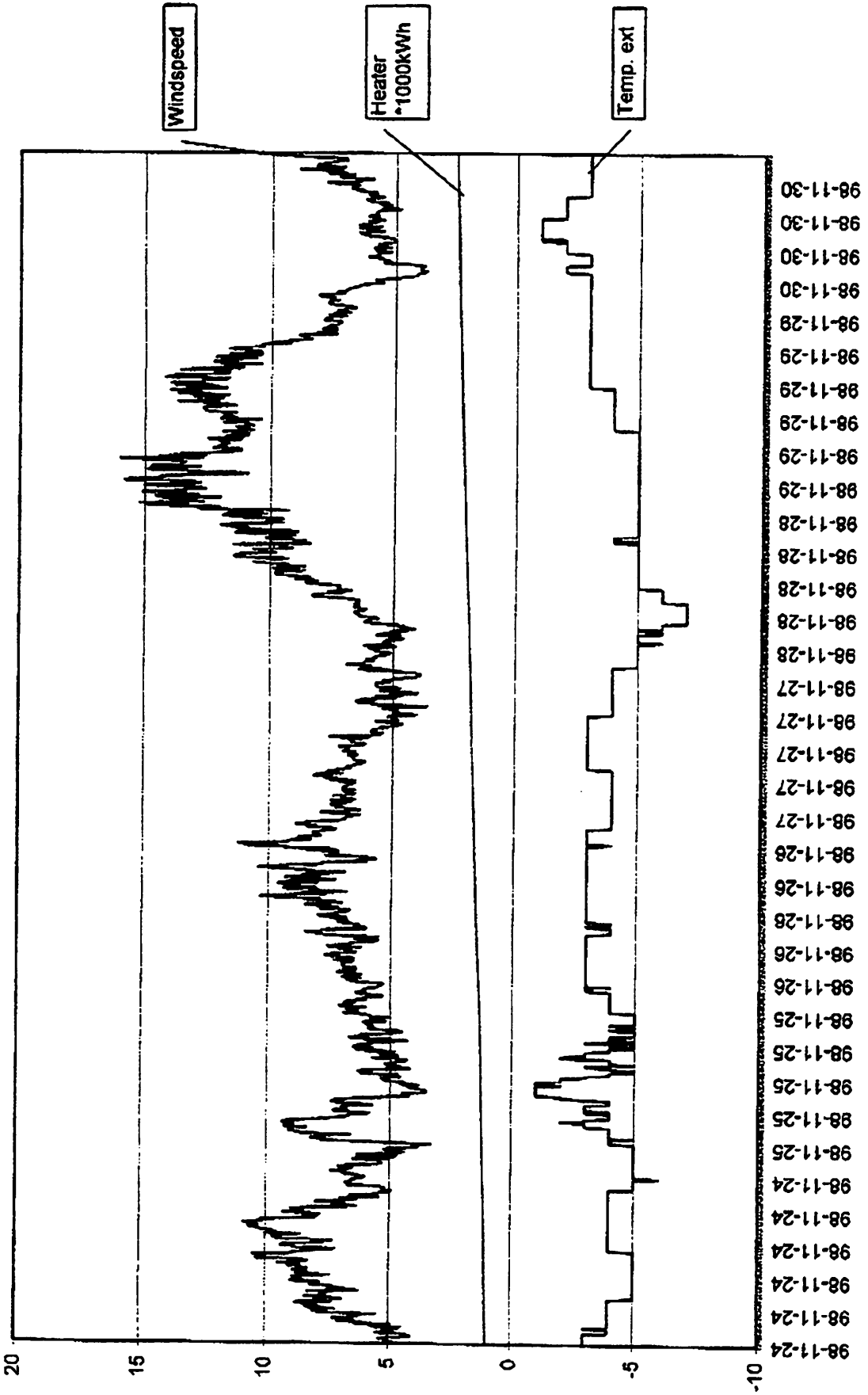
Fanden med mark. Bonus
 Marka Δ
 Aktivind 1982

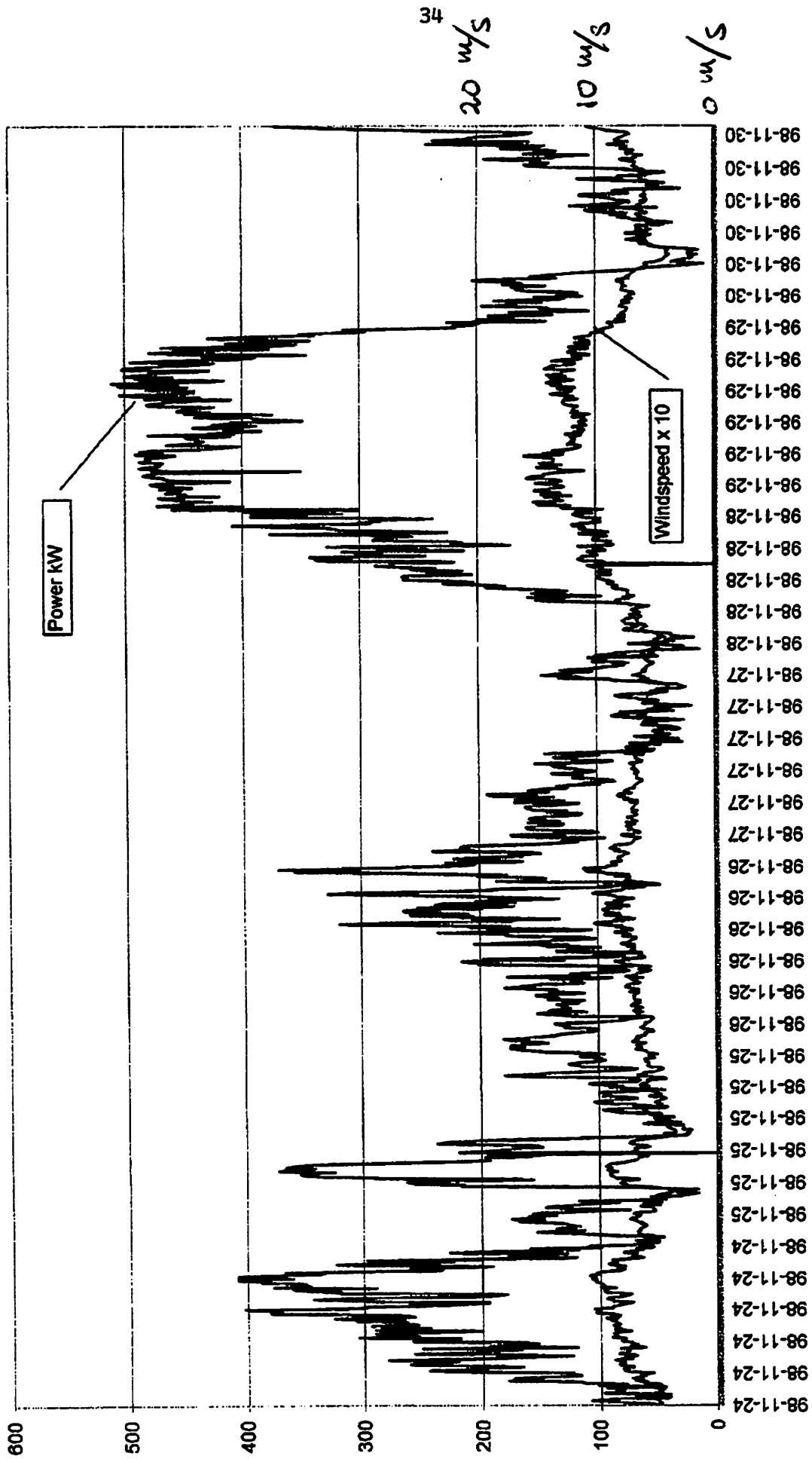




1.0

2.0





DEVELOPMENT AND EXPERIENCES OF ARCTIC WIND TECHNOLOGY IN FINLAND

Esa Peltola
Kemijoki Arctic Technology

Mauri Marjaniemi, Jonas Wolff, Hannele Holttinen
VTT Energy

Bengt Tammelin
Finnish Meteorological Institute

1. Introduction

The climatic conditions of Lapland set special technical requirements for wind power production. The most difficult problem regarding wind power production in arctic regions is the build-up of hard and rime ice on structures of the wind turbine. Ice accretion on rotor blades decreases power production and causes additional loading due to mass and aerodynamic imbalances and blade bending. Icing and ice masses also cause problems in starting up of a turbine after a stand by period.

Development of wind power techniques for arctic weather conditions started already at the first stage of the NEMO research programme 1988–1992. Wind measurements showed soon, that wind conditions on top of fells were exceptionally promising with annual mean wind speeds higher than 8 m/s on most of the fells. Tests with a small wind power generator were performed on the Pyhätunturi fell giving first, practical information of measurements in arctic fell conditions.

During NEMO2, the research has focused on full-scale test station, 225 kW Wind World turbine on Pyhätunturi fell. Measurements and modelling of ice loads have been performed and heating elements and control and wind and icing sensors have been tested and improved during the project.

Kemijoki Oy, VTT Energy and Finnish Meteorological institute (FMI) have been the main contributors in the arctic wind energy research and development. In addition to them there are some other companies, which have developed arctic wind power technology. Vaisala Oy has developed wind anemometers and meteorological stations, Labko Oy has developed ice detecting and heating systems, Combinent Oy has developed slip rings and Wind World, Nordtank and Bonus have assisted the development process as suppliers of the wind turbines at Lammasoivi, Pyhätunturi and Paljasselkä.

Presently the principal part of arctic wind power research has been done at the test station on the Pyhätunturi fell. The aim has been to improve, test and develop the technology which will be used in modern wind turbines in arctic weather conditions in Lapland and elsewhere in similar conditions. The main research and development areas have been:

- wind resources and icing risk
- instrumentation: wind anemometers and ice detectors,
- development of the measuring system (data acquisition)
- development of blade heating system: principles of design, installations and measurements,
- ice loads: measurements and predictions by means of computational tools

As wind power in Lapland most often means connecting the wind turbines to a weak network with long radials the effects of wind turbines to the network are important to find the maximum amount of wind power that can be installed to a site.

2. Research and development

2.1 Climate research

Wind measurements made at the top of arctic mountains, fells, in northern Finland indicate a good wind climate for wind energy production. However, production of wind energy will undergo many problems in the fell areas. The main problem of operation and production of wind turbine will be caused by rime accretion and icing. Disadvantages caused by rime and ice have to be taken into consideration when estimating volume of the regional and local wind energy production in the top areas of fells.

2.1.1 Wind resources

Wind measurements have been made at a number of fells during the NEMO-programme. According to these measurements it is clear that the monthly mean wind speeds on the peaks of the fells are much higher and the annual variation significantly larger than at the synoptic stations. Actually the winds at the tops of the fells are very alike the winds at the sea areas.

The high wind speeds measured at the top of the fells and low wind speeds at the synoptic stations are often related to the existence of ground inversion. In Lapland the inversion height is very low during the winter months and many of the fells reach above the inversion layer. Thus during the winter months the wind speed on the top areas is related to geostrophic rather than the surface wind.

Figure 1 shows the mean monthly wind speed measured by soundings at the Sodankylä station. Based on this it can be said that in the eastern Lapland the fells higher than 500 m should have wind resources similar to geostrophic winds.

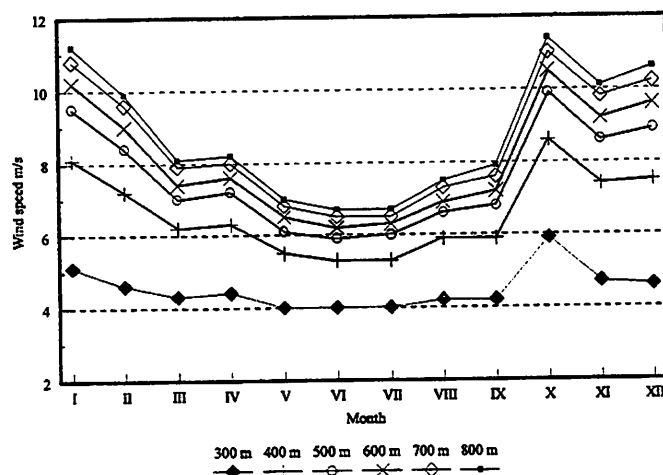


Fig. 1. Monthly mean wind speed (m/s) at different heights a.s.l. observed by Sodankylä soundings in 1987-89.

2.1.2 Icing

Rime is formed when supercooled cloud droplets, carried by air stream, strike surface of the structure and then begin to freeze, forming significant rime loads. Rime accretion takes place when the fell is within a cloud and temperature is below 0°C . Due to the deviation of cloud height and increasing wind speed with increasing height the amount of accreted rime correlates with the height. Freezing precipitation and wet snow also cause small loads on structures, but they are not significant.

Rime accretion and its intensity is dependent on local cloudiness, height of clouds, rate and size of supercooled water droplets, air temperature and wind speed.

Probability and frequency of rime accretion at the fell are dependent on geographical location and height of the fell. The number of days when rime accretion takes place is estimated using wind speeds and air temperatures observed by Sodankylä soundings. Cloud observations are also made at Sodankylä meteorological observatory in 1987-1989.

In the area of Sodankylä rime days occur during eight months of a year. The period of rime accretion starts in October and ends in May. Rime days occur most frequently in the beginning of the year (fig. 1). At the top of high fells rime formation is almost daily phenomenon during January-February. At the most there can be 20-25 consecutive rime days. Sequence of rime days is also dependent of the observed height.

Also the intensity of rime accretion varies considerably during the eight months period of appearance. From January to March rime accretion is most intensive. Rime accretion is at the most at an altitude over 500 meters above sea level.

Unfortunately continuous long term rime observations has not been made in Lapland. Thus usable rime data for comparison is not available.

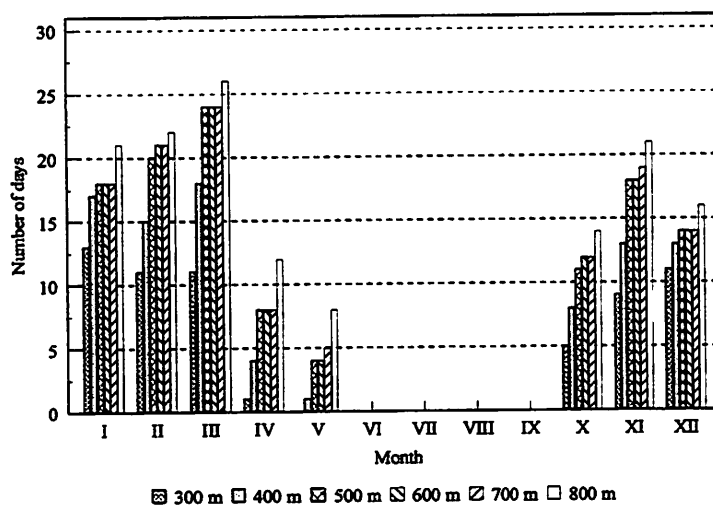


Fig. 2. Calculated monthly mean number of rime days at Sodankylä in 1987-89. Weather station's altitude h_s is 178 m a.s.l.

2.2 Arctic wind technology

2.2.1 Instruments

Wind gauges, such as anemometers and vanes, are very sensible to icing effects. Even a small amount of ice or rime reduces remarkably the wind speed, while large amount of ice, rime or wet snow will stop the anemometer totally. For instance in the case of small amount of hard rime upon the cups and shafts (Fig. 3) the underestimation of wind speed is about 30 % at wind speed of 10 m/s. Thus, it is very typical, that at cold climate sites in average (annual, monthly and daily) wind speed is underestimated. The degree of underestimation depends on the degree and duration of icing and the local climate.

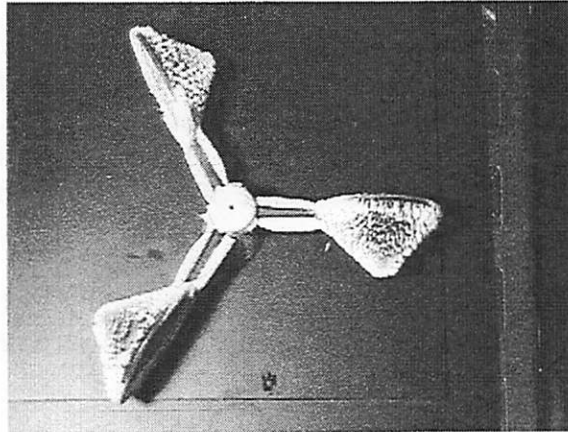


Fig. 3. Iced anemometer in a wind tunnel test.

Within the frame of the project heated anemometers of a new type, developed by Vaisala Oy, have been taken in use both on wind measurement sites on fells and for the control system of the Pyhäntunturi test site. Several types of wind anemometers have been tested at the site by Finnish Meteorological Institute.

In addition, the ice detector of Labko Oy has been developed to suite the control strategy of the heating of the blades. The ice detector developed by Labko Oy is based on measuring of ultra sound propagation in a metallic detecting wire. Both a separate ground based and a blade integrated version of the detector has been developed. The separate detector has been in use since February 1994 and the blade integrated feeder since autumn 1994. The electronics and signal transmission of the detector have been developed and improved in 1996–97. The improved version is in use in Lammasoaiwi wind farm.

By using an ice detector the operating hours of the heating system and thus the energy needed may be significantly reduced compared to simple manual or temperature control. The ice detector has also been taken in use in some European wind test stations as a meteorological sensor to study the icing risk and the number of icing incidents. It can be used also as a warning and safety device in wind farms to stop the turbines during icing.

2.2.2 Blade heating systems

The first small test turbines on Pyhäntunturi fell were in operation from 1989 to 1992. It became very obvious that the rime accretion prevents economical wind energy production. Several means to prevent the icing were considered theoretically and the first tests with special coatings were made.

The ice accreted on wind turbine blades in Lapland is rime ice. It appears, when the top of the fell is covered by clouds and the temperature falls below 0 °C. The heating energy needed and the area to be heated depends on:

- turbine blade geometry (blade thickness, chord length, torsion and pitch angle) and rotational speed,

- wind speed,
- outdoor temperature and
- cloud droplet size.

Theoretical work on ice accretion models was started in 1991. The model TURBICE was developed and it was later adapted to form the basic tools in a blade heating system design process. This process developed by VTT takes place in four phases.

During the NEMO2-programme a computer programme HEAT has been developed, by which the heated area can be defined and the needed energy can be calculated. Using the developed model HEAT with model TURBICE, which calculates the area of ice accretion as well as the form and quantity of accreted ice, it has been possible to reduce the heating power needed by blade length unit as described in Figure 4.

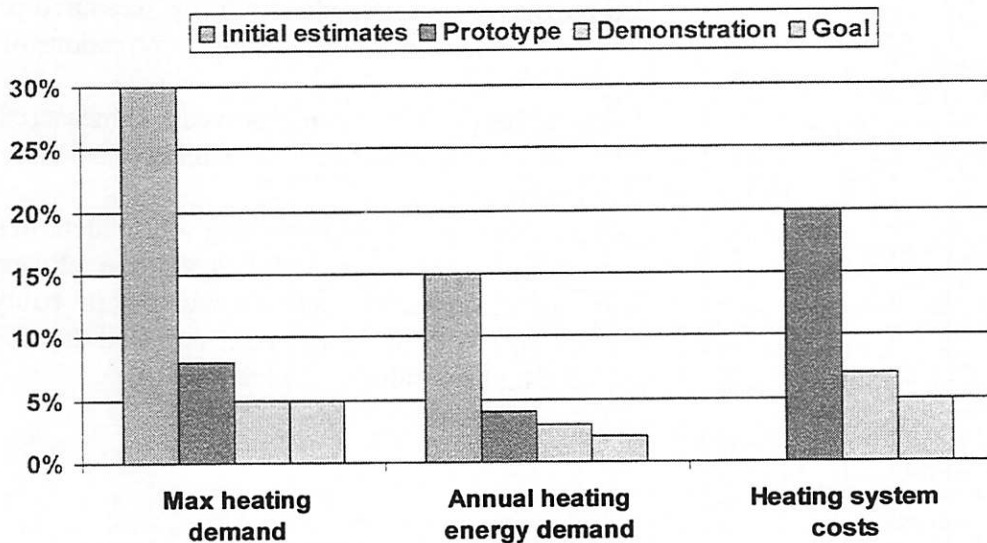


Figure 4. Heating power needed to keep the blade free from ice by different assumptions.

The heating system of today is made of integrated heating elements, which are protected from severe mechanical wear and erosion and are insensitive to local defects in the element material. Also a continuously optimised surface heating power can be reached with the new element type. The blade with integrated heating element does not differ from standard blade either in appearance or aerodynamically.

The heating system is already at a stage of commercialising. As a commercial product the heating system will comprise:

- heating elements, which are designed for every turbine and blade configuration,
- an ice detector, to help switching the heating on only when icing conditions occur,
- a control system, that according to blade geometry, icing conditions and wind speed switches heating elements on only when needed, and
- auxiliary equipment.

2.2.3 Loads and materials

On fells ice is accreted on wind turbine structures despite heating. The additional loads on the blades and on the structure as a whole are problematic especially in non-symmetrical loading situations (as ice will not fall off the blades simultaneously) and during operational changes (start-up, emergency stop). On the Pyhänturi test turbine specific ice mass of even 700 kg/m^3 has been measured. If no heating is applied or during malfunctions of heating, ice accretion may even double the mass of the tip-brake.

The Pyhätunturi wind turbine is equipped also for load measurements. Measurements are compared to simulations with the ADAMS computer programme. This programme has been taken in use during the project and is especially suited for calculating loads during operational changes.

The analysis of some cases of measured severe icing in Pyhätunturi show that for the iced blades the standard deviation of flap moment is reduced considerably, whereas the standard deviation of edge moment is increased. Heavy tower vibrations occur at icing. Change of eigenfrequencies of the construction due to ice-mass on the blades was hardly observed in the analysed case of severe icing.

Based on analysis of load measurements during icing incidents made both for the Pyhätunturi wind turbine and a 1 MW turbine in Denmark the following conclusions have been made:

Even light icing causes serious losses of power output and the loss grows with icing, which in itself makes operation with severe icing of the rotor a doubtful business. Predictions on the basis of quasi steady C_l and C_d values measured for iced profiles do not immediately fit the measured power data, but this is probably due to uncertainty about the actual shape of icing, as simple corrections of C_l and C_d can eliminate the differences.

Very serious tower vibration at the tower eigenfrequency has been observed and measured in the case of severe rotor icing. Aeroelastic modelling shows that this is not caused by mass unbalance, and the phenomenon is for the time being without any explanation.

Increased tendency towards stall induced edgewise vibrations due to icing was evident in all analysed measurements. As the measurements in all cases have many uncertainties no more information on the dynamics of the aerodynamics can be obtained, but very important information is probably hidden here. What is the risk of stall induced vibrations at icing? What is the risk of severe stall induced vibrations in case of blade heating which leaves lumps of ice on both sides of the blades?

2.2.4 Operation and maintenance

The maintenance activities have been developed during the operation of the wind power plants with emphasis to the special requirements due to long distances. On top of careful design and manufacture of the wind turbine to cold and icing climate, the continuous follow-up, the high degree of preparedness of the maintenance staff, adequate tools and spare part reserves and use of local help in small disturbances are key factors in reaching the high availability.

Kemijoki Oy operates owns and operates four wind turbines in Lapland and a further three units are to be constructed in 1998. It is observed that many of the malfunctions and faults in the turbines are direct or indirect consequences of the climatic conditions and usually a combination of several environmental factors.

To enable and ease the inspection and maintenance activities during the winter time a special lift has been taken into operation. With this e.g. the condition of the blade surface can be inspected without a large crane.

2.2.5 Integration to energy system

In addition to Pyhätunturi test station, also measurements in Lammasoivi wind park have been performed in order to assess the effects of wind turbines to the network, which is quite weak at the area due to long radial feeders. The voltage drops due to grid-connecting were the most notable effects found when analysing the short-term measurements. The voltage drops of 8–9 % were found for 450 kW generator, and 3.5 % for the small 95 kW generator. This is the main reason limiting the size of wind turbines that can be installed at the site. There is a possibility to improve the grid-connection to weak grids by changing the operations of soft-starter power electronics.

2.3 Commercialisation

2.3.1 Wind farms

Today there are four operational wind turbines in arctic conditions in Lapland. The first commercial arctic wind turbines, 2 x 450 kW Bonus, were installed in October -96 on Lammasoivi fell, Enontekiö. In 1998, the Lammasoivi installation was enlarged by adding another 600 kW turbine. At Olostutnuri the first 2 x 600 kW turbines and that installation will be enlarged in 1999 with 3 x 600 kW.

The 65 kW turbine in Paljasselkä of Enontekiö was erected as a first test turbine in 1991 to a site with moderate icing. It has been a part of Kemijoki Oy's research programme, and with de-icing system installed in 1994 is now in commercial production. The arctic demonstration turbine on Pyhätunturi in Pelkosenniemi was built in October 1993 as co-operation between the Technical Research Centre of Finland (VTT), The Finnish Meteorological Institute and Kemijoki Oy. The turbine itself with its measurement equipment forms a good test unit for technical development in real scale. Pyhätunturi plant is connected to the low voltage network and in addition to research results, it is producing electric power to local distribution network. The turbine has since April 1998 taken in commercial use although the measurement activities are continued.

As a result of many years of practical testing and theoretical studies changes to components and functions of the standard wind turbines have been applied in arctic turbines. Pyhätunturi test station has had a series of anti-icing systems, resulting in the heating system which is installed in Lammasoivi. In addition, significant modifications are made to the hydraulic system and in the selection of lubricants and component materials.

2.3.2 Blade heating technology

JE-system is the name for the ice prevention system for wind turbine blades developed by Kemijoki Arctic Technology Oy (KAT) based on the system development done during NEMO2 in cooperation with VTT. The JE-system is designed to prevent the ice accretion on the blades during the operation to avoid turbine stops. The heating is switched on as soon as the icing conditions are observed to avoid production losses.

The heating system can be seen as set of modifications that shall be done both in the blades and in the turbine. This means also that these modifications must be designed together with the blade and turbine manufacturers.

2.3.3 Production and marketing

KAT is producing the heating systems for their own projects as well as for other projects in Finland and abroad. In both cases KAT acts as a subsupplier for the wind turbine manufacturer. The different phases in the production have been split by agreements between KAT, the blade manufacturer and the turbine manufacturer.

For the time being, the JE-system is sold only with Bonus wind turbines.

In 1998, the system was exported to Sweden and used in two installations in the Swedish fells. There are also negotiations with Austrian, French and German developers.

3. Future

3.1 Arctic wind energy production outlook in Finland

A large study, which mapped and classified the fell areas of Lapland according to possibilities to install wind farms, was finalized in 1997. This study will serve as a basis and guideline for the future wind farm developments. The study was performed in cooperation and communication with regional and communal authorities, the electricity distribution companies in Lapland and various other interest groups such as the reindeer farmers and tourism industry. The main part of the study was done by Ekono-Energy.

The study serves as the basis for the commercial development of wind power production in Lapland. The production potential feasible for next 15 years was estimated to 250 MW, which is about 30 % of the electricity consumption in Lapland north of the arctic circle.

Preparations for and first drafts of a long term wind energy construction plan have been started. At this stage the economic models, partly already used in hydropower projects, to evaluate and compare different projects on economic terms have been applied and taken into use. More detailed models and tools to support the economic comparisons are needed in future. These include e.g. improved energy production prediction tools and wind farm layout optimization tools tuned for the environment.

In addition to Finnish Lapland, the blade-heating system will also be tested and used in some wind turbine installations on the Finnish coastline. The reason for this is that in wind turbines larger than 1 MW, the blade tips already reach cloud levels and there is at least a risk for ice accretion on the tip part of the blade.

3.2 Arctic wind technology

There are less traditional low land sites available for wind turbines in countries, where wind energy is more widely used. For reasons like visual impact and conflicting interests in land use, there is, therefore, a growing interest to build and operate wind turbines on many of the northern and central European fells and mountains, where there are good wind conditions yet occasionally severe weather conditions as found in the Arctic. The owners and operators of the turbines located on these sites show a growing concern that the icing of the rotor blades can, at times, seriously effect the output of otherwise efficient wind turbines.

Ice accretion on wind turbine blades has been observed and reported in many operational wind turbines e.g. in Germany, United Kingdom and Italy. Icing conditions are found also in northern parts of Russia, USA and Canada.

The market for wind turbines in EU-countries has been estimated to about 40 000 MW to the year 2010. It has been estimated that about 25 % of this market will locate in areas where at least moderate icing occurs. In these sites reliable and cost effective ice free anemometers and ice sensors could improve the reliability of wind farms.

3.3 R&D needs

There is a clear need for further research and development in the area of arctic wind technology although a lot of development has already taken place. The main aims for future R&D could be

- reduction of the cost of energy
- minimizing the uncertainties during the planning phase

- improving the reliability of the turbines

Wind resources and icing

- improved tools for resource estimation
- enhanced network of wind and other climatic measurements in mountain areas
- inclusion of ice incident measurements on weather stations

improved instruments both for synoptic purposes and for wind turbine control

Wind turbines and technology

- improved knowledge on wind turbine loads both in harsh environment including the effects of inclined flow, partial icing of blades and structures by further measurements and by improved prediction tools
- cold climate tuning of components: generators, gear boxes, lubrication, hydraulics
- turbine design modifications to ease the turbine service in cold conditions
- development of the blade heating technology to a wide variety of the existing turbines

Wind farm planning

- planning guidelines for wind farms in icing environments
- planning tools for wind farms in icing environments
- grid integration and hybrid systems for remote and isolated areas.

These tasks fit well as a part of a European research effort and could not be covered by a national programme alone. There is, however, a need for continued national effort where the research institutes, component industry and the utilities and end users have all their contribution to be given.

Wind turbines in Finland 1999

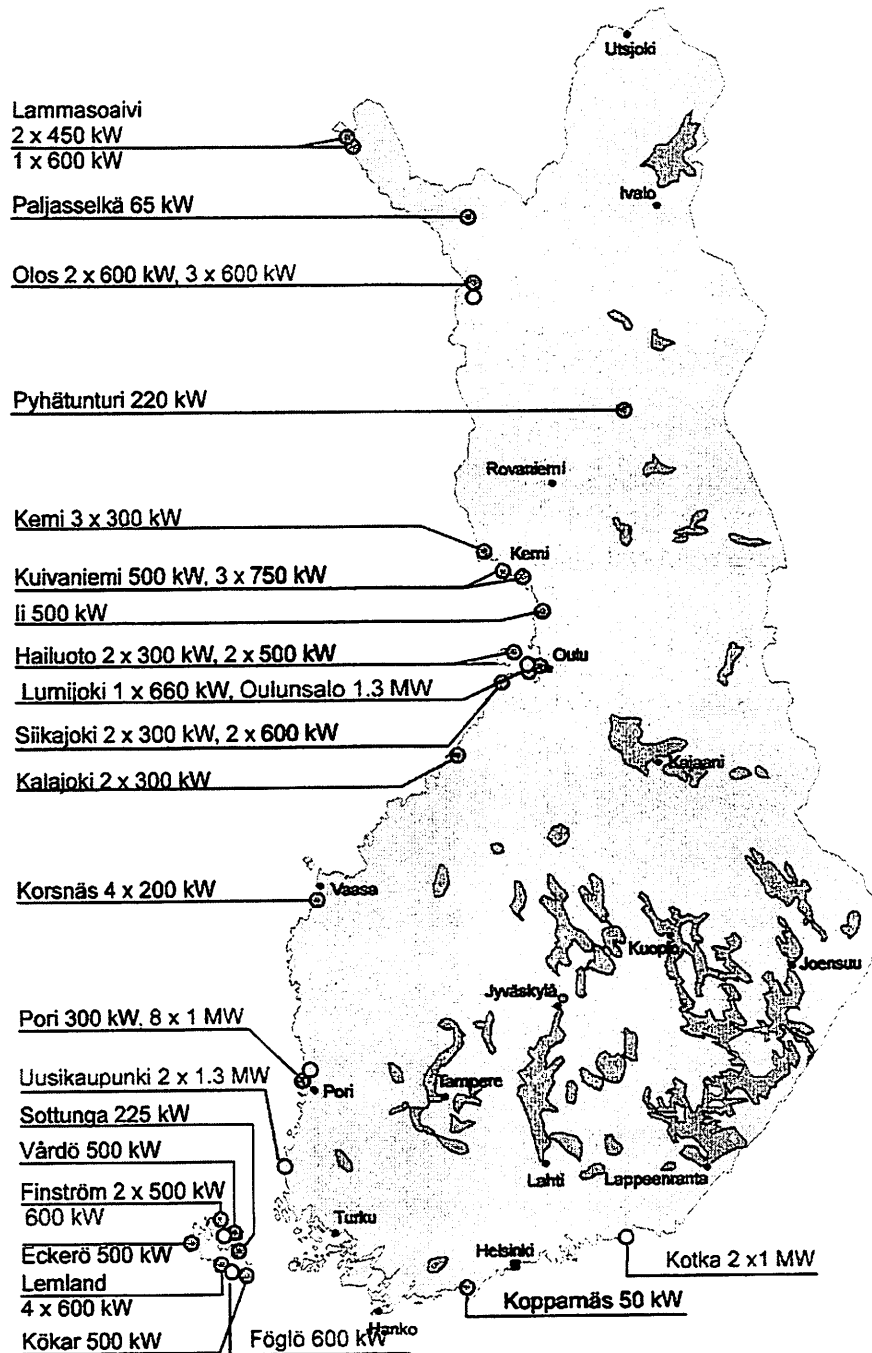


Figure 6. Wind turbines in Finland by the end of 1999. Blade heating is used at the four northernmost sites and additionally at some of the 1 MW turbines at Pori on the west-coast.

Wind Energy and Icing in Norway

Tor Anders Nygaard
Institute for Energy Technology
P.O. Box 40
2027 Kjeller
Norway

1 Introduction

During the period 1986-1993, ten wind turbines were installed in Norway with 50 % public funding, to get some practical experience with wind energy.

Icing was one of the issues of interest. The time frames and funding levels did however not allow a detailed examination of this issue. Instead a practical approach had to be adopted. When evaluating potential sites, local power line maintenance crews were interviewed to avoid areas with potential ice problems.

Icing problems seems to appear mainly at sites higher than 300-500 m above sea level. As a consequence of this, and the good wind resources in the outer coastal regions, one wind turbine is located 237 m asl, and the rest below 100 m asl.

There are few problems with icing on the existing wind turbines. Icing issues are however back on the agenda, since developers now are examining sites with elevations up to 700 m asl.

2 Some preliminary site evaluations

Some sites have recently been evaluated (Tallhaug 1999) with a method developed at the Finnish Meteorological Institute (Tammelin, B. and K. Säntti 1997). The basic idea is that icing occurs when the cloud height is lower than the site, and the temperature is below freezing.

For a site located 500 m asl, temperature recordings were used to establish a linear relationship with simultaneous temperature recordings at the weather station located nearby (at sea level). Historical observations of cloud height and temperature at the weather station were then used to establish statistics for the number of days with icing at the site.

This method has been compared with icing events detected from the wind monitoring at the site. Zero velocity and static wind direction has been interpreted as an icing event. Figure 1 shows observed and predicted icing events. The month and day numbers are on the horizontal and vertical axes respectively. The dots indicate an icing event. The results are encouraging, and this method will undergo further testing in the near future.

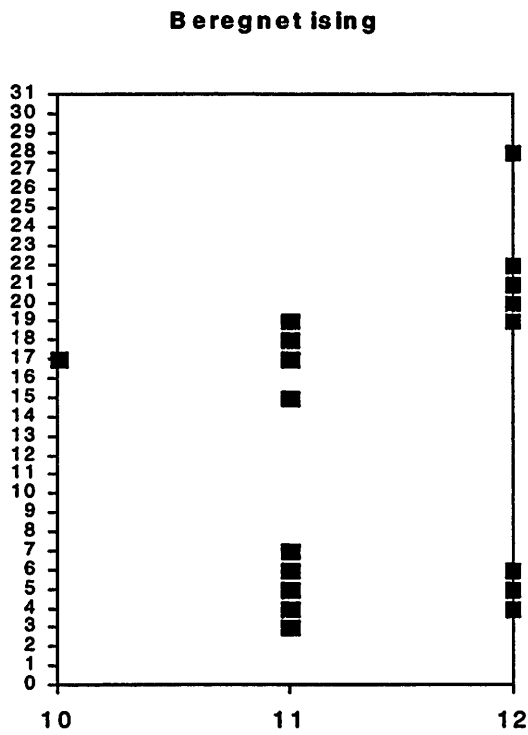
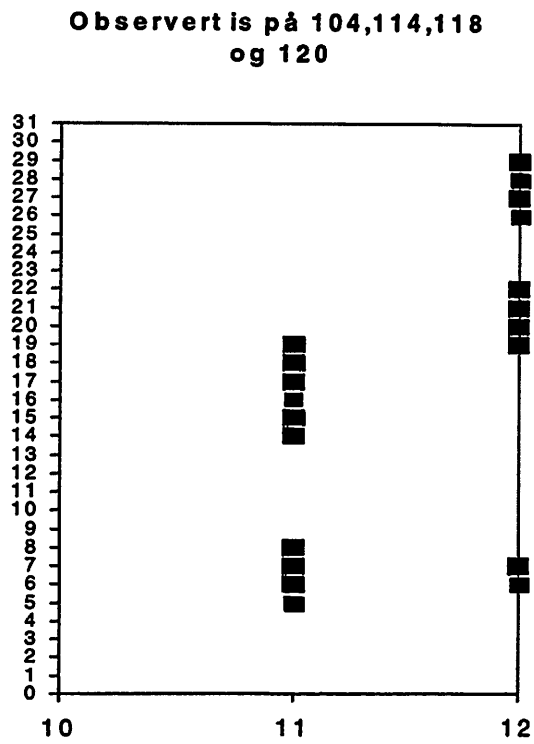


Figure 1: Observed and predicted days with icing October-December 1998.

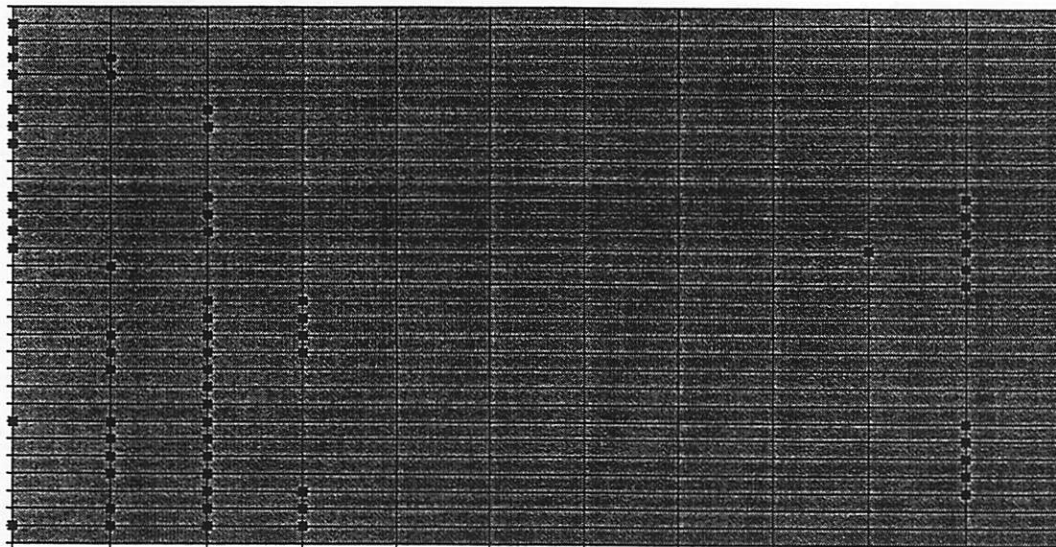
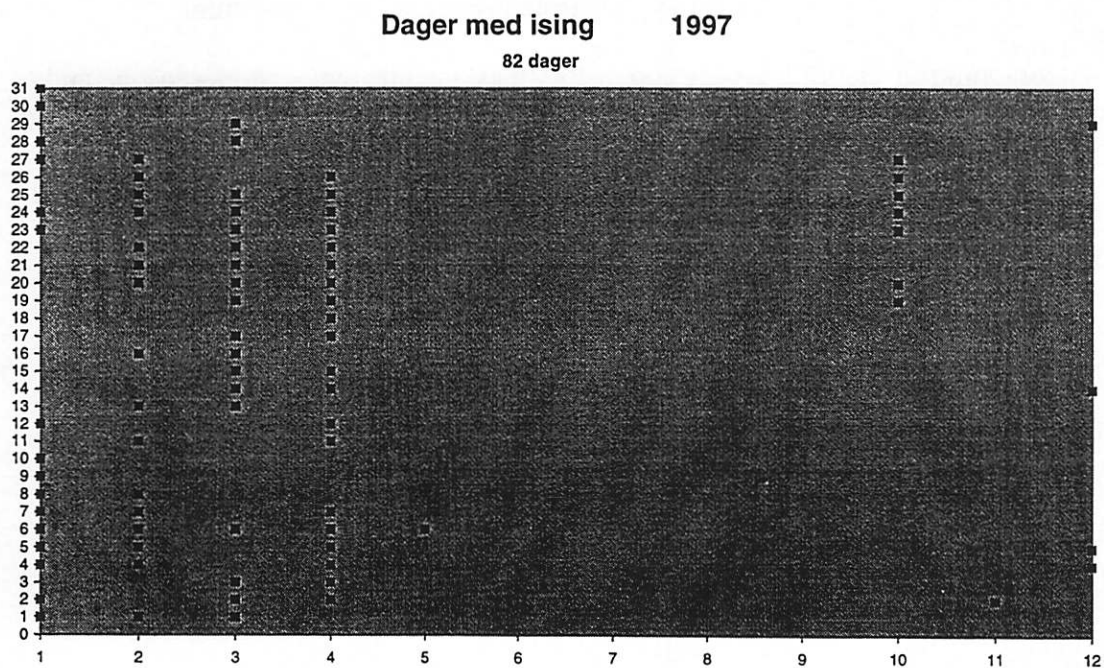


Figure 2: Estimated icing events

3 Conclusions and further work.

Icing has so far not been problem for the wind turbines located in Norway, due to the low elevation on these sites.

Icing is however an important issue for sites above 300 m asl.

A method for site classification has been tested with encouraging results.

Wind monitoring stations at sites above 300 m asl include temperature sensors, and methods for site classification will therefore be compared with observed ice events in the future.

A good map showing regions with potential ice problems would be helpful for the development of wind energy in Norway.

4 References

Tallhaug, L. (1999). *Ising på vindturbiner* (in Norwegian). KVT notat 5. Kjeller Vindteknikk AS.

Tammelin, B. and K. Säntti (1997). *Icing in Europe*. Proceedings of European Wind Energy Conference 1997. Irish Wind Energy Association.

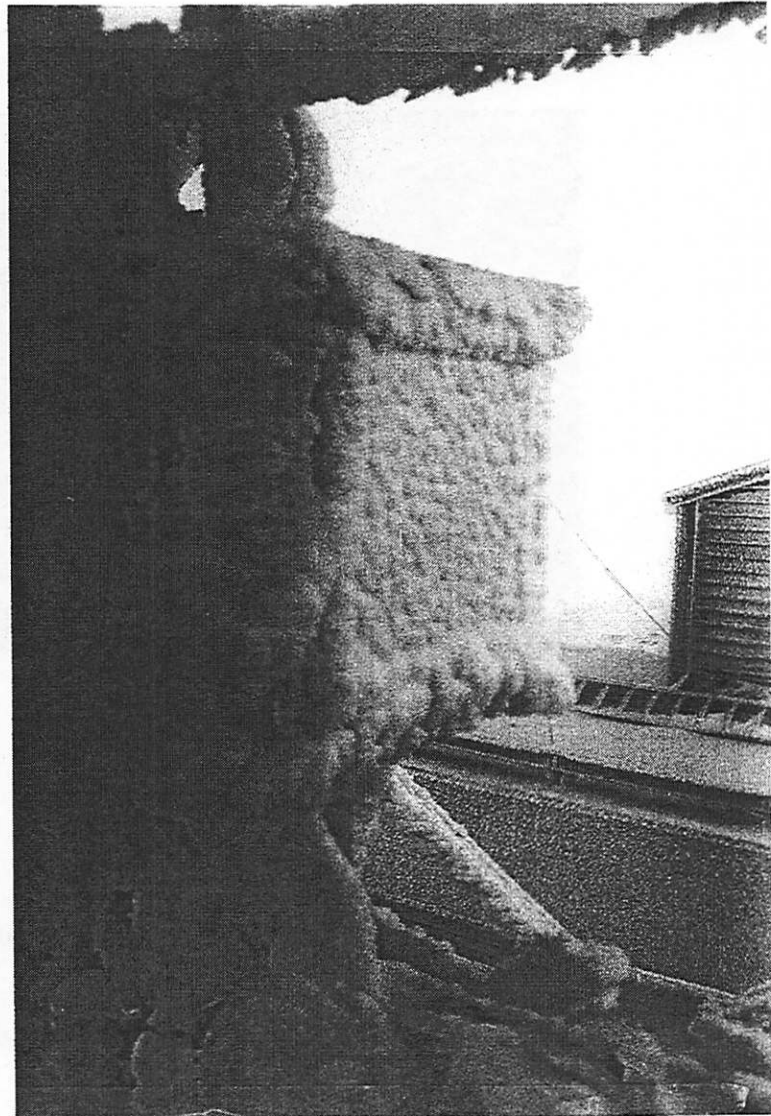


Figure 3: Instrument box 700 m asl.

WIND CONDITIONS UNDER COLD CLIMATES

IEA Experts meeting
22 - 23 MARCH 1999
Espoo, Finland

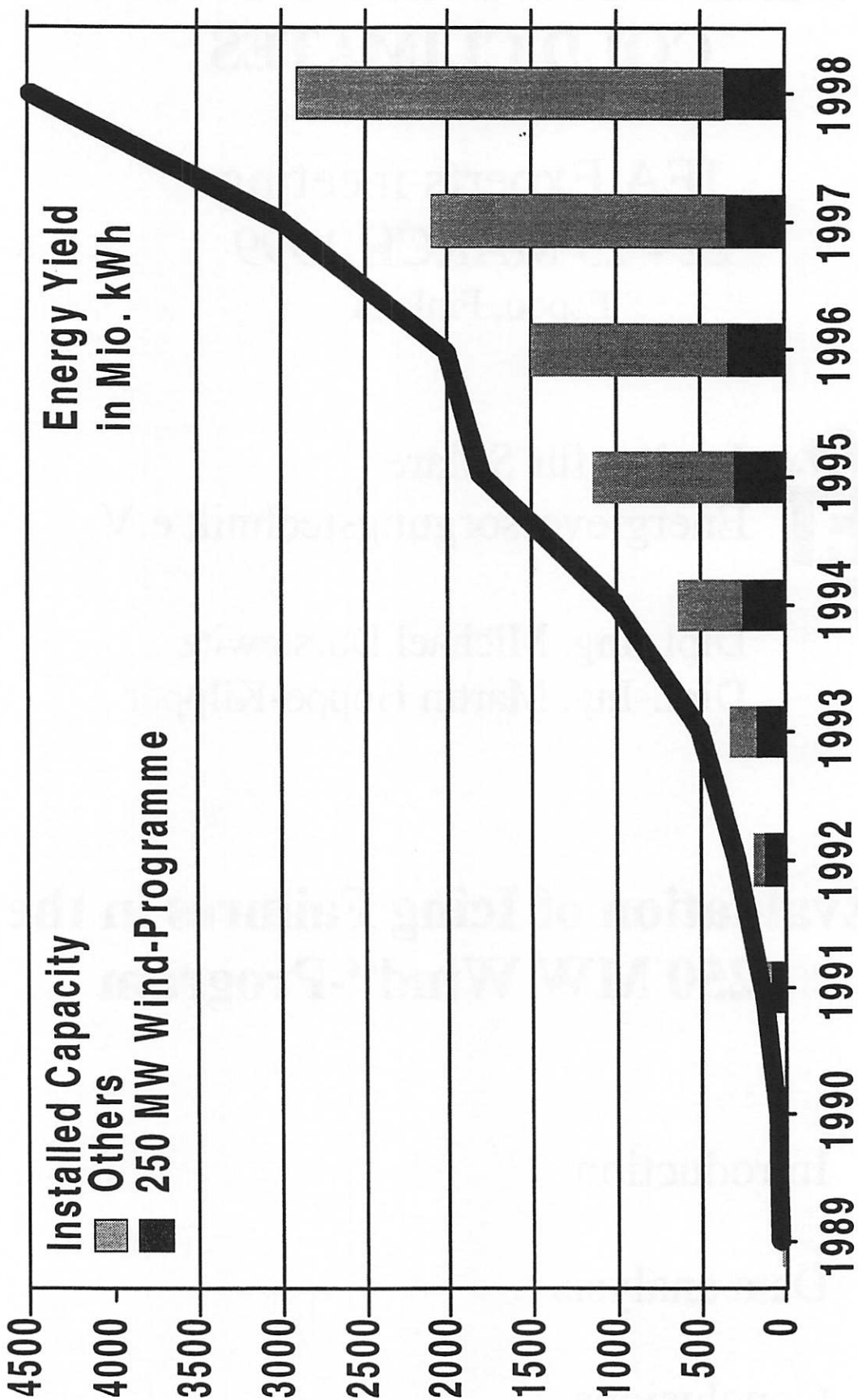


Institut für Solare
Energieversorgungstechnik e.V.

Dipl.-Ing. Michael Durstewitz
Dipl.-Ing. Martin Hoppe-Kilpper

Evaluation of Icing Failures in the „250 MW Wind“-Program

- Introduction
- Data analysis
- Conclusions



Development of wind energy use in Germany

Summary of failure causes

Failure cause	Percentage of events	Percentage of downtime
Storm	7%	6%
Grid	5%	1%
Lightning	6%	9%
Icing	2%	1%
External	20%	17%
Internal	80%	83%
Total	100%	100%

Summary of evaluation data

general

number of WECs	1500
rated power (total)	310 MW
reports (total)	+17000

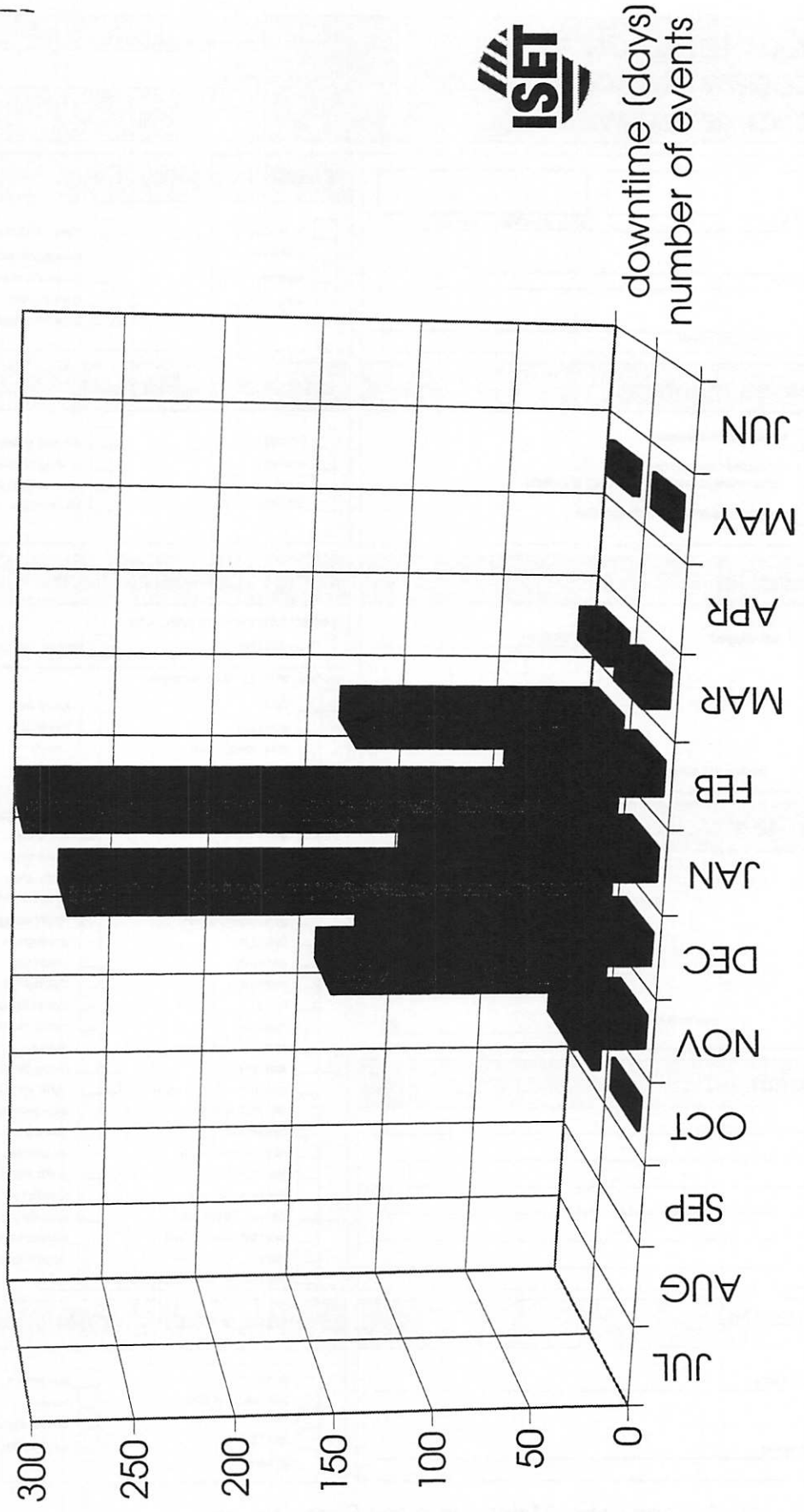
reports of malfunction due to icing

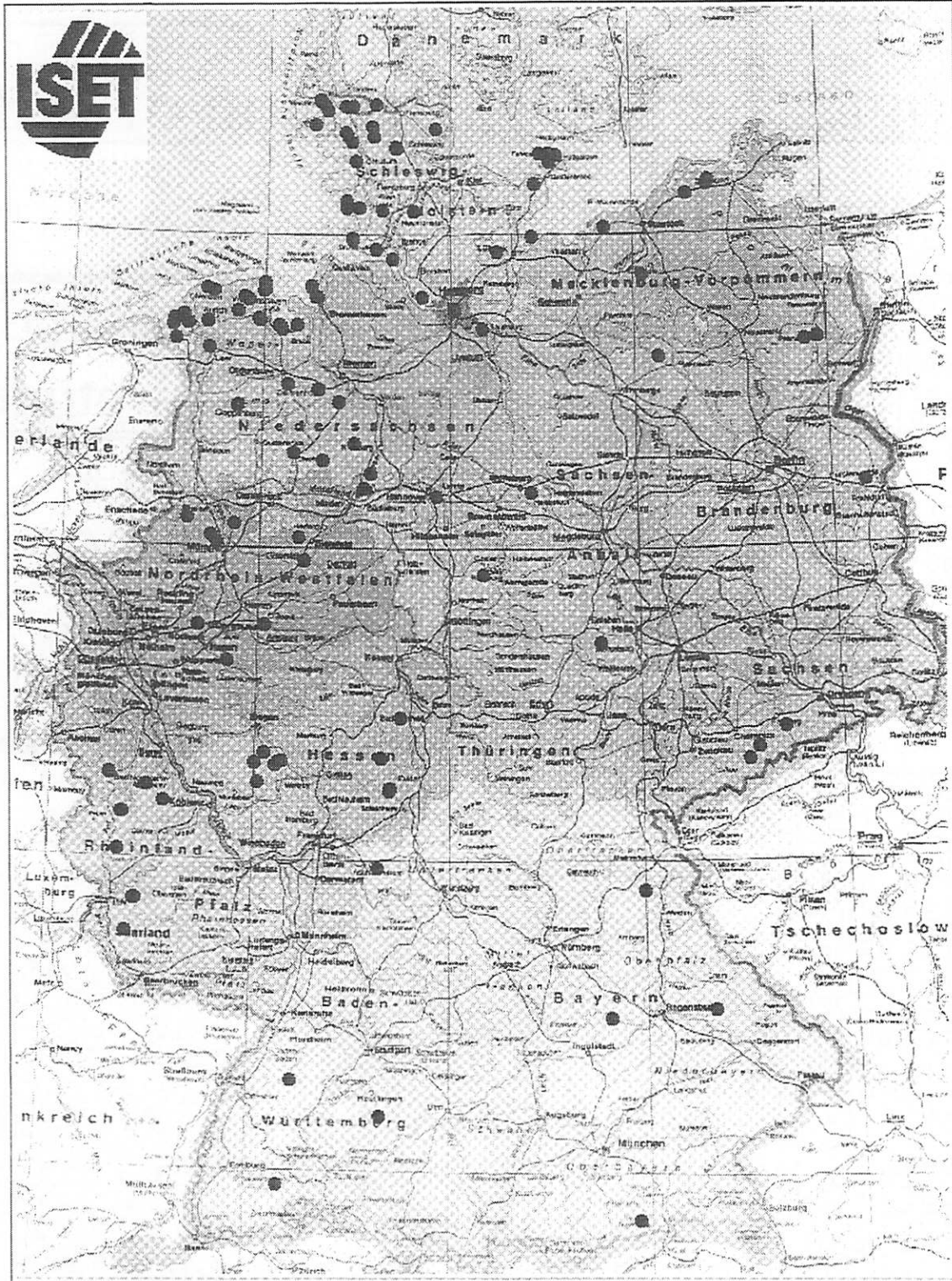
reports (total)	+ 370
	≈ 2,1%
down time (total)	900 days
repair costs (total)	DEM 17000

<h1 style="margin: 0;">Maintenance and Repair Report</h1> <h2 style="margin: 0;">WMEP 250 MW-Wind</h2>		work carried out <table style="width: 100%; border: none;"> <tr> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> </tr> <tr> <td style="font-size: 8px;">day</td> <td style="font-size: 8px;">month</td> <td style="font-size: 8px;">year</td> <td></td> </tr> </table>					day	month	year		report-nr. <div style="border: 1px solid black; width: 50px; height: 20px;"></div>				
day	month	year													
<div style="border: 1px solid black; width: 150px; height: 20px; margin-bottom: 5px;"></div> post code	<div style="border: 1px solid black; width: 150px; height: 20px; margin-bottom: 5px;"></div> plant identification number	<h3 style="margin: 0;">cause of malfunction</h3> <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> <input type="checkbox"/> high wind <input type="checkbox"/> grid failure <input type="checkbox"/> lightning <input type="checkbox"/> icing </td> <td style="width: 50%; vertical-align: top;"> <input type="checkbox"/> malfunction of control system <input type="checkbox"/> component wear or failure <input type="checkbox"/> loosening of parts <input type="checkbox"/> other causes <input type="checkbox"/> cause unknown </td> </tr> </table>		<input type="checkbox"/> high wind <input type="checkbox"/> grid failure <input type="checkbox"/> lightning <input type="checkbox"/> icing	<input type="checkbox"/> malfunction of control system <input type="checkbox"/> component wear or failure <input type="checkbox"/> loosening of parts <input type="checkbox"/> other causes <input type="checkbox"/> cause unknown										
<input type="checkbox"/> high wind <input type="checkbox"/> grid failure <input type="checkbox"/> lightning <input type="checkbox"/> icing	<input type="checkbox"/> malfunction of control system <input type="checkbox"/> component wear or failure <input type="checkbox"/> loosening of parts <input type="checkbox"/> other causes <input type="checkbox"/> cause unknown														
<div style="border: 1px solid black; width: 100%; height: 20px; margin-bottom: 5px;"></div> operator															
<div style="border: 1px solid black; width: 100%; height: 20px;"></div> manufacturer and model															
<h3 style="margin: 0;">reason for repair</h3>		<h3 style="margin: 0;">effect of malfunction</h3>													
<input type="checkbox"/> scheduled maintenance <input type="checkbox"/> scheduled maintenance with replacement of worn parts or repair of defects <input type="checkbox"/> unscheduled repair after malfunction		<input type="checkbox"/> overspeed <input type="checkbox"/> overload <input type="checkbox"/> noise <input type="checkbox"/> vibration													
<input type="checkbox"/> reduced power causing follow-up damage <input type="checkbox"/> plant stoppage <input type="checkbox"/> other consequences															
<h3 style="margin: 0;">down time</h3>		<h3 style="margin: 0;">removal of malfunction</h3>													
<input type="checkbox"/> not stopped <input type="checkbox"/> stopped		perfect functioning of plant after <input type="checkbox"/> control reset <input type="checkbox"/> changing of control parameters													
from <table style="width: 100%; border: none;"> <tr> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> </tr> <tr> <td style="font-size: 8px;">day</td> <td style="font-size: 8px;">month</td> <td style="font-size: 8px;">time</td> </tr> </table>					day	month	time	repaired or replaced components							
day	month	time													
to <table style="width: 100%; border: none;"> <tr> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> <td style="border: 1px solid black; width: 20px; height: 20px;"></td> </tr> <tr> <td style="font-size: 8px;">day</td> <td style="font-size: 8px;">month</td> <td style="font-size: 8px;">time</td> </tr> </table>					day	month	time	<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> <input type="checkbox"/> hub <input type="checkbox"/> hub body <input type="checkbox"/> pitch mechanism <input type="checkbox"/> pitch bearings <input type="checkbox"/> rotor blades <input type="checkbox"/> blade bolts <input type="checkbox"/> blade shell <input type="checkbox"/> aerodynamic brakes <input type="checkbox"/> generator <input type="checkbox"/> generator windings <input type="checkbox"/> generator brushes <input type="checkbox"/> bearings <input type="checkbox"/> electric <input type="checkbox"/> converter <input type="checkbox"/> fuses <input type="checkbox"/> switches <input type="checkbox"/> cables/connections <input type="checkbox"/> sensors <input type="checkbox"/> anemometer/wind vane <input type="checkbox"/> vibration switch <input type="checkbox"/> temperature <input type="checkbox"/> oil pressure switch <input type="checkbox"/> power sensor <input type="checkbox"/> revolution counter <input type="checkbox"/> control system <input type="checkbox"/> electronic control unit <input type="checkbox"/> relay <input type="checkbox"/> measurement cables and connections </td> <td style="width: 50%; vertical-align: top;"> <input type="checkbox"/> gear box <input type="checkbox"/> bearings <input type="checkbox"/> wheels <input type="checkbox"/> gear shaft <input type="checkbox"/> sealings <input type="checkbox"/> mechanical brake <input type="checkbox"/> brake disc <input type="checkbox"/> brake pads <input type="checkbox"/> brake shoe <input type="checkbox"/> drive train <input type="checkbox"/> rotor bearings <input type="checkbox"/> drive shafts <input type="checkbox"/> couplings <input type="checkbox"/> hydraulic system <input type="checkbox"/> hydraulic pump <input type="checkbox"/> pump motor <input type="checkbox"/> valves <input type="checkbox"/> hydraulic pipes/hoses <input type="checkbox"/> yaw system <input type="checkbox"/> yaw bearings <input type="checkbox"/> yaw motor <input type="checkbox"/> wheels and pinions <input type="checkbox"/> structural parts/housing <input type="checkbox"/> foundation <input type="checkbox"/> tower/tower bolts <input type="checkbox"/> nacelle frame <input type="checkbox"/> nacelle cover <input type="checkbox"/> ladder </td> </tr> </table>		<input type="checkbox"/> hub <input type="checkbox"/> hub body <input type="checkbox"/> pitch mechanism <input type="checkbox"/> pitch bearings <input type="checkbox"/> rotor blades <input type="checkbox"/> blade bolts <input type="checkbox"/> blade shell <input type="checkbox"/> aerodynamic brakes <input type="checkbox"/> generator <input type="checkbox"/> generator windings <input type="checkbox"/> generator brushes <input type="checkbox"/> bearings <input type="checkbox"/> electric <input type="checkbox"/> converter <input type="checkbox"/> fuses <input type="checkbox"/> switches <input type="checkbox"/> cables/connections <input type="checkbox"/> sensors <input type="checkbox"/> anemometer/wind vane <input type="checkbox"/> vibration switch <input type="checkbox"/> temperature <input type="checkbox"/> oil pressure switch <input type="checkbox"/> power sensor <input type="checkbox"/> revolution counter <input type="checkbox"/> control system <input type="checkbox"/> electronic control unit <input type="checkbox"/> relay <input type="checkbox"/> measurement cables and connections	<input type="checkbox"/> gear box <input type="checkbox"/> bearings <input type="checkbox"/> wheels <input type="checkbox"/> gear shaft <input type="checkbox"/> sealings <input type="checkbox"/> mechanical brake <input type="checkbox"/> brake disc <input type="checkbox"/> brake pads <input type="checkbox"/> brake shoe <input type="checkbox"/> drive train <input type="checkbox"/> rotor bearings <input type="checkbox"/> drive shafts <input type="checkbox"/> couplings <input type="checkbox"/> hydraulic system <input type="checkbox"/> hydraulic pump <input type="checkbox"/> pump motor <input type="checkbox"/> valves <input type="checkbox"/> hydraulic pipes/hoses <input type="checkbox"/> yaw system <input type="checkbox"/> yaw bearings <input type="checkbox"/> yaw motor <input type="checkbox"/> wheels and pinions <input type="checkbox"/> structural parts/housing <input type="checkbox"/> foundation <input type="checkbox"/> tower/tower bolts <input type="checkbox"/> nacelle frame <input type="checkbox"/> nacelle cover <input type="checkbox"/> ladder				
day	month	time													
<input type="checkbox"/> hub <input type="checkbox"/> hub body <input type="checkbox"/> pitch mechanism <input type="checkbox"/> pitch bearings <input type="checkbox"/> rotor blades <input type="checkbox"/> blade bolts <input type="checkbox"/> blade shell <input type="checkbox"/> aerodynamic brakes <input type="checkbox"/> generator <input type="checkbox"/> generator windings <input type="checkbox"/> generator brushes <input type="checkbox"/> bearings <input type="checkbox"/> electric <input type="checkbox"/> converter <input type="checkbox"/> fuses <input type="checkbox"/> switches <input type="checkbox"/> cables/connections <input type="checkbox"/> sensors <input type="checkbox"/> anemometer/wind vane <input type="checkbox"/> vibration switch <input type="checkbox"/> temperature <input type="checkbox"/> oil pressure switch <input type="checkbox"/> power sensor <input type="checkbox"/> revolution counter <input type="checkbox"/> control system <input type="checkbox"/> electronic control unit <input type="checkbox"/> relay <input type="checkbox"/> measurement cables and connections	<input type="checkbox"/> gear box <input type="checkbox"/> bearings <input type="checkbox"/> wheels <input type="checkbox"/> gear shaft <input type="checkbox"/> sealings <input type="checkbox"/> mechanical brake <input type="checkbox"/> brake disc <input type="checkbox"/> brake pads <input type="checkbox"/> brake shoe <input type="checkbox"/> drive train <input type="checkbox"/> rotor bearings <input type="checkbox"/> drive shafts <input type="checkbox"/> couplings <input type="checkbox"/> hydraulic system <input type="checkbox"/> hydraulic pump <input type="checkbox"/> pump motor <input type="checkbox"/> valves <input type="checkbox"/> hydraulic pipes/hoses <input type="checkbox"/> yaw system <input type="checkbox"/> yaw bearings <input type="checkbox"/> yaw motor <input type="checkbox"/> wheels and pinions <input type="checkbox"/> structural parts/housing <input type="checkbox"/> foundation <input type="checkbox"/> tower/tower bolts <input type="checkbox"/> nacelle frame <input type="checkbox"/> nacelle cover <input type="checkbox"/> ladder														
reading of hour counter															
<h3 style="margin: 0;">costs stated on bill</h3>		<table style="width: 100%; border: none;"> <tr> <td style="width: 20%;">material</td> <td style="border: 1px solid black; width: 150px; height: 20px;"></td> <td style="width: 10%; text-align: right;">DM</td> </tr> <tr> <td>labour</td> <td style="border: 1px solid black; width: 150px; height: 20px;"></td> <td style="text-align: right;">DM</td> </tr> <tr> <td>journey</td> <td style="border: 1px solid black; width: 150px; height: 20px;"></td> <td style="text-align: right;">DM</td> </tr> <tr> <td>total cost incl. VAT</td> <td style="border: 1px solid black; width: 150px; height: 20px;"></td> <td style="text-align: right;">DM</td> </tr> </table>		material		DM	labour		DM	journey		DM	total cost incl. VAT		DM
material				DM											
labour		DM													
journey		DM													
total cost incl. VAT		DM													
comments															
<div style="border: 1px solid black; height: 100px;"></div>		<h3 style="margin: 0;">replaced main components</h3> <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> <input type="checkbox"/> nacelle <input type="checkbox"/> rotorblade/blades <input type="checkbox"/> hub <input type="checkbox"/> gear box <input type="checkbox"/> generator </td> <td style="width: 50%; vertical-align: top;"> <input type="checkbox"/> yaw system <input type="checkbox"/> tower <input type="checkbox"/> control system cabinet <input type="checkbox"/> transformer </td> </tr> </table>		<input type="checkbox"/> nacelle <input type="checkbox"/> rotorblade/blades <input type="checkbox"/> hub <input type="checkbox"/> gear box <input type="checkbox"/> generator	<input type="checkbox"/> yaw system <input type="checkbox"/> tower <input type="checkbox"/> control system cabinet <input type="checkbox"/> transformer										
<input type="checkbox"/> nacelle <input type="checkbox"/> rotorblade/blades <input type="checkbox"/> hub <input type="checkbox"/> gear box <input type="checkbox"/> generator	<input type="checkbox"/> yaw system <input type="checkbox"/> tower <input type="checkbox"/> control system cabinet <input type="checkbox"/> transformer														
<div style="border: 1px solid black; width: 100%; height: 20px; margin-bottom: 5px;"></div> place/date		operator													
<div style="border: 1px solid black; width: 100%; height: 20px;"></div> signature															

Appendix 1: Form sheet 'Maintenance and Repair Report'

Events and WEC downtimes due to icing



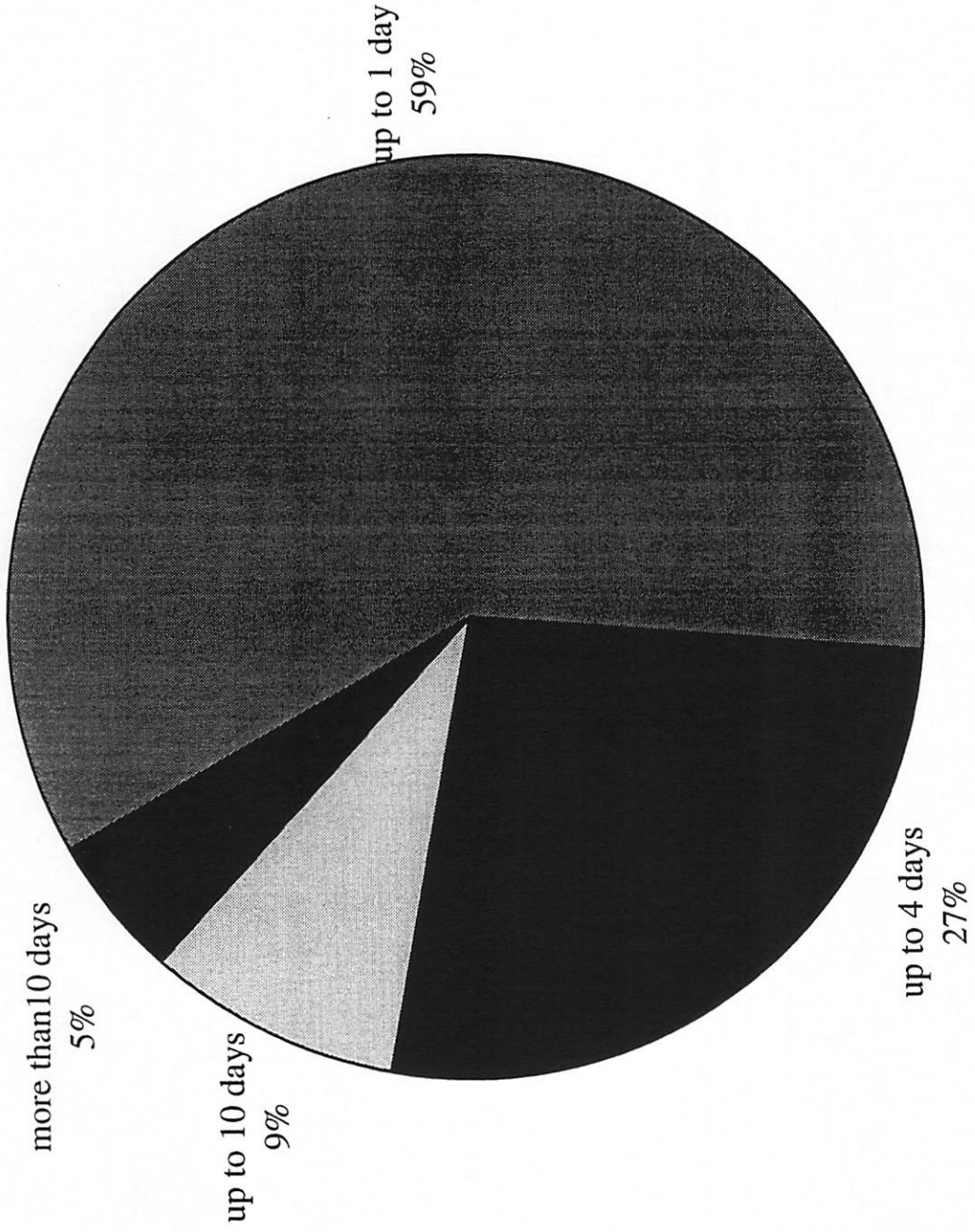


Appendix 2: Map of registered icing events in the "250 MW Wind"-Programme

Geographical Distribution of Icing

site category	percentage of reports	percentage of downtime
coastal	28%	8%
inland	19%	10%
mountainous	53%	82%
total	100 %	100 %

Duration of operation disruption



Effects of malfunction

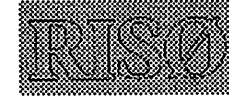
- plant stoppage (95%)
 - vibration,
 - reduced power output,
 - noise
-
- downtimes: from hours...> two months

Malfunction details

- plant could not start due to frozen anemometer
- wind vane was covered with snow
- ... 40 mm ice coating of the rotor blades
- brakes of yaw system were frozen after a long foggy period followed by strong frost
- manual plant stop
- plant operates only with temperatures above 0 C

Conclusions

- $\approx 2\%$ of all reported failures
- majority of reported events in mountainous regions
- downtime from hours up to several weeks
- costs for repairing relatively low
- additional costs for the operators due to losses in energy yield
- secondary failures of the infrastructure (roads, powerlines) can influence the downtime of WECs especially in mountainous regions



Wind Energy in Cold Climates Danish Experience

Per Lundsager

IEA Expert Meeting 21 - 22 March, 1999
VTT, Espoo, Finland

21-22 March, 1999

IEA Expert Meeting: Wind Energy in
Cold Climates



Overview

- Arctic Seminar & Charter (1993)
- Experience in Denmark
- Experience in Greenland
- Experience in Other Countries
- Projects

Arctic Seminar @ Risø, June 1993

■ Background

- ◆ Incentives, key issues & barriers for RE in cold climates

■ Outline

- ◆ 50 experts from 7 countries
- ◆ Country reports by rapporteurs
- ◆ Round table discussions

■ Output

- ◆ An arctic Wind Energy Charter
- ◆ An action plan to reduce barriers & increase application
- ◆



Arctic Seminar @ Risø, June 1993

- The Arctic Wind Energy Charter (1993)
 - ◆ Arctic environment is vulnerable & slow to recover
 - ◆ Reliable & clean electricity supply is important
 - ◆ Large areas of the arctic have plenty of wind resources
 - ◆ Wind energy technology is a mature & realistic option
 - ◆ Key issues of an action plan for arctic wind power
 - ◆ A strategy & plan for circumpolar cooperation



Arctic Seminar @ Risø, June 1993

- Key issues of an action plan
 - ◆ Identification & quantification of requirements & needs
 - ◆ Data & methods for assessment of wind & land resources
 - ◆ Technology & methods incl add-on packages & demo
 - ◆ Norms, standards & recommended practices
 - ◆ Economics incl markets & "true-worth-of-the-watt"
 - ◆ Cooperation and information exchange & transfer



Arctic Seminar @ Risø, June 1993

- An Action plan to reduce barriers & enhance drivers
 - ◆ Consensus on critical issues
 - ◆ Consensus on needs for formal international cooperation
 - ◆ Identifications of actors & their roles
 - ◆ Ensure compliance with national programmes & identify national sources of funding
 - ◆ *Institute regular meetings & other fora for info exchange*
 - ◆ Initiate & coordinate actions of common interest on national, regional & international levels

Experience in Denmark

- Denmark is not a cold climate country
 - ◆ DK inland conditions are within usual international standards
 - ◆ Icing of blades occur once in a while, but is not a problem
 - ◆ Large scale offshore expansion may put more emphasis on blade icing in the future
- Blade icing on ELKRAFT 1 MW test turbine (1997)
 - ◆ 25% reduction of mean power output
 - ◆ 50% reduction of power std. dev.
 - ◆ Marginal ice-induced increase of structural loads
 - ◆ Marginal ice-induced changes of structural load std. dev.



Experience in Greenland

- Greenland has an arctic climate (mean temp < 0 deg C)
- Main wind energy related activities
 - ◆ Small wind turbines for telecommunication (1950's - 1980's)
 - ◆ WindMatic 55 kW pilot installation (1983 - 1988)
 - ◆ Wind Farm feasibility study (late 1980's)
 - ◆ Wind Energy feasibility study (1994)
 - ◆ Energy plan 2010 for Greenland (1994)



Experience in Greenland

- Small wind turbines for telecommunication
 - ◆ Applied in VHF radio links during 1950's to 1990's
 - ◆ From few hundred Watts to several kW in stand-alone & hybrid battery charging configurations
 - ◆ Based on Aerowatt design, upgraded by TeleGreenland & Ruheiko (DK) to complete arctic specifications
 - ◆ Phased out due to increased power demand from digital VHF radio links
 - ◆ Replaced during the 1990's by hybrid PV-Gas-Battery power supply

Experience in Greenland

- WindMatic 55 kW pilot installation (1983 - 1988)
 - ◆ Pilot plant at Nuuk, the capital city
 - ◆ Connected to Nuuk's diesel grid, loads 2 - 7 MW
 - ◆ A few cold climate modifications
 - Low temperature steel for critical components
 - Turbine stopped a temp < -20 deg C and/or wind > 25 m/s
 - ◆ Many technical breakdowns, availability around 90%
- Conclusions (1988)
 - ◆ WTG technology not yet mature for arctic applications
 - ◆ Wind energy not competitive with new hydro power plant

Experience in Greenland

- Wind Farm feasibility study (late 1980's)
 - ◆ To be connected to Nuuk's new hydro power plant (1993)
 - ◆ 4 x 300 kW wind turbines (state of the art at the time)
 - ◆ Detailed layout of civil & electrical works
- Conclusions
 - ◆ The Wind farm would be technically feasible in Nuuk
 - ◆ The Wind farm would not be economically feasible in Nuuk
 - ◆ The wind farm was not built
 - ◆



Experience in Greenland

- Wind Energy feasibility study (1994)
 - ◆ A follow-up on the arctic seminar @ Risø (1993)
 - ◆ Screening of villages & settlements on the west coast
 - ◆ Study of technical-economical feasibility of wind energy
 - Villages Nanortalik & Sisimiut and a few nearby settlements
 - ◆ Conclusion & Recommendations (1994)
 - Technically feasible, economically barely feasible
 - Demonstration of 150 kW WTG in Nanortalik
 - Wind & solar measurement program for selected settlements
 - ◆ Status 1999: On hold, pending political decision



Experience in Greenland

- Energy plan 2010 for Greenland (1994)
 - ◆ Scope similar to the Danish energy plan 2000
 - ◆ Status
 - 55,000 people, dispersed over a very large area
 - 17 villages and 66 settlements, all except Nuuk are diesel powered
 - Tariff 0.67 USD/kWh, production cost up to 1.5 USD/kWh
 - ◆ Plans include renewable energy, primarily wind
 - Wind & wind-diesel, especially in settlements
 - Improved wind resource assessment
 - Technical-economical assessments are called for

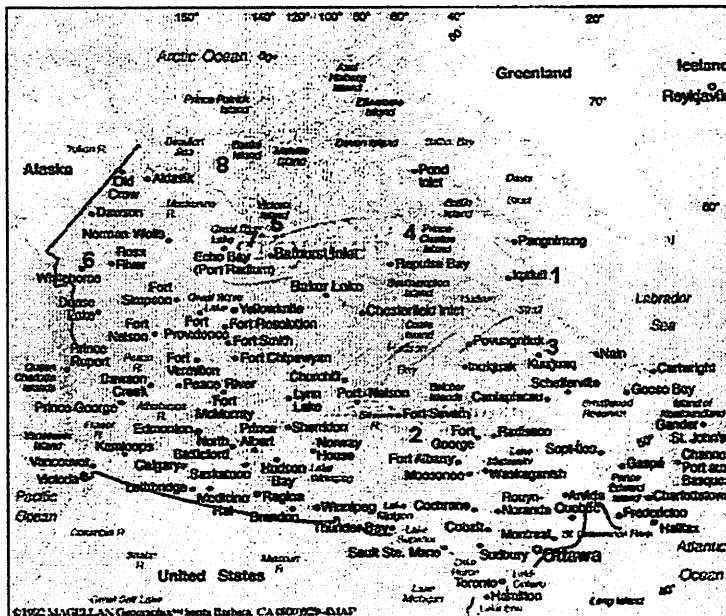


Experience in other countries

- Danish wind turbines for cold climates
 - ◆ Standard cold climate package (+15% cost)
 - ◆ Blade de-icing additional add-on package (individual cost)
- Danish wind turbines in cold climates
 - ◆ 55 kW Bonus in Kuujuaq Canada, down to -65 deg C
 - ◆ Several DK turbine makes in arctic Finland
 - ◆ Cooperation with Finland on blade de-icing equipment
- Danish bi-lateral cooperation in specific projects, e.g.
 - ◆ Adaptation of wind turbine technology to Russian conditions

Wind Energy Experience in Arctic Regions of Canada

Malcolm A. Lodge, P., Eng.
 Island Technologies Incorporated
 P.O. Box 832
 Charlottetown, P.E.I.
 C1A 7L9
 Canada



Submitted to International Energy Agency Annex X1
 VTT at Espoo
 Helsinki, Finland
 March 22-23, 1999



Wind Energy Experience in Arctic Regions of Canada

Malcolm A. Lodge, P., Eng.
Island Technologies Incorporated
P.O. Box 832
Charlottetown, P.E.I.
C1A 7L9
Canada

1. INTRODUCTION

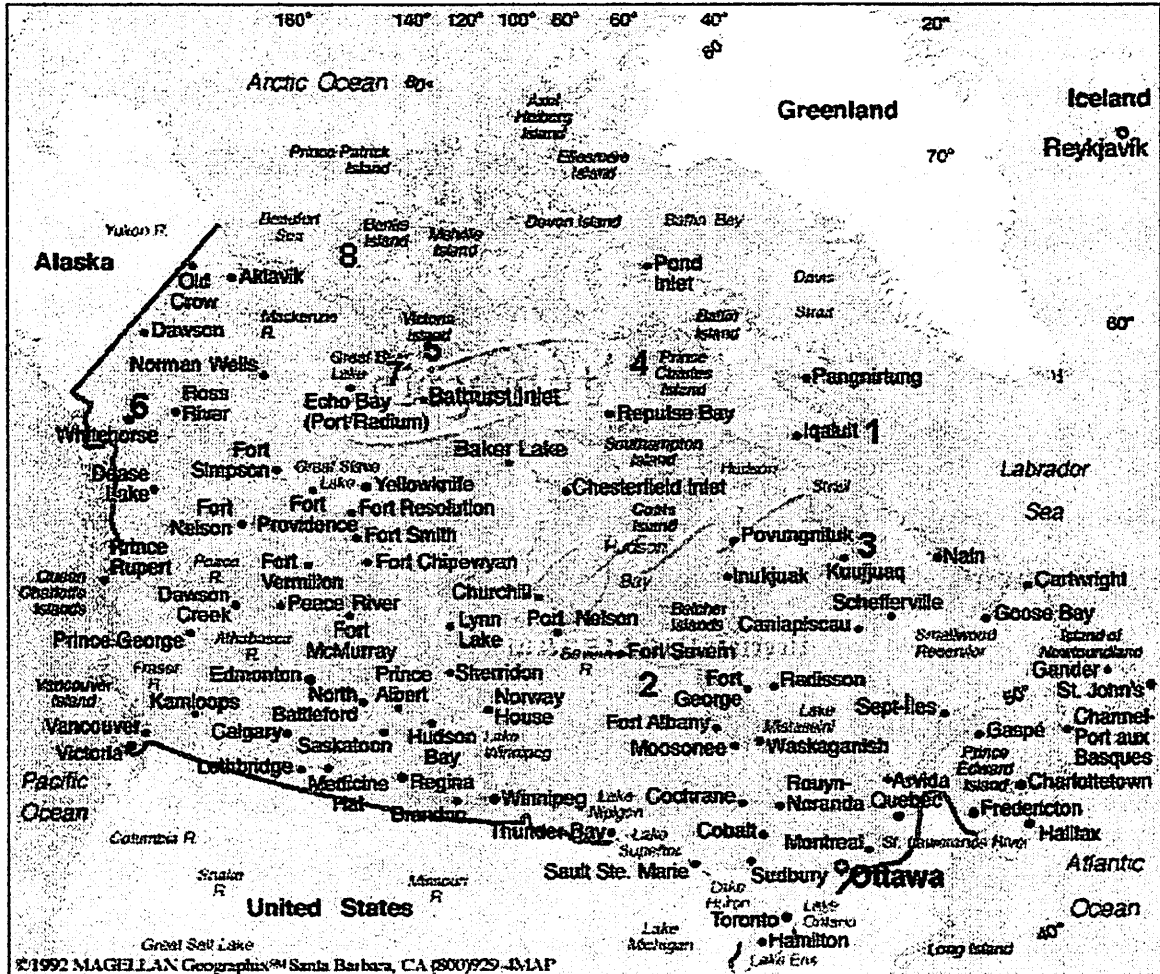
Wind energy has been a part of the history of energy supply in the Arctic regions of Canada since the early 1930's when small windmills started to be used to supply electricity for Hudson's Bay Company trading posts and depots of the Royal Canadian Mounted Police (RCMP). The electricity was used primarily to charge batteries for long wave radio transceivers which enabled communication with southern headquarters. These wind mills were used for several years until Arctic communities became more consolidated and required central diesel powered electricity plants and more frequent air transport. After establishment of the power plants, the use of electricity for normal everyday purposes by the residents of the communities grew rapidly. There are now about 50,000 residents of Canada who live in remote communities and rely on diesel power plants for their electricity. The communities they live in vary in population from a few hundred to several thousand persons.

Today the per capita consumption of electricity by northern Canada residents is typically greater than that of any area of the world. Because the cost of fuel and all other related services required is influenced by the high costs for transportation, electricity production costs range from \$0.15 - \$1.00/kWh or more and these are conservative utility estimates. Because the economies of these northern communities are not nearly sustainable, all services and life support systems are highly subsidized by the government of Canada. Ever since the redevelopment of modern wind turbines and wind technology commenced in the mid 1970's, interest in wind turbines has grown in the government agencies who must provide the subsidy. Unfortunately this interest has not been shared as greatly by the utilities and users who receive the subsidy and who do not welcome change in the status quo. As a result, the use of wind energy to offset the production of electricity has been minimal in spite of the now highly developed state of the art of wind energy technology. Most applications are considered as experiments or demonstrations and not as serious efforts to implement a new electricity supply strategy.

The few wind energy projects which have been constructed in the Arctic in Canada have yielded some experience with operation of wind turbines under cold climate conditions. This experience has been generally positive and has indicated that although there may be problems in certain areas and with certain wind turbine designs and equipment, these are not so serious that they should prevent further development. It is estimated that there are about 150 or so remote northern communities in Canada which could use wind turbines to supplement the supply of power from diesel power plants.

2. WIND TURBINE EXPERIENCE

Refer to the map for the last digit of the section number following for approximate location of the sites listed in this section. The projects listed are not necessarily all of those constructed but are



those with which the author is familiar or has been able to obtain information.

Map of Canada

2.1 Iqaluit, NWT, 1978, (pop: 3,5000).

The first modern wind turbine was installed in the Canadian Arctic in about 1978 when a small two bladed vertical axis machine rated at about 20 kW was installed at Frobisher Bay (more recently named Iqaluit). This machine was installed immediately beside the diesel power plant. It proved to be totally inappropriate and never operated. The result was the long term negative opinion of the utility regarding wind turbines in general.

2.2 Winisk, ON, 1983.

A Bergey 10 kW wind turbine was installed in a hybrid wind-diesel cycle charge hybrid system to provide electricity and heat to a remote residence for seasonal use by field officers of a government environmental agency. After an early structural fatigue failure of a weld in the main frame, the wind turbine operated very satisfactorily for two years until the project was dismantled following flooding of the region. The machine used a gin pole self erecting means which was problematic during winter when hard packed snow prevented proper and safe lowering of the tower for maintenance. There were no machines available to remove the snow which was too hard and plentiful for manual removal.

Foundations were in marsh land and constructed with imbedded concrete blocks

2.3 Kuujuaq, QC, 1985, (pop: 1,500).

A bonus 65 kW was installed as a demonstration by Hydro Quebec. The machine used special steel in the tower and mainframe and a gearbox heater. It has operated without major incident since then. Icing of the blades is not a significant problem in this region which experiences sub zero temperature and low humidity for most of the winter. Icing usually occurs only during onset and end of winter weather. Ice which does form either melts or sublimates within a few hours or days of forming.

Foundations are imbedded rock anchor and concrete cap which are considered cost effective for the site.

2.4 Hall Beach and Igloolik, NWT, 1986, (pop: 1,200).

Two Aerowatt 10 kW grid connected machines were installed at Hall Beach for demonstration. The machines operated well except for frequent failure of the passive rotor blade pitch mechanisms. These were not associated with the Arctic climate. Rime icing caused by ice fog was observed on a few occasions but was quickly dispersed by sublimation and wind erosion as the fog conditions ceased. It was noted on several occasions following very cold calm (-35°C) conditions that the free wheeling rotor failed to start up due to stiff gearbox lubricant. This condition sometimes persisted for several days and represented considerable lost production.

The machines had been installed immediately beside a health care facility. In 1998 it was decided to remove them for safety reasons and re-install them in Igloolik, a neighbouring community, where they operated in a similar fashion. They are now inoperable due to concerns regarding rotor safety following the third loss of a blade. It was also observed that the machines consistently overproduced in cold dry air. Ten minute average outputs were sometimes 20% over rated.

When the machines were first installed by a government agency the foundations were constructed of reinforced concrete at a cost in excess of \$30,000.00. At Igloolik an ad-freeze steel piling technique was used which reduced the cost by a factor of 3.

2.5 Cambridge Bay, NWT, 1986, (pop: 1,200)

Four Carter 25 kW wind turbines were installed in a utility demonstration program. The machines

operated well for a few months before beginning to fail due to structural limitations and problems with performance of the passive pitching dampers during very cold periods. It was concluded that the gearbox was not sufficiently robust for the application and that the rotor pitch mechanism was not suited for operation in extremely cold regions. There was also some overproduction. Blade icing was not considered to be a severe or frequent problem. In 1996, these machines were replaced with a Lagerwey 80 kW machine which has been operating satisfactorily.

Foundations here have been in permafrost with ad-freeze pilings and imbedded steel lattice and are considered cost effective.

2.6 Hackle Hill, YK, 1988.

A Nordtank 150 kW was installed on the top of a 1,200 metre hill near the city of Whitehorse in the interior of the territory. The site was challenging from an engineering standpoint because of transportation and access reasons as well as winter climate. There is frequent icing because of the elevation. Various blade de-icing techniques have been and are being tried.

2.7 Coppermine, NWT, 1994. (pop: 1,000).

Two Lagerwey 80 kW were installed which have been operating satisfactorily. Blade icing and gearbox lubricant stiffness during start up does not appear to be a problem.

2.8 Sachs Harbour, NWT, 1998, (pop: 250)

An AOC 15/50 wind turbine is installed. During commissioning in December 1998 at temperatures of -10°C it was noted that the rotor was lightly iced with frozen snow deposited a few days earlier during a period of snow and relatively moist air. In temperatures of about -12°C the machine failed to free wheel and accelerate to start in winds of 8-9 m/s. The snow was relatively easy to remove with a broom while standing on the tower.

There is ongoing analysis of the issue of cold climate performance of the AOC 15/50 wind turbine both by the manufacturer and by users. Some of the considerations are a combination of seasonally used heating and an insulated blanket for the gearbox.

3. REVIEW OF EXPERIENCE

The experience to date with wind turbines in the Canadian Arctic has not indicated any significant problems which could not be resolved with reasonable special engineering effort. Blade icing does not appear to be so severe or frequent that it should limit applications in the far north.

During very cold periods lubricants seem to be a problem for wind turbines which must free wheel up to operating speed. This is especially true following periods of very cold calm weather. Heating and insulation may be the reasonable solution.

Icing could well be a problem in some cold climate areas such as coastal regions along the coast of Newfoundland, Labrador and the Quebec North Shore in the Gulf of Saint Lawrence.

4. ARCTIC WIND ENERGY TECHNICAL ISSUES

Experience with existing and previous Arctic wind turbine installations has identified the following technical issues and questions to be of particular interest in the planning, design, construction and operation of wind turbine installations.

Design	Are special lubricants or materials required for proper performance?
Reliability	Will the wind turbine(s) operate at acceptable and specified availability?
Performance	Will the wind turbine(s) produce the specified power?
Size	Can the wind turbine(s) be transported and erected with reasonable effort?
Rating	Will the wind turbine(s) integrate properly with the diesel plant and grid?
Construction	Can foundations and other items be reasonably constructed?
O & M	Will rotor blade icing effect performance with out de-icing means and can routine functions and repairs be reasonably performed?

4.1 Design

Certain Arctic regions may experience sustained periods where temperatures are below -30°C for extended periods. At these temperatures normal mild steel components, some plastic materials, wire and cable sheathings and other items may be damaged or cause operational problems due to brittleness or change in physical properties.

Lubricants which although rated and intended for cold climate use may be sufficiently viscous at very cold temperature as to prevent proper operation and lubrication of critical components. This may be of particular importance for wind turbines whose initial rotation and acceleration to operating speed is dependent on aerodynamic forces alone. In the Canadian Arctic it is very common that extremely cold periods have low wind speeds. These periods are usually followed by warming trends with high winds. If the wind turbine gear box lubricant remains too viscous for several hours following a cold period, the wind turbine may not start up when the wind speed increases to well above the rated cut in speed. In this case there may be considerable lost production.

Solutions for these issues are the proper selection of materials for the application and the use of heaters and possibly seasonally applied insulation components during the cold periods.

4.2 Reliability

Reliability of a wind turbine in extremely cold climates is expected to be lower than it would be in a warmer climate. The causes are usually associated with design issues but may also be due to greater difficulty to provide adequate service and maintenance. In many cases the wind turbines may be located in very hard to reach locations and where there are no qualified personnel.

The reliability of wind turbines may be increased by the use of monitoring and interactive SCADA systems which enable remote monitoring, testing and fault diagnosis.

4.3 Performance.

The power and energy production performance of a wind turbine should meet the expectations of the user. Where this does not occur it is usually due to one of the following causes:

The wind turbine is not properly rated and specified for the site.

The wind resource has been overestimated.

The wind turbine is not reliable.

The wind turbine is not adequately maintained.

There are other control and operational difficulties in the connected system.

4.4 Size

Wind turbines for remote regions often must be selected for size as well as other performance and reliability reasons. Often the optimum size is determined by considerations of diversity and smoothness of power supply and by the ease and methods of transportation, assembly, erection and construction of foundations.

4.5 Rating

Wind turbine rating considerations are generally related to such issues as diversity, control and flexibility in planning future expansion and adjustment of the penetration of wind energy into a small remote grid.

4.6 Construction

Construction in very cold regions often requires special consideration of the availability of resources, equipment, materials, capable workers, site access and the condition of soils and other situations.

Deep frost penetration of permafrost may prevail which requires special design and construction methods.

4.7 Operation & Maintenance

Operation and maintenance of wind turbines which have been installed in some northern communities in Canada has been compromised by the lack of qualified and committed personnel in the community who are able, willing or authorized to carry out routine O & M functions. In some instances the reason is given that personnel are not trained in the safety requirements for climbing a tower on an external ladder and using standard safety procedures for such work.

In locations where there are personnel who are able to carry out routine O & M, the operational success is much higher.

IEA Topical Expert Meeting Wind Energy under Cold Climate Conditions

83

Frans Van Hulle (ECN, Solar & Wind Energy)



IEA Expert Meeting : Wind Energy & Cold Climate Helsinki 22-23 March

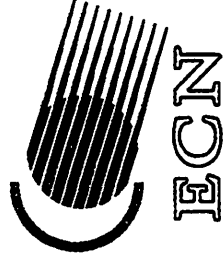
Subjects

- **technical requirements for certification**
- **experiences / needs from field projects**



Design Evaluation Requirements in Cold Climate

- IEC 61400-1 ed.2 standard requirements
 - temperature:
 - normal: -10 degrees
 - extreme : -20 degrees
 - icing: no minimum requirements



Design Evaluation Requirements in Cold Climate

- Additional Requirements:
 - material properties (metals, plastics)
 - functionality of mechanisms
 - pitch
 - yaw
 - functionality of electr(on)ic devices
 - lubrication
 - seals

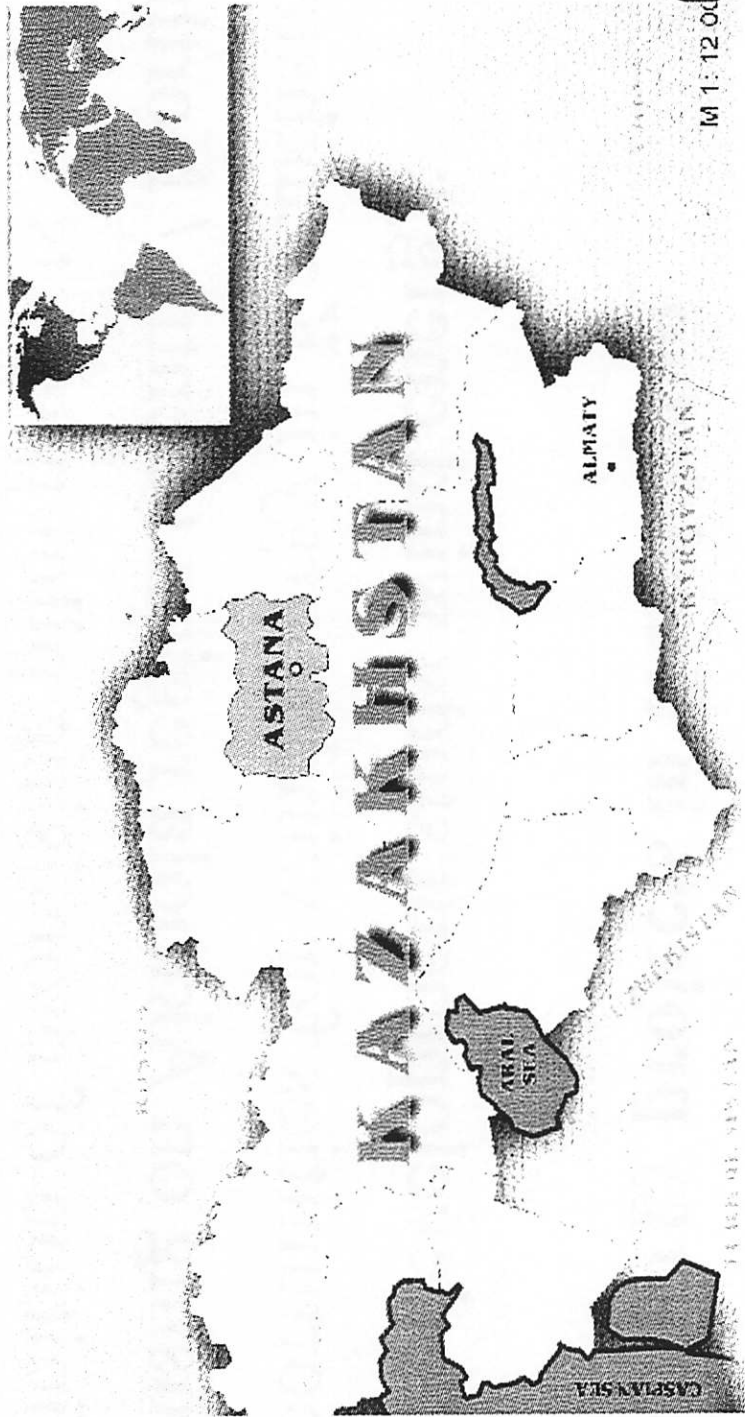
Wind energy projects in Kazakhstan

Market development study wind energy:

- **opportunities for wind energy in Kazakhstan**
- **focusing on Akmola region (Centre / North)**
- **definition of promising pilot projects**
- **period of study: 1998**
- **supported by GoN (Embassy)**

Wind energy projects in Kazakhstan

Focus on region of Astana - new capital of Kazakhstan



Kazakhstan: main data

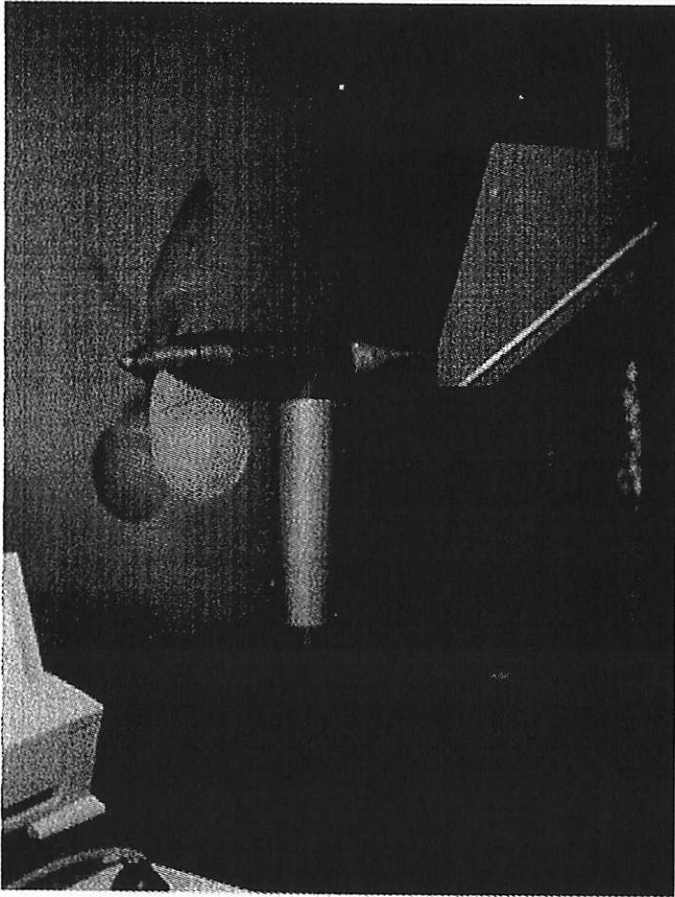
- Country area: 2.7 Million km²
- population: 16 Million (6 / km²)
- electricity consumption: appr. 60 TWh/year
- wind power to be installed @ 10%: 3000 MW



Akmola Oblast : main data

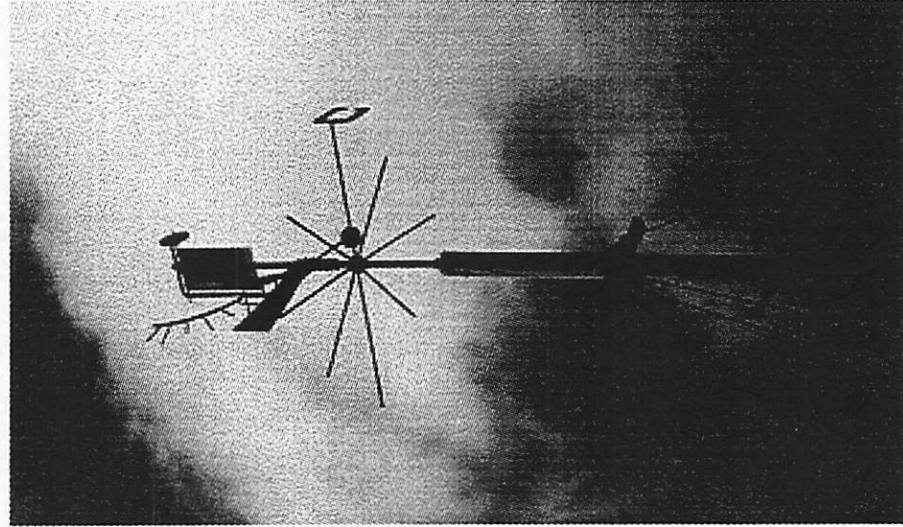
- **Oblast area: $121 \times 10^3 \text{ km}^2$**
- **population: 0.92 Million ($7.6 / \text{km}^2$)**
- **electricity consumption: appr. 4.5 TWh/year**
- **wind power to be installed @ 10%: 175 MW**

Wind speed measurements in Kazakhstan



- rugged propeller anemometer used by national meteorological institutes

Wind speed measurements in Kazakhstan



heavy plate anemometer

- range upto 40 m/s

Wind regimes for 17 stations in Kazakhstan

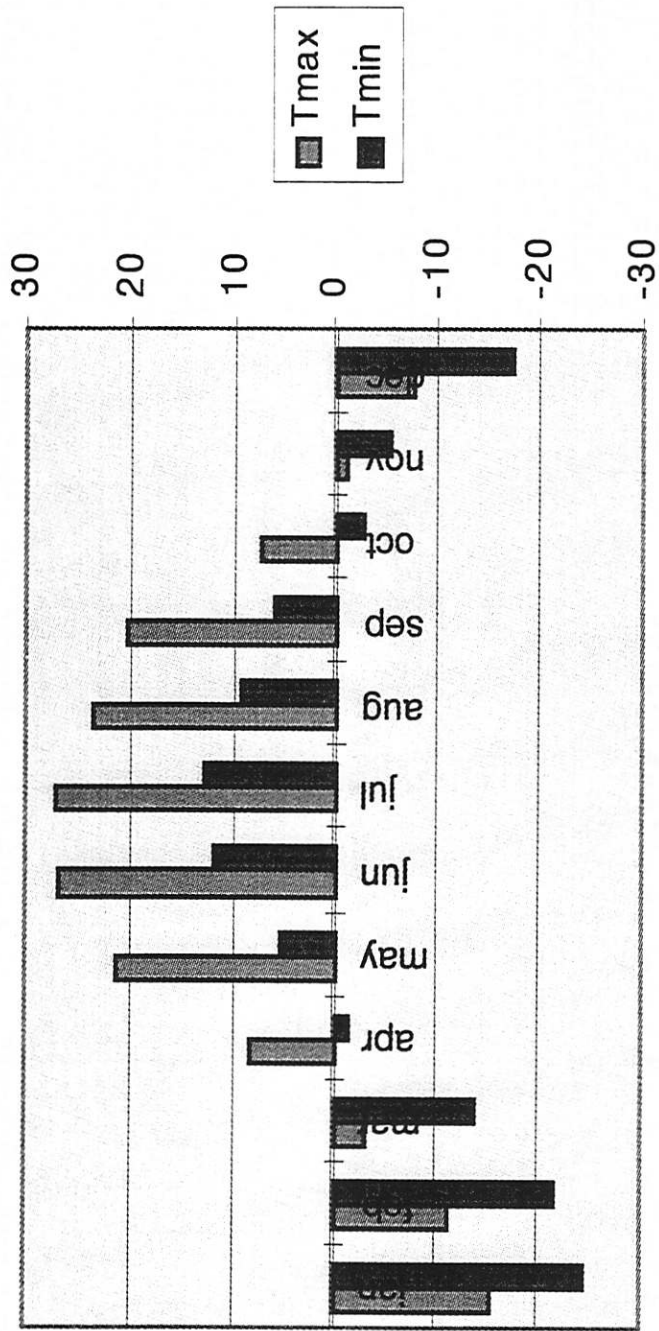
Mean velocity, m/s	Wind speed classes														V	A	k
	0,75	2,5	4,5	6,5	8,5	10,5	12,5	14,5	16,5	19	22,5	26,5	31,5	37,5	m/s	m/s	-
Drujba	12,3	13,2	17,6	14,1	16,9	12	5,9	2,4	2,5	2,2	0,4	0,3	0,1	0,1	7,0	8.2	1.7
Jungaria	25,2	17,3	14,6	9,1	5,2	6	4,8	5,8	3,1	5,9	1,8	0,5	0,4	0,2	6,8	6.8	1.09
Kara-Bagaz-Gol	6,7	14	21,9	22,8	15,2	10	5,1	2,5	1,2	0,6	0,05	0,01	0	0	6,5	7.4	1.92
Kokchetav	15,2	19	19,5	15,2	10,7	8,1	3,9	2,4	3,8	1,9	0,2	0,1	0,04	0,01	6,1	6.7	1.39
Kurdai	15,7	24,3	17,2	13,6	7,4	7,9	4,2	3,5	2,4	2,5	0,7	0,3	0,2	0,1	6,1	6.4	1.2
Karaganda	17,3	19,5	21,7	16,1	10,3	5	4,2	1,6	2,4	1,5	0,2	0,1	0,05	0,01	5,6	6.1	1.3
Petropavlovsk	11,6	22,5	24,9	17,5	11,1	4,1	4,7	1,4	1,9	0,3	0,02	0,01	0,005	0	5,4	6	1.49
Astana	18	21	21,9	15,8	9,9	3,2	4,6	2,3	2	1	0,2	0,1	0,002	0	5,4	5.6	1.49
Chokpar	18	21,6	22,4	15,8	8,7	5	2,9	2	1,7	1,3	0,3	0,2	0,1	0,002	5,3	5.7	1.24
Balhash	13,1	22	26,1	19,6	10,4	4,6	2,8	0,7	0,5	0,2	0	0	0	0	5,0	5.7	1.69
Algazi o.	10,8	25,8	27,2	17,3	9,5	4,9	2,3	1,4	0,6	0,2	0,01	0	0,002	0	5,0	5.6	1.57
Bet-Pak-Dala	21,6	20	23,3	16,6	10	3,8	2,8	0,7	0,9	0,3	0,02	0	0	0	4,7	5.4	1.51
Aiaguz	31,1	20,5	18,7	13,2	6,5	3,9	2,9	1,2	1,1	0,4	0,01	0	0	0	4,2	4.7	1.24
Jermentau	20,2	17	17,5	12,6	11,4	8	5,1	3,3	2,5	2	0,3	0,1	0	0	6,0	6.7	1.37
Kurgaljino	13,8	26	26	14,6	9,3	5,3	2,6	1,3	0,8	0,3	0	0	0	0	4,9	5.4	1.46
Atbasar	13,9	24,3	25,1	15,6	10,8	5,7	2,7	1	0,5	0,2	0,1	0,1	0	0	5,0	5.8	1.31
Shortandi	29,1	21,3	18,3	11,7	10,5	3,7	2	1,8	0,7	0,8	0,1	0	0	0	4,4	4.9	1.24

Climatic conditions in Akmola region

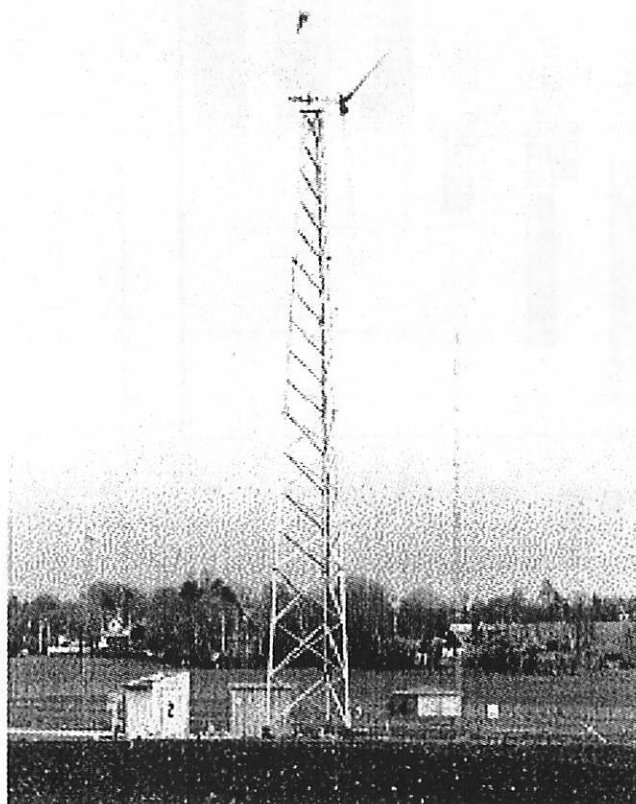
- normal minimum winter temperature:
- 20 to - 25 °C
- minimum registered winter temperature:
- 52°C
- humidity ? no quantitative data available

Climatic conditions in Akmola region

Maximum and minimum temperatures
Shortandy (1976-1980)



Pilot Project Kagimukhan



Site Co-ordinates	51° 15' N 71° 05' E
Average wind speed 10 m	5.4 m/s
Average wind speed 25 m	6.2 m/s
application	electricity supply for rural village (48 farm houses)
power demand	100 MWh / year
wind turbine	AOC 15/50
diameter	15 m
rated power	50 kW
expected AEO	114 MWh / year

Cold climate package AOC 15/50

- **transmission heater**
- **enclosure heater and insulation**
- **special generator shaft (material, bearings)**
- **modified parking brake**



Pilot project Jermentau



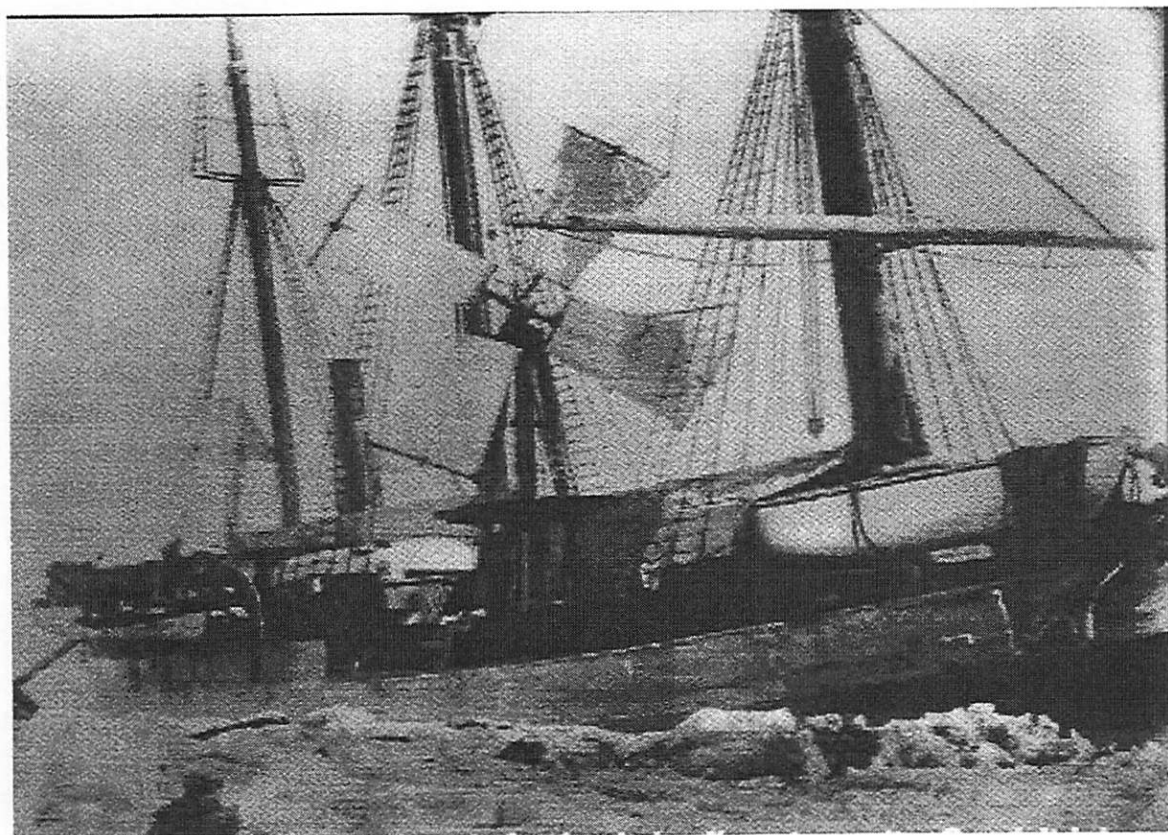
Site Co-ordinates	51° 15' N 71° 05' E
Average wind speed 10 m	6.1 m/s
Average wind speed 50 m	7.9 m/s
application	electricity supply for town 17 000 inh.
power demand	40 GWh / year
wind turbine	600 kW, variable speed techn. 8 machines
diameter	48 m
rated power	8 x 600 kW = 4.8 MW
expected AEO	15 GWh / year

IEA Wind R&D

32nd Topical Experts Meeting, 22.3.1999

International Co-operation in Cold Climate Wind Energy

Jonas Wolff, VTT Energy



FRAM 1893–96: The first polar electrical wind turbine. At Fram the saloon was lighted with electricity from the wind driven generator.

Cold climate definitions

The development of wind turbine technology for the harsh weather conditions of northern Finland and similar regions has usually been given the notion "arctic wind technology". However, the "Arctic" is geographically defined as the region where the average temperature in the warmest month does not exceed 10 °C and adapted wind turbine technology is needed also in areas that do not fall into this definition. Thus the introduction of the concept "cold climate" wind technology.

There are two technical challenges, i.e. low temperatures and icing. Low temperatures covers even extremes as low as – 65 °C but also large variations in temperatures as e.g. from minus 30 to plus 30 °C in one day. Icing again covers a variety of phenomena dependent on location and climate [1].

- **Frost** is formed when moisture from the air is condensed on cooling surfaces in conditions of low wind speed or no wind. It's often seen on car windscreens on cold mornings.
- **Glaze**, also called blue ice, is a transparent ice deposit. It usually forms as freezing rain and is generally associated with weather fronts.
- **Freezing rain** mainly occurs as drizzle, which comes from low-level stratus clouds, during low wind speeds. The clear ice has then a smooth surface, and it is difficult to remove the ice mechanically. Freezing rain may also occur during higher wind speeds consisting of bigger rain drops.
- **Wet snow** is a mixture of snow flakes and water droplets or just melting snow flakes. The flakes are often quite large. The wet snow clings on surfaces, and will be difficult to remove if it happens to freeze.
- **Rime** is formed on the upwind side of structures. Supercooled cloud droplets and some wind is needed to form rime on objects which are colder than 0 °C. The types of rime are mainly defined in accordance with their density, hardness and outward appearance:
 - **Rime ice** is a smooth-surfaced, dense formation of ice which is usually transparent. Its crystalline structure is rather irregular, its surface uneven, and it resembles glazed frost in form.
 - **Hard rime** is a granular, usually white ice formation. It forms ice granules among which there are some air spaces. Hard rime adheres firmly to its base, although it can be scalped off.
 - **Soft rime** is a fragile, snow-like formation composed mainly of thin ice needles or flakes of ice.
 - **Metamorphosed rime ice**. During the time rime ice goes through a metamorphosis due to sublimation. The effect of solar radiation when the air temperature is well below 0 °C the metamorphosed rime ice may become very durable.

All type of icing may occur as well as at coastal than mountainous areas. In mountains icing is more frequent than at the coasts, when same geographical areas are discussed. At cap areas of hills and mountains the primary icing problem for wind farms results from in-cloud ice accretion.

Effect on wind turbines

The effect icing has on wind turbines varies naturally on the type and rate of icing. In the sub-arctic regions, like on the mountains in northern Scandinavia and northern Canada, and high in the Alps there is a continuous accretion of rime ice on the turbine and especially the turbine blades. Both due to the additional loads and to the heavily influenced aerodynamic properties, a wind turbine will not operate under these conditions without some preventing measures.

In central Europe, there has been incidents of occasional glaze-ice formation on wind turbines. As these events are occasional and temporary, the loss of production is not necessarily significant. However, there is a concern regarding public safety under these conditions, especially related to possible loose pieces (even up to 1–2 kg) of hard ice being thrown off the blades.

Whether anything is to be done to have turbines operating under ice storms with heavy freezing rain is not clear. Anyway, turbines should, as when there is a concern for public safety, be shut down during these events.

Adapted wind turbines

It seems to be quite straightforward to adapt wind turbines to even extremely low temperatures by ordinary engineering. Measures include selection of proper materials, lubricants and seals, and heating of certain instruments, sensors and possibly even whole components (e.g. the gear-box or its oil). This has been done on several turbines as far as in China and northern Canada [2].

In Finland the research on icing of wind turbines has concentrated on the development of a blade-heating systems to prevent ice from forming on the leading edge on the blade. This is a preventing system designed especially for rime-ice conditions. This technology has been developed since 1993 and was commercialised in 1998. So far it has been used in Finland and Sweden and is sold with Bonus wind turbines. The development of blade-heating systems is going on also elsewhere.

During 1999, the blade-heating system will be tested also on wind turbines at coastal sites in Finland. As the turbines are getting bigger, there is a risk that the blades at least partly will reach cloud height with ice formation as a result. If this proves accurate there will be a huge market for the blade-heating technology also in areas where icing isn't usually recognised as a problem.

Except for the heating of blades, i.e. leading edges, by thermal resistors other solutions are also tried out. These include ventilation of "hot air" through the blades or painting blades black, to have them heated by solar radiation. The actual performance of these is however unverified.

National activities

Research and testing of turbines under icing conditions has continued in Finland since the late 80's with technological development during the 90's. Development is also going on in other countries.

The use of wind energy under cold climate conditions is made even more complicated as the sites often are remote and have difficult access. E.g. in Russia and China but also elsewhere

there is especially a need for autonomous energy systems. The combination of adapted cold-climate technology and wind-diesel systems is yet to be tested.

In addition, problems related to icing of anemometers and the difficulty of resource estimates makes the use of wind energy in cold climate even more difficult.

Various national activities and interests are presented in the following table.

Activity	Energy production under harsh icing conditions	Occasional icing	Test site	Technical development	Wind-diesel activities under icing conditions
Country	Finland Sweden USA Canada	Germany UK	Finland Italy Canada	Finland Denmark Germany	Canada Denmark France the Antarctic
Prospective markets	Alpine regions, etc. Norway Russia China				Russia China

International co-operation

There has been also international co-operation in this field. The most notable is the series of conferences in northern Finland under the name of Boreas. The first one was arranged in 1992 and the activity has continued biannually. The number of participants has increased steadily with a particular shift from research to industry. The fifth Boreas conference is scheduled for March 2000.

There was also a arctic wind seminar at Risø in June 1993, where an action plan was made and an arctic charter written. There has also been a series of conferences in Canada, touching the issue.

Co-operation in research has been carried out within the EU research programmes. The following projects can be noted:

- Icing of wind turbines (Joule2)
- Wind energy production in cold climates (Joule3)
- A feasibility study on the Kola peninsula (Joule3)

Proposed IEA activity

The development of applied technology has entered some different paths and different solutions are tried out. With regard to blade heating different systems are being marketed, i.e. electrical, hot-air and microwave heating. Other technology adapted for cold/icing conditions concerns anemometers, material selections and other monitoring equipment. I.e. Technical development is going on and several solutions are being demonstrated. As the applications are entering a commercial phase, there is a request to gather the experiences in a form that can be utilised by developers, manufacturers and, consultants and other financiers.

The objectives of the co-operation proposed to the IEA Implementing Agreement on Wind Energy R&D are to:

- gather and share information of wind turbines operating in cold climates.
- establish a site-classification formula, combining meteorological conditions and local needs. This is of relevance for wind turbine designers, manufacturers, project developers and wind energy producers.
- monitor the reliability and availability of standard and adapted wind turbine technology that has been applied.
- recommend practices for applying wind energy in cold climates.

Such a monitoring programme is best carried out as a broad international co-operation. This ensures

References

1. Tammelin, B. Wind energy in cold climates. Final report. (to be published 1999)).
2. Stiesdahl, H. and Kruse, H. 10 years with arctic modifications – a manufacturers experience. In the proceedings of Boreas 4 (in print).

**32d IEA Meeting of Experts
Wind Energy under Cold Climate Conditions**

Helsinki, Finland, March 22.-23., 1999

List of Participants

NAME	ADDRESS	PHONE/FAX NUMBERS/ E-MAIL
Georg Böhmeke	PVO Engineering Mikonkatu 15 A FIN 00101 Helsinki Finland	Tel: (+358) 9 69306 363 Fax: (+358) 9 69306 557 georg.bohmeke@pvo.fi
John Ellermann	LM Glasfiber Rollesmøllevej 1 6640 Lunderskov Denmark	Tel: (+45) 7558 5122 Fax: (+45) 7558 6202 jej@lm.dk
Hannele Holttinen	P.O.Box 1606 FIN-02044 VTT Finland	Tel: (+358) 9 456 5798 Fax: (+358) 9 456 6538 hannele.holttinen@vtt.fi
Frans Van Hulle	P.O.Box 1 1755 ZG Petten the Netherlands	Tel: (+31) 224 564274 Fax: (+31) 224 563214 vanhulle@ecn.nl
Martin Hoppe-Kilpper	Königstor 59 34119 Kassel Germany	Tel: (+49) 561 7294-341 Fax: (+49) 561 7294-200 m.hoppe-kilpper@iset. uni-kassel.de
Malcolm A. Lodge	Island Techn. Inc. P.O.Box 832 Charlottetown P.E.I. C1A 7L9, Canada	Tel: (+1) 902 368 7171 Fax: (+1) 902 368 7139 iti@isn.net
Jan Norling	Vattenfall Utveckling AB 814 26 Älvkarleby Sweden	Tel: (+46) 2683 521 Fax: (+46) 2683 670 jan.norling@utveckling. vattenfall.se
Tor Anders Nygaard	IFE P.O.Box 40 2027 Kjeller Norway	Tel: (+47) 6380 6108 Fax: (+47) 6381 2905 torn@ife.no
B.Maribo Pedersen	Dept. of Energy Engineering Techn. University of Denmark Building 404, 2800 Lyngby Denmark	Tel: (+45) 4525 4312 Fax: (+45) 4588 2421 bmp@inet.zitech.dk

Esa Peltola	Kemijoki Arctic Techn. Oy Annankatu 34-36 B FI-00019 IVU Finland	Tel: (+358) 9 8561 6637 Fax: (+358) 9 6941 846 esa.peltola@kemijoki.fi
Göran Ronsten	FFA P.O.Box 11021 SE-16111 Bromma Sweden	Tel: (+46) 8 555 49007 Fax: (+46) 8 253 481 goran.ronsten@ffa.se
Anders Schönborg	Agrivind AB Hjälso Borgunda 520 50 Stenstorp Sweden	Tel: (+46) 410352 Fax: (+46) 451035 mj.sh@swipnet.se
Jonas Wolff	VTT Energy P.O.Box 1606 FIN-02044 VTT Finland	Tel: (+358) 9 456 5790 Fax: (+358) 9 456 6538 jonas.wolff@vtt.fi

IEA R&D WIND - ANNEX XI TOPICAL EXPERT MEETINGS

1. **Seminar on Structural Dynamics,
Munich, October 12, 1978**
2. **Control of LS-WECS and Adaptation of Wind Electricity to the Network,
Copenhagen, April 4, 1979**
3. **Data Acquisition and Analysis for LS-WECS,
Blowing Rock, North Carolina, September 26 - 27, 1979**
4. **Rotor Blade Technology with Special Respect to Fatigue Design Problems,
Stockholm, April 21 - 22, 1980**
5. **Environmental and Safety Aspects of the Present LS WECS,
Munich, September 25 - 26, 1980**
6. **Reliability and Maintenance Problems of LS WECS,
Aalborg, April 29 - 30, 1981**
7. **Costings for Wind Turbines,
Copenhagen, November 18 - 19, 1981**
8. **Safety Assurance and Quality Control of LS WECS during Assembly, Erection and
Acceptance Testing,
Stockholm, May 26 - 27, 1982**
9. **Structural Design Criteria for LS WECS,
Greenford, March 7 - 8, 1983**
10. **Utility and Operational Experiences and Issues from Major Wind Installations,
Palo Alto, October 12 - 14, 1983**
11. **General Environmental Aspects,
Munich, May 7 - 9, 1984**
12. **Aerodynamic Calculational Methods for WECS,
Copenhagen, October 29 - 30, 1984**
13. **Economic Aspects of Wind Turbines,
Petten, May 30 - 31, 1985**
14. **Modelling of Atmospheric Turbulence for Use in WECS Rotor Loading Calculations,
Stockholm, December 4 - 5, 1985**

15. **General Planning and Environmental Issues of LS WECS Installations, Hamburg, December 2, 1987**
16. **Requirements for Safety Systems for LS WECS, Rome, October 17 - 18, 1988**
17. **Integrating Wind Turbines into Utility Power Systems, Virginia, April 11 - 12, 1989**
18. **Noise Generating Mechanisms for Wind Turbines, Petten, November 27 - 28, 1989**
19. **Wind Turbine Control Systems, Strategy and Problems. London, May 3 - 4, 1990**
20. **Wind Characteristics of Relevance for Wind Turbine Design, Stockholm, March 7 - 8, 1991**
21. **Electrical Systems for Wind Turbines with Constant or Variable Speed, Göteborg, October 7 - 8, 1991**
22. **Effects of Environment on Wind Turbine Safety and Performance, Wilhelmshaven, June 16, 1992**
23. **Fatigue of Wind Turbines, Golden Co., October 15 - 16, 1992**
24. **Wind Conditions for Wind Turbine Design, Risø, April 29 - 30, 1993**
25. **Increased Loads in Wind Power Stations, "Wind Farms", Göteborg, May 3 - 4, 1993**
26. **Lightning Protection of Wind Turbine Generator Systems and EMC Problems in the Associated Control Systems, Milan, March 8 - 9, 1994**
27. **Current R&D Needs in Wind Energy Technology, Utrecht, September 11 - 12, 1995**
28. **State of the Art of Aeroelastic Codes for Wind Turbine Calculations, Lyngby, Denmark, April 11 - 12, 1996**
29. **Aero-acoustic Noise of Wind Turbines, Noise Prediction Models, Milano, Italy, March 17 - 18, 1997**

30. **State of the Art on Power Performance Assessments for Wind Energy Conversion Systems, Athens, Greece, December 8 - 9, 1997**
31. **State of the Art on Wind Resource Estimation, Risø, Denmark, October 29 - 30, 1998**
32. **Wind Energy under Cold Climate Conditions, Helsinki, Finland, March 22 - 23, 1999**